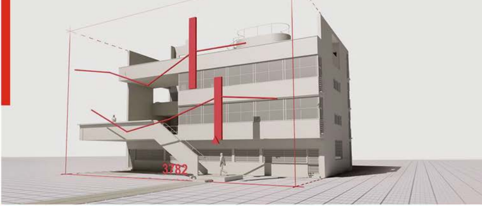
Mathematics and the Built Environment 3



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The Mathematics of the Modernist Villa

Architectural Analysis Using Space Syntax and Isovists

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Mathematics and the Built Environment
Volume 3

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ISSN 2512-157X ISSN 2512-1561 (electronic)
Mathematics and the Built Environment
ISBN 978-3-319-71645-9 ISBN 978-3-319-71647-3 (eBook)
https://doi.org/10.1007/978-3-319-71647-3

Library of Congress Control Number: 2018932177

Printed on acid-free paper

This book is published under the imprint Birkhäuser, www.birkhauser-science.com by the registered company Springer International Publishing AG part of Springer Nature
The registered company address is: Gewerbestrasse 11, 6330 Cham, Switzerland

Preface

The origins of the Modern movement in architecture are generally traced to the late nineteenth century, and despite reaching its pinnacle in the first half of the twentieth century, it remains highly influential to the present day. The architecture of the Modern movement is typically characterised as employing industrial materials and a machine-made, minimal aesthetic to express the *zeitgeist*, or spirit of the age. For the Modern architect, technology and science offered humanity a new beginning, a *tabula rasa* from which a more enlightened and healthy society would arise. The new materials and construction techniques that became available at the end of the nineteenth century gave architects the freedom to create pure, geometric forms and expansive, light-filled spaces. The streamlined forms of the Modern architecture of this era were inspired by cars, aircrafts and ocean liners, and Modern architects sought to evoke the functional elegance of these machines in their detailing.

Today, Modernism—whether it is in art, literature or architecture—is regarded as one of the most important philosophical and ideological movements of the twentieth century. Historians and critics have repeatedly documented, analysed and explored its origins and impact. Using archival techniques and qualitative interpretation, scholars have identified various properties of the Modern movement that are present in both the manifestos of the era and in its completed works. The characteristics of Modern architecture listed in the previous paragraph are examples of ones that are readily apparent in both the theories and works of the movement. Indeed, the standard definitions of Modern architecture found in histories and encyclopaedias are dominated by such themes and properties. But there are also arguments in the original manifestos that have been largely ignored by historians. Furthermore, several famous theories about Modern architecture have been widely accepted by scholars and practitioners even though there is little or no evidence in support of them. This situation provides the impetus for the present book, which uses quantitative methods to revisit a series of arguments about the social, cognitive and perceptual ambitions of Modern architecture.

Using mathematical and computational approaches, this book examines various properties of the works of early Modern architects, Frank Lloyd Wright, Mies van der Rohe and Richard Neutra, and Late Modern architect, Glenn Murcutt. The canonical descriptions of these architects' works tend to stress aesthetic and tectonic properties that are aligned to theories about form, expression and the *zeitgeist*. However, designs by these architects have also been explained in terms of their social, cognitive and experiential properties. It is these secondary arguments—sometimes raised by the architects themselves, but also developed independently by scholars and critics—which are examined in the present book.

The methods used for this examination are drawn from Space Syntax and viewshed analysis. The former approach, often described as 'syntactical' analysis, uses graph theory and a range of abstraction processes to derive data from an architectural plan in order to provide insights into its social and cognitive properties. The latter approach uses isovists, a type of spatio-visual geometry, to examine the visibility-related, experiential properties of space. Part I of this book introduces these methods and discusses recent developments and debates about their applications and limitations. Despite being used extensively in past research, there are surprisingly few detailed descriptions of these methods or worked examples available to introduce them to new users. For this reason, all of Part I is set aside to explain how they work. In Part II, syntactical analysis is used to examine arguments about the social and experiential properties of the open plan in Mies's domestic architecture, the perceptual and cognitive properties of Neutra's Californian houses and the relationship between form and social function in Murcutt's rural architecture. In Part III, isovist analysis is used to investigate the perceptual properties of Wright's Prairie Style, Textile-block and Usonian designs. In total, thirty-seven Modernist designs are analysed in this book.

This book has been written for people with an interest in looking beyond the conventional art-historical readings of Modernism and in approaching some of the most famous buildings of the twentieth century with a more mathematical mindset. However, this does not mean that we ignore the history and theory of Modernism. Instead, the analytical chapters commence with a consideration of arguments that have been developed by architects or scholars about the social, cognitive and experiential aspects of space and form. Then, computational and mathematical methods are used to test the evidence for these arguments in the buildings they have been used to describe. Finally, each chapter returns to the original proposition to determine if there is support for it and whether the analysis has revealed any new insights into the buildings being examined.

The anticipated readership of this book includes designers, historians and postgraduates who are familiar with architectural concepts, but are not experts in mathematics. For this reason, the mathematical methods used—geometry, graph theory and statistics—are explained in Part I. The particular mathematical and computational methods were chosen to provide a balance between accessibility of results and level of insight provided. The process of testing a qualitative claim about architecture should not necessarily require the use of an overly intricate or arduous quantitative method. In some cases in this book, a simple numerical comparison of the frequency of a particular feature in a design is enough to test an idea. In other cases, standard syntactical methods are used, and in a few cases we employ new or more advanced variations. Thus, rather than applying the same methods and level of analytical detail to every design, in each case the method is tailored to the hypothesis being tested.

The designs analysed in this book include some of the Modern movement's most famous works. Mies van der Rohe's *Farnsworth House*, Richard Neutra's *Kaufmann Desert House* and Glenn Murcutt's *Marie Short House* were all instrumental in changing the way people think about architecture. The list of Wright's highly regarded works examined in this book is especially extensive. From his Prairie Style *Heurtley* and *Robie* houses to the Textile-block *Ennis* and *Millard* homes and the *Affleck* and *Palmer* Usonian designs, Wright's architecture presents a rich opportunity for analysis. Significantly, this book not only considers his three great stylistic periods, but it also examines his famous intermediate works, the *Aline Barnsdall* ('Hollyhock House') and the *Edgar J. Kaufmann* ('Fallingwater') houses.

Many of the buildings analysed in this book have been the subject of intense speculation and repeated qualitative examination in the past. They are keystone projects around which the vaults of twentieth-century architectural history have been constructed. The application of mathematical and computational analysis to these designs presents a unique opportunity to revisit their properties, both the seemingly well known and the rarely considered.

Newcastle, Australia — Michael J. Ostwald
2018 — Michael J. Dawes

Acknowledgements

Many people have supported this research throughout the last seven years. We would especially like to thank our colleagues and research assistants, Maria Roberts, Shashank Bhatia, Josephine Vaughan, Anni Dosen, Romi McPherson, Lachlan Seegers, Sarah Jozefiak and Jasmine Richardson. Michael J. Ostwald wrote the original analysis of Richard Neutra and the excitation response (the catalyst for Chap. 6) with Raeana Henderson, and her role in the development of this argument is gratefully acknowledged. Thanks to Dion Neutra for providing access to drawings in his father's archive, and the Frank Lloyd Wright Foundation for assisting with access to materials and buildings. The early inspiration for this work came from various sources, including Anthony Vidler's seminars at UCLA, Michael Benedikt's research at the University of Texas at Austin and Glenn Murcutt's masterclasses at Riversdale. John Peponis provided generous advice and direction for two early draft chapters written for this book. The Australian Research Council (ARC) supported this project financially with a Discovery Grant (DP1094154) and a Future Fellowship (FT0991309), which allowed for many of the buildings analysed in this book to be visited, photographed or measured. Special thanks must also go to Sarah Goob and Thomas Hempfling (Birkhäuser), and Kim Williams, series editor of *Mathematics and the Built Environment*, for their support.

Some sections of this book are derived from material that was previously published in journals and chapters and has been substantially revised, expanded or updated for the present work. Specifically, Chap. 2 draws on material published in: Michael J. Dawes, and Michael J. Ostwald, 2013, Applications of Graph Theory in Architectural Analysis, *Graph Theory*, Nova Scientific, New York. Chapter 3 includes revised sections from three previous publications: Michael J. Ostwald, 2011a, The Mathematics of Spatial Configuration, *Nexus Network Journal* 13(2); Michael J. Ostwald and Michael J. Dawes, 2011, Axial Line Analysis Revisited. *International Journal of the Constructed Environment* 1(3); and Michael J. Dawes and Michael J. Ostwald, 2013, Precise Locations in Space, *Architecture Research* 3(1). Chapter 4 is a revised and expanded version of: Michael J. Ostwald and Michael J. Dawes, 2013c, Using Isovists to Analyse Architecture: Methodological

Considerations and New Approaches, *International Journal of the Constructed Environment* 3(1). Chapter 5 includes revised sections and ideas originally developed in: Michael J. Ostwald and Michael J. Dawes, 2013a, Miesian Intersections, *Graph Theory*, Nova Scientific, New York. Chapter 6 encapsulates ideas developed over the course of three papers: Michael J. Ostwald and Raeana Henderson, 2012, The Modern Interior and the Excitation Response: Richard Neutra's Ocular-centric Phenomenology, *Architecture Research* 2(3); Michael J. Ostwald and Michael J. Dawes, 2012, Differentiating between Line and Point Maps on the Basis of Spatial Experience: Considering Richard Neutra's Lovell House, *Nexus Network Journal* 14(3); and Michael J. Ostwald, 2014b, Space and Sound: Harmonies of Modernism and Music in Richard Neutra's Clark House*, Centre* 18. The mathematical analysis and content of Chap. 6 are partially drawn from: Michael J. Dawes and Michael J. Ostwald, 2012, Lines of Sight, Paths of Socialization: An Axial Line Analysis of Five Domestic Designs by Richard Neutra, *International Journal of the Constructed Environment* 1(4). Chapter 7 expands and combines ideas originally published in: Michael J. Ostwald, 2011b, A Justified Plan Graph Analysis of the Early Houses (1975–1982) of Glenn Murcutt, *Nexus Network Journal* 13(3); Michael J. Ostwald, 2011c, Examining the Relationship Between Topology and Geometry: A Configurational Analysis of the Rural Houses (1984–2005) of Glenn Murcutt, *The Journal of Space Syntax* 2(2). Chapter 8 is a revised and expanded version of: Michael J. Dawes and Michael J. Ostwald, 2013c, Using Isovists to Analyse Prospect-Refuge Theory, *International Journal of the Constructed Environment* 3(1). Chapter 10 includes expanded and updated material and results published in preliminary form in: Michael J. Ostwald and Michael J. Dawes, 2013b, Prospect-refuge Patterns in Frank Lloyd Wright's Prairie Houses, *The Journal of Space Syntax* 4(1); Michael J. Dawes and Michael J. Ostwald, 2014a, Prospect-Refuge Theory and the Textile-block Houses of Frank Lloyd Wright, *Building and Environment* 80; and Michael J. Dawes and Michael J. Ostwald, 2015, Testing the Wright Space: Using Isovists to Analyse Prospect-Refuge Characteristics in Usonian Architecture, *The Journal of Architecture* 19(5). Full details of these publications are contained in the references.

We gratefully acknowledge the advice and support of the many referees and editors involved in the production of these works, including those from *Building and Environment*, *Centre*, *Graph Theory, International Journal of the Constructed Environment, Journal of Architecture, Journal of Space Syntax* and *Nexus Network Journal: Architecture and Mathematics.*

Contents

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Michael J. Dawes has bachelor degrees in Science (Architecture) and Construction Management and a masters degree in Architecture. He is currently completing a Ph.D. investigating Christopher Alexander's *A Pattern Language*. Since 2010, he has worked as a Research Associate and Academic at the University of Newcastle (Australia). His publications include refereed journal papers and chapters on graph theory, syntactical analysis and isovists. His research combines computational and mathematical analysis with architectural history and theory.

Chapter 1
Introduction

1.1 Background

Possibly the most famous essay about architecture and mathematics was written by Colin Rowe in 1947. Rowe's essay, 'The Mathematics of the Ideal Villa,' compares formal and spatial properties in the architecture of Palladio and Le Corbusier. The 'ideal villa' in Rowe's title, is a freestanding, 'pure' geometric structure which encapsulates the aspirations or practices of a designer or movement. Near the start of his essay, Rowe reveals that Palladio's sixteenth century *Villa Malcontenta* at Mira and Le Corbusier's twentieth century Modernist *Villa Stein-de Monzie* at Garches share the same system of mathematical regulation in their plans. In essence, Rowe's startling observation is that these houses, designed more than 360 years apart, have a common, underlying proportional framework. However, before his reader has had a chance to assimilate the implications of this revelation about architectural form, Rowe rejects its significance and suggests instead that the spatial differences are more profound. In particular, he describes the experience of each space, and of movement through each building, emphasising the differences in terms of 'emotional impact' (Rowe 1976: 13). Navigation through the plan of a Renaissance villa is static, episodic and controlled, while the process of moving through and discovering a Modernist villa is dynamic, continuous and unconstrained. The social structures created in the planning of the two villas are similarly diverse, the former being hierarchical and the latter emancipatory. Ultimately Rowe's essay argues that Palladio and Le Corbusier may share a common, mathematical standard and a similar commitment to pure formal aesthetics, but substantial differences exist in terms of spatial articulation, connectivity and directionality.

The title of the present book, *The Mathematics of the Modern Villa*, deliberately echoes Rowe's work. Like his essay, this book is concerned with the way spaces are articulated, arranged and connected within a building. These properties are important because they shape the way people use architecture, understand it

M. J. Ostwald and M. J. Dawes, *The Mathematics of the Modernist Villa*,
Mathematics and the Built Environment 3,
https://doi.org/10.1007/978-3-319-71647-3_1

intellectually and respond to it emotionally. Whereas form-based reasoning and evidence have tended to dominate the conventional historical analysis of architecture, this book investigates spatial topology and visibility in Modernism. There are three further parallels between the content of this book and Rowe's essay. First, the mind-set we bring to the topic is emphatically mathematical. Like Rowe's work, the content of this book is embedded in the traditions of architectural history and theory, but its outlook is analytical and quantitative. Second, just as Rowe chose to focus on 'villas', so too the designs analysed in this book are all examples of domestic architecture. Houses are often the earliest projects available to architects to express their ideas and, as Amos Rapoport argues, 'social and cultural factors, rather than physical forces, are most influential in the creation of house form' (1969: 58). The third connection to Rowe's essay is that the designs analysed in this book are all 'ideal' in his sense of the word. They are freestanding structures that have, in many cases, been designed to be viewed 'in the round' or are sited in natural settings. Indeed, several of the Modernist designs featured in this book have been likened to Palladian villas or Classical Greek temples because of the way their simple geometric forms suggest a timeless quality. Thus, while this book does not examine any of the same works considered by Rowe, the designs chosen for the present book have a similar geometric purity and rigour about them.

This book examines a series of arguments about the social, cognitive and experiential properties of the domestic architecture of Frank Lloyd Wright (1867–1959), Mies van der Rohe (1886–1969), Richard Neutra (1892–1970) and Glenn Murcutt (1936–). These architects represent, respectively, the 'Organic', 'Functionalist', 'Californian' and 'Regionalist' variations of Modernism. The designs examined in this book were constructed in America, Poland, Germany and Australia between 1905 and 2005. In a sense, these designs encapsulate a century of Modernism, from its rise in America and Europe to its most recent incarnation on the Pacific Rim. Notwithstanding such factors, the primary reason for choosing these architects and projects is that in each case there is an obvious lacunae or gap in our knowledge about them.

As noted in the Preface, conventional definitions of architectural Modernism tend to emphasise particular ideological dimensions that have a corresponding aesthetic expression. Thus, most architectural definitions are dominated by references to machine-made aesthetics, the spirit of the age and functional expression, in each case combining an aspiration with evidence of its application in design. These facets of Modern architecture are useful for both generalising its properties and dissecting its deficiencies. However, historians and critics have tended to ignore important arguments about the social, cognitive and perceptual aspirations of Modernism. This is not a new observation. Sigfried Giedion's *Space, time and architecture* famously argues that the myriad of formal, aesthetic and stylistic interpretations of Modernism fail to take into account its more important social and ontological potential. For Giedion, the fundamental rupture that Modernism needs to address is 'between thinking and feeling' (1941: x). Giedion's solution to this dilemma lies in shifting architecture's focus away from form, and the immediate present, to space and an appreciation of time as both an irreversible part of life and a necessity for progress.

There are multiple examples of scholars who have noted that the art-historical fixation on form and function in Modernism belies its actual diversity, and its potentially more important spatial and temporal ambitions. For example, William Curtis describes the early historians of Modernism as 'mythographers', because of their tendency to 'isolate their subject, to oversimplify it, to highlight its uniqueness in order to show how different the new creature was from its predecessors' (1996: 13). Colin St John Wilson (1995) makes a similar point in his rejection of both the stylistically focussed histories of architecture and the criticisms levelled at the Modern movement. Hassan-Uddin Kahn also argues that Modernism 'was concerned with social agendas as well as form, an aspect that is now sometimes forgotten' (2001: 7). Like Curtis, Giedion and Wilson, Kahn is concerned with the way in which the canonical histories of Modernism fail to take into account its complex social agenda and its inherent sense of time and progress. Many Modern spaces were designed to assist a person to understand their location in a building (being a cognitive property) and their place in the world (an ontological property). More recently, Hans Rudolf Morgenthaler has suggested that the fixation on form found in most histories of the Modern movement has effectively erased the central significance of personal experience in the manifestos and works of Modernism. Specifically he asks, 'would Modern architecture's meaning become more clear, if one focused on perceptual experience to understand it?' (2015: 3). This suggestion is entirely warranted, as many Modern architects, including Richard Neutra and Frank Lloyd Wright, developed detailed arguments about personal experience and understanding. Yet, these properties are seldom mentioned in histories of the Modern movement.

These reflections—from Giedion, Curtis, Wilson, Kahn and Morgenthaler—affirm that the Modern movement in architecture had important social, cognitive and perceptual aspirations and affects. However, these dimensions of the Modern movement have tended to be overlooked or forgotten because they rely on complex manipulation of space, time and movement, rather than formal, aesthetic or stylistic analysis. The fact that space, time and movement might be neglected is not unexpected. Anthony Vidler (1998: 105) observes that space 'has proved to be the most elusive' characteristic of architecture. Space is 'essentially intangible' and 'indeed, can only be characterized through a study of what is not represented—the white ground of a plan, the implied sense of visual and bodily projection in perspective views' (1998: 105). Space has to be understood in terms of connections and perceptions of the passage of time or of movement. As such, space, time and movement are tied to the social, cognitive and experiential properties of architecture. In contrast, the formal, functional, tectonic and stylistic properties of architecture are, 'if not tangible, at least knowable through one representational means or another—physical description, analytical drawing, three-dimensional model' (Vidler 1998: 105).

The practical impact of the difficulty of examining the social, cognitive and experiential claims about Modernism can be seen in many examples. For instance, Mies's lectures and interviews reveal that one purpose of the 'free plan', a central strategy in Modernism, is to create a new social structure that blurs the distinction between inhabitation and movement and increases flexibility of choice (Norberg-Schulz 1965). The free plan, or 'open plan' as it is more commonly known today, requires the minimisation of walls and divisions in a design along with the extension of the floor plane into the site. The growing importance of the free plan is readily apparent in any examination of Mies's architecture and as such, it dominates explanations of his contribution to the Modern movement. But what of his rationale for introducing the free plan? Does the free plan actually change the social structure of space or the relationship between inhabitation and movement? Does it actually increase flexibility in terms of how users can access and avail themselves of the major functional zones of a design? This aspect of Mies's theory is rarely mentioned by historians and has never been convincingly analysed. In a similar way, Richard Neutra argues that space and form in his designs have been carefully planned to create a high degree of cognitive clarity. Indeed, he maintains that certain structural members should be almost invisible so as not to hinder spatial understanding and awareness (Neutra 1956). In recent histories of Modernism, the first part of this argument is often simplified to focus on Neutra's use of expansive glass walls. The apparent transparency of these walls is also sometimes enhanced by his use of thin steel structural supports, which are often painted silver so that they almost disappear from sight (Lamprecht 2000). These two characteristics of Neutra's architecture are noted in many descriptions of his work. But what about his rationale for employing these strategies? Neutra's treatment of space and structure is motivated by the desire to initiate a cognitive and experiential response that will choreograph a specific physiological outcome. Unfortunately, this aspect of Neutra's theory is rarely mentioned, seemingly being dismissed as either extraneous or, perhaps, too difficult to assess. The realisation that such important facets of Modernist theory have been overlooked or neglected is the first catalyst for this book.

The second catalyst for this work is associated with a different type of gap in the history and theory of architecture. This gap occurs where an argument or position is seemingly universally accepted, even though there is no evidence available for it. For example, historians and critics describe Murcutt's architecture as being spatially and formally refined to such an extent that it constitutes a special 'type' (Fromonot 1995; Frampton 2006). The form-based evidence for this proposition is compelling. Even a cursory examination of Murcutt's rural architecture reveals its underlying linear pavilion type. But what about the social properties of Murcutt's architecture? It cannot be assumed that just because there is an unwavering commitment to a particular formal language that an equally consistent and considered spatial relationship is at its core. A similar type of gap, albeit a much larger and more profound one, is associated with arguments about the experience of Wright's architecture. One of the most famous explanations of the power of Wright's architecture maintains that a pattern of spatial relations and progressions exists in his plans, which collectively evoke a special type of emotional response (Hildebrand 1991; Kite 2003). Such is the power of this proposition that it has since been extrapolated to explain the work of many other designers, it has been accepted as a major theory of architecture and it has even found its way into design guides and textbooks. Nevertheless, this proposition has never been rigorously tested in terms of Wright's architecture.

These four gaps in our knowledge about the architecture of Wright, Mies, Neutra and Murcutt are examined in the present work, along with other arguments about the social, cognitive and experiential properties of Modernism. All of these gaps are associated with the way spaces are defined, constrained, connected and controlled, and as such, it is not surprising that they exist. Arguments about the formal properties of architecture can generally be tested using a simple, qualitative review of photographs or drawings of a building. In contrast, claims about the social, cognitive and experiential properties of architecture require special methods and approaches. This is where the present book departs significantly from Rowe's themes and methods, as it uses two computational and mathematical approaches—Space Syntax and isovist analysis—to extract measurements or data from the designs of Wright, Mies, Neutra and Murcutt. These methods have been developed for analysing social patterns and relations along with spatio-visual and cognitive properties in architecture. The results of these methods have also been correlated to human perceptions and behaviours. Thus, the data derived from application of these methods can be used to test various arguments about the way people perceive, use, understand and respond to Modern architecture.

The following sections expand on several of these themes. In particular, the next section presents a brief overview of Modernism to provide a context for the larger architectural movement and a background for readers who are less familiar with the topic. The third section differentiates between form and space in architecture, positioning the two in terms of the classic tripartite Vitruvian definition. That section explains the significance of space in architecture and why spatial relations are conceptualised as the 'syntax' of an architectural 'language'. The fourth section describes the specific social, cognitive and experiential properties of architecture that are examined in this book. This explanation is necessary because each of these three terms can encompass a wide range of meanings, but for the present research the only properties considered are those that are embedded in the spatial relations found in architectural plans. Finally, the chapter describes the structure of the book, both in terms of its content and the way it approaches architecture.

1.2 Modernism

This section is about two major traditions of Modernity, the first being developed in philosophy, sociology and critical theory, and the second in architecture, art and design. The two share several concerns and attitudes but they developed in parallel and responded to the pressures of the Modern world in different ways (Heynen 1999). In this section some of the common values are initially described before focussing on the architectural variant. The reason this section considers the non-architectural tradition is that three of its fundamental concerns—space, time and movement—play an important role in the social, cognitive and experiential properties of architecture.

The adjective 'Modernist' is typically used to describe theories or works which reject classical, traditional or local approaches, in favour of those that are more technologically progressive, socially equitable or universally applicable (Collins 1965; Mallgrave 2005). The philosophical origins of this shift are often traced to the Scientific Revolution of the sixteenth and seventeenth centuries in Europe or to the French Enlightenment of the eighteenth century (Rykwert 1983; Cordua 2010). During this period there was a growth in the application of rational and empirical thinking and a parallel questioning of social hierarchies and religious dogma. The Industrial Revolution of the nineteenth century effectively heralded the rise of Modernism with the changes to social structures, economic systems, educational models and personal values it triggered. Hilde Heynen observes that these changes produced a 'rupture with tradition' that had 'a profound impact on ways of life and daily habits' (1999: 3).

Many of the changes that occurred in society as a result of the rise of Modernism are associated with its fetish for efficiency, economy and productivity. The Industrial Revolution first encouraged and later necessitated a complete reconceptualization of labour. Under the auspices of Taylorism and Fordism the worker was no longer seen as a craftsperson with a particular or unique skill-set; instead, he or she had become a cog in a larger apparatus of production. Paradoxically, the products of their new labours were both exciting and disposable. Cars, trains, ships and aircrafts made travel more accessible to people and changed the way distance and space were perceived. Technology effectively altered perceptions of spatial separation, definition and movement (Vidler 1998). Indeed, the concept of 'progress', which was central to the Modern movement, refers to a sense of increased quality of life, as well as the passage of time and the movement of the body. Time, in Modernism, is a linear concept, tracing a trajectory to the better world that also inevitably erases the previous one. Marshall Berman's book, *All that is solid melts into air,* captures this concept not only in its title (a quote from Marx), but when in noting that 'to be Modern is to find ourselves in an environment that promises us adventure, power, joy, growth [and] transformation [and] at the same time, that threatens to destroy everything we have, everything we know, everything we are' (1988: 15). Philosophically, the challenges addressed by the Modern movement may have been accelerated by the Industrial Revolution, but they are, at the core, associated with changing conceptions of space, time and movement.

While the Industrial Revolution precipitated widespread social change, it also provided architects with the materials, techniques, project types, and clients required to embrace a new way of thinking (Risebero 1982; Benevolo 1997a). In the nineteenth century architects began to use steel and mass production to create factories and offices for wealthy industrialists, whereas previously they had used brick and stone to construct palaces and churches for princes and clergy (Walden 2011). The Industrial Revolution gave architects an opportunity to explore design approaches which expressed the spirit of the age and appeared to resolve the social dilemmas of the era. The Italian Futurists and Russian Constructivists embraced these possibilities in the early years of the twentieth century, and by the 1920s Le Corbusier, Mies van der Rohe and Walter Gropius had developed the basic architectural vocabulary of Modernism: functional geometric forms, white or unadorned surfaces and open-planned spaces (Collins 1965; Colquhoun 2002). In America, Wright and Neutra produced organic and scientific variations of Modernism and in 1934 Philip Johnson and Henry-Russell Hitchcock rebranded it the 'International Style' (Benevolo 1997b). Over time, several theories of Modernism—condensed into the phrases 'form follows function', 'ornament is crime' and 'less is more'—became mantras for the movement. These sayings, paraphrased from Louis Sullivan, Adolf Loos and Mies van der Rohe, not only represented philosophical positions, they effectively told an architect how to design. In essence, architectural expression should arise solely from the functional needs of a building.

While these ideological arguments may have called for a particular architectural expression, it only became feasible because architects stopped being reliant on masonry and timber construction and began to take advantage of the possibilities offered by steel and concrete. For example, whereas masonry structures required complex vaults or domes to enclose a space, concrete slab and column structures were modular and repetitive, offering seemingly endless possibilities for extension and expansion. Windows in masonry walls required lintels or arches and were typically narrow and deep-set, whereas steel-framed windows could be wide, uninterrupted by mullions and stand free of the structure. Masonry was heavy and dark in appearance, while steel and concrete appeared relatively light in comparison, a property emphasised by many Modernists who painted their structures white or silver. Masonry walls needed complex abatements or required corbelled and stepped courses, while concrete could be rendered to suggest a seamless, flat surface. Collectively the new construction techniques and materials, and the way they could be emphasised or expressed, led to many early Modern buildings having a pristine clarity of expression which contrasted greatly with what had come before. The appeal of such pure geometric forms was noted in Le Corbusier's famous call to architects to embrace 'primary forms', because they are innately 'beautiful' and 'can be clearly appreciated' (1931: 23). Le Corbusier argues that Phileban solids, 'cubes, cones, spheres, cylinders or pyramids', are ones 'which light reveals to advantage' (1931: 29). The examples he provides in *Vers une Architecture* of the power of these primary forms are dominated by industrial buildings and structures, being instances of what he calls the 'engineer's aesthetic'. They are also free-standing, iconic works, like temples to the power of geometry and industry. Le Corbusier even praises some of these same qualities in Renaissance and Egyptian architecture, noting the timeless beauty of primary geometric forms, and in doing so he effectively opened the door for Rowe (1976) to compare the properties of Palladian and Modernist villas.

While Modernism may have reached its apogee in the 1940s, its nadir soon followed. In the aftermath of the second world war many Modern architects were commissioned to design entire suburbs or districts. These utopian projects, often comprising brutal, repetitive apartment complexes, may have been predicated on the need for a brave new world, but they generally transplanted existing social problems (unemployment, social stratification, racial segregation and crime) into a new setting (Colquhoun 2002; Coleman 2005). Furthermore, a range of unforeseen, negative side effects of Modernism were soon identified in these districts, including social isolation and a lack of a sense of ownership or place (Brolin 1976). Such was the speed with which the social order in these new communities deteriorated, that in a celebrated example, architect Minoru Yamasaki's Pruitt-Igoe development in St Louis, was demolished barely two decades after it was completed (Jencks 1977).

In the aftermath of Modern architecture's apparent failure, the architectural media promulgated a diverse range of alternative theories and approaches. These included historical revivalist strategies, ironic or camp variations of Classicism, and designs structured around popular and eclectic iconography. Many of these approaches were eventually gathered under the banner of Post-Modernism, which remained a dominant force in architecture until the 1990s. However, despite appearances, not all architects rejected Modernism after the post-war period. The work of many regional Modernists, sometimes called the 'other Modern' tradition (Wilson 1995; Kahn 2001), including Alvar Aalto, Oscar Niemeyer, Alvaro Siza, Luis Barragan and Glenn Murcutt, continued to be an inspiration for designers (Frampton 1985; 1995). The enduring fascination with technology throughout this era is conspicuous in the work of Norman Foster, Richard Rogers and Renzo Piano. These so-called 'Late', 'Neo' or 'New' Modernists took a more considered approach to tectonic practices and regional identity (Jencks 1990). They accepted that the utopian social agendas of Le Corbusier and Mies van der Rohe were at best misguided and at worst deeply totalitarian and destructive. The Late Modernists also acknowledged that the fixation on aesthetic expression often resulted in a highly contrived architecture. Nevertheless, they continued to work in a technologically progressive manner, but also with a heightened sensitivity and respect for history, culture and society.

Ultimately, the adjective 'Modern' encapsulates many of the issues raised in this section. It refers to a philosophical position, a particular aesthetic predilection and an era. Because there were variations of Modernism—including those associated with particular locations (like 'Californian Modernism'), aspects of its ideology ('High Tech' architecture), or local conditions and concerns (Regionalism)—no single definition can adequately capture its diversity or richness. More importantly, the various labels applied to the movement are useful, but 'they do not account for complex historic overlaps or ambiguities that require a deeper reading' (Kahn 2001: 8). As such, at the end of this book it will not be possible to generalise the specific findings to construct a grand, alternative narrative about Modernism. The issues examined in this book are major ones, and several foundation theories are tested, but the goal is not to challenge current readings of Modernism, but to enrich them.

1.3 The Significance of Space

During the first century BC, the Roman author, military engineer and architect, Marcus Vitruvius Pollio, proposed one of the oldest surviving definitions of architecture. For Vitruvius, architecture must demonstrate refinement and responsiveness in terms of three distinct properties: *firmitas*, *utilitas* and *venustas*. The first of these, *firmitas*, refers to firmness or soundness, while the second, *utilitas*, relates to utility or commodity. The last, v*enustas*, is associated with delight and attractiveness (Rowland and Howe 1999). Regardless of the precise interpretation, the first of these three has grown to be associated with form and the last with various transcendent qualities including beauty, poetry and spirituality. Indeed, recent explanations of the essential properties of architecture tend to reinforce the importance of both of these dimensions. For example, twentieth-century scholars repeatedly define architecture as the art and science of constructing form, a reference to the first part of the Vitruvian triad (Kruft 1994; Ching 2007). However, many architects and theorists expand this definition to emphasise that the form of a building must also be a masterful assemblage of materials, which evokes a higher order of appreciation (Le Corbusier 1931; Pallasmaa 1996). Such definitions stress the importance of both *firmitas* and *venustas*, and imply that the two are closely connected. This position is not unexpected, given that architectural form is the tangible presence of a building or design.

Architectural form has shape, dimensionality and actual or intended physical properties, meaning that it can be directly experienced and thereby evoke multiple reactions or communicate different intentions (Gelernter 1995). Indeed, the particular way a form is modulated or moulded, in combination with its tectonic expression, is regarded as an important means of classifying and understanding architecture in stylistic, symbolic, phenomenal or philosophical terms (Birkerts 1994; Weston 2002). For example, Nikolaus Pevsner's (1984) celebration of architectural signification and Kenneth Frampton's (1995) call for a regional tectonic practice, each foreground the moral or ethical significance of form (Ostwald 2006; 2010). Similarly, Juhani Pallasmaa's (2006) arguments about the phenomenology of place and those of Charles Jencks and George Baird (1969) on semiotics, confirm that architecture must be understood in terms of both its formal expression and the way in which the human body experiences or interprets that expression. Significantly, all of these diverse ways of understanding architecture are drawn primarily from just two of the three pillars of classical Vitruvian thought: firmness and delight. In contrast, the final pillar, commodity, has had, in relative terms, less impact on the analysis of architectural history and design.

Vitruvius describes *utilitas* as the property of a design that facilitates 'faultless, unimpeded use through the disposition of space' (qtd. in Rowland and Howe 1999: 26). When translated as utility, *utilitas* suggests a degree of usefulness or functionality, whereas another translation renders it as commodiousness, referring to things that are capacious or accommodating. Collectively, the concepts of utility and commodity signal the importance of space and its use in any understanding or experience of architecture.

In architectural theory, space is that which is either enclosed by, or shaped by, form. Thus, the form of a building—its physical presence—delineates both the space it contains (its interior) and the space it is contained within (its site or context) (Fig. 1.1). For this reason Francis Ching describes the relationship between form and space as a 'unity of opposites' (2007: 96). The role of form in architecture is to structure and define the spaces we live in. However, we cannot inhabit form, we can only inhabit the voids that are framed or demarcated by form. Thus, as Bill Hillier notes, the built environment exists 'for us in two ways: as the physical forms that we build and see, and as the spaces that we use and move through' (2005: 97). This observation acknowledges that our experience of space is closely associated with both time and motion. To 'use' and to 'move through' suggest both the passage of time and the change of location. This understanding of space as necessarily connected to time and motion is alluded to in the previous section and is especially pertinent to Modernism. For example, in *Space, time and architecture* Giedion quotes from the mathematician Hermann Minkowski, who argues that 'henceforth space by itself and time by itself, are doomed to fade away into mere shadows, and only a kind of union of the two will preserve an independent reality' (qtd. in Giedion 1941: 14). In the modern world, space and time come together in an 'indivisible continuum' (Giedion 1941: 14) where spatial structure, awareness, understanding and appreciation are reliant on motion and the passage of time. As Heynen observes, Giedion's reading of Modern architecture 'proclaims and affirms time as a fourth dimension in a way that was quite unprecedented' (1999: 40). As a result of this, Modern architecture was conceptualised as being no longer reliant on the 'static qualities of a fixed space but by an uninterrupted play of simultaneous experiences of varying (spatial) character [including] dynamism, transparency … and a suggestive flexibility' (Heynen 1999: 40).

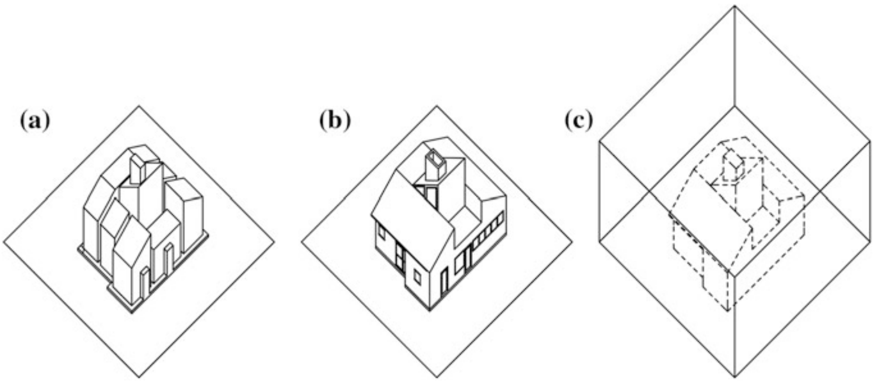


Fig. 1.1 A building contains **a** internal space, it has **b** form and dimensions and **c** is itself contained within space

The importance of space has been observed by many architectural historians (Zevi 1957; Giedion 1941), but while there is an extensive record of the assessment and critique of form, excluding space, it wasn't until 1984 that it was suggested that the reverse situation was not only possible, but advantageous. In the *Social logic of space,* Bill Hillier and Julienne Hanson argue that, '[h]owever much we may prefer to discuss architecture in terms of visual styles, its most far-reaching practical effects are not at the level of appearances at all, but at the level of space' (1984: ix). Space is the fundamental medium through which architects accommodate and structure society and serve the basic needs of communities. Most importantly, the focus on space, rather than form, shifts the emphasis away from issues of style or tectonics and towards social phenomena and cognitive or experiential properties. But how to describe this focus on the properties of architectural space?

Paul Crossley and Georgia Clarke (2000) suggest that one of the oldest analogies which has been used to describe and thereby understand architecture is language. For example, in the Renaissance it was thought that a concise 'grammar' of architecture could be found in the Classical orders. Despite the fact that the linguistic conceit is arguably at its strongest as a form of productive parallelism with only limited application, its appeal has endured. For this reason, in the late 1970s and early 1980s, when computational methods began to be developed by architects for generating architectural form, they become known as 'shape grammars' (Stiny and Gips 1972; Stiny and Mitchell 1978; Steadman 1983). If, then, form provides the grammatical basis for the language of architecture, by extension, space must furnish its syntactical basis. Thus, Hillier's and Hanson's theory, along with its associated set of computational techniques for understanding the relationship between space and social patterns, became known as Space Syntax.

1.4 The Social, Cognitive and Experiential

This section begins to explain how the social, cognitive and experiential properties of space can be conceptualised in architectural terms. All of these concepts are developed in later chapters, but in this section some general principles are introduced. Throughout this section it is also worth remembering that social structures tend to be spatial, time is often associated with cognition and experience with movement. Thus, a partial mapping is possible between the three main themes of this book (social, cognitive and experiential), and three major themes of the Modernist tradition (space, time and movement).

1.4.1 Social Properties

Social factors are those that relate to the organisation of a collective or group (Firth 1971). A society is effectively a group of people who share a pattern of relationships, attitudes or behaviours (Merton 1957). Such patterns are normally referred to as the ‘structures’ or ‘pillars’ of a society, because they both support and maintain the distinctive features of a group (Cruthers 1996). While sociologists tend to focus their attentions on class-based, gendered, racial or economic structures, some of the most tangible and enduring social structures are embodied in buildings. Just as class, gender and racial structures control access, determine significance or power and enforce a level of order on the interactions of a group, so too an architectural plan serves the same functions. For example, a society enshrines its acceptable patterns of behaviour in laws—statutory, constitutional or moral—whereas architecture uses walls and doors. In much the same way that the political structures of a society control each person’s capacity to be involved in decisions affecting that group, so too architecture shapes each person’s capacity to have access to particular locations, people or opportunities. Indeed, philosophers Jacques Rancière (2004) and Alain Badiou (2005) argue that the primary purpose of a politico-social structure is to control or organise the parts of society that are visible or accessible. This is precisely what architecture does through the manipulation of space and form (Ostwald 2007; 2009; 2014a).

Architecture is a reflection of the functional needs of the society that commissioned it; thereafter its continued physical presence restricts or enables various social interactions. This relationship has been noted many times in the past. For example, in a speech to the House of Commons in 1943, Winston Churchill observed that, ‘we shape our buildings and thereafter they shape us’. Similarly, Steen Rasmussen argues that architecture ‘confines space so we can dwell in it’ and in doing so ‘creates the framework around our lives’ (1959: 10). In essence, the way space is arranged in a plan is a manifestation of a particular pattern of social relationships that it both enables and perpetuates (Markus 1993; Peponis and Wineman 2002). Certainly buildings are adaptable and society can change, but these processes are typically slow. In the meantime, buildings capture or enshrine particular social patterns or structures in the spatial relationships they create (Hanson 1998; Dovey 1999). Consider the following example of a simple way in which a single room can be mapped to its significance in the social structure of a building.

Imagine a small room that is square in plan and has a ceiling height that is the same dimension as each wall. This cube of space is located at the centre of small building and it has one door in each wall leading to a room on each side. Relative to the other spaces in the building, this room has an increased likelihood of people passing through it, by virtue of both the fact it has multiple connections to adjacent spaces and it occupies a pivotal location in the plan. While we do not know if this room functions as a thoroughfare, informal meeting space or security check-point, we can determine that its significance in the social structure of the building is heightened for some reason. Now imagine that there is a second, identically proportioned cubic room in the same plan, but it is located at the edge and it has only one door. All other things being equal, the likelihood of people meeting one another in this room is much lower. This is because, peripheral locations, regardless of their function, tend to have reduced opportunities for social interaction (Montello 2007). The social properties of each of these cubic rooms are determined by the topology of the plan, which defines where they are positioned in the larger network of spatial connections that make up the building (Markus 1993). The proportions of the two rooms, regardless of how interesting and significant they may seem at first glance, turn out to be far less significant (or even completely insignificant) in terms of the building's social structure. The social properties of Modern architecture that are investigated in this book are all associated with spatial topology.

1.4.2 Cognitive Properties

In conventional usage, the term 'cognition' refers to the acquisition of knowledge. Most commonly, knowledge is acquired through direct experience, although structured learning processes, logical deduction and other equivalent strategies are also effective. Several branches of cognitive psychology are well known to architectural researchers. For example, design cognition (Cross 2007) is the process of developing knowledge and skills associated with designing, either through the act itself or through education, mentoring or apprenticeship. Of greater relevance in the present context is spatial cognition. Some of the most important cognitive skills required for human survival and advancement are concerned with a capacity to acquire and apply environmental information (Newcombe and Huttenlocher 2003; Waller and Nadel 2013). Spatial cognition is associated with navigation, exploration and surveillance (Hudson 1995; Ellard 2009). It is essential for protecting resources, finding safety and tracking prey (Kaplan and Kaplan 1982; 1989; Kaplan 1987). Past research in spatial psychology has also observed patterns in the way the human mind interprets or relies on various environmental or spatial factors. Such studies, while primarily concerned with human responses to environments, also provide evidence about the factors that are more or less likely to support cognition (Devlin 2001; Allen 2004). This is especially the case for studies about wayfinding, which identify various factors that can provide a measure of an environment's cognitive clarity or efficiency. This is the type of cognition that is considered in the present book. It is associated with the properties of an architectural plan that support the acquisition of spatial knowledge through movement and vision. Peter Blundell Jones emphasises the cognitive significance of movement when he argues that 'walking remains essential' to spatial experience and understanding, 'it is the basis of who and where we are, the means by which we gather and separate, by which we first traverse territories and give them definition. Our understanding of space begins with the body, and the body is the first geometer, journeys being also a primary metaphor for the construction of memory and narrative' (Jones 2015: 4). Given this background, consider the following two examples.

It is possible (as we will see in Part I) to measure and compare the extent to which an architectural plan can be efficiently traversed or searched. Thus, we can measure if one plan is more conducive to being surveyed or patrolled than another. Such measures are indicators of the degree to which spatial knowledge about the plan can be gleaned. A plan that is highly inefficient to traverse will require a more substantial investment in spatial cognition than one that is more efficient. In this way, a mathematical analysis of a series of architectural plans can be used to measure the general cognitive efficiency of each. Of course, individual people may approach the task of understanding a plan in different ways. However, if all other factors are equal (including the level of spatial experience of the observer, the area of the floor plan and the number of rooms), a plan which accommodates a more efficient means of viewing or traversing will, on average, be more conducive to cognition.

Another spatial property that has an impact on the acquisition of knowledge is associated with vistas or views. Long, wide vistas in an environment, whether built or natural, typically provide more information than short narrow vistas, and are therefore more likely to support spatial cognition. This is a generalisation, and clearly individual instances may differ: a particular long, wide vista may actually show nothing of interest, while another short narrow one may be filled with information. Nevertheless, despite this possibility existing, it is logically and statistically less likely to occur. The larger the volume of visible space, the more chance there is that it will contain useful information. For this reason, a study of the width and depth of vistas can provide comparative data about the general information-bearing capacity of an environment, which is in turn an indicator of spatial cognition.

While later chapters which deal with cognitive arguments will provide more concise definitions of the relevant factors, the approach taken in this book is focussed on a narrow interpretation of the measurable properties of an environment that are known to have an impact on the acquisition of spatial knowledge. These are typically associated with movement and vision.

1.4.3 Experiential Properties

The word 'experience' implies the existence of two conditions. The first condition is a level of proximity or immediacy, because experience implies a direct engagement. The second is a sensory capacity to process information, because experience suggests a level of reception. There are also parallels between experience and cognition because both rely on the senses to acquire knowledge, but cognition is about understanding, whereas experience is about being or feeling (Bloomer and Moore 1977; Golledge and Stimson 1997). Moreover, the human senses require different levels of proximity to function, either cognitively or experientially (Gold 1980). Thus, taste requires consumption and touch requires contact, both of which are personal and immediate. Smell and sound may still have an impact on the senses at a longer range, and vision is often regarded as the most all-encompassing and far-reaching in its capacity for shaping experience.

Architects often attempt to explain or choreograph spatial experience through imagined accounts. For example, Le Corbusier presented an account of the changing experience of movement through space and over time in the *Maison La*

Roche-Jeanneret. His account commences with the observation that after entry, 'the architectural spectacle at once offers itself to the eye. You follow an itinerary and the perspectives develop with great variety, developing a play of light on the walls or making pools of shadow' (qtd. in Boesiger 1995a: 60). In the *Villa Savoye*, the visitor is presented with a veritable *promenade architecturale* of 'prospects which are constantly changing and unexpected, even astonishing'. 'It is by moving about', through the 'rigorous scheme of pillars and beams', that experience and understanding are shaped (qtd. in Boesiger 1995b: 24). In these accounts Le Corbusier stresses the way the human body is seemingly led by his design to experience a particular itinerary of visual experience. Richard Neutra also offers an imagined account of the experience of one of his designs, but he emphasizes the physiology of spatial experience. Neutra's description, framed in a universal first-person narrative, describes how 'we' respond to architecture in terms of our collective actions and feelings. Neutra not only describes the perception of architecture, but the involuntary muscular and sensory response of the body. These examples, drawn from two of the most important proponents of Modernism, have different motives and methods, but they each seek to explain the relationship between architecture and experience in such a way as to suggest it is universal and ineluctable. Such accounts typically stress the power of directionality and the more poetic, or mysterious, properties associated with the passage of time and movement through space.

In this book, several of the methods we use provide a measure of various visual properties of buildings. These methods do not model the experience of an individual, rather they measure generalised spatio-visual properties, many of which have been convincingly connected to human experience. Consider the following two examples about spatial experience, the first of which is concerned with directionality and the second, mystery.

One of the most basic human spatial experiences is associated with directionality. Directionality occurs when architectural space and form emphasise a particular axis or orientation, attracting a person's sight and enticing them to look, or even move, in that direction. This property of directionality is associated with difference. If all directions in a room have the same distance, and the ceiling above and floor below are flat (and there are no objects, elements or distractions in a room), then there is little or no enticement to move. But if the same room has a barrel-vaulted ceiling, it immediately changes the experience of that space by giving it a sense of direction. If the room is not rectilinear in plan, but narrows to one wall, an additional spatial dynamism is introduced (Thiis-Evensen 1987). All of these changes are geometric and measurable, and using past research as a guide, simple generalisations can be made about the spatial experience of a room or plan. While such generalisations have the problem that they cannot represent the experience of a particular individual, they have the advantage of being repeatable and comparable across multiple architectural plans.

As a second example, a room which is completely visible from a single observation point, and which has no visual obstructions, could be said to possess a low level of mystery. Assuming that there are no additional elements in the room that might evoke a sense of intrigue—like *tromp l'oeil*, dramatic lighting effects, mirrored surfaces or other inhabitants—then such a room could be regarded as not inspiring a desire to explore. But if a room has multiple corners, wide columns and screened bay windows, then parts of the space, however fragmentary, are hidden. The capacity to sense how much of a space is not available for viewing is associated with heightened feelings of mystery. Or conversely, as multiple authors have observed, there is a correlation between the degree of concealment offered by an environment and the sense of mystery it evokes (Baker 1995; Dee 2001).

These examples of approaching the experience of space in terms of directionality and mystery are relatively narrow and limited, but along with other spatio-visual factors, they are pivotal to several arguments about Modern architecture.

1.5 Structuring the Research

There are challenges inherent in using mathematical and computational methods to investigate complex design theories and celebrated buildings. For one thing, a degree of interpretation is necessary to translate the arguments of architects and historians into a format that is sufficiently rigorous that they can be tested. For another, few buildings are perfect reflections of their architect's ideologies or design strategies. Architecture is always contingent on a client's site, program and budget, as well as the availability of materials, technology and skilled labour. As such, buildings are rarely perfect subjects for quantitative analysis. But with sufficient sensitivity and background knowledge, much can be learnt about architecture by adopting a mathematical and computational perspective. This is especially the case when examining themes—like the social, cognitive and perceptual ambitions of Modernism—that would be difficult to investigate without these more recent, quantitative techniques. But it also places pressure on us to be clear about which aspects of architecture we will be approaching using these methods. This section describes both the approach taken to constructing an investigation of the three properties of Modern design, and the structure of the book itself.

Architectural scholars are often forced to differentiate between design as a *process*, a *product,* a *position* and as a type of *provenance*. The first of these, the process of design, refers to the act of creating a particular combination of space and form that will fulfil a pre-determined function. The second, the product, is the outcome of the design process, being the architect's final scheme as comprehensively delineated in a set of drawings and models or as physically constructed. The third category is concerned with design as a theoretical position. It refers to the arguments, principles or philosophies espoused by the architect to support or explain his or her product. The final of these four facets of design is associated with the way the product and its position—the building and its underlying theory—are used by scholars to frame its reception. Thus, the provenance of design is concerned with the way scholars position a building as part of a larger narrative about the history of architecture.

For people who are unfamiliar with the way buildings are designed, realised, debated and framed, the fact that these four are not the same, may come as a surprise. Surely the architect's attitudes and practices are clearly visible in the completed design, and historians simply record these for prosperity? Unfortunately, this is not the case. As Paul Alan Johnson (1994) warns, we cannot assume that the architect's product is actually a true reflection of his or her position. Moreover, the history of the Modern movement in architecture tells us as much about the historians who wrote it (their values and prejudices), as it does about the architecture itself (Tournikiotis 1999; Hartoonian 2013). To borrow a concept from semiotics, there is no 'social contract' that ensures that architects do as they say, or that historians and critics provide a transparent or distortion-free account of their works. There is always some deformation, mis-alignment or disagreement between *process*, *product*, *position* and *provenance.* However, rather than being innately problematic, this distance allows and even encourages historians to question and interpret the past. It also authorizes a wide range of investigations into both the theorised and actual properties of buildings. In the context of the present book, it confirms the importance of comparing the spatial properties of an architectural design with the explanations provided for it by its designer, and the interpretations of it offered by scholars, critics and historians.

Instead of considering the process of design—which we rarely have adequate access to or documentation of—this book has its practical foundation in the process of spatial analysis. Part I of the book has three chapters, the first of which provides an overview of syntactical analysis, including its philosophical and mathematical foundations. Four specific syntactical techniques are introduced in Chap. 2: convex space analysis, axial line analysis, intersection point analysis and isovist field analysis. Chap. 3 provides detailed worked examples of the first three of these techniques, which analyse the relationships embedded in a plan between spaces, lines of sight or movement and the intersections between them. Formulas and sample calculations and interpretations of the results are also presented for each technique. In Chap. 4 the focus shifts to the history, theory and application of isovist analysis. While collectively the chapters in Part I describe what might be called the 'standard' or 'accepted' variation of each technique, we also discuss more advanced variants, alongside some new developments or alternative applications proposed in this book.

In Parts II and III, these analytical techniques are used to gather data from thirty-seven Modern designs. For all of the designs analysed in this way, new three-dimensional computer models were created based on either final working drawings produced by their architects, or surveys after their completion. To confirm the accuracy of the models, photographic records of the completed works were also accessed, along with archival material from the architects' practices. Site visits were undertaken to many of the houses between 2010 and 2015 to confirm the physical properties of several designs. While the majority of the research investigations in this book rely on plans derived from these models as their primary source of data, sectional and three-dimensional spatial characteristics are also considered in some chapters.

Throughout Parts II and III, each chapter commences with a review of specific theories or arguments about the spatial properties of designs by an individual architect. These arguments are then reframed as a series of hypotheses about the properties that would be anticipated in a building that conformed to the substance of the claims. The hypotheses are used to narrow the scope of each investigation to something that can be interrogated using the particular technique, and provide insight into either the architecture being examined, or arguments that have been made about it. In most cases the designs are considered both individually and as part of a set of works by the architect. In this way the underlying general or statistical pattern in a group of designs (a genotype) can be compared with the properties of specific instances of that pattern (a phenotype).

Part II contains three chapters, the first of which, Chap. 5 examines spatial properties that are allegedly a by-product of Mies van der Rohe's development of the free plan and are seen most clearly in his *Farnsworth House*. However, it is unclear if these properties were also present in his earlier, less overtly open-planned designs, and whether they are as significant as suggested. The spatial properties that are analysed are concerned with the way Mies's domestic architecture is inhabited, moved through and viewed. In addition to the *Farnsworth House*, the designs that are analysed include the *Wolf*, *Esters*, *Lange* and *Lemke* houses. In Chap. 6 we examine Richard Neutra's famous paired axiom, paraphrased as 'vision leads to movement and experience leads to understanding'. The first of these suggests that long, controlled vistas in a plan can lead a person through space, while the second proposes that this movement provides a person with a heightened sense of both the spaces in the building and of the environment in which it is set. Along with Neutra's celebrated *Kaufmann Desert House,* the chapter examines the *Tremaine*, *Moore*, *Kramer* and *Oxley* houses. In Chap. 7 a series of assumptions about the social structure of Glenn Murcutt's rural domestic designs are examined using ten of his designs. The core position tested in this chapter is that Murcutt's rural domestic type represents a consistent and deliberate approach to social structure, which is at least as important as his response to environmental and formal issues.

The chapters in Part III focus on the spatio-visual properties of Wright's domestic architecture, and in particular a range of theories about the experience of either inhabiting his living spaces or moving through his houses. These chapters have a common foundation in spatial cognition and environmental preference theories. They use isovists to measure various properties of space, or space as experienced through movement, including indicators of outlook, enclosure, mystery, complexity and enticement. One of Wright's most famous design strategies, 'reduplication', is also examined mathematically for the first time. In Chap. 8, a detailed review of theorised properties and isovist measures is undertaken using Wright's *Heurtley House* as a test case. Using the results of this process, in Chap. 9, living spaces in seventeen of Wright's houses are examined for their theorised spatio-visual properties, in each case with the emphasis being placed on whether there is evidence of the proposed pattern in the architecture. As part of this process, the properties of Wright's 'Hollyhock' (*Aline Barnsdall*) and 'Fallingwater' (*Edgar J. Kaufmann*) houses are also compared with those of his Prairie Style, Textile-block and Usonian works, to investigate another claim about the development of Wright's architectural style. In Chap. 10 the shifting spatio-visual experience of movement through Wright's architecture is examined. In one of the largest comparative applications of isovist analysis undertaken, fifteen of Wright's designs are methodically examined and compared against their theorised properties.

In the conclusion in Chap. 11, the book revisits the specific social, cognitive and experiential properties that were measured previously and asks whether, within the limits of its small sample of canonical works of Modern architecture, evidence can be found of an alignment between position, product and provenance.

1.6 Presentation and Precision

Throughout this book rendered perspective images are provided to assist readers to understand the three-dimensional properties of the buildings being analysed. In contrast, line drawings are employed to depict the plans, axonometric views and syntactical maps. With the exception of a few entourage elements (people and vehicles) to provide a sense of scale, the perspectives are deliberately abstract and focussed on form. As such, they provide a counterpoint to the rest of the content of this book, which is about space. The particular perspective views chosen have no other significance.

Finally, the question of precision is an interesting one when analysing architecture. In a book about mathematics it might be expected that every number would be reported to the same level of precision, leading to an early decision about 'significant digits'. But the present book is fundamentally about architecture, and the themes it examines are derived from design history and theory, neither of which are mathematical disciplines. Furthermore, as past research into design reveals (Caciagli 2001; Groat and Wang 2002), a high level of accuracy is not necessarily any better for arriving at a convincing outcome than a lower level. The issue isn't accuracy but appropriateness. For this reason the present book generally adopts three levels of precision and reporting. First, in Part I, when introducing the analytical methods, data is typically reported to just two decimal places. As the data is only being used to explain or demonstrate an approach, a higher level of accuracy isn't required. Second, for the primary analysis in Parts II and III of this book, we typically report results to four decimal places. Third, when we summarise or discuss the results in the text, or test various hypotheses, we often use percentages that are rounded to the nearest integer. Thus, the three orders of precision in this book vary depending on whether they are used for explaining, developing or discussing results.

Part I
Methods

Chapter 2
Space Syntax, Theory and Techniques

This chapter provides an overview of Space Syntax theory and its associated analytical techniques, four of which are used in later chapters to examine various arguments about Modern architecture. The first three techniques possess a common mathematical basis in graph theory, whereas the fourth, in its earliest form at least, was more reliant on analytical and planar geometry. The first three techniques are convex space analysis, axial line analysis and intersection point analysis. These three, respectively, can be used to examine the relationships between visually defined spaces or rooms, paths or vistas through space and pause-points where decisions are made about orientation or movement. The fourth technique, isovist analysis, measures the spatio-visual properties of an environment. There are multiple variations of the last technique, of which visibility graph analysis is the most common. Significantly, visibility graph analysis also relies on graph theory to interpret or generalise measures derived from sets of isovists, to analyse space more holistically. All four techniques are predominantly used for the assessment and comparison of the two-dimensional properties of architectural plans, although sectional and, in some cases, three-dimensional versions of these methods exist.

This chapter commences with a background to Space Syntax and its foundation principles. This is followed by a review of the origins of graph theory, its role in the development of Space Syntax theory and the use of graph measures in architecture. The next four sections feature short explanations of the abstraction or mapping techniques used to translate complex environments into graphs or representations of spatio-visual geometry. This is the central purpose of the chapter, to introduce these techniques, their abstraction, measurement and interpretative methods and limits. Chapters 3 and 4 contain more detailed explanations of the techniques, their mathematical processes and how the results are interpreted.

M. J. Ostwald and M. J. Dawes, *The Mathematics of the Modernist Villa*,
Mathematics and the Built Environment 3,
https://doi.org/10.1007/978-3-319-71647-3_2

2.1 Introduction

In 1984, with the publication of the *Social Logic of Space*, Bill Hillier and Julienne Hanson encouraged a paradigm shift in architecture by suggesting that the study of the structure of space should be divorced from the more innately subjective study of architectural form. They argued that space may be empty, invisible and amorphous, but it does have several critical properties, including appreciable difference and permeability, which exert a significant hold over architecture and its social function. The first of these properties, difference, relates to the capacity to distinguish one space from any other; the second, permeability, refers to the way in which spaces are connected or configured. However, somewhat controversially, the idea of severing the connection between space and form also entails the rejection of two conventional 'geographic' concerns in architecture, 'the concept of location' and the 'notion of distance' (Hillier and Hanson 1984: xii). By removing direct consideration of form, scale and dimension from architectural analysis, the new, non-geographic method could focus exclusively on topological qualities including spatial structure, permeability and relative complexity.

The syntactical theory of space is constructed around a complimentary arrangement between two ideas. First, it proposes that 'a spatial layout can reflect and embody a social pattern' (Hillier 2005: 104). Such a pattern serves to enshrine the collective social structures and values of a group in the spatial configuration of buildings which have been designed to accommodate them. Second, 'space can also shape a social pattern' (Hillier 2005: 104), because of the way an architectural or urban plan places certain areas in more central positions and locates others to the periphery. Thus, when considering aggregate movement patterns between any two spaces, occupants will be more likely to pass through the central ones more frequently. In this way centralised spaces offer greater potential for co-presence of inhabitants and subsequent heightened social interaction (Montello 2007). This also means that adjusting the spatial structure alters the potential for social interaction.

John Peponis and Jean Wineman summarise this two-way dependency between spatial and social structures with the observation that 'it is possible to identify certain underlying structures of space that are linked to observable patterns of behaviour and that these patterns, in turn, create social function, whether generative or reproductive' (2002: 272). Sonit Bafna offers a similar account of this reciprocal dependency, as being 'that social structure is inherently spatial and inversely that the configuration of inhabited space has a fundamentally social logic' (2003: 18). Space Syntax, therefore, offers a way of studying the relationship between configurational patterns in the built environment and their generative or reproductive social structures along with psychological properties associated with spatial experience.

While this background provides a theoretical foundation for Space Syntax, in an operational sense its analytical techniques have three stages, which have been described as either abstraction, analysis and interpretation, or representation, configuration and interpretation (Hillier and Tzortzi 2006). The first stage reduces, or abstracts, an environment—typically an architectural or urban plan—into a series of differentiated components (spaces, paths, points or vistas) and the connections between them. The resulting set of connected components is often called a map, although it is also, in mathematical terms, a graph. In the second stage the topological properties of the map are examined visually and mathematically using graph theory. Consequently, the majority of the connections that are identified between spatial and social structures are reliant on graph-theoretic measures. In the third stage, mathematical measures derived from the map are used to interpret various social or perceptual properties of the original architectural or urban plan. Before we look at these three stages and how they operate in each of the major techniques, the following section provides a background to graph theory and its application in the analysis of spatial properties.

2.2 Graphs and Space

The origins of graph theory are conventionally traced to a particular arrangement of bridges over the Pregel River in the city of Konigsberg in Prussia. Historic accounts suggest that, in the late fifteenth century, the bridges were a source of a popular local conundrum. Each year the local populace would attempt to walk a circuit of these bridges, visiting each of the town's four landmasses in turn, by crossing each bridge only once, before returning to their point of departure (Hopkins and Wilson 2004). Despite multiple attempts to identify a route through the city that would achieve this goal, it wasn't until 1736 that Leonhard Euler proved that it wasn't possible. Euler's proof involved divesting this problem of its geographic properties (distance and orientation) and converting the spaces and the connections between them into an abstract set of relationships. From this new topological perspective, Euler was able to develop a pure insight into the structure of the bridges of Konigsberg, which allowed him to determine that a solution was impossible. As a result of this process, Euler developed a general theorem to address similar problems of topological relationships, including alternative configurations of landmasses and bridges. Despite their novelty, these ideas remained largely undeveloped until the mid-nineteenth century when modern node and edge diagrams emerged and the study of graph theory began to be formalised. Node and edge diagrams offer a simplified representation of complex spatial relationships. In the case of Konigsberg, the landmasses could be abstracted to become graph nodes and the bridges to become graph edges, producing a diagrammatic representation of space that could be used to analyse the relationship between the two (Fig. 2.1).

By the second half of the twentieth century, the process of abstracting spatial relationships into graphs had begun to be used for the analysis of accessibility and land use (Hansen 1959), transport networks (Kansky 1963; Taaffe et al. 1973) and facility planning (Seppanen and Moore 1970). In one of the first architectural examples of this approach, Lionel March and Philip Steadman (1971) created a graph representing the topological relationships between rooms in a building and

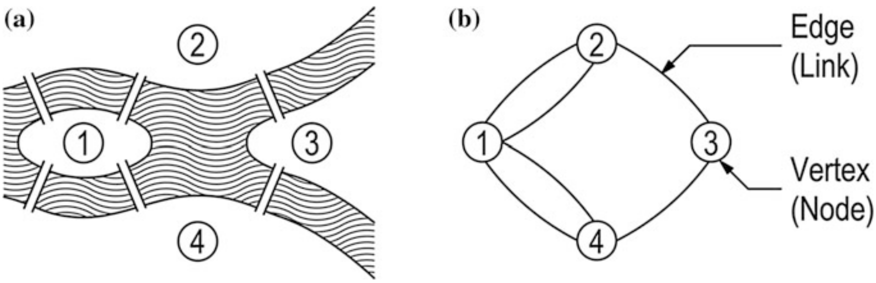


Fig. 2.1 **a** A map of the arrangement of bridges and landmasses in Konigsberg and **b** a graph of these topological relationships expressed as a node and edge diagram

used this to demonstrate the use of graph theory for design development and evaluation. However, despite their proposal, more than a decade passed before architectural researchers realised that a graph of spatial relationships also offered a means of understanding the underlying social structure of a building. It was at this point that the isolation of space from form, or topology from geography, became crucial for architectural research. This shift also posed a challenge for architectural scholars at the time; the realisation that the appearance or form of a building may be less important than its underlying spatial configuration.

In order to understand what this shift from geographic to topological thinking entailed, consider an example of three hypothetical villas. These villas are each positioned on adjacent sites and they have been designed in different architectural styles, respectively Neo-Classical, Modernist and Post-Modernist (Fig. 2.2). A conventional architectural analysis of these villas—judging them in terms of stylistic details, building form and materiality—would conclude that the three have little in common. The first has Doric columns beneath a Greek pediment, the second has a flat roof and an asymmetrical, rectilinear geometry and the third features a raked and modelled silhouette, with a bifurcated gable framing a dominant chimney. Despite these differences, the three villas share the same internal spatial structure and

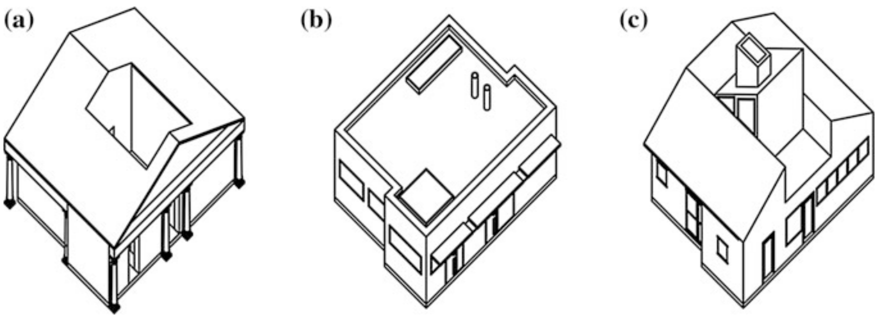


Fig. 2.2 Axonometric views of three villas in different architectural styles or formal languages: **a** Neo-Classical **b** Modernist and **c** Post-Modernist

are thus, in a social sense, identical (Fig. 2.3). Conversely, it is also possible that three villas, each identical in external appearance, could contain radically different spatial structures. Thus, space and form do not exist in a fixed or predictable relationship. Furthermore, whereas the exterior form of the villa might express something about the values of the original client or architect, the spatial structure of its interior is more likely to be a reflection of the social orders and hierarchies that exist in the wider community and which the house fundamentally serves.

While this revelation—that the relationship between form and space might be reciprocal, but the relationship between visual expression and social structure is not—has been gradually accepted over the last few decades, the real innovation proposed by early Space Syntax researchers was to develop a method for analysing space without form. This method required a means of studying spatial topology that was rigorous, repeatable and logical. The solution offered by Hillier and Hanson involved a process for representing or abstracting the plan of a building in such a way as to produce a map or graph made up of nodes and edges. Once such a graph is created, its configurational or structural properties can be analysed visually and mathematically and these results can be used in turn to interpret various properties

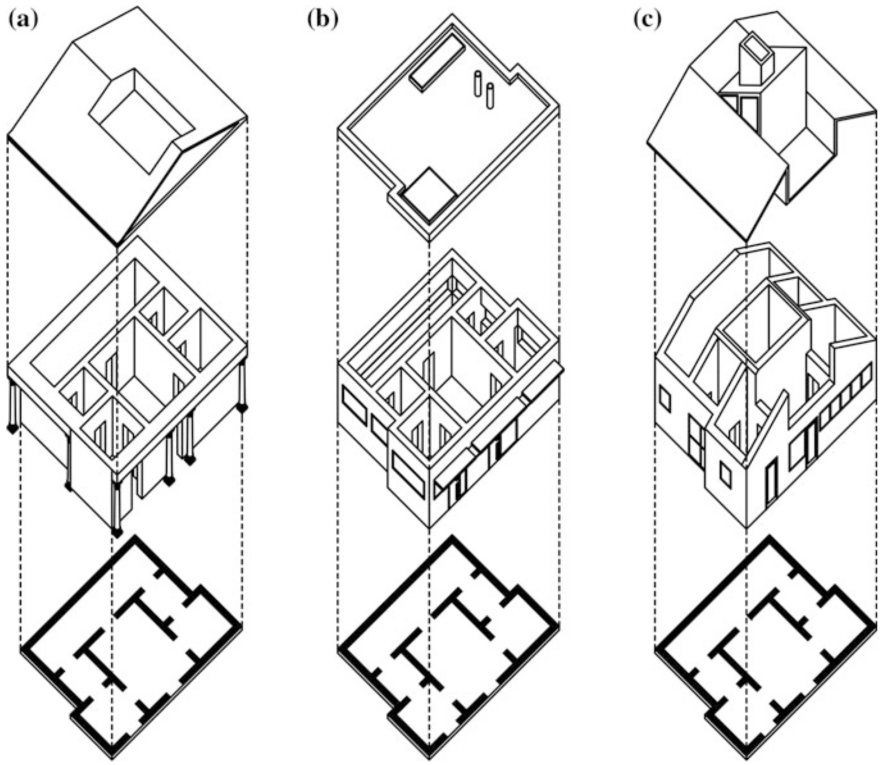


Fig. 2.3 The identical underlying spatial structure of the three villas is revealed

of the original plan. Indeed, the early Space Syntax techniques all repeated this tripartite process of abstraction, analysis and interpretation. The primary element that differed across these techniques was the abstraction process which, depending on the variation used, developed graphs of different architectural properties. The mathematical concepts, processes and formulas remained largely unchanged, while the interpretation of the results was modified to investigate or critique the particular features of the plan which had been mapped.

The first stage of each of the major Space Syntax techniques commences with the abstraction of the plan into a map of elements and the connections between them, a process that actually produces a graph made up of nodes and edges. For example, the convex space technique commences by abstracting the environment into the fewest number of visually coherent spaces and the connections between them. When derived from an architectural plan, these spaces are convex in shape, which means that their entire perimeter is visible from any point within. This technique is used to investigate the configurational relationship between spaces as defined by the capacity to pass between them. Thus, the resultant map is effectively a graph of spaces (nodes) and their connections or adjacencies (edges). The axial line technique commences by mapping a plan to the fewest number of straight lines that surveil all spaces in the environment. Axial lines represent idealised paths through space and the analysis of the topological relationships between axial lines is effectively an investigation of the movement potential of an environment. The maps produced as part of this technique abstract the environment into a network of paths (nodes) and the connections between them (edges). A third technique maps an environment into the set of intersections, being choice or pause points, created by the crossings of the fewest number of straight lines that surveil all spaces in an environment. These intersection points—and in some variants of the technique, the end-points of the lines which define them—are the optimal or minimal set of locations where decisions are made about movement, surveillance and navigation. For this technique, the resultant map is of intersection points (nodes) and the paths that connect them (edges). A fourth abstraction technique converts the plan of an environment into a series of isovists located at a regular spacing. An isovist represents the portion of the environment that is visible from a particular location. This technique commences by overlaying a regular grid of squares on the environment and the centres of the squares are linked to determine which observation points are visible from each. Depending on the input data, the analysis of these relationships reveals the visible (sight-related) or traversable (movement-related) properties of the space. The first three of these abstraction techniques focus attention on the topology of an architectural plan in terms of the connections between spaces, paths and intersection points, while the fourth is concerned with the geometry of visible space (Fig. 2.4). Each of these techniques possesses unique strengths and weaknesses that are examined in more detail in the following sections. However, before progressing with the overview of the second and third stages of the classic Space Syntax method, two additional features of the graph abstraction must be briefly described.

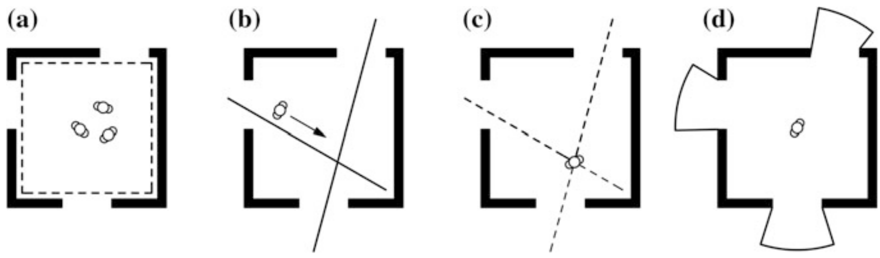


Fig. 2.4 Four different abstraction models **a** spaces, **b** paths, **c** intersections and **d** spatio-visual geometry

A graph is a network of nodes and edges. Because graphs do not possess traditional geographic features, like orientation or dimensionality, they can be rearranged in various different ways, to emphasise or illuminate particular features, providing none of their connections are broken. This also means that the maps created during the first stage of the analytical process can be arranged to emphasise different architectural properties. As an example of what this implies, consider a permeability graph of the spaces in an architectural plan—that is, a graph of rooms (nodes) and doors that allow access between them (edges). A key functional requirement of such a plan is not only to control access between rooms, but also between the exterior and the interior of the building. For this reason, an additional node is almost always added in architectural analysis representing the exterior world and signified by a crossed circle (⊕). Thus, the set of rooms plus the exterior, and the connections between them, can be used to map the spatial structure of a plan.

An important principle in syntactical analysis is that the 'spatial layout not only looks but is different when seen from different points of view in the layout' (Hillier 2005: 101). In order to visualise how this difference operates, a permeability graph can be rearranged in multiple ways to highlight different features of the plan. For example, arranging the spaces relative to the exterior is a way of representing the accessibility conditions faced by visitors. Rearranging the graph relative to the living room represents the accessibility conditions experienced by inhabitants. The space which is at the root or foundation of the rearranged graph is called the 'carrier', and it is conventionally placed at the base of the graph and spaces attached to it are arranged above it, and so on. This process is described as 'justifying' the graph relative to different carriers. There are as many different ways of justifying a graph as there are nodes in it. Redrawing the graph in this way maintains its topological structure while supporting alternative intuitive readings of the properties of the plan (Fig. 2.5). Importantly, changing the carrier in this way does not change the mathematical properties of the graph.

The second stage in the typical Space Syntax technique involves the mathematical analysis of the newly abstracted map of spaces, paths or intersections. The analysis generally commences with the derivation of simple summative measures, including the number of nodes, edges or types of social spaces (for example, 'public' or 'private' spaces). As a proportion of the total, these can be compared with the results

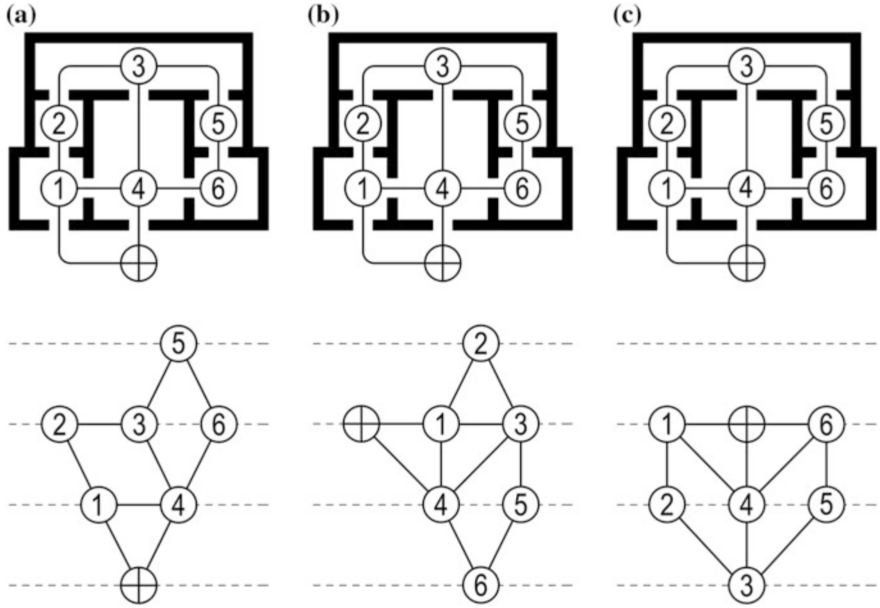


Fig. 2.5 Graphs of a plan justified to reflect alternative spatial positions: **a** visitor, **b** occupant in a more public space, **c** occupant in a more private space

of other, similarly constructed graphs. More commonly, the centrality or closeness of each node, in relation to all other nodes, provides the basis for comparison. The Total Depth (*TD*) or Mean Depth (*MD*) of nodes are typically determined along with measures for Relative Asymmetry (*RA*), Control Value (*CV*) and integration (*i*). Nevertheless, to be useful, several of these measures must be normalised in some way to allow for comparisons to be constructed between different size graphs. Hillier and Hanson's (1984) solution to this problem was to propose an alternative measure, Real Relative Asymmetry (*RRA*), which is derived from a formula that normalises relative asymmetry values against those of an idealised diamond-shaped graph. Although this measure is still widely used, the rationale for the use of a diamond-shaped graph is not necessarily compelling and many other graphs could equally serve as a normalising benchmark (Teklenburg et al. 1993).

The final stage in the Space Syntax approach, wherein the results of the mathematical analysis are used to interpret a building plan, remains, even after four decades of research, a contested topic. For example, Khadiga Osman and Mamoun Suliman argue that the 'interpretation process of the numerical results remains complex [and] subjective' (1994: 190). Kim Dovey claims that the explanations and methods are 'at times highly difficult to understand' (1999: 24) and the interpretation is over-reliant on ambiguous terminology. Most often, in the various Space Syntax techniques, numerical results are reported and used to sequence or compare the values derived from various nodes, before the overall properties are described qualitatively in terms of spaces that are either 'shallow' and 'integrated', or 'deep' and ‘segregated’. However, derived values can also be ‘related to psychological variables such as memorability’ (Montello 2007: iv). The following sections focus on the four major abstraction methods, how they operate and how they have been used to interpret the results of the graph analysis.

2.3 Convex Space Analysis

Convex space analysis is one of the two original techniques described in *The Social Logic of Space*. This approach abstracts the environment into the minimum number of visually coherent areas known as convex spaces. The set of convex spaces is often described as an environment’s ‘fewest and fattest spaces that cover the entire plan, the former always prevailing over the latter’ (Markus 1993: 14). A convex space is a psychologically self-contained unit of space where every point of the perimeter is visible from every point within. It is also a space wherein ‘no line drawn between any two points in the space goes outside the space’ (Hillier and Hanson 1984: 98). Thus, an ‘L-shaped’ space is not convex and must be divided into two smaller spaces for it to comply with the rule (Fig. 2.6). Convex spaces are visually coherent locations of social interaction. John Peponis and Tahar Bellal state that a ‘convex map represents the maximal units of potential reciprocal coawareness that are implied by a given disposition of boundaries’ (2010: 984). Architectural interiors are the most common subjects of convex space analysis, as these environments tend to contain well defined two-dimensional spaces, as opposed to urban scale areas which are typically dominated by long streets that often have a lower level of visual coherence.

Convex space analysis functions by abstracting an environment into a set of connected convex space s before analysing this set both visually and mathematically. Figure 2.7 shows three simple villa plans that have been abstracted into a graph of connected convex spaces (in this example, doorway-thickness and the wall-thickness associated with them, are not considered convex spaces). In a mathematical analysis,

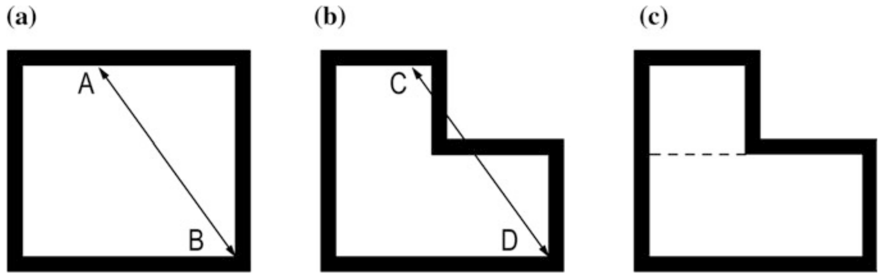


Fig. 2.6 A convex shape is one where any point on the perimeter may be linked directly to all other points on the perimeter (A-B) without moving outside the perimeter (C-D). **a** Convex space, **b** non-convex space, and **c** non-convex space partitioned into two convex spaces

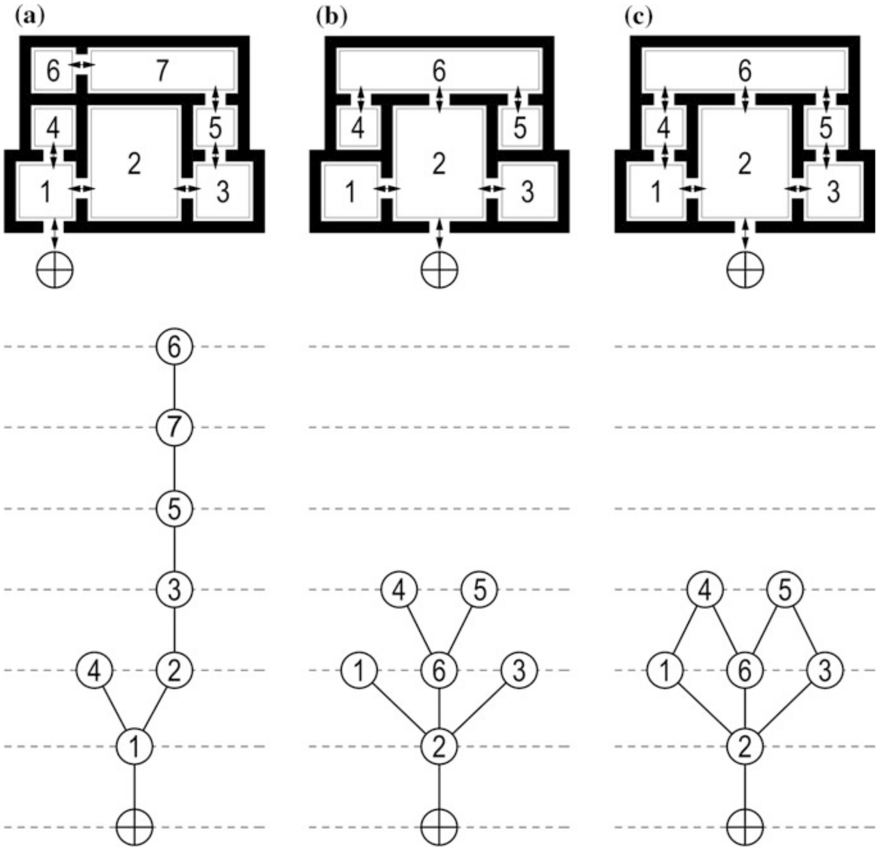


Fig. 2.7 Convex maps of three simple villas—**a** *Epsilon*, **b** *Zeta* and **c** *Eta*—and their representation as graphs justified to an external carrier

each convex space becomes a graph node with the doorways being the edges. When the graph is drawn it is then a simple procedure to calculate various graph theoretic measures for each space and for the entire plan (Ostwald 2011a).

A convex graph, like any spatial graph, can also be interpreted visually, although this is necessarily more subjective. For example, the shape of the graph, when justified with a particular carrier, can be used to describe its general properties relative to that carrier. Thus, a graph that has a branching or arborescent topological structure is often described as, 'bush-like' or 'tree-like', depending on how shallow or deep the hierarchical structure is (Fig. 2.8). Arborescent structures balance flexibility and control, because users have to pass through some key spaces each time they wish to access other parts of the plan. More connected graphs are said to possess a rhizomorphous topological structure, which is sometimes described as 'looped', 'ringed' or 'latticed' (Fig. 2.9). Rhizomorphous structures provide their inhabitants with a high degree of choice and flexibility in how they will move though space. In contrast linear graphs, which possess an enfilade structure, exert a high level of

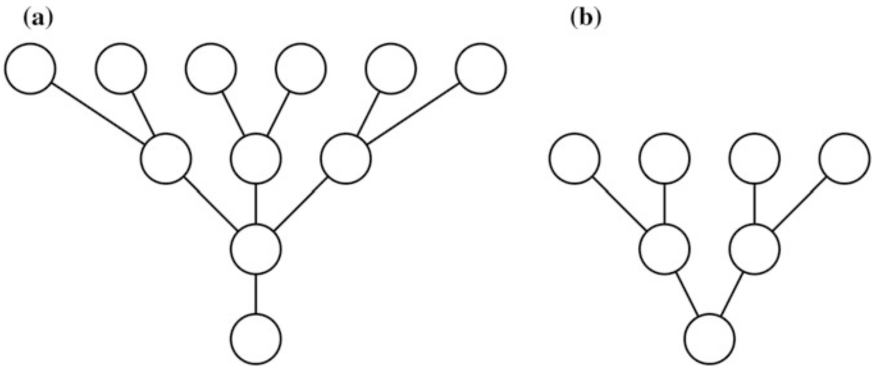


Fig. 2.8 Arborescent graphs; **a** 'tree' and **b** 'bush'

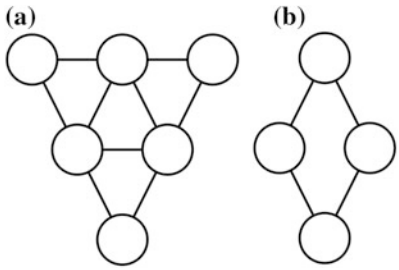


Fig. 2.9 Rhizomorphous graphs; **a** 'lattice' and **b** 'ring'

control over an occupant's spatial experience. In addition to these three spatial structures, it is common for multiple different substructural types (including loops, bushes and enfilade branches) to be present in the same graph. For example, public spaces in a plan might be located on the flexible looped parts of the graph, while private spaces may be located within more controlled, hierarchical sections.

Convex space analysis is often used to identify structural genotypes (Hanson et al. 1987; Conroy-Dalton and Kirsan 2008). A structural genotype is a socially authorised, ideal spatial configuration, for a particular programmatic type. Identifying a genotype requires a consistent analysis of large numbers of functionally similar buildings within a given socio-cultural context. Dovey has gone so far as to argue that the 'great achievement of spatial syntax analysis has been … [to] reveal a social ideology embedded in structural genotypes' (1999: 24). Convex space analysis has been used to track spatial manifestations of socio-cultural trends (Hanson 1998) and to analyse power relations within institutional buildings (Markus 1987, 1993; Dovey 1999, 2010) and historic spaces (Ferguson 1996; Cooper 1997; Bustard 1999; Dawson 2001). In addition, it has been used to provide insights into the way architects think about spatial and social structures (Bafna 1999; Major and Sarris 1999; Ostwald 2011b, c). Convex space analysis has also been used as a basis for parametrically generating new plans that replicate selected socio-spatial properties of historic designs (Yu et al. 2015, 2016a).

Despite multiple examples of the application of this technique, the lack of clarity in the original methodological description has made it difficult to replicate many of the results. This is because it is possible for multiple, slightly different but still equally 'correct', convex map s to exist for the same environment. Hillier and Hanson's early algorithmic definition of a convex map—relying on the use of circular geometry to determine the largest circle that can be traced in a plan without breaking the convexity of the space—has proven to be insufficient to reproduce their own convex maps or determine the fewest number of convex spaces required for a map (deBerg et al. 1997; Peponis et al. 1997a; Desyllas and Duxbury 2001; Yoon 2009). Hillier and Hanson (1984) also suggest that it is possible to intuitively develop a convex map. However, that approach is innately subjective and non-repeatable, leading to a situation where a single spatial configuration will produce multiple, different, but still valid, abstractions. Nevertheless, the ambiguity in the abstraction techniques is not the Achilles heel it may initially appear to be. The reason for this is that there has been a gradual shift away from the desire to rigorously map convex spaces. Instead, the more common variant today is known as 'functional space analysis'.

In the functional space variation, the convexity rule is ignored and stated room functions guide the abstraction procedure (Markus 1993; Hanson 1998; Dovey 1999, 2010; Ostwald 2011b). This variation calls for single-purpose rooms (such as kitchens, bedrooms or meeting rooms), regardless of whether they contain multiple convex spaces or not, to be treated as a single graph node. This process not only avoids the difficulty associated with developing a perfect convex map, but it also provides a solution for the criticism that Space Syntax produces unrealistic abstractions of some articulated spaces. This variation also allows for smaller convex spaces, such as those created within doorways, to be incorporated into larger adjacent spaces, thereby simplifying the graph and allowing it to be more closely mapped to the actual use of space. A further variation of this approach groups multiple, similarly themed and located rooms into 'dwelling sectors' (Amorim 1999; Lee et al. 2015a, 2016).

One criticism of the convex space technique is that its focus on geometry means that it may fail to account for some important social aspects of an environment. For example, Osman and Suliman (1994) argue that this technique may be incapable of accurately documenting social structures where those structures are not delineated through physical partitions, such as those found in the traditional single-room communal dwellings of the Amazonian Bari, the North African Berber and the Madagascan Bestilo peoples. This is because many traditional or primitive communities constructed large, single-room buildings to house a diverse range of functions and social groups. In reality though, ‘each of these cultural groups has a distinct set of rules which is used to divide the internal space and regulate the relationship among its members’ (Osman and Suliman 1994: 200). Thus, within a single convex space, important practical and symbolic divisions may exist meaning that the strict topological structure of space, as defined by visually coherent convex zones, may be irrelevant to interpreting its larger social order. Criticisms like this were no doubt instrumental in encouraging Hillier (1999) to acknowledge that selecting the correct abstraction model is critical for producing an insightful analysis. In the case of the primitive long house, dividing the single room into adjacent functional zones or dwelling sectors might prove more informative. Nevertheless, this critique of convex space analysis highlights the fact that it provides a single set of measures for each graph node. Thus a room is abstracted into a single node, which is then described by a single mean depth, or integration value, regardless of its size or any secondary functions within it.

2.4 Axial Line Analysis

Axial line analysis involves abstracting the built environment into the minimum number of connected straight lines that survey all non-trivial spatial features. Alternatively, the axial map could be understood as the set of fewest and longest lines that can get everywhere and see everything in a plan. An axial line is a straight vector of potential movement and vision. Hillier (2005) argues that people who are walking with a clear purpose tend to move in straight lines and thus the axial line represents an idealised maximum extension of one of these paths. Note the word ‘idealised’: because axial lines are optimal geometric paths they will only ever approximate human paths. Humans have physical properties (including width, height, visual acuity and stride length) which prevent them from consistently following ideal mathematical paths through space. Furthermore, in the real world various impediments—including furniture, level changes, people and vehicles—can obstruct direct movement or vision, causing a person to move away from the perfect path (Jalalian et al. 2011; Wong et al. 2012). Nevertheless, while the axial path is necessarily an idealised one, this has its advantages. For example, ‘[u]nlike metric distance, axial distance is about changes in direction. This is why it corresponds to our sense of intelligibility of spatial patterns and our sense of orientation within them’ (Peponis et al. 1997b: 15). Axial lines are especially useful for considering the way we construct our mental maps of space and then decide how to navigate through an environment (Montello 2007).

An axial map is produced by abstracting the built environment into a set of paths (nodes) and their connections (edges) and then analysing the resultant graph visually and mathematically. A typical axial map looks like a set of angled lines, all of which intersect at least one other line. Despite this visual representation, the axial map is still a graph. However, it is rarely depicted as a node and edge diagram (Fig. 2.10). Visual analysis of an axial map is typically limited to identifying the longest lines in a system or noting the location of groups of short lines. This type of analysis is more effective when the lines in the map are colour-coded to represent their mathematical properties. In such representations high values are often shown in red and low values in blue or violet, with intermediate values distributed along a colour gradient. Colouring the axial map in this way provides researchers with an opportunity to intuitively seek patterns in the data before using mathematics to examine the map more objectively. Despite this potential, as the process of abstracting a map from an urban environment may yield hundreds, if not thousands of axial line s, the primary form of analysis is mathematical.

Mathematical measures derived from the axial map rely on correlations between calculated measures and observational data to explain sociological phenomena such as pedestrian traffic and co-presence (Hillier et al. 1993; Peponis et al. 1997c; Desyllas and Duxbury 2001). For example, it has been argued that 'the best predictor of movement is integration' (Hillier et al. 1987: 237). This means that there is a high level of correlation between the graph theory value integration (*i*) for a line in an axial map and the volume of movement observed along the equivalent urban

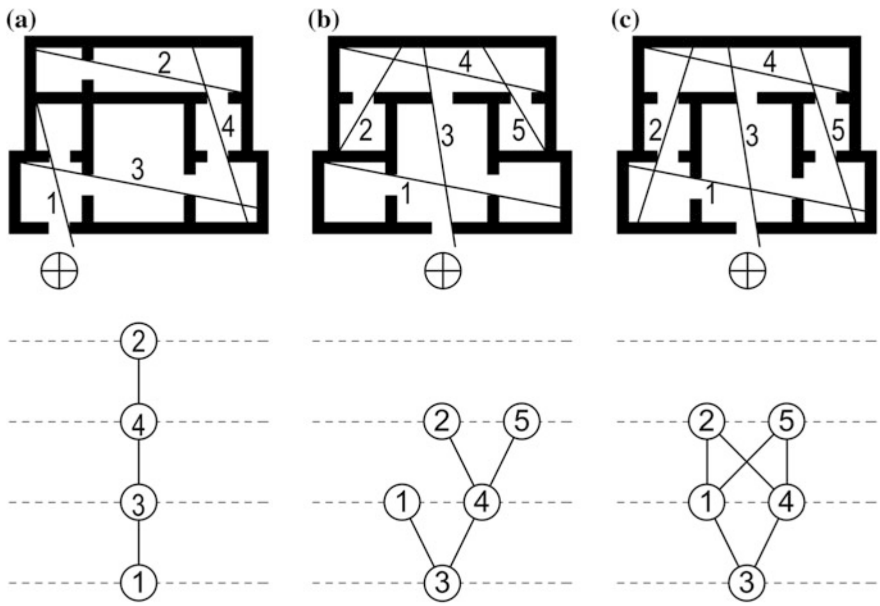


Fig. 2.10 Axial line maps for three simple villas—**a** *Epsilon*, **b** *Zeta* and **c** *Eta*—and their representations as graphs

street or building corridor (Hillier 1993; Hillier 1996). The syntactic measures derived from axial maps have also been shown to correlate to levels of criminal activity (Hillier and Shu 2000; Friedrich et al. 2009), whereas commercial property values and rental returns correlate with visual and spatial prominence within an urban environment (Desyllas 2000). At an architectural scale, axial maps can be used to analyse movement potential to predict the social encounters in office buildings (Ermal and Peponis 2008), or identify spatial structures causing navigation problems in hospitals (Haq and Girotto 2003; Haq and Zimring 2003). Axial maps have also been used to compare the work of different architects, or patterns in design thinking present in buildings by a single designer (Hanson 1998; Dawes and Ostwald 2012). Notwithstanding some disagreements about the extent to which the axial map can be used to model movement in urban spaces and transport networks (Ratti 2004a, b; Paul 2012), it remains a viable and accepted method.

Like convex space analysis, the main challenge faced by those implementing axial line analysis is the lack of a rigorous and repeatable method for abstracting a map. The original procedure called for the axial map to contain the minimal set of 'straight lines which pass through each convex space' (Hillier and Hanson 1984: 92). Therefore, the confusion implicit in the convex space abstraction method is carried over into and attenuated in the axial line technique. Nevertheless, during the last two decades the axial abstraction procedure has undergone a series of refinements in an attempt to standardise and automate the process of generating axial maps. As one of the first steps, researchers abandoned the convex map stage of the abstraction procedure in favour of methods which approximated such conditions using an extension of surface vertices or visible areas (Penn et al. 1997; Peponis et al. 1997b; Turner et al. 2005; Ostwald and Dawes 2011). Other researchers rejected the process of dividing the space entirely, using isovists to identify long sight lines to substitute for axial lines (Batty and Rana 2004), or generating the set of all possible axial lines and reducing these to a minimal set using specially-designed software (Penn et al. 1997). Further alternatives combined axial lines with GIS data (Jiang et al. 2000a, b; Jiang and Claramunt 2002) or simply used street names to define axial line locations (Jiang and Claramunt 2004).

Whereas the original convex space technique soon gave way to multiple versions, like functional space analysis, the axial line technique has remained more consistent in its application, with only two practical variations in the mapping process. The first variation is concerned with whether the axial line is used to map movement, sight or both. If sight alone is being considered, then some obstructions (low walls, furniture) and transparent surfaces (glass) must be ignored in the abstraction process. Conversely, if only movement is to be mapped, then physical obstructions and glass must be treated as solid walls for the purposes of the map. The second variable condition is concerned with which spaces to include or exclude. For example, most studies of urban environments deliberately exclude interiors, and most studies of building interiors exclude the outside world. Many studies are also only concerned with habitable spaces and thus exclude storage areas and plant rooms. Decisions about what the axial lines represent and which spaces must be surveilled on each map to effectively cover an area must be made using a consistent and transparent logic.

One well-known challenge for axial line analysis is the so-called ‘edge effect’. When examining a building interior, for example, the axial line method uses graph measures to differentiate between highly integrated and important spaces, and those that are more isolated or hidden. As Jake Desyllas and Elspeth Duxbury observe, such measures ‘always create an “edge effect” and that is the whole point’ (2001: 27.9), that is, they mathematically determine what is at the edge and what is at the centre. However, the edge effect can be a problem for urban or complex architectural analysis, where the boundaries separating the study area from its surroundings are not always clear. At an urban scale neat demarcations between spaces are often unachievable and any decision about limits will necessarily exclude topological links that fall beyond the periphery of the study area. Here, the edge effect is significant because nodes that represent lines close to the demarcation zone become artificially segregated relative to those closer to the centre. Early solutions to this problem included expanding the axial map beyond the area of interest (Hillier et al. 1993), leading researchers to map a 3×3 grid of space, when they were actually only interested in syntactic measures for the central square (Turner 2003). Later developments adjusted the mathematical formulas to minimise the impact of the edge effect (Hillier 1996). The consequence of this change is that, rather than calculating global integration as in traditional applications of the technique, researchers calculated local integration. Where global integration determines the depth of one node relative to all other nodes, local integration calculates the depth of a node in respect of other nodes at a predefined depth. For example, some applications of this variation calculate depth based on the number of nodes within three graph steps, while later work suggests calculating local integration using the mean depth of the system (Hillier and Penn 2004). The edge effect actually occurs in all Space Syntax analyses where only a portion of the larger system (like a neighbourhood within an urban context) is analysed. However, this is usually not an issue for other Space Syntax techniques, because these typically analyse entire independent systems (such as all convex spaces in a building).

Desyllas and Duxbury offer an alternative solution to the problem of the edge effect, which is to ‘use local measures that are not dependent on any relations to the entire graph, such as the visual connectivity of a point … or the clustering co-efficient’ (2001: 27.9). However, utilising non-topological measures in this way undermines the fundamental basis of syntactical analysis, which advocates focussing on the relation of every space to every other space. Furthermore, patterns of integration also change with the scale of the study and ‘integration values are not independent of the size of urban areas. Consequently it is difficult to compare areas of different size’ (Teklenburg et al. 1993: 347). While acknowledging this position, integration measures calculated using Real Relative Asymmetry (*RRA*) offer an opportunity to compare graphs of different sizes, provided one accepts the normalisation logic that is the basis for its calculation.

More serious critiques of the axial line approach to graph analysis focus on the limitations inherent in abstracting an entire environment into a set of lines. Probably the most famous of these criticisms is from Carlo Ratti (2004a, b) who argues that, for example, axial line analysis records an identical distance for a New Yorker walking around the corner of a city block to a similar resident walking the entire length and breadth of Central Park. Bill Hillier and Alan Penn's response is that axial line analysis 'deals only with observed flows and thus only with aggregate statistical effects' (2004: 504); meaning that it does not account for the actions of a single person, but rather for the aggregate pattern of actions of the entire populace. More importantly, the axial line technique only considers the aggregate movement potential of every location relative to every other location and is therefore incapable of describing the spatial experience of individual journeys, except for suggesting locations along the trip that are more or less likely to be shared with others. To model actual journeys requires some form of agent-based model with specific origins and destinations (Batty et al. 1998). Alternatively, Michael Batty (2004a) explores methods for introducing metric distances into the axial line map, an idea that has not yet been widely adopted by researchers.

A further criticism raised by Ratti (2004a, b) relates to the axial map's inability to handle regular grids. Ratti demonstrates that in cities like New York it is possible to select a study area where every East-West street intersects every North-South street (and vice versa) so that every street in the analysis shares an identical Total Depth (*TD*). This spatial configuration necessitates that subsequent derived measures, like integration, will also be identical for all streets. This problem is largely theoretical, because in real-world environments some streets in a grid will connect with distant areas while others will not. The solution is that the researcher must expand the area of study so that at least one street possesses a variable connection to create differentiated results throughout the entire grid.

A seemingly more interesting problem arises when a regular grid is slightly deformed. Using such an example, Ratti (2004a, b) demonstrates a critical juncture in an urban plan, where an infinitely small rotation of the city block requires multiple axial line s be produced in the abstraction process rather than the original single line, even though very little else has changed spatially, socially or experientially. The issue here is that a rigorously produced axial line map may, under particular circumstances, produce multiple lines and connections for almost straight streets that would otherwise constitute a single psychological unit of space (Thomson 2004). Ratti argues that such a minor adjustment of city blocks would not significantly alter movement patterns. 'The question then is: are such marginally produced discontinuities—or continuities—important in urban space? Two kinds of evidence, morphological and behavioural, suggest they are' (Hillier and Penn 2004: 501). Hillier and Penn explain this response by identifying differences in average line connectivity in a range of cultural settings and suggest that these variations are key to different spatial cultures (Hillier 2002). They also point to behavioural evidence presented by Ruth Conroy (2001), which found that people exhibit superior abilities to navigate a diagonal line through regular grids in comparison to distorted grids. While this answer is plausible, to completely resolve this issue would require a dedicated experiment, similar to those undertaken by Conroy and designed to test the response of Hillier and Penn.

The further criticism of the axial line technique is derived from the methodological assumption that within a spatial system there is an even distribution of populations and addresses, along with starting points and end points of journeys. The problem is that urban space is almost never distributed in such a uniform way and, for example, taller buildings are more significant generators and attractors of movement than shorter buildings. This position is confirmed by significant correlations that have been found between movement and building height. For example, Penn et al. (1998a, b) show that 'building height was a significant variable in pedestrian movement at the level of the area, though not at the level of the individual road segment' (Hillier and Penn 2004: 504). Contradicting an earlier, and much less satisfactory, suggestion of simply adding additional lines (graph nodes) to the map where social attractors are located (Hillier 1999), Hillier and Penn's response to this criticism is that, 'for research purposes we prefer not to obscure the effects of spatial configuration by compounding it with other variables' (2004: 504). This statement illustrates that it is important to remember that axial line analysis is not a model of actual movement patterns within space. It is a means of determining movement potential based on spatial configuration alone, and while often demonstrating significant correlations to observational data, it ultimately fails to account for all variables that will affect actual movement patterns. This also means that while the method is open to reasonable criticism, it still allows for rapid and repeatable analyses of different environments. Hillier does, however, leave open the potential for additional variables when he talks about a revised technique which 'works at the level of the line segment, rather than the whole line, and [where] connections between segments can be weighted for metric distance, or the angle of change, as well as for complexity distance' (2005: 111). This suggestion also addresses a fundamental difficulty with the axial line technique; the inability of the method to articulate spatial differences along the length of a single line.

In the traditional graph approach to axial line s each line provides only one calculated measure, despite potentially passing through a variety of spatial experiences. The possibility of segmenting the axial line in some way would appear to circumvent this problem without resorting to alternative variations such as intersection point analysis (Batty 2004b; Ostwald and Dawes 2012; 2013a, b), angular segment analysis (Turner 2007) and multiple centrality assessment (Crucitti et al. 2006), or reverting to the final mode of abstraction considered in this chapter, visibility graph analysis (Turner et al. 2001). Focusing on the segments of lines between intersection points also has the advantage that it mirrors the data held in many GIS databases. This would allow researchers to forego the process of creating an axial map, along with complex interpretations of GIS data (Jiang et al. 2000a, b; Jiang and Claramunt 2002). Ultimately, like all forms of syntactic analysis, it is important to understand the limitations of the technique and not blindly rely on mathematical measures for an absolute description of socio-spatial phenomena.

2.5 Intersection Point Analysis

As discussed previously, one limitation of the axial line method is that each line, meaning each individual path across a potentially complex plan, has a single set of mathematical properties that are consistent across its entire length. If such a line is examined as part of a larger, distributed, statistical system for understanding movement potential, then this may be ideal. But intuitively, shouldn't a path that passes through multiple different spaces, some public and others private, somehow reflect these changes? This concern about the usefulness of the axial line map echoes a previous critique of the convex space technique, wherein each visually defined room, regardless of how socially complex or extensive it is, generates a single set of mathematical measures to describe the entire space. Surely, as Osman and Suliman (1994) argue, some locations in a room could be more significant than others? The reason both of these intuitive criticisms sound reasonable is because our most basic knowledge of space is experientially derived. We can understand intellectually how a line functions in a topological map, but emotionally, we are aware that space is more immediate. The problem with both the convex space and axial line techniques is that they are concerned with generalised notions of space and social patterns. This gives these techniques a high degree of numerical validity, but they cannot be used to discuss a specific location in space, or on a path, or even the possible experience of a person at such a location.

It is not unreasonable that researchers using mathematics to model the social patterns of space have rarely considered individual spatial experience at distinct locations. This type of analysis is typically undertaken as part of the phenomenological tradition of reading space and form (Thiis-Evensen 1987). In architectural phenomenology, personal observations of texture, temperature, acoustics and lines of sight are used to interpret the experience of being in a distinct location in a building (Pallasmaa 1996). Such an approach privileges the role of the observer as being uniquely capable of processing the complete range of sensory experience. Dovey (1993) argues that the implication of this proposition is that a clear separation exists between 'lived space' (the realm of personal feelings, emotions and particulars) and 'geometric space' (the space of plans, forms and universals). However, while the mathematical analysis of geometric space may be incompatible with the intricacy of personal experience, it does offer an important 'universal language of spatial representation [which] has predictive value' (Dovey 1993: 250). Thus, while attempts to use mathematical analysis to examine the social or experiential qualities of architecture are necessarily both limited and abstract, they have the advantage of being transparent, consistent and repeatable. Moreover, some approaches to geometric analysis, including mathematical techniques that model vision and movement, are also potentially significant from the point of view of the experience of lived space (Benedikt and Burnham 1985; Aspinall 1993; Montello 2003). Given this context, how do experiential and location-specific issues fit into the suite of Space Syntax techniques?

As previously stated, patterns of spatial configuration both reflect and shape the values and behaviours of groups of people. By implication such patterns confirm the existence of a similarly artificial, but nevertheless representative, individual. In essence, the behaviours and values of a collective are predicated on the existence of individuals who have behaviours and values which relate to, either formatively or summatively, the collective. From an analytical perspective, the social and the experiential are related patterns that may be used to interpret these behaviours and values (Montello 2007). Conversely, the social and the experiential could be said to evoke two versions of the same pattern (Aspinall 1993). This is because a social pattern is a statistical reflection of the behaviour of a set of individuals. This simple line of reasoning does not mean that topological analysis is capable of replicating personal experience, but it does suggest that certain approaches to plan analysis may, if capable of inversion or focussing, provide insights into both social and experiential patterns.

It is this type of reasoning, coupled with the availability of data about distinct locations in space, which has led several researchers to suggest that it would be beneficial to invert the axial line graph to focus attention on the intersections between paths, rather than the paths themselves (Batty 2004b; Jiang and Claramunt 2004; Turner 2005; Porta et al. 2006a, b; Ostwald and Dawes 2013a, b). Such a change shifts the emphasis of the map away from being a general network of movement or vision potential, to a consideration of the properties of precise locations in space. It also encourages a shift in perspective away from larger scale social patterns to issues associated with spatial cognition and experience. This is because points in space are locations where a person can pause and make a decision about how to navigate, access and explore an area. Nevertheless, while the idea of inverting the axial map to produce an intersection map appears to offer a valuable, finer-grained way of examining space and experience, the abstraction process for achieving this is not so straightforward.

From a graph theory perspective, whereas in the axial map, lines are nodes and intersections are edges, the point map does the reverse, defining intersections as nodes and lines as edges. This has led to many researchers describing the intersection point map is a *dual* of the line map *primal* graph; meaning the two are numerically comparable. However, from a pure graph theory perspective, the point graph is an inversion of the line graph. While a subtle distinction, it has ramifications for the abstraction process for the point map and it requires a brief diversion to consider the difference between planar and non-planar graphs.

A planar graph is one wherein the edges between nodes do not cross other edges. If any edges cross, it is a non-planar graph (Fig. 2.11). Any planar graph can be represented (or conceptualised) in two ways: the original, known as the *primal* graph, and its inversion, or *dual* graph. In graph theory, the primal and the dual have a reciprocal relationship, with a new set of nodes being located within or between the spaces of the primal map, and new edges drawn connecting these nodes. For example, consider a functional space map derived from the floor plan of the hypothetical *Villa Eta* (Fig. 2.12a). The justified permeability and accessibility graph (sometimes called an ‘access graph’), the primal form, features seven spaces

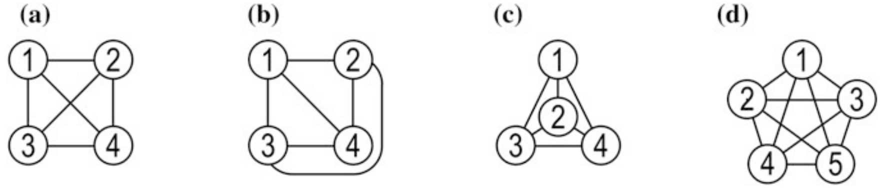


Fig. 2.11 **a** A graph which appears to be non-planar, but is actually planar, as demonstrated in two ways (**b** and **c**). A non-planar graph **d** will always possess edges that cross, regardless of arrangement

(A to F and the exterior, $\oplus^1$) (Fig. 2.12b). The dual of this graph is made by placing a node in each graph region and connecting these new nodes with edges that cross each edge in the original, primal map (Fig. 2.12c). Three new nodes are required for this procedure, X, Y and an additional exterior, $\oplus^2$. This procedure effectively changes the emphasis of the graph from spaces and their connections to the walls that isolate and define these relationships. When the primal graph is removed, and the dual of the *Villa Eta* is all that remains, it is clear that only three walls are required to construct the general topology of the plan (designated X, Y, $\oplus^2$) and its eight connections, the edges (Fig. 2.12d). While there are several potential uses for a dual of a functional space graph (Stevens 1990), its sole purpose here is to demonstrate how it is constructed. But what if the starting graph isn't planar? Axial maps, unlike convex maps, are rarely planar, so constructing its inverted state—the intersection point graph—requires an additional step.

Batty (2004b) suggests that to invert the axial map while maintaining its integrity, every intersection point must be treated as if it is one topological step from every other intersection point of that line. For example, consider a simple axial map with four lines (1, 2, 3, 4) which cross at three intersection points (X, Y, Z) (Fig. 2.13a). In its primal form (Fig. 2.13b) this graph has four nodes (1, 2, 3, 4) and three edges (X, Y, Z). However, if we focus just on line 1, it has three edges and when the graph is inverted, it becomes a single edge which is required to connect to three nodes

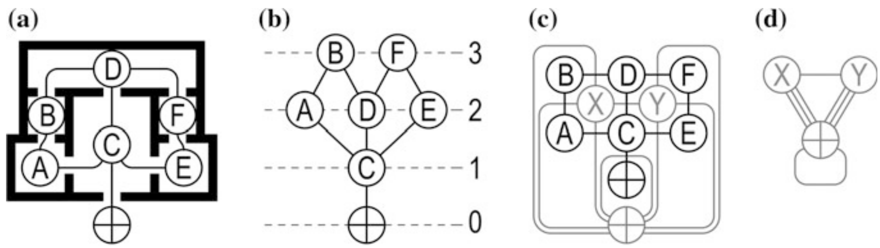


Fig. 2.12 A building plan **a** and associated justified permeability graph (**b**), form the basis of dual graph (**c**). The dual graph (the dotted lines in **c**) places a node in each region of the permeability graph with edges linking adjacent dual graph nodes (**d**). It is possible for a node in the dual graph to be adjacent to, and therefore link to, itself

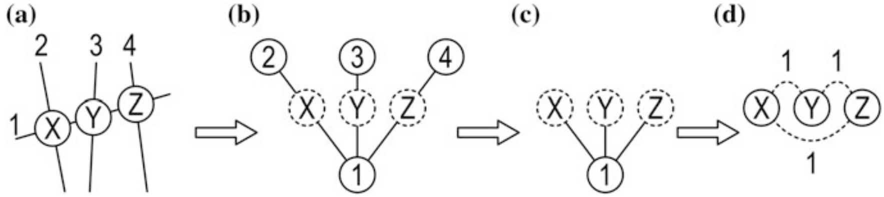


Fig. 2.13 Inversion of a simple axial map (**a**) to an intersection graph (**d**)

(previously intersections X, Y, Z), which is impossible (Fig. 2.13c). Additional edges are therefore required to ensure all nodes are connected (Fig. 2.13d). This is the standard approach used in most applications of this technique.

A further complication associated with inverting the axial map involves the decision to include or exclude the 'ends', or 'stubs' of axial lines. The stub is the portion of an axial line between its end and its first intersection point. Excluding axial line stubs focuses the analysis of the inverted axial map purely on line intersections, the locations of maximal visual information. However, an advantage of the inverted axial map is that it offers a researcher the ability to quantify the difference of spatial experiences at multiple locations along axial lines, including at their ends.

The procedure for including line stubs in the intersection graph is simple; add a node to the end of each stub (Batty 2004b). The procedure for excluding line stubs is to ignore them. The difficulty arises from the fact that some line stubs are clearly more significant than others (Fig. 2.14). For example, some line stubs contribute to plan surveillance or comprise the majority of an axial line's length, while others are so short as to appear insignificant. Furthermore, an axial line intersecting only a single other line will consist entirely of two line stubs (Fig. 2.14, line 2) and excluding these reduces the significance of the axial line in the analytical results. For these reasons, axial line stubs would appear to be needed to produce an inclusive map of the entire environment. But which stubs are significant and why?

Alasdair Turner (2005) considers a similar problem when developing a procedure for angular segment analysis. He suggests that the length of the stub, relative to

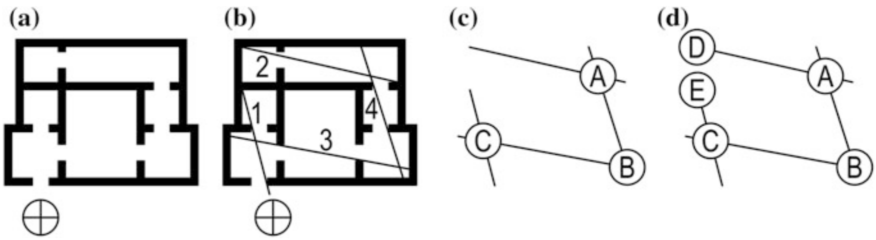


Fig. 2.14 Lines 1 and 2 in the axial line map (**b**) are required to surveil convex spaces B and C of the plan (**a**). Axial line intersection points (**c**) fail to describe the entirety of the building configuration, whereas adding nodes D and E to surveil rooms B and C solves this problem (**d**)

the entire line, can be used to determine whether or not it should be retained in the analysis. Turner proposes ‘a segmentation routine that cuts off any stub of greater than, for example, 25% of the overall length of the line’ (2005: 148). This suggests a system by which line stubs can be classified as long or short, based on their length expressed as a percentage of the complete line length. Angular segment analysis excludes short stubs as being irrelevant and cuts long stubs from their parent line to create and retain new line segments. For abstracting a point map a similar logic would apply—stubs shorter than 25% of the line length are ignored, while long stubs are included. Such a process would also take into account Batty’s observation that ‘a street increases in importance as the number of nodes associated with it increases’ (2004b: 5). Therefore, including only those stubs which represent substantial lines (that is, greater than 25% of the total length) might provide a balanced solution, whereas including all stubs could artificially increase the value of some otherwise minor endpoints.

Despite the apparent simplicity of this solution, it has at least one major problem. The length of a line does not necessarily have anything to do with its capacity to provide surveillance (or, by inference, model experience) of a particular space. Thus, a stub that is only 20% of a line length might be the only point that is within a particular room. Conversely, an axial line could be entirely within the one convex space, and including its stub, even if it is 70% of the entire length, might provide no new information. Thus, a further procedure, for use in conjunction with, or instead of, a length-based measure is required. This procedure (detailed in Chap. 3) effectively checks whether each stub possesses unique surveillance properties; if it does, it is retained (Dawes and Ostwald 2013b).

Before leaving the axial line and intersection point methods behind, we wish to reiterate that both are potentially useful for analysing aspects of wayfinding or the structural clarity of a space. While several syntactical measures can be used to investigate these two cognitive properties, the most well known is ‘intelligibility’ (Peponis et al. 1990; Haq and Girotto 2003). Intelligibility is a measure of the global-local relationships; that is, how well the entire configuration of a plan is understood by traversing through, or being located at, the various components of the configuration. The intelligibility measure is a correlation coefficient developed from a scatter graph of the connection and integration values of each line in an axial map, or point in an intersection map. The logic behind this process is that integration represents a global measure of the connectivity of a given line/point to all other lines/points in the system. The number of connections the line/point makes represents how much of a configuration can be seen from each; therefore the relationship between these measures indicates how intelligible a plan is. More precisely, the higher the correlation of points, the more intelligible the system. While intelligibility is most often calculated using axial lines and intersection points, it can also be determined using convex space maps and isovists, the subject of the next section.

An additional factor that makes the intersection map an attractive option is that in a modified form it can be used for investigating claims about significant locations in a plan, regardless of whether they correspond to axial paths or not. Thus, the version described in this book takes as its starting point the axial line map, and then works from that basis. But it would also be possible to undertake a variant of this approach that is more akin to the functional space version of convex space analysis. For instance, if an architect identifies a series of locations in a large building or urban space which are allegedly significant sites of experience or navigation potential, then a graph could be constructed using these exact points as the basis for a modified intersection map. This would be especially advantageous in the case of large urban piazzas which lack sufficient boundaries to identify an optimal axial map, but which have locations in them that are culturally or symbolically significant.

Such a situation is found in Le Corbusier's design of the ceremonial plaza in Chandigarh, India, in which he identified several important lines of sight as well as multiple critical intersection points and axes on this plaza. As Norma Evenson notes, the 'generating motif of the [Chandigarh] complex, like that of the city itself, is a cross axis, but the arrangement of buildings is carefully plotted to avoid the static balance of rigid symmetry' (1966: 72). However, this plaza is essentially open, with only a few carefully choreographed natural and constructed objects blocking sight lines. It would be difficult, if not impossible to generate an axial map of this plaza; there are simply not enough constraints. Yet, Le Corbusier's planned axes (some intended for movement, and others for ceremonial functions), along with key symbolic locations, could be used to construct a point map of the ceremonial plaza. This is significant in the context of both historic and modern buildings, because architects have a much greater tendency to identify the planned properties of a precise location than of an angled path through space.

2.6 Visibility Graph Analysis

The final technique featured in this chapter is visibility graph analysis. Its origins lie in the work of environmental psychologist James Gibson (1947). Gibson proposed that visible space could be represented as a polygon, called an optic array, and he illustrated the way in which the properties of these polygons changed as the observation locations shifted. Michael Benedikt was the first to call these polygons 'isovists' and to develop mathematical measures to describe their properties. Benedikt defined an isovist as 'the set of all points visible from a single vantage point in space with respect to an environment' (1979: 47) and, with Larry Davis, developed a stable, repeatable algorithmic procedure for generating and measuring isovists (Davis and Benedikt 1979).

Conceptually at least, the isovist completes the gradual shift that has occurred across the four techniques in this chapter, from generalised properties to particular ones and from social to experiential patterns. Thus, whereas the convex space technique abstracted social patterns from the configurational properties of a plan, an isovist represents the visual experience of space from a specific location. For this reason, isovists offer 'an intuitively attractive way of thinking about a spatial environment, because they provide a description of the space "from inside", from the point of view of individuals, as they perceive it, interact with it, and move through it' (Turner et al. 2001: 103). Isovists can be used to 'describe spatial properties from an inside beholder-centred perspective' which is significant because 'there is … empirical evidence that they capture environmental properties of space that are relevant for spatial behaviour and experience' (Wiener and Franz 2005, 44).

While local isovist measures—that is, isolated results derived from single locations in space—are valuable at an experiential level, global measures allow for a more comprehensive mapping of an environment. For this reason, from the earliest research into the properties of isovists, attempts were made to create more holistic maps of the spatio-visual properties of entire environments. Probably the earliest of these variations was the isovist field. Developed by Davis and Benedikt (1979), it superimposed a regular grid on an environment's plan and generated an isovist at the centre of each grid square, before representing the measures derived from each of these isovists on a scalar field (similar to a synoptic chart or topographic map). This was effectively the first type of visibility map, even though all of the measures derived from it were based on the metric values of isolated isovists. However, over the following decades, several researchers began to develop ways of producing global visibility measures from such a map (De Floriani et al. 1994). For example, by treating each observation point as a graph node and then linking any two mutually visible observation points with a graph edge, it is possible to derive various topological measures from the isovist field (Turner and Penn 1999; Turner et al. 2001; Turner 2003). In this way, over time the isovist field evolved into a visibility graph.

Visibility graph analysis commences by abstracting an environment into a set of connected isovists before analysing this set visually and mathematically. The mathematical process superimposes a regular grid over the environment and locates an isovist observation point at the centre of each grid square. These observation points become graph nodes and each is linked to every other node that it is possible to draw a straight line to, thereby creating the graph (Fig. 2.15). The calculation of various measures then follows the standard graph theory approach and the results are typically analysed using statistical software. In addition to these topological measures, a range of metric properties can be derived from the isovist polygon and used to produce normalised or statistical measures (Benedikt 1979; Batty 2001; Stamps 2005; Dawes and Ostwald 2013a). The most common graphical representation of the visibility graph applies colour to each grid square to represent the relative measures of the isovist observation point contained within. A further visual analysis approach depicts each isovist in miniature at the centre of its grid square (Christenson 2010).

After an early isolated application of visibility graph analysis in design (Braaksma and Cook 1980), its primary use has been in the identification of regions of space that are more or less central to the entire environment or more or less likely to be a location from which it is possible to see other occupants. This information can be used to predict rates of spatial occupation and social encounters, though like all syntactical approaches, the prediction is limited to relative distributions rather

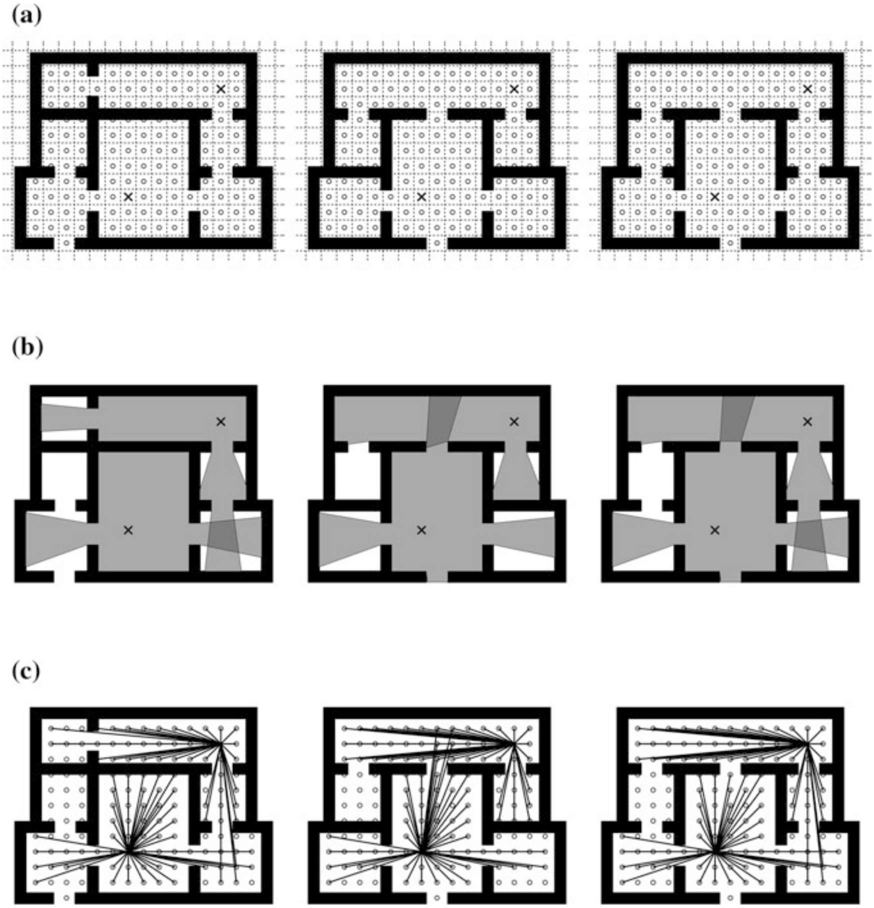


Fig. 2.15 Three villa plans (from left to right, *Epsilon*, *Zeta* and *Eta*) showing: **a** a regular grid locating observation positions, **b** the isovists at three selected positions, **c** graph edges to other visible observation positions for the two selected positions and grid squares shaded for integration values

than absolute figures (Desyllas and Duxbury 2001; Ueno et al. 2009). Visibility graph analysis is also useful for understanding the structure of space in terms of its visual properties. This includes providing insights into social interaction and the rationale for the positioning of workstations within office buildings (Steen and Markhede 2010) and spatial use in urban plazas (Bada and Farhi 2009). Visibility graph analysis also contributes to an understanding of navigation, behaviour and spatial experience (Conroy-Dalton 2001; Wiener and Franz 2005; Hölscher et al. 2006). In addition, identifying the visual properties of an environment allows for a comparison of properties within a series of buildings by the same architect to be undertaken (Choudhary et al. 2007) or a greater understanding of single canonical residences produced (Peponis and Bellal 2010). Visibility graph analysis can also be used to investigate complex perceptual properties including mystery and transparency (Yu et al. 2016b). A variation of the standard visibility graph technique identifies a significant path through an environment and then sequentially plots the values of each grid square along this path. This produces a pseudo-timeline of changing spatial experiences associated with the path, assuming an equal time for an occupant to pass from one grid square to the next (Conroy-Dalton 2001; Ostwald and Dawes 2013b).

The major strength of the visibility graph method is its stability and repeatability. This is largely due to the clear, algorithmic descriptions of the procedures that have been developed. This clarity is likely reinforced by the scale of this form of analysis and the requirement to automate mundane tasks. However, this stability does not eliminate flexibility from the method. One source of flexibility is the size of the grid used to locate isovist observation points. For example, Turner et al. adopt 'the pragmatic approach of using "human-scale" grid spacing of around one metre' (2001: 106). A smaller spacing might assist in locating observation points in constricted locations, but it will come at the cost of greater numbers of graph nodes and subsequently greater resources required for the analysis. Fine-scale grids may also be appropriate at an architectural scale but are often unmanageable for urban analysis. Adjusting the actual location of the grid offers an additional degree of flexibility in that it is possible to locate a critical isovist observation point while allowing the grid to locate the remaining points. One advantage of the large number of graph nodes required for visibility graph analysis is the potential density of measures generated. Whereas convex space analysis will produce a single integration value for an entire room, and axial line for a long vista or path, visibility graph analysis can provide a measure of integration for every grid position in an environment. Therefore, because there are potentially numerous isovists located in the same space as a single axial line, visibility graph analysis offers the potential for a greater articulation of measures.

A further source of flexibility arises from altering the height of the isovist plane. The isovists used in visibility graph analysis are two-dimensional and usually located at the eye level of a standing observer, thereby recording the visual perception of that individual. A useful variation is the visual permeability graph: 'the special case of a visibility graph constructed at floor level' (Turner et al. 2001: 108). This variation models the movement perception of the occupant, although it may require designating areas as 'inaccessible' to avoid the confusion arising from being able to 'see under' an object (a table for instance) that does not allow for movement. Designating part of a map as inaccessible also offers additional flexibility through the capacity to exclude particular areas from an analysis. It may, for example, be useful, when the research focus is on the habitable areas of a building, to exclude any services areas or storage spaces.

A further strength of visibility graph analysis is the variety of measures that can be derived from a plan. In addition to the graph theory measures, metric and statistical measures are also produced by software such as UCL Depthmap. This leads to opportunities to calculate hybrid measures normally unavailable to Space Syntax researchers. One weakness arising from this potential is that the evidence available about which of these measures correlate to particular socio-spatial concepts or behaviours is mixed (see Chap. 8 for a more detailed discussion).

Finally, in recent years various methods have been developed for examining three-dimensional isovists or visibility graphs (Penn et al. 1997; Yang et al. 2007). Traditional visibility graph analysis abstracts the environment into a horizontal plane incapable of differentiating between the spatial experience of standing under a low and claustrophobic roof, or a high and uplifting one, and unable to document visibility up or down staircases. Like their two-dimensional counterparts, these three-dimensional isovists may be either a full 360° modelling of space or a partial modelling of space which more closely approximates a human cone of vision (say, 180°). Initially, three-dimensional isovists were utilised to study local properties, such as spatial openness (Fisher-Gewirtzman et al. 2003; Fisher-Gewirtzman and Wagner 2003) and the effects of changing urban forms (Yang et al. 2007; Wong et al. 2012). However, the third dimension contains significant information used in wayfinding or measures of spatial salience or differentiation (Bhatia et al. 2013), such as a distant view to a church bell tower used to orientate oneself within the global environment of a traditional town. Morello and Ratti (2009) approach this concept of building cognition by developing a three-dimensional visibility graph capable of identifying the frequency with which building surfaces are visible from any location in an urban environment. This approach can, theoretically, identify the importance of specific buildings in urban navigation and builds on Conroy-Dalton and Bafna's (2003) work to quantitatively reinterrogate navigation concepts originally described in Kevin Lynch's *The Image of the City* (1960).

2.7 Conclusion

Across the four techniques presented in this chapter there is a gradual narrowing of the subject material (from the room, to the path, to the point and the vista) and a parallel shift from the social to the experiential (from large-scale patterns of inhabitation, to the space than can be seen from a particular location). Notwithstanding the fact that visibility graph analysis broadens the scope once more, back to a more holistic consideration of space, these techniques offer ways of investigating a range of spatial, social, cognitive and experiential properties of architecture. Furthermore, while these methods are all ostensibly focussed on topological spatial properties, they can also be used to analyse various characteristics of architectural form. For example, spatial structure can be used as an indirect means of analysing formal complexity. Convex spaces are, by definition, formally modelled and constrained zones, and the ratio between convex space s and functional space s in a plan illuminates the formal character of a building. Inverted permeability graphs actually provide information about walls, and indeed wall layouts can be analysed and categorised using graphs (Jupp and Gero 2010). Finally, isovists capture aspects of both space (that which is seen) and form (that which restricts vision).

One of the important messages of this chapter is that all of these techniques have a common system of application which starts with a process of abstracting or mapping information in a plan, then moves to the visual review of these maps, then the mathematical derivation of various properties from them, before these are used to interpret the plan. A further significant message is that the mathematical basis for most of these techniques is found in classical graph theory. While graph theory proponents in mathematics have developed new techniques for analysing factorisation and connectivity in networks, along with dual, non-separable and automorphic graphs (Bondy and Murty 2008; Naimzada et al. 2009), the efforts of architectural researchers have been directed more to the application of classical principles in new ways. There are certainly exceptions to this, like the work of Michael Batty (2004b), but the core syntactical application of graph theory has not been substantially revised since the 1990s, even though many hundreds of minor refinements have occurred in its application and interpretation.

Chapter 3
Spaces, Lines and Intersections

The previous chapter described the origins of contemporary syntactical analysis and introduced the established techniques for investigating the properties of spaces, paths, points and vision. In each case, the theoretical or conceptual foundation of the techniques was introduced, along with a discussion of its application and any specific findings developed through its use. In addition, the limitations of each technique were also described and the substance of any on-going debates associated with them. As this discussion revealed, one of the concerns with these methods is that they tend to be poorly understood outside small groups of experts. There are multiple reasons for this problem, including the way these techniques draw on diverse concepts and methods from mathematics, sociology and psychology to explain architectural ideas. Such a combination of traditionally separate bodies of knowledge is a challenge for any scholar who is versed in only one discipline.

An additional barrier is that the abstraction process has been largely automated in recent years through the use of analytical software. Such software allows researchers to undertake large-scale analysis with a high degree of efficiency, however this comes at the cost of obscuring the process, and risks leaving non-expert users without a detailed knowledge of why and how it works. The mathematical basis for the results is equally obscured when software is used to develop syntactical results from plan graphs. For all of these reasons, the present chapter offers a detailed explanation of the processes of abstracting a map from an architectural plan, mathematically analysing its configuration and then interpreting the results.

3.1 Introduction

This chapter describes and demonstrates the stages and steps involved in applying three different Space Syntax techniques: convex space analysis, axial line analysis and intersection point analysis. Each of these techniques repeats the same three-stage process, commencing with the abstraction of a map or graph from a

M. J. Ostwald and M. J. Dawes, *The Mathematics of the Modernist Villa*,
Mathematics and the Built Environment 3,
https://doi.org/10.1007/978-3-319-71647-3_3

plan, followed by the mathematical analysis of this graph, and finally the interpretation of the results. Within several of the stages there are various secondary steps and in some cases tertiary protocols. For example, the process of abstracting an axial line map has ten steps and its configurational analysis has eleven steps. The ninth step in the abstraction process for this axial map also includes six protocols. Furthermore, just as the same three stages are repeated in each technique, so too there are similarities in the various secondary steps. For example, the configurational analysis stage follows a similar sequence for every technique and the same mathematical formulas are also used each time. For this reason, the level of detail in each subsequent demonstration of the mathematics involved is reduced.

Following Julienne Hanson's (1998) lead, a series of hypothetical villa plans are used in this chapter to explain and demonstrate the different techniques. These are the villas *Alpha* (*V*α), *Beta* (*V*β), *Gamma* (*V*ζ), *Epsilon* (*V*γ), *Zeta* (*V*ζ) and *Eta* (Vη). These villas have the same plan footprint and dimensions, but their internal spatial configurations differ in a variety of ways. For example, the villas *Alpha* and *Epsilon* have relatively linear spatial structures, meaning that they provide few choices in the way people can move through these plans to methodically explore or use their rooms. In contrast, the villas *Beta* and *Zeta* have branching configurations wherein spaces will often possess a choice of alternative routes to deeper rooms, but a person must return back to a more shallow space to access other parts of the plan. Finally the villas *Gamma* and *Eta* have rhizomorphous structures, where multiple possible connections exist between spaces at different depths, allowing for highly flexible patterns of use. These six plans are useful for developing an understanding of how the abstraction, analysis and interpretation stages work for convex spaces, axial lines and intersection points.

The variations of the techniques described hereafter are what might be called 'second generation'. When each of these techniques was first published—the 'first generation'—they became the subject of intense scrutiny and testing, which developed more refined and stable variations, leading to this 'second generation'. However, with further advances in computer software, subsequent variations of each were soon published, many of which employ different rules, revised algorithms and shortcuts to achieve an outcome that appears similar to the original and might even be better in some ways. These third or later generations are possibly the most advanced, but also the least well understood by users. In this present book we apply both second and third generation techniques in later chapters to analyse modern architecture, but for understanding the abstraction principles and mathematical processes, the second generation is an ideal starting point.

3.2 Convex Space Analysis

As Chap. 2 has shown, a convex space is one that can be viewed, in its totality, from every point within that space. From a social perspective, a convex space is one where any people present in that space are visible to all others and where movement out of that space reduces the immediacy or viability of social interaction or connection. In a cognitive or experiential sense, a convex space is a defined unit of visible territory or a psychologically self-contained unit of space that allows for sensory-knowledge to be absorbed, compartmentalised and then understood or appreciated. If a space is concave (that is, part of the space is occluded or hidden from view), then prior to analysis it must first be partitioned or divided into smaller convex spaces (see Fig. 2.6).

As a precursor to determining which convex spaces exist in a plan, a decision needs to be made about the scale and purpose of the analysis. For example, protruding or recessed window and doors frames will actually produce miniscule concavities, or tiny portions of space that are not completely visible in an otherwise open room. Similarly, some engaged columns and recessed shelves also produce small portions of concave space. In practice however, such visual interruptions are typically excluded from the convex map, as they are neither potential locations of social interaction nor cognitively defined units of space. Thus, for a simple architectural plan, convex spaces often equate to rooms. This is also why it has become increasingly common in more recent applications of the technique to graph the structure of functional space s (rooms with a defined purpose) rather than convex spaces.

Stage 1, Abstraction Process

Consider the floor plan of a hypothetical design, the *Villa Alpha* (Fig. 3.1). There are six major convex space s in this plan—which correspond to rooms A, B, C, D, E and F—and there are five internal connections between them. In addition, there is a door from the interior (A) to the exterior (⊕) of the villa. There are a further six narrow slivers of space within doorways, which are too small to be inhabited or exist as visually coherent zones, and so they are excluded from the analysis. Taking into account all of these factors, the convex plan of the *Villa Alpha* can be represented as a set of seven spaces (six rooms and the exterior) and the six connections between them (five interior doorways and one between interior and exterior)

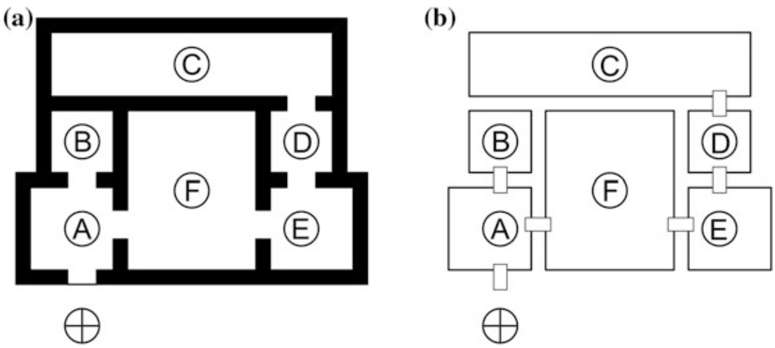


Fig. 3.1 **a** *Villa Alpha*, plan view, and **b** diagram of spaces and connections

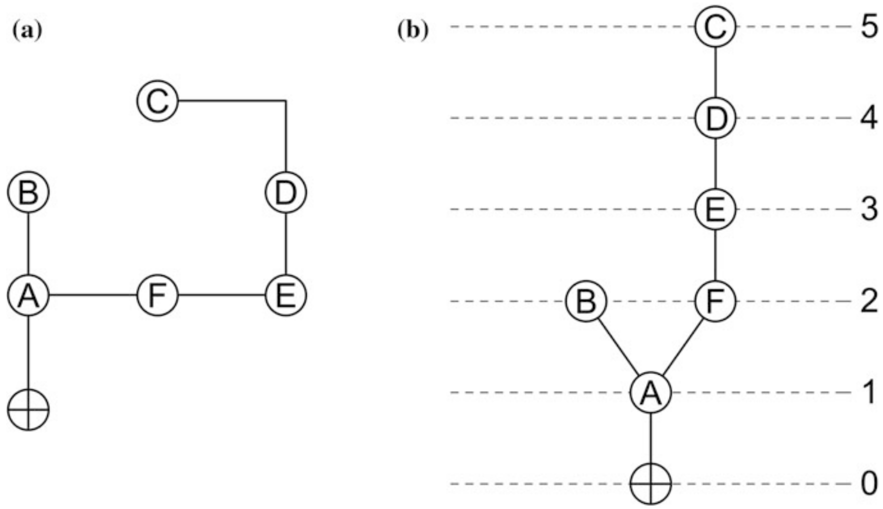


Fig. 3.2 **a** *Villa Alpha*, partial plan graph, and **b** justified graph with exterior as carrier

(Fig. 3.1). If we ignore the geography of the space (the dimensions of the rooms) we can turn this abstract variation of the plan into a topological diagram of nodes and edges (Fig. 3.2). To complete the abstraction of the plan into a graph, the last geographic feature, orientation of connections, is also removed (Fig. 3.2).

The justified graph of the *Villa Alpha* plan has several significant features. First, the graph is constructed around a series of vertical layers—horizontal dotted lines, which can be numbered consecutively from 0, the lowest line. Each dotted line represents a level of separation between rooms. The lowest level of this graph (marked 0) is reserved for the carrier, which in this case is the outside world. Those spaces that are directly connected to the carrier are located on the line above (marked 1). Further spaces directly connected to those on line 1 are placed on line 2, and so on. This graph captures the topological structure of the *Villa Alpha* when mapped in accordance with accessibility or permeability. This graph makes it readily apparent that, for example, to access space C from the exterior, a person would have to pass through spaces A, F, E and D, in that order.

The justification of the *Villa Alpha* convex space graph with the exterior as carrier, emphasises the spatial relations of the plan, relative to the position of a visitor, or person entering from outside. The spatial structure of the villa can also be visualised from any space, including the public antechamber (B) adjacent to the entry hall, or the private space at the rear of the villa (C). Each of these relationships can be represented by justifying the graph in different ways to illustrate the perceived spatial structure from the point of view of people in these spaces, respectively a visitor (⊕) and two types of occupants (B and C). This process also allows for some simple mathematical insights to be developed about the experience and use of this plan. For example, the *Villa Alpha* graphs that have been justified using nodes E and F as carriers, have a maximum room depth of 3 levels, meaning that these two rooms are no more than three spaces away from anywhere in the villa or the exterior. However, carriers ⊕, C and B are all five levels away from the furthest space (Fig. 3.3). Alternative justifications of a permeability graph can be used to understand the different social structures implicit in a plan in terms of public and private relationships.

Bill Hillier and Julienne Hanson (1984) propose that there are two distinct types of social relations revealed in a spatial permeability graph. Kim Dovey summarises these relations as, 'those between inhabitants (kinship relations or organizational hierarchies) and those between inhabitants and visitors' (1999: 22). Inhabitant-visitor relations can be represented in a permeability graph with the exterior as carrier, but inhabitant-inhabitant relations are more complex and require the generation of graphs using multiple alternative carriers. For example a close review of the *Villa Alpha* plan graph reveals that, from the point of view of a visitor (carrier ⊕) the plan is linear, controlling and asymmetrical. However, for an inhabitant (carriers E or F) the plan is less linear, less deep and more symmetrical. A visual analysis of the properties of this plan graph might suggest that the villa features a somewhat defensive attitude to visitors (or conversely, a heightened desire for privacy), but a more balanced approach to inhabitation. However, while this interpretation might seem reasonable, additional information, both mathematical (data derived from the graph) and archival (accounts of the villa's design and its function) would assist in

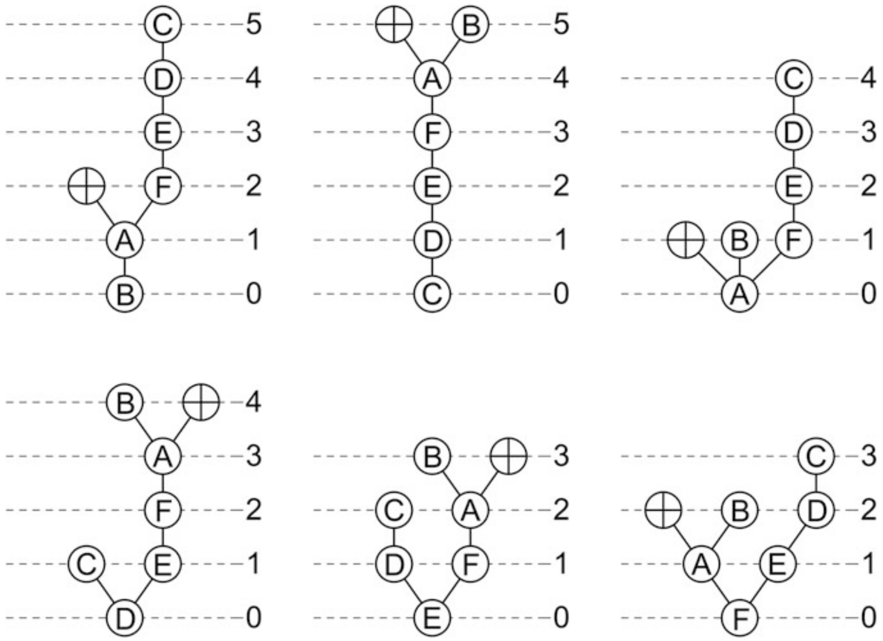


Fig. 3.3 *Villa Alpha*, alternative justified graphs

determining how viable this interpretation is. Nevertheless, visual analysis of graphs can be used to develop deep insights into the structure of space (Markus 1987; 1993; Hanson 1998; Dovey 1999). Furthermore, colour coding or other types of graphic representation can be used to identify functional and social patterns in a building. However, as graph size increases, it quickly becomes impossible to ascertain useful information using visual analysis alone, which is why mathematical analysis is usually the next step.

Stage 2, Configurational Analysis

The process for mathematically analysing a convex plan typically involves between seven and ten steps, depending on the number of measures that need to be derived from the map. The end result of this process is a table of data, with between five and seven (but possibly more) measures for individual spaces. The most common measures derived from the convex plan graph for individual spaces are: Total Depth (*TD*), Mean Depth (*MD*), Relative Asymmetry (*RA*), integration in terms of *RA* (i_{RA}), Real Relative Asymmetry (*RRA*), integration in terms of *RRA* (i_{RRA}) and Control Value (*CV*) or Choice (*C*). In addition, two holistic properties of the plan conclude the basic data set, unrelativised Difference Factor (*H*) and Relative Difference Factor (*H**). All of these measures are explained in the following sections as we provide a detailed example of the construction of such a syntactical table of data.

Step 1. Determine the total number (*K*) of nodes in the graph. The depth of each node, relative to a carrier, is also calculated; that is, how many levels (*L*) deep in the graph is the node. The number of nodes at a given level and for a given carrier is also recorded (n_x). The number of levels is counted in the graph starting from the lowest, the carrier at 0. For example, for the *Villa Alpha*, *K* = 7 (that is, there are 7 nodes; A, B, C, D, E, F and ⊕) and there are 6 levels (0, 1, 2, 3, 4, 5) when justified with ⊕ as carrier, as in Fig. 3.2b. Further, in that same graph, the *L* value for node E = 3. This process is repeated for every node, for every carrier configuration, producing a 'distance matrix' (Table 3.1). In this matrix, the depth of each carrier relative to itself is always zero.

Table 3.1 *Villa Alpha*, depth of each node relative to carrier

Vα	**Nodes at each level**				
Carrier	1	2	3	4	5
Space ⊕	A	B F	E	D	C
Space A	⊕ B F	E	D	C	
Space B	A	⊕ F	E	D	C
Space F	A E	⊕ B	D	C	
Space E	F D	A C	⊕ B		
Space D	E C	F	⊕ B	A	
Space C	D	E	F	A	⊕ B

Step 2. Calculate the Total Depth (*TD*) of the graph for a given carrier. *TD* is the sum of the number of connections between a particular node and every other node in the set, weighted by level (*L*). *TD* is calculated by determining the number of nodes (n_x) at each depth level and multiplying this number by their depth level *L*. Thus, for the *Villa Alpha*, with exterior as carrier:

$$TD = (0 \times n_x) + (1 \times n_x) + (2 \times n_x) + \ldots(X \times n_x)$$
$$TD_{V\alpha} = (0 \times 1) + (1 \times 1) + (2 \times 2) + (1 \times 3) + (1 \times 4) + (1 \times 5)$$
$$TD_{V\alpha} = 0 + 1 + 4 + 3 + 4 + 5$$
$$TD_{V\alpha} = 17$$

This means that for the *Villa Alpha*, with the exterior as carrier, *TD* = 17. This process is then repeated for every carrier and the mean *TD* is also calculated (Table 3.2).

Step 3. The Mean Depth (*MD*) is the average depth of a node in a graph. A depth that is higher than the mean is therefore more isolated in the graph than one which is lower than the mean. *MD* is calculated by dividing the Total Depth (*TD*) by the number of nodes (*K*) minus one (that is, without itself). Therefore, *MD* for the exterior (⊕) of the *Villa Alpha* is:

$$MD = \frac{TD}{(K-1)}$$
$$MD_{V\alpha} = \frac{17}{(7-1)}$$
$$MD_{V\alpha} = 2.833$$

This result suggests that relative to the exterior, spaces A (*L* = 1), B (*L* = 2) and F (*L* = 2), are all more accessible than spaces C (*L* = 5), D (*L* = 4) and E (*L* = 3). This process is then repeated for every carrier and the mean, *MD* is calculated (Table 3.3).

Table 3.2 *Villa Alpha*, Total Depth of each node relative to carrier

Vα	***TD***	***MD***	***RA***	i_{RA}	***RRA***	i_{RRA}	***CV***
Space ⊕	17						
Space A	12						
Space B	17						
Space F	11						
Space E	12						
Space D	15						
Space C	20						
Mean	14.85						
H							
H*							

Table 3.3 *Villa Alpha*, Mean Depth of each node relative to carrier

Vα	***TD***	***MD***	***RA***	i_{RA}	***RRA***	i_{RRA}	***CV***
Space ⊕	17	2.83					
Space A	12	2.00					
Space B	17	2.83					
Space F	11	1.83					
Space E	12	2.00					
Space D	15	2.50					
Space C	20	3.33					
Mean	14.85	2.47					
H							
H*							

Step 4. The *MD* results allow for the calculation of a further measure, Relative Asymmetry (*RA*). *RA* allows a researcher to compare values derived from different graphs by normalising *MD* values to a range between 0.0 and 1.0. The *RA* for the *Villa Alpha*, with exterior as carrier, is calculated as follows:

$$RA = \frac{2(MD - 1)}{K - 2}$$
$$RA_{V\alpha} = \frac{2(2.833 - 1)}{7 - 2}$$
$$RA_{V\alpha} = \frac{2 \times 1.833}{5}$$
$$RA_{V\alpha} = 0.7332$$

When this calculation is repeated for all of the carriers for the *Villa Alpha* a sequence can be constructed from the most isolated node to the least isolated: C (0.93), ⊕ (0.73), B (0.73), D (0.60), E (0.40), A (0.40) and F (0.33). Finally, the mean *RA* is calculated (Table 3.4).

Because the *RA* results are normalised to a range between 0.0 and 1.0, nodes in different graphs may be compared if the overall number of nodes (*K*) is similar. Thus, the *RA* values of two houses, each with nine rooms, may be directly compared. Arguably, the *RA* values for two houses with, say, *K* values of nine and eleven might also be compared, but the larger the difference between *K* values the less valid the comparison. In order to make a valid comparison between different size sets, an idealised benchmark (*RRA* in *Step 6*) must be used.

Step 5. If the *RA* for a carrier space is a reflection of its relative *isolation*, then the degree of *integration* (*i*) of that node in the graph can be calculated by taking its reciprocal. Therefore, the integration value for the exterior of the *Villa Alpha* may be calculated as follows:

Table 3.4 *Villa Alpha*, Relative Asymmetry of each node relative to carrier

Vα	*TD*	*MD*	*RA*	i_{RA}	*RRA*	i_{RRA}	*CV*
Space ⊕	17	2.83	0.73				
Space A	12	2.00	0.40				
Space B	17	2.83	0.73				
Space F	11	1.83	0.33				
Space E	12	2.00	0.40				
Space D	15	2.50	0.60				
Space C	20	3.33	0.93				
Mean	14.85	2.47	0.59				
H							
H*							

$$i = \frac{1}{RA}$$
$$i_{V\alpha} = \frac{1}{0.733}$$
$$i_{V\alpha} = 1.364$$

Once again, while this value is relatively meaningless in isolation, it is more informative when compared with either the rest of the building it is part of, or alternatively, an ideally distributed benchmark plan (Table 3.5). In the first instance, for the *Villa Alpha* a comparison between *i* results for each room reveals a hierarchy of space from least integrated to most integrated as follows: C (1.07), ⊕ (1.36), B (1.36), D (1.66), E (2.50), A (2.50) and F (3.00). Because of the reciprocal relationship between *i* and *RA*, this is simply the reverse order of the previous result recorded in *Step 4*. However, whereas *RA* results are limited to a range between 0.0 and 1.0, *i* results start at 1.0 and have no upper limit. Nevertheless, in order to use this data to construct a comparison with a building of a radically different size, a comparison must be constructed against an optimal benchmark (see *Steps 6* and *7*).

Table 3.5 *Villa Alpha*, integration of each node relative to carrier

Vα	*TD*	*MD*	*RA*	i_{RA}	*RRA*	i_{RRA}	*CV*
Space ⊕	17	2.83	0.73	1.36			
Space A	12	2.00	0.40	2.50			
Space B	17	2.83	0.73	1.36			
Space F	11	1.83	0.33	3.00			
Space E	12	2.00	0.40	2.50			
Space D	15	2.50	0.60	1.66			
Space C	20	3.33	0.93	1.07			
Mean	14.85	2.47	0.59	1.92			
H							
H*							

Step 6. Real Relative Asymmetry (*RRA*) describes the degree of isolation or depth of a node not only in comparison to its complete graph but also in comparison with a suitably scaled and idealised benchmark configuration. Thus, while *RA* results are effectively normalised or standardised against a set range of results (0–1) relative to *K*, *RRA* results are relativised against a scalable benchmark configuration. *RRA* results are useful for comparisons between graphs with radically different *K* values because, as graphs grow in configurational complexity and scale, their *RA* values typically fall. Despite this, there remains ongoing debate about the merits of using *RRA* over *RA* (Kruger 1989; Asami et al. 2003) with some preferring the latter (Shapiro 2005: Thayler 2005; Manum et al. 2005).

Calculating *RRA* starts with the construction of a scalable spatial configuration against which sets of results may be relativised. The scale-able configuration chosen is a diamond shape and its *RA* value is called a *D*-value (D_K) in recognition of this starting point. Hillier and Hanson describe the diamond configuration as one 'in which there are *K* spaces at mean depth level, *K*/2 at one level above and below, *K*/4 at two levels above and below, and so on until there is one space at the shallowest … and deepest points' (1984: 111–112). They then provide a table of '*D*-values for *K* spaces.' The origin of the table is found in the work of Evlabia Periklaki and John Peponis (Peponis 1985). The Periklaki and Peponis formula produces correct values for graphs with certain node numbers (*K* = 4, 10, 22, …) and extrapolates for 'other' *K* values. *RRA* is produced by dividing the subject *RA* by the relativised *RA* or *D*-value. Therefore, for the *Villa Alpha*, where the *D*-value for a *K* of 7 = 0.34, the *RRA* is as follows:

$$RRA = \frac{RA}{D_K}$$

$$RRA_{V\alpha} = \frac{0.733}{0.34}$$
$$RRA_{V\alpha} = 2.155$$

Step 7. If the *RRA* for a carrier space is a reflection of the relative isolation of a node in a graph (in comparison with an otherwise optimal and symmetrical graph), then the degree of integration (*i*) of that can be calculated by taking the reciprocal of *RRA*.

$$i = \frac{D_K}{RA}$$

or, alternatively,

$$i = \frac{1}{RRA}$$

The i_{RRA} value for the *Villa Alpha*, with exterior as carrier, and in comparison with a symmetrical configuration of the same *K* value, is therefore (Table 3.6):

Table 3.6 *Villa Alpha*, *RRA* and integration, relative to *RRA*, of each node

Vα	*TD*	*MD*	*RA*	i_{RA}	*RRA*	i_{RRA}	*CV*
Space ⊕	17	2.83	0.73	1.36	2.15	0.46	
Space A	12	2.00	0.40	2.50	1.17	0.85	
Space B	17	2.83	0.73	1.36	2.14	0.46	
Space F	11	1.83	0.33	3.00	0.97	1.03	
Space E	12	2.00	0.40	2.50	1.17	0.85	
Space D	15	2.50	0.60	1.66	1.76	0.56	
Space C	20	3.33	0.93	1.07	2.73	0.36	
Mean	14.85	2.47	0.59	1.92	1.72	0.65	
H							
H*							

$$i_{V\alpha} = \frac{0.34}{0.733}$$
$$i_{V\alpha} = 0.463$$

Step 8. The Control Value (*CV*) of a node is the degree of local influence it exerts in the graph (Jiang et al. 2000b: Xinqi et al. 2008). For example, Björn Klarqvist describes it as ‘a dynamic local measure’ that determines ‘the degree to which a space controls access to its immediate neighbours’ (1993: 11). Actually, in a building any space has the potential to be a site of control, and certain spatial configurations may increase that potential, so *CV* is about power or control in an otherwise evenly distributed, local system. Peponis (1985) offers one of the early formulas wherein the *CV* of a given node (*a*), and where *Val*(*b*) is the number of connections to a node *b*, is determined by the following formula:

$$CV(a) = \sum_{D(a,b)=1} \frac{1}{Val(b)}$$

The standard definition of control is that it must be ‘thought of as a measure of relative strength … in “pulling” the potential [of the system] from its immediate neighbours’ (Asami et al. 2003: 48.6). While this is close to the machinations of the formula, there is a notion in network theory called ‘distributed equilibrium’ that also closely approximates the properties of *CV*. Assume that a network has ‘capacity’ and that without outside influence this network will strive for equilibrium by automatically passing that capacity from one node equally to all adjacent nodes in the system (but no further and not back again). Once all of the capacity in the system has been simultaneously divided amongst its immediate neighbouring nodes, the system will have achieved a state of equilibrium through the controlled, but unequal, distribution of its capacity. The difference between nodes in this balanced state with more or less capacity is simply a factor of adjacent network configuration. Viewed in this way, *CV* identifies sites of attraction, pulling potential or capacity. However, whereas *CV* limits the equilibrium-finding process to a radius of 1—as the value only flows to nodes adjacent to those from which it originated—an alternative measure, Choice (*C*) continues dividing the value until reaching the furthest node in the graph. Conceptually, Choice could be regarded as the global equivalent on Control.

Jason Shapiro describes the construction of *CV* as beginning with ‘counting the number of neighbours of each space’ in the graph (2005: 52). That is, ‘the spaces with which it has a direct connection’; this is the NC_n value. Then, ‘each space gives to its neighbours a value equal to 1/n of its “control”’ (Shapiro 2005: 52). The distributed or shared value of each node is *CVe*: thus, $CVe = 1/NC_n$. Once the complete set of *CVe* values has been shared across the graph, then the *CV* value for each node is calculated. Calculating *CV* therefore requires a holistic approach which methodically traces where every node is influenced by every connection it has. Thus, in the case of the *Villa Alpha* the following are three example calculations of *CV*.

In the first example, ⊕ has only one connection, A, so it must distribute 1/1 or 1 *CVe* to the space it is connected to, leaving it with an interim CV of 0. However, A is connected to three spaces including ⊕ and so it must distribute 1/3 or 0.33 *CVe* to each of these. Thus, the *CV* for ⊕ is 0 + 0.33 = 0.33. In the second example, the *CV* for A is calculated by taking 1/n for each of spaces ⊕ (1/1 = 1), B (1/1 = 1) and F (1/2 = 0.50). Therefore, the *CV* for A is (1 + 1+0.50) = 2.50. Finally, the *CV* for space B is calculated by determining how many connections it has ($NC_n = 1$) and placing that in the formula $CVe = 1/NC_n$, which produces a $CVe = 1$. Thus, space B distributes its *CVe* of 1 to A, leaving it with an interim *CV* value of 0. However, space A also distributes its *CVe* three ways including to B, passing a *CVe* of 0.33 back to B, giving space B a final *CV* of 0.33 (Fig. 3.4).

The complete set of NC_n, *CVe* and *CV* results for the *Villa Alpha* are in Table 3.7. They reveal that node A, *CV* = 2.5, has the greatest natural attraction, followed by node D, *CV* = 1.5. Shapiro (2005) suggests that control values above

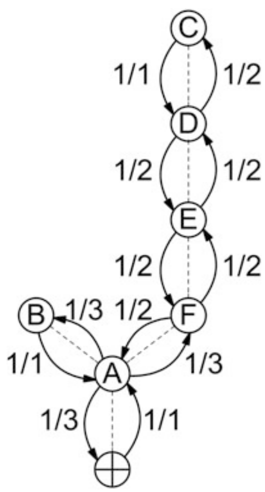


Fig. 3.4 *Villa Alpha*, distribution of ‘control’ to determine *CV*

Table 3.7 *Villa Alpha*, control data

Vα	Nodes							NC_n	*CVe*	*CV*
	⊕	A	B	F	E	D	C			
⊕	0	1	0	0	0	0	0	1.00	1.00	0.33
A	1	0	1	1	0	0	0	3.00	0.33	2.50
B	0	1	0	0	0	0	0	1.00	1.00	0.33
F	0	1	0	0	1	0	0	2.00	0.50	0.83
E	0	0	0	1	0	1	0	2.00	0.50	1.00
D	0	0	0	0	1	0	1	2.00	0.50	1.50
C	0	0	0	0	0	1	0	1.00	1.00	0.50

1.00 are considered relatively high and typically define rooms that permit or enable access. Certainly room A in the *Villa Alpha* plan is a pivotal space from the point of view of access and security, but room D (the second highest) has none of these qualities. This is why the simple definition of a *CV* value as pertaining to control is less convincing than seeing it as a site of natural influence or, even better, of natural congregation. *CV* values below 1.00 'have only weak control over adjacent spaces' (Shapiro 2005: 52). If this is true, then in the *Villa Alpha*, nodes ⊕, B and C—all of which are terminating branches in the graph—would have amongst the lowest capacities to exert influence over other nodes. In reviewing the plan, this may be true for rooms B and C, but it is less convincing for ⊕.

Step 9. In this step a measure is derived from the data to differentiate between spaces in terms of integration. This stage in the analytical process has its origins in Shannon's (1949) H-Measure, which is a determination of transition probabilities, or entropy in information systems (Zako 2006). In Space Syntax the *H* measure, or Difference Factor, 'quantifies the spread or degree of configurational differentiation among integration values' (Hanson 1998: 30). 'The closer to 0 the difference factor, the more differentiated and structured the spaces …; the closer to 1, the more homogenised the spaces or labels, to a point where all have equal integration values and hence no configurational differences exist between them' (Hanson 1998: 30–31). It is assumed that in a set of similar projects—for example houses of the same scale, same geographic location and social structure—the distribution of space is intentional and therefore similar configurational strategies will be uncovered by calculating *H*. The solution to this is to take three values that represent the spread of results and then use those as a basis against which to test other nodes. The spread is made up of the maximum *RA* (*a*), the mean *RA* (*b*) and the minimum *RA* (*c*) or, for comparing different size plans, maximum *RRA* (*a*), the mean *RRA* (*b*) and the minimum *RRA* (*c*) The sum of results *a*, *b* and *c* is known as *t* ($a + b + c = t$). Therefore, for the *Villa Alpha,* $a = 0.93$, $b = 0.59$, $c = 0.33$ and $t = 1.85$.

The unrelativised Difference Factor (*H*) is calculated using natural logarithms as follows:

$$H = -\sum \left[\frac{a}{t} In\left(\frac{a}{t}\right)\right] + \left[\frac{b}{t} In\left(\frac{b}{t}\right)\right] + \left[\frac{c}{t} In\left(\frac{c}{t}\right)\right]$$

For the *Villa Alpha* the calculation is:

$$\begin{aligned}
H &= -\left[\frac{0.93}{1.85} \times \ln\left(\frac{0.93}{1.85}\right)\right] + \left[\frac{0.59}{1.85} \times \ln\left(\frac{0.59}{1.85}\right)\right] + \left[\frac{0.33}{1.85} \times \ln\left(\frac{0.33}{1.85}\right)\right] \\
H &= -[0.5027 \times -0.6877] + [0.318 \times -1.145] + [0.178 \times -1.725] \\
H &= -[-0.3457] + [-0.3644] + [-0.3074] \\
H &= 1.0175
\end{aligned}$$

The Relative Difference Factor, H^* normalises the unrelativised H result into a scale between $ln2$ and $ln3$ and is calculated as follows:

$$H* = \frac{(H - \ln 2)}{(\ln 3 - \ln 2)}$$

For the *Villa Alpha* this results in:

$$\begin{aligned}
H* &= \frac{(1.0175 - 0.693)}{(1.0986 - 0.693)} \\
H* &= \frac{0.3245}{0.4056} \\
H* &= 0.711
\end{aligned}$$

Step 10. The complete set of data for the graph is inserted in the table, recording mean results for *TD*, *MD*, *RA*, *i* and *CV* as well *H* and *H** results (Table 3.8).

Table 3.8 *Villa Alpha*, results

Vα	***TD***	***MD***	***RA***	i_{RA}	***RRA***	i_{RRA}	***CV***
Space ⊕	17	2.83	0.73	1.36	2.15	0.46	0.33
Space A	12	2.00	0.40	2.50	1.17	0.85	2.50
Space B	17	2.83	0.73	1.36	2.14	0.46	0.33
Space F	11	1.83	0.33	3.00	0.97	1.03	0.83
Space E	12	2.00	0.40	2.50	1.17	0.85	1.00
Space D	15	2.50	0.60	1.66	1.76	0.56	1.50
Space C	20	3.33	0.93	1.07	2.73	0.36	0.50
Mean	14.85	2.47	0.59	1.92	1.72	0.65	1.00
H							1.017
H*							0.711

Stage 3, Interpretation

In this section the results for the *Villa Alpha* are interpreted in the context of two other small buildings, the *Villa Beta* (Table 3.9, Fig. 3.5) and the *Villa Gamma* (Table 3.10, Fig. 3.6), both of which have the same number of nodes (K) as the *Villa Alpha*. Because of this, either i_{RA} or i_{RRA} can be used for a simple comparison, and in this particular example, we use the former.

Of the three plans, the *Villa Alpha* has the deepest individual space, C (TD = 20), while the deepest spaces in the *Villa Beta* (A, B, C and D) and the *Villa Gamma* (B and D) all have a total depth of 12. This confirms the common sense reading of the plans, but it is also apparent that *Beta* and *Gamma*, despite having the same highest *TD* results, are also quite different. Thus it may be more informative to compare mean *TD* results: $TD_{V\alpha}$ = 14.85, $TD_{V\beta}$ = 11.42, $TD_{V\gamma}$ = 10.85. Given the same K values for each of the dwellings, it is not surprising that the degree of difference is reduced when the average weighted depth for the spatial configuration is determined. Mean *MD* for the villas is as follows: $MD_{V\alpha}$ = 2.47, $MD_{V\beta}$ = 1.90,

Table 3.9 *Villa Beta*, results

Vβ	***TD***	***MD***	***RA***	i_{RA}	***RRA***	i_{RRA}	***CV***
Space ⊕	15	2.50	0.60	1.66	1.76	0.56	0.50
Space F	7	1.16	0.06	15.00	0.17	5.88	4.50
Space A	12	2.00	0.40	2.50	1.17	0.85	0.20
Space B	12	2.00	0.40	2.50	1.17	0.85	0.20
Space C	12	2.00	0.40	2.50	1.17	0.85	0.20
Space D	12	2.00	0.40	2.50	1.17	0.85	0.20
Space E	10	1.66	0.26	3.75	0.72	1.38	1.20
Mean	11.42	1.90	0.36	4.34	1.04	1.60	1.00
H							0.76
H*							0.18

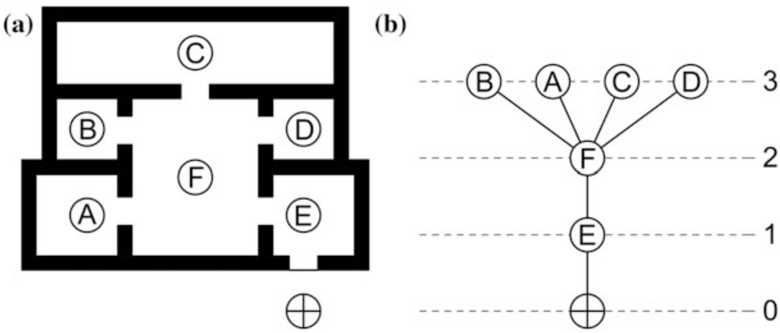


Fig. 3.5 *Villa Beta*, **a** plan, and **b** justified graph

Table 3.10 *Villa Gamma*, results

Vγ	*TD*	*MD*	*RA*	i_{RA}	*RRA*	i_{RRA}	*CV*
Space ⊕	13	2.16	0.46	2.14	1.35	0.74	0.25
Space F	8	1.33	0.13	7.50	0.38	2.63	2.33
Space A	11	1.83	0.33	3.00	0.97	1.03	0.75
Space C	9	1.50	0.20	5.00	0.58	1.72	1.25
Space E	11	1.83	0.33	3.00	0.97	1.03	0.75
Space B	12	2.00	0.40	2.50	1.17	0.85	0.83
Space D	12	2.00	0.40	2.50	1.17	0.85	0.83
Mean	10.85	1.80	0.32	3.66	0.94	1.26	1.00
H							0.99
H*							0.73

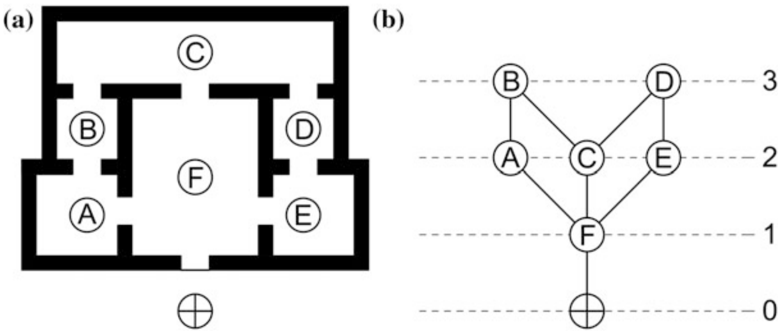


Fig. 3.6 *Villa Gamma* **a** plan, and **b** justified graph

$MD_{V\gamma}$ = 1.80. Thus, the plan of the *Villa Beta* is slightly deeper on average, than the plan for the *Villa Gamma*. While for the three villas this difference isn't especially revealing, knowing which rooms are more or less deep can be useful for examining larger spatial configurations. For example, Hanson (1998) uses this method to examine *Bearwood Hall*, a seventeenth century English manor house with 134 rooms; in such a plan, depth is very revealing.

Considering *RA* results, Hillier and Hanson (1984) suggest that a perfect shallow and symmetrical composition should have an *RA* closer to 0.00, while a linear structure should have a result closer to 1.00. The *Villa Alpha* is a mostly linear structure, with one exception, and its mean result, $RA_{V\alpha}$ = 0.59, is closer to a value of 1, which seems to confirm this general property. In contrast, the *Villa Beta* is a relatively shallow and symmetrical structure. Only the presence of the entry and hall spaces, E and F, removes the distribution of nodes from an ideal structure by adding two levels of depth; this leads to a mean $RA_{V\beta}$ = 0.36. This result is closer to 0 (shallow and distributed) than to 1 (linear) once again supporting the standard interpretation. Finally, the *Villa Gamma* has the lowest mean result, $RA_V\gamma = 0.32$, which confirms it is the most shallow of the plans, but only by a small margin.

Integration results are typically used to distinguish rooms, or sequences of rooms, which are pivotal to a spatial configuration, from those that are not. The use of *i* to rank a set of rooms is also a special type of data set. As Sonit Bafna records, the 'ranking of programmatic labelled spaces according to their mean depth (most often described in terms of integration values)' is called an 'inequality genotype' (2001: 20.1). For the *Villa Alpha*, the inequality genotype is: F (3.00) > E and A (2.50) > D (1.66) > B and ⊕ (both 1.36) > C (1.07). Hanson (1998) suggests that such a sequence is a reflection of 'inhabitant-visitor' relations and that it may be more important in the analysis of a house to consider only 'inhabitant-inhabitant' relations. When the graph data for the *Villa Alpha* is recalculated without the presence of an exterior node, then the following is the integration sequence: F and E (both 2.50) > D and A (both 1.66) > B and C (both 1.00). This change flattens the results for the *Villa Alpha*, identifying three clear zones of integration and replicating the visual affect of the graph if it is produced with F as carrier (Fig. 3.3). When this process is undertaken for the *Villa Beta* an i_{RA} range of 1.66 to 15.00 drops to between 0.20 and 5.00. For the *Villa Gamma* the i_{RA} range for the whole set is 2.14 to 7.50 whereas for only the interior set it is reduced to between 2.50 to 5.00.

The *CV* results for the *Villa Beta* show, not surprisingly that space F—the central hall which connects all other interior spaces—is not only the most influential space, but that it is between 3.75 and 22.5 times more influential than any other space in the villa. While an astute designer would visually identify this space as the most important, it helps to be able to quantify the importance of spaces, particularly in larger and more complex designs. For the *Villa Gamma*, with its ringed, permeable structure, only space C, a mid-depth, secondary foyer (and the most direct path to spaces B and D), has a slightly elevated level of influence or attraction and only the exterior node has a much-reduced level. All of the other nodes have similar results (ranging from 0.75 to 1.25).

The Relative Difference Factor H^* provides an indication of the degree to which a complete graph is homogenous (has similar *i* values) or is differentiated (has dissimilar *i* values). For the *Villa Alpha*, $H^* = 0.71$ and for the *Villa Gamma*, $H^* = 0.73$. These are not only both similar results, but they are both closer to 1.00 than to 0.00 so they fall into the category of graphs that are 'more homogenised' or 'where all have equal integration values' (Hanson 1998: 31). In contrast, the result for the *Villa Beta* is $H^* = 0.181$, which suggests a highly differentiated or structured graph. This occurs because the central controlling hall (*F*) has an *i* value which is much higher than the remainder of the rooms, supporting one particular interpretation of the idea of differentiated or structured space. Ultimately, the use of H^* values for the analysis of three simple structures, which are already almost archetypes, is of limited use; a larger and more complex body of data is required for H^* to be truly informative (see Chap. 7).

3.3 Axial Line Analysis

The technical definition of an axial line map has three parts. First, it is the set of the fewest and longest straight lines required to cover every convex space in a plan. Second, it must ensure that all lines in the set that can be connected are connected. Third, all non-trivial circulation loops must be included in the set. In this definition, a 'line' is a straight path through space allowing for either direct movement or unimpeded vision. The existence of a line implies that a person can either walk or, depending on the definition, see directly along a vector on a plan. A line begins and ends where it intersects with a wall or surface that restricts further movement or vision. A line can 'cover' a space by passing into or through it. This means that the line provides visual or physical coverage of a space.

In the first part of the definition, the words 'fewest' and 'longest' are concerned with achieving a map that is both efficient and inclusive. The fewer lines there are, and the more effective each line is in covering the spaces in a plan, the more efficient the map is likely to be. Importantly, the notion of spatial coverage is tied to convex spaces. This is because the axial line map is concerned with the way in which space is understood or constructed through vision and movement. As such, substantial recesses in walls and irregularly shaped rooms can have an impact on the map. If the lines cover all of the convex spaces in a plan, then all visually and physically accessible parts of the plan are included in the map. The second part of the definition is about creating a continuous network of connections across the map. If all of the lines that can be connected are connected, then the entire movement or vision potential of the plan is embodied into a single map. The final part of the definition is concerned with circulation loops. A circulation loop is a path around a space that connects back to another part of the plan. If the path is visually connected at all points (or has only minor visual obstructions such as columns) then it is considered a 'trivial' loop. If the obstruction is sufficient to disconnect the experience of a space, it is a 'non-trivial' loop (Fig. 3.7). The axial line map must include lines that connect around non-trivial loops. The requirement to include both all convex spaces and all non-trivial loops in the axial line map is aimed at ensuring the completeness of the map.

When these three different parts of the definition come together, it becomes apparent that the axial line map is the simplest, most efficient network of paths that can represent a complete building plan. In practice the axial line map looks like a set of angled, annotated lines, all of which intersect at least one other line.

In the following section a manual procedure is presented for abstracting a plan into an axial line map. This manual method is inspired by two of the more stable and repeatable construction techniques (Peponis et al. 1997b; Turner et al. 2005), which have been modified to reflect the spirit of the original variation (Hillier and Hanson 1984). Importantly, while the manual method might be slow to produce a result, if it is followed meticulously it will produce one that is objective, reproducible, and valid and in doing so, provide the person constructing the map with a deeper insight into the method itself. There is also an additional advantage to using

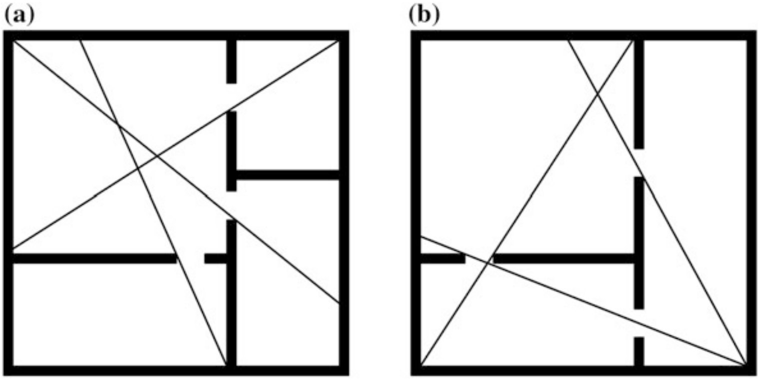


Fig. 3.7 **a** A trivial circulation loop, in the centre of the main room, and **b** a non-trivial circulation loops, through three rooms

the manual method; it allows the researcher time to become immersed in the spatial qualities of the plan prior to the mathematical results being calculated. This is useful because without this level of intuitive spatial understanding any errors in the software calculations are unlikely to be immediately recognizable as such.

Stage 1, Abstraction Process

The manual abstraction process for an axial line map commences with the plan being partitioned into convex spaces. This involves extending the planar surface beyond reflex vertices to form a surface line (s-line). The wall is only visible from one side of this demarcation. Once this step is completed, the s-lines will have divided the plan into a series of concise zones known as ‘s-spaces’. Importantly, it is not necessary to draw s-lines between convex wall angles, and s-lines do not extend along the generating wall’s surface. S-lines represent a demarcation boundary that must be crossed for an entire wall surface to become visible (Fig. 3.8).

With the plan partitioned into s-spaces, the next step is to draw the longest possible line on the plan that crosses at least one s-line. If this longest line has no equivalences elsewhere in the plan (that is, lines of the same length and which traverse the same s-lines), it will appear in the final axial map and is designated as an ‘m-line’. There are actually multiple different types of m-lines which have been classified in accordance with the way their ends are defined by convex corners, surfaces or reflex points (Turner et al. 2005) (Fig. 3.9). While such distinctions are potentially relevant for examining certain questions about space, they are not significant for the present purpose. Returning to the map, it is possible that a number of potential m-lines will possess identical characteristics (length, connections and s-line intersections) and if this occurs, a decision must be made about which one to keep and which to remove. There are multiple different approaches to this issue. For example, Peponis et al. (1997b) advocate randomly selecting and deleting these lines until only one remains, whereas Turner et al. (2005) note that such an approach may compromise the selection of later m-lines and possibly undermine

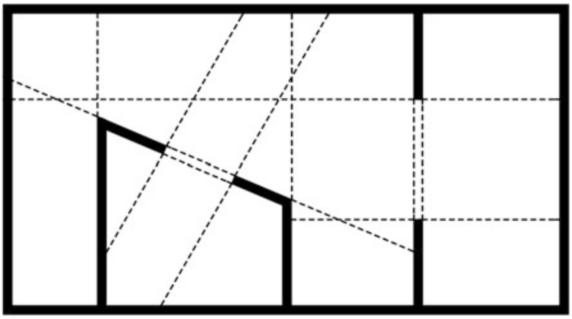


Fig. 3.8 An example of s-lines (dotted) extended from reflex wall angles

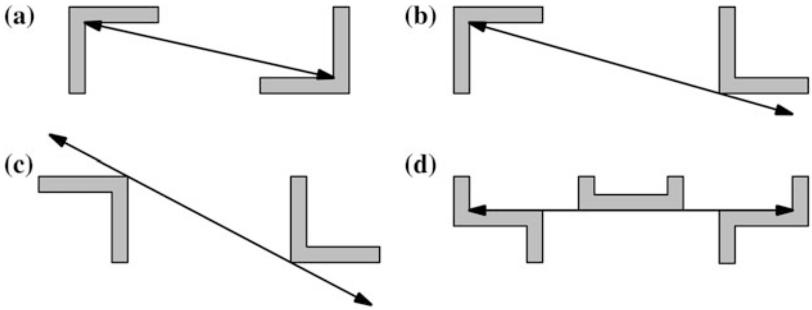


Fig. 3.9 Four example m-line types, **a** convex-convex, **b** convex-reflex, **c** reflex-reflex, **d** surface. Based on (Turner et al. 2005)

the properties of the map. The solution proposed in this chapter is that the identical lines are all 'sketched' into the map and designated as potential lines (or 'p-lines'). Once the remainder of the map is complete, an informed decision is then made about which p-line to convert into an m-line, and which to delete (Fig. 3.10). It is also possible, as we will see in the next section, for two m-lines to be reconciled into one in the final map in accordance with several secondary rules.

Once the first m-line (or equivalent p-line) is identified, then any s-lines crossed by it are removed as a sign that this zone or partition in the plan has been adequately covered. Then the next longest m-line intersecting at least one s-line is drawn and the process is repeated until all of the s-lines are removed and only m-lines and p-lines remain. Any p-lines can then be revisited, and the superfluous ones deleted, leaving only m-lines. Finally, a check is made to ensure that all non-trivial circulation loops are included in the map. At the end of the process, the only thing that

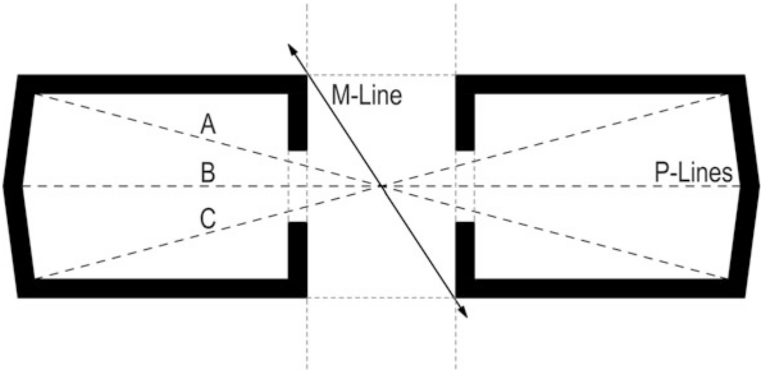


Fig. 3.10 Three potential lines (p-lines A, B and C) with identical length, connections and s-line intersections. Only one of these is required for the final map

remains of the plan is a set of angled, intersecting m-lines, which may be numbered for reference; these are collectively called an axial line map. In total, there are ten discrete steps in the manual process of constructing the axial line map, although not all of these are relevant for all plans. In this section the plans of three hypothetical villas—*Epsilon*, *Zeta* and *Eta*—are used to demonstrate the abstraction process.

Step 1. Produce a plan drawing which is stripped of any detail other than its base geometric properties (Fig. 3.11).

Step 2. Trace all s-lines in the plan. Notably, despite having superficially similar plans, the number of s-spaces in the three villas differs, with the villas *Epsilon*, *Zeta* and *Eta* having, respectively, forty, thirty-four and forty-eight s-spaces (Fig. 3.12).

Step 3. Once the s-lines are completed, then the process of drawing m-lines commences. In this step it is recommended that as each m-line is generated it is given a unique identity label (typically a number). The first m-line is located by running a ruler over the plan, seeking the longest axis that intersects at least one s-line. If two m-lines of equal length are identified which intersect different s-lines,

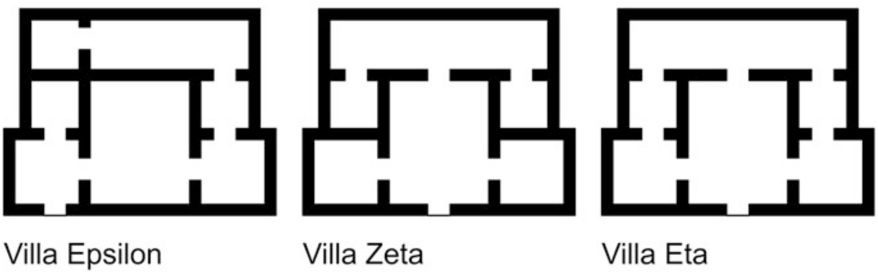


Fig. 3.11 Floor plans for the villas *Epsilon*, *Zeta* and *Eta*

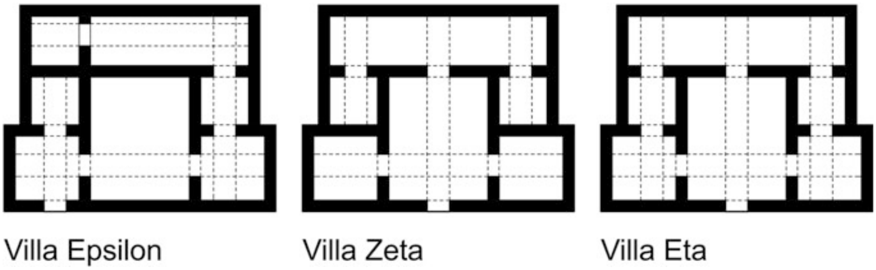


Fig. 3.12 S-Lines marked on floor plans

both are drawn and labelled. If they intersect the same lines, then they are drawn, but designated as p-lines, and in a later stage all but one of these matching lines will be deleted. For each of the three villa plans there are two clear starting m-lines (1 and 2) both of which have the same length but intersect different s-lines, and so at this stage they are all retained (Fig. 3.13). Any s-lines crossed by these m-lines are then reduced in opacity or deleted.

Step 4. Once the first m-line (or equivalent set of p-lines) is drawn, then the next longest m-line is identified. The method for generating the 'second' m-line is identical to the first; locate the longest m-line in the system that intersects at least one (remaining) s-line. Again, if two lines of equal length intersect different s-lines then draw both; if multiple lines of equal length intersect the same s-lines also draw them all and annotate them as p-lines. In the case of the three villas, the *Villa Epsilon* has a clear second m-line, whereas the other two villas each have a pair of identical p-lines, one of which will later be deleted (Fig. 3.14).

Step 5. The process of identifying the next longest m-line that intersects an s-line, is repeated until all s-lines have been intersected by m-lines (or equivalent p-lines). This step ensures that every wall surface in the plan is surveyed by one line. For the *Villa Epsilon* seven iterations of this step are required to intersect all s-lines, whereas for the villas *Zeta* and *Eta*, four and five iterations, respectively, are needed

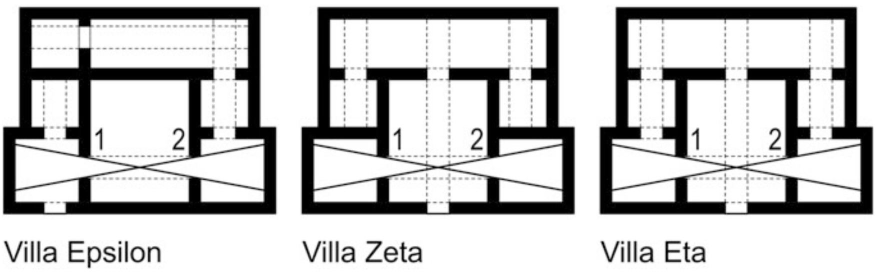


Fig. 3.13 The longest lines are marked on the floor plans (in all three cases two m-lines, identical in length but intersecting different s-lines are generated)

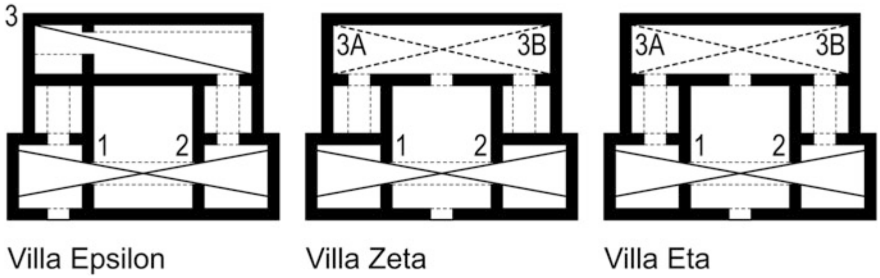


Fig. 3.14 The 'second' longest lines are marked on the floor plans (in the case of the Villas *Zeta* and *Eta* they are p-lines)

(Figs. 3.15, 3.16 and 3.17). Here lines of equal length that intersect different s-lines are drawn simultaneously.

Step 6. While the stages outlined thus far may identify the m- or p-lines that intersect every s-line, they do not guarantee that all non-trivial circulation loops have been completed. This situation occurs whenever it is possible to circulate completely around a wall or space; a situation that is typically described as resulting from the existence of an 'island' space. To check that all non-trivial circulation loops have been completed extend a polygon from the surfaces of each island until it meets another wall, island, m- or p-line. If the polygon reaches a wall or island, additional m-lines (*Step 7*) are required. This procedure provides a similar outcome to Peponis et al.'s (1997b) rigorous definition required to automate the process. This step is not required for the villas *Epsilon* or *Zeta*, but it is for the *Villa Eta* in which there are two symmetrically opposed looping circuits through the space. However, because both extended polygons (shaded in the *Villa Eta* plan, Fig. 3.18) do not meet a surface, the rule confirms that the existing m- or p-lines are sufficient to comprehensively represent the villa's spatial configuration.

Step 7. This step is required if polygon contact occurs as part of the previous step and additional m-lines are required. In this instance the goal is to seek the fewest, in number, and longest, in length, m-lines (prioritized in that order) that will prevent contact occurring. Where the polygons of multiple islands make contact with other wall-sets, this process is conducted simultaneously for all polygons. The *Villa Eta*, in the previous step, displayed the simultaneous development of two polygons but neither needed additional m-lines.

Step 8. It is unlikely, but theoretically possible, that discrete, separated sets of lines can be generated in a plan. If this is the case, it is necessary to add the fewest and longest lines that can singularly connect any previously unconnected lines. In the three villa plans all connections have been made prior to this step.

Step 9. A decision must now be made regarding which p-lines to keep and whether there are any superfluous m-lines that need to be removed. This process involves working through a hierarchical series of protocols that must be undertaken in a

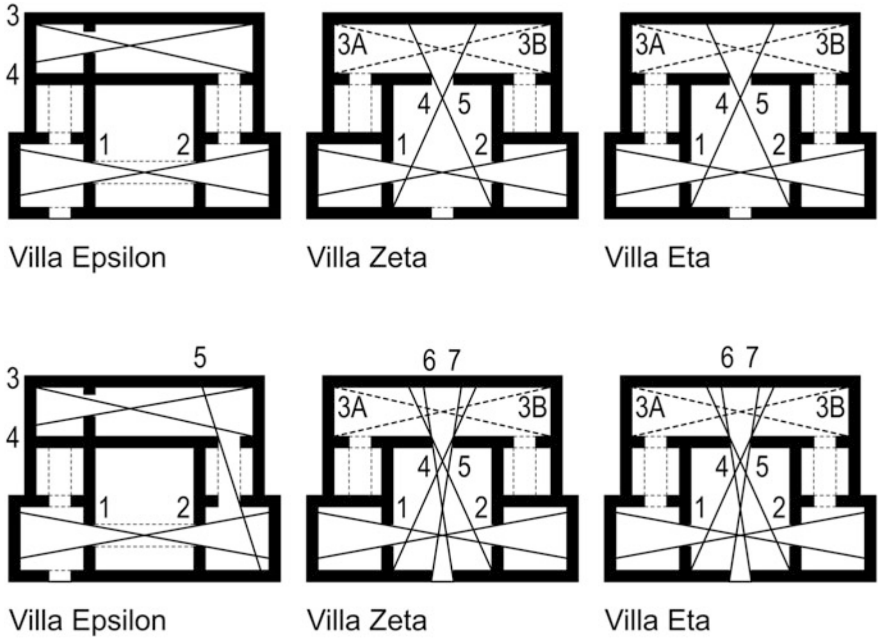


Fig. 3.15 Iterations one and two of Step 5, the process of ensuring that all s-lines have been crossed by m- or p-lines

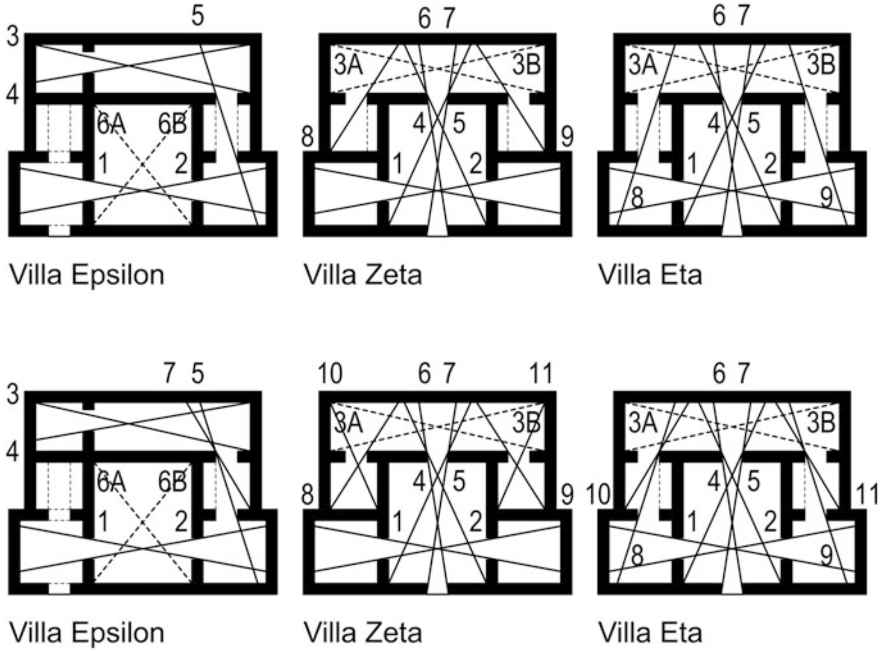


Fig. 3.16 Iterations three and four of Step 5, the process of ensuring that all s-lines have been crossed by m- or p-lines

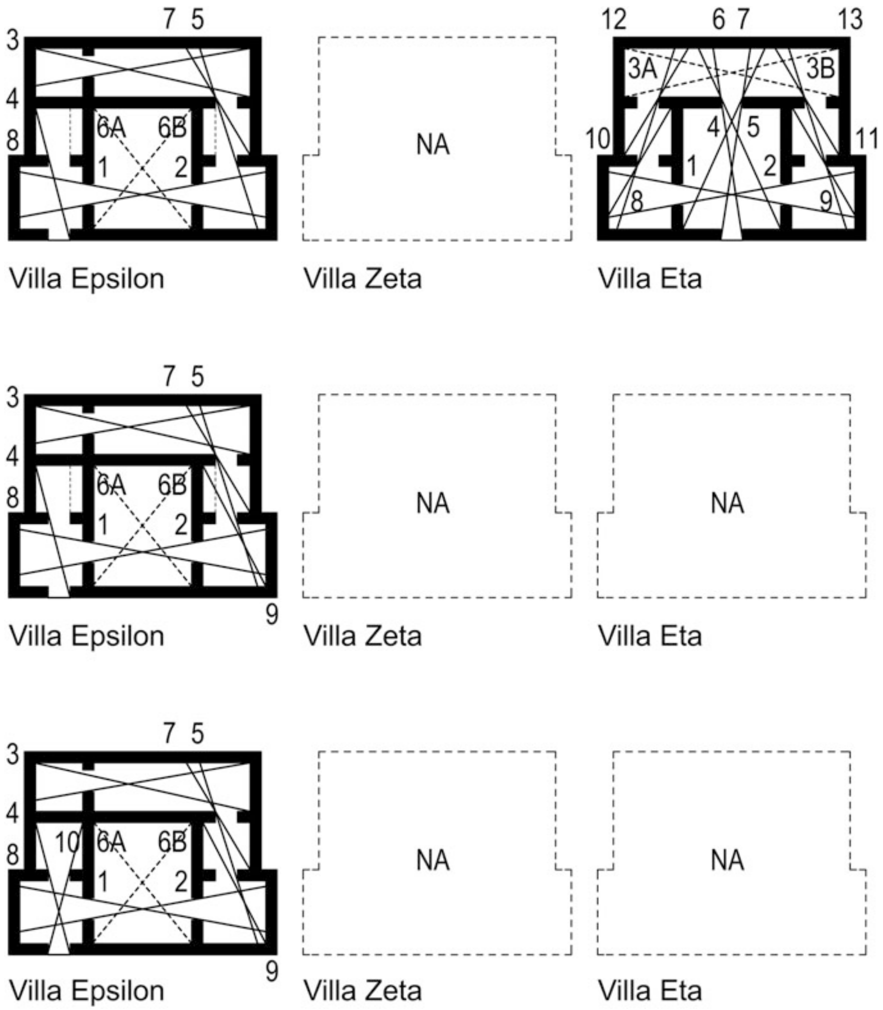


Fig. 3.17 Iterations five, six and seven of Step 5, the process of ensuring that all s-lines have been crossed by m- or p-lines (NA = not applicable, because some plans require repetition of various steps while others do not)

sequential manner and where later protocols must respect earlier ones. These protocols may then trigger the need for a procedure to correct or revise the map. There are six protocols and three procedures. The protocols for finalising the map are as follows.

1. Begin with a consideration of each line in turn, starting with the longest and progressing towards the shortest.
2. No line may be deleted if it will result in an associated space no longer being surveilled.

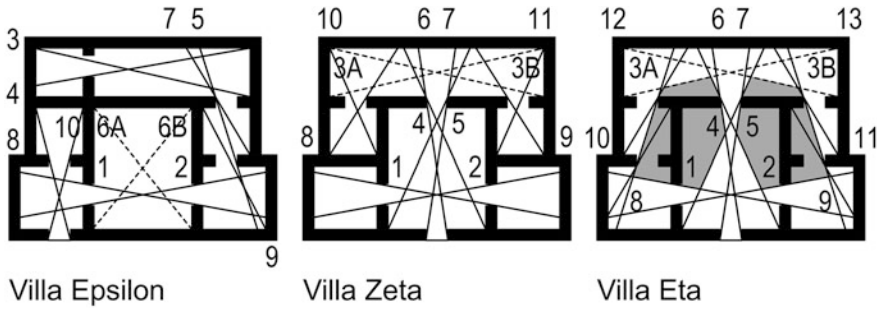


Fig. 3.18 Checking for islands in the plans and using the extended polygon method for the two islands in the *Villa Eta*

3. No lines may be removed which will allow an island surface extension polygon to meet a wall-set or other island.
4. Any line with connections that are a subset of the connections of another line is a possible candidate for deletion (see procedure 2).
5. If multiple lines make identical connections, the shorter line(s) may be removed.
6. If multiple lines are identical in all respects, adopt the convention of retaining the line running northwest to southeast (see procedure 3). This protocol removes superfluous lines and provides a repeatable and consistent representational approach.

The three procedures, which may be triggered by the previous protocols, are as follows.

1. Check selected points associated with a line (for example, in the *Villa Epsilon* point A is associated with lines 8 and 10, point B with lines 3, 4, 5, 7 and 9) draw straight check lines (called c-lines) from surface vertices to all possible other surface vertices, without intersecting an intermediary surface. If a c-line only intersects one m-line, that m-line must not be deleted. C-lines could be generated from an all-line map, or by drawing all lines (as demonstrated for points A and B in Fig. 3.19.
2. Using Turner et al.'s (2005) algorithmic process as the basis for line deletion, the connections of a line are determined as follows, using the *Villa Epsilon* as an example. Line 1 connections are, C1 = {1, 2, 5, 6a, 6b, 8, 9, 10} and the connections for line 8 are, C8 = {1, 2, 8, 10}. This means that the connections of line 8 are a subset of line 1, and therefore line 8 is a candidate for possible deletion.
3. If two lines are identical in all of their properties then a decision must be made to remove one. The nature of the decision does not affect the mathematical measures that are derived from the map, but it can lead to confusion when trying to replicate it. For this reason we propose retaining the line which runs closest to 45° from the upper left corner to the lower right corner (or running northwest to

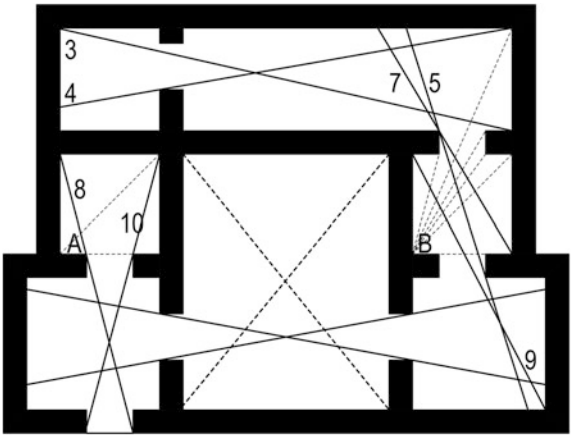


Fig. 3.19 Example of points associated with m-lines. Lines not relevant to point A or B are depicted with long dashes, c-lines with short dashes

southeast, if the orientation of the plan is known); the other line is then removed. If two lines diverge equally from a 45° angle retain the line closer to a north/south orientation. In the case of *Villa Epsilon* the lines removed are 2, 4, 6a and 6b, 7, 9 and 10 (Figs. 3.20, 3.21 and 3.22). This also means that the *Villa Epsilon* requires six iterations of this procedure, whereas the villas *Zeta* and *Eta* require, respectively, five and seven.

Step 10. In this final step, the plan is removed, leaving only the axial line map, which is all that is required for the mathematical analysis (Fig. 3.23). The axial line map finally contains just the set of the fewest and longest lines required to represent the complete spatial configuration and accommodate any non-trivial circulation loops. For the villas *Epsilon*, *Zeta* and *Eta* there are, respectively, four, five and five lines in their final maps. Also remember that axial lines are graph nodes and their intersections are graph edges. Thus it is possible to prepare node-edge diagrams like those seen in the convex space section previously in this chapter; however, this representation is rarely used.

Stage 2, Configurational Analysis

Having arrived at an objective and efficient axial line map, mathematical analysis is then used to derive various characteristics of the plan. This process, which has eleven steps, parallels the method used in the previous analysis of convex spaces and permeability. In this section the *Villa Epsilon* axial line map is used as an example.

Step 1. As a starting point, the number of lines in the complete system is determined (*K*). The axial map of the *Villa Epsilon* has four lines (K = 4).

Step 2. As in convex spaces, here too it is also possible to determine the depth levels of each line relative to a specific carrier. Depth is measured as the number of steps, or intersections, between a starting line and another line. Total Depth (*TD*), is the number of connections each line makes with all others, referenced to the relative

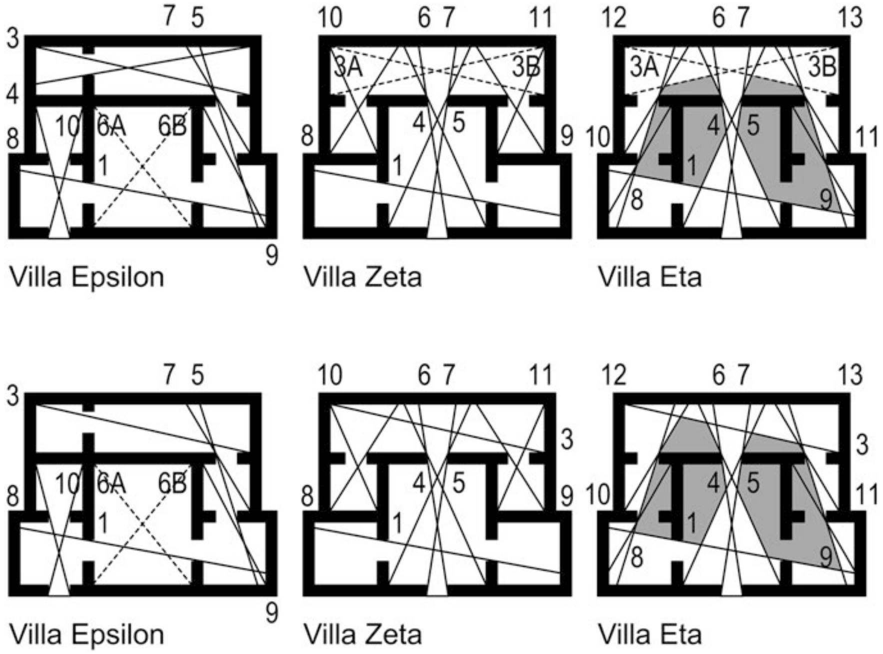


Fig. 3.20 Iterations one and two of Step 9; the complete set of lines for the three villas are tested and, following the protocol, lines are removed until only an optimal set remains for each plan

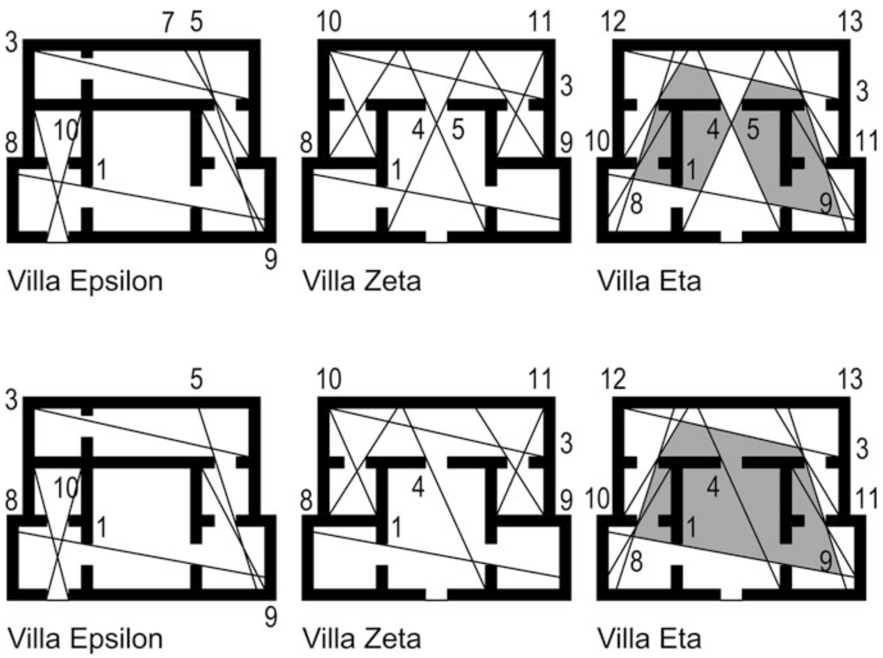


Fig. 3.21 Iterations three and four of Step 9; the complete set of lines for the three villas are tested and, following the protocol, lines are removed until only an optimal set remains for each plan

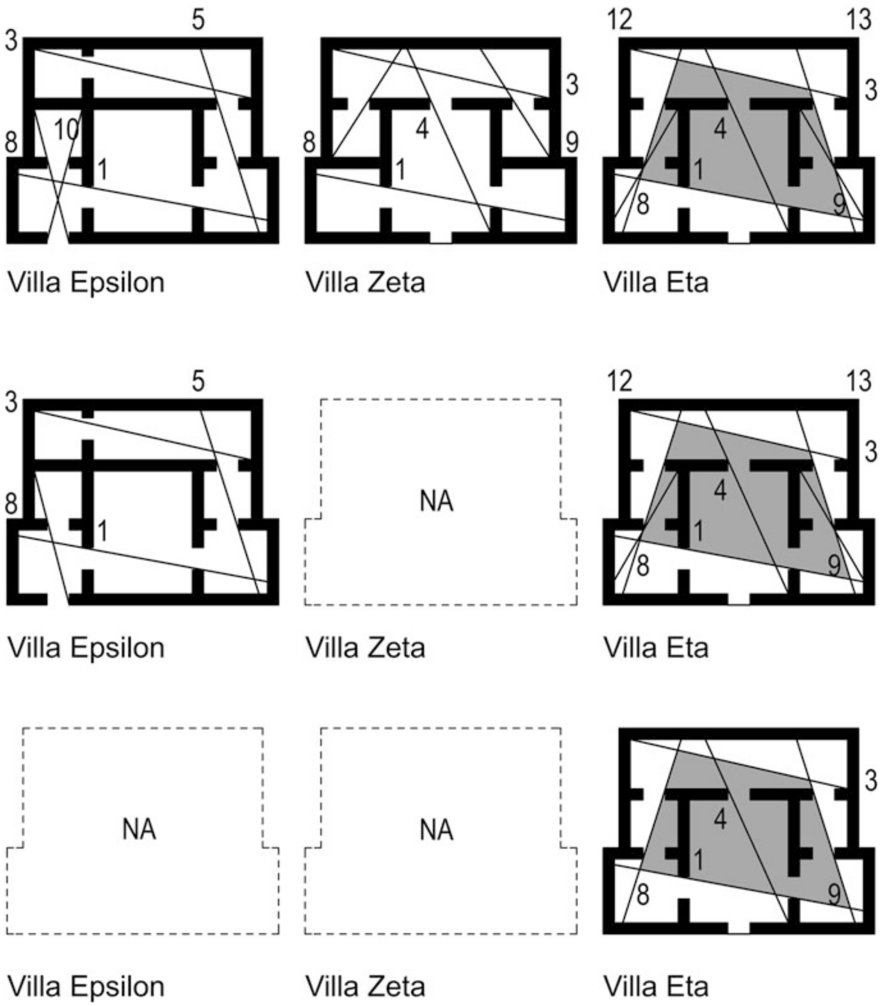


Fig. 3.22 Iterations five, six and seven of Step 9; the complete set of lines for the three villas are tested and, following the protocol, lines are removed until only an optimal set remains for each plan. (NA = not applicable, because some plans require repetition of various steps while others do not)

depth of those lines. In the case of the *Villa Epsilon*, line 1 'connects' to itself at depth 0, to lines 3 and 5 at a depth of 1, and to line 8 at a depth of 2. Similarly, line 3 connects to itself at depth 0, to line 5 at depth 1, to line 1 at depth 2 and line 8 at depth 3. *TD* is the sum of the number of connections between a particular line and every other line in the set weighted by level (L). It is calculated by adding together, for each level of the graph, the number of nodes (n_x) at that level of depth multiplied by L (0, 1, 2, 3, 4, …). Thus:

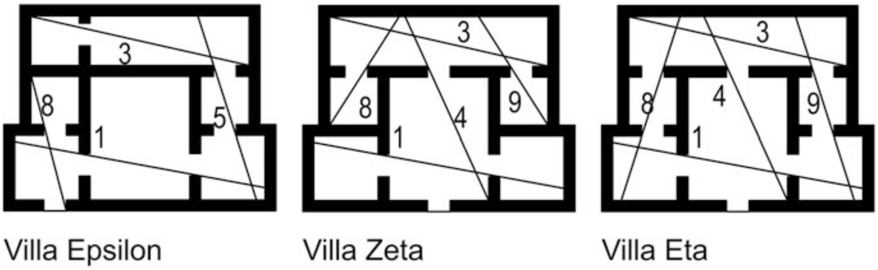


Fig. 3.23 Final axial line maps of the three villas

$$TD = (0 \times n_x) + (1 \times n_x) + (2 \times n_x) + \ldots (X \times n_x)$$

In the case of the *Villa Epsilon*, the four lines are evenly divided between two *TD* values, 4 and 6 (Table 3.11).

Step 3. Calculating Mean Depth (*MD*) in the axial line map is achieved by dividing the total depth of a line by one less than the total number of lines in the system, or:

$$MD = \frac{TD}{(K - 1)}$$

For the *Villa Epsilon*, because the system is evenly divided between two *TD* values, it is also evenly divided between two *MD* values, 1.33 and 2 (Table 3.12).

Step 4. This stage involves the calculation of Relative Asymmetry (*RA*), a way of normalizing the range of possible results to between 0.0 and 1.0 (Table 3.13). This stage is important because it allows for a direct comparison to be made between the results of different axial maps which have a similar number of nodes. The *RA* for the system is calculated as follows:

$$RA = \frac{2(MD - 1)}{(K - 2)}$$

Step 5. The level of integration (*i*) of each line in the system is then calculated relative to an idealised benchmark (Table 3.14). Being a function of relative

Table 3.11 *Villa Epsilon*, Total Depth of each line

Vγ	**Lines at each level**				***TD***
	0	1	2	3	
Line 1	1	5, 8	3		4.00
Line 3	3	5	1	8	6.00
Line 5	5	3, 1	8		4.00
Line 8	8	1	5	3	6.00

Table 3.12 *Villa Epsilon*, Mean Depth of each line

Vγ	*TD*	*MD*	*RA*	i_{RA}	*RRA*	i_{RRA}	*CV*
Line 1	4	1.33					
Line 3	6	2.00					
Line 5	4	1.33					
Line 8	6	2.00					
Mean	5.00	1.66					
H							
H*							

Table 3.13 *Villa Epsilon*, Relative Asymmetry of each line

Vγ	*TD*	*MD*	*RA*	i_{RA}	*RRA*	i_{RRA}	*CV*
Line 1	4	1.33	0.33				
Line 3	6	2.00	1.00				
Line 5	4	1.33	0.33				
Line 8	6	2.00	1.00				
Mean	5.00	1.66	0.66				
H							
H*							

Table 3.14 *Villa Epsilon*, integration of each line

Vγ	*TD*	*MD*	*RA*	i_{RA}	*RRA*	i_{RRA}	*CV*
Line 1	4	1.33	0.33	3.00			
Line 3	6	2.00	1.00	1.00			
Line 5	4	1.33	0.33	3.00			
Line 8	6	2.00	1.00	1.00			
Mean	5.00	1.66	0.66	2.00			
H							
H*							

asymmetry, this version of i can also be used (and frequently is) to compare different axial map s. The formula for i is as follows:

$$i = \frac{1}{RA}$$

Step 6. Real Relative Asymmetry (*RRA*) allows for a comparison to be constructed between a line and a scaled, idealized benchmark configuration. *RRA* is calculated as follows:

Table 3.15 *Villa Epsilon*, Real Relative Asymmetry of each line

Vγ	*TD*	*MD*	*RA*	i_{RA}	*RRA*	i_{RRA}	*CV*
Line 1	4	1.33	0.33	3.00	0.93		
Line 3	6	2.00	1.00	1.00	2.80		
Line 5	4	1.33	0.33	3.00	0.93		
Line 8	6	2.00	1.00	1.00	2.80		
Mean	5.00	1.66	0.66	2.00	1.86		
H							
H*							

$$RRA = \frac{RA}{D_K}$$

In this formula *D* is a value indexed against graph size (Hillier and Hanson 1984: 112); for a system containing four axial lines *D* can also be calculated using Peponis's and Periklaki's formula (Peponis 1985). For the present example, a *D* value of 0.357 has been used for the calculations (Table 3.15).

Step 7. Integration (*i*) relative to *RRA* is also calculated for comparative purposes as follows (Table 3.16):

$$i = \frac{1}{RRA}$$

Step 8. Control value (*CV*) is a measure of the number of axial lines that are accessible only through specific axial lines in the system. In order to calculate *CV*, first create an intersection matrix showing the lines that intersect with each other; then calculate the number of connections (NC_n) for each line. *CVe* values for each line are calculated using the following formula:

$$CVe = \frac{1}{NC_n}$$

Table 3.16 *Villa Epsilon*, integration of each line

Vγ	*TD*	*MD*	*RA*	i_{RA}	*RRA*	i_{RRA}	*CV*
Line 1	4	1.33	0.33	3.00	0.93	1.07	
Line 3	6	2.00	1.00	1.00	2.80	0.35	
Line 5	4	1.33	0.33	3.00	0.93	1.07	
Line 8	6	2.00	1.00	1.00	2.80	0.35	
Mean	5.00	1.66	0.66	2.00	1.86	0.71	
H							
H*							

Table 3.17 *Villa Epsilon*, control data

Vγ	*NCn*					*CVe*	*CV calc*	*CV*
	Line 1	Line 2	Line 3	Line 4	*NCn*	0.5		
Line 1	0	0	1	1	2	1	1	0.50
Line 3	0	0	1	0	1	0.5	0.5 + 1	1.50
Line 5	1	1	0	0	2	1	1	0.50
Line 8	1	0	0	0	1	0.5	0.5 + 1	1.50

The *CV* value for a line is produced by adding the *CVe* value(s) of each line it intersects. For example, in the *Villa Epsilon*, line 1 intersects line 8 (*CVe* 0.5) and line 5 (*CVe* 1) to produce a total *CV* = 1.5 (Table 3.17).

Step 9. While the use of the Difference Factor (*H*) for axial line maps is less common than for convex space maps, it is calculated using the formula:

$$H = -\sum \left\lfloor \frac{a}{t} In\left(\frac{a}{t}\right) \right\rfloor + \left\lfloor \frac{b}{t} In\left(\frac{b}{t}\right) \right\rfloor + \left\lfloor \frac{c}{t} In\left(\frac{c}{t}\right) \right\rfloor$$

where a = Max *RRA*, b = Mean *RRA*, c = Min *RRA*, $t = a + b +$ c and *ln* is natural logarithm. In the case of the *Villa Epsilon*, H = 1.0113.

Step 10. The Relative Difference Factor ($H*$) normalizes the unrelativized H result into a scale between *ln*2 and *ln*3 (Zako 2006) and is calculated as follows:

$$H* = \frac{(H - \ln 2)}{(\ln 3 - \ln 2)}$$

For the *Villa Epsilon*, $H*$ = 0.7846

Step 11. The complete set of results are then combined into a single matrix summarizing the most important information about the axial map and, by inference, the plan it was derived from. The results for the villas *Epsilon* (Table 3.18), *Zeta* (Table 3.19) and *Eta* (Table 3.20) can then be compared and interpreted in the final stage of the analysis.

Stage 3, Interpretation

The focus of axial line analysis has traditionally been on the calculation of integration or, conversely, segregation values, as these have been shown to correlate to a number of social phenomena. One of the most widely accepted of these relationships, although it is not without criticism, is between integration and volume of movement. This correlation can be informative at any scale, from building interiors to urban fabric, although it can only be used to predict relative aggregate trends. Such is the significance of integration that axial maps are often graphically coded (by colour, shading or line thickness) to indicate which lines are more significant and to support more immediate and intuitive readings of the data (Fig. 3.24).

Table 3.18 *Villa Epsilon*, axial line results

$V\gamma$	*TD*	*MD*	*RA*	i_{RA}	*RRA*	i_{RRA}	*CV*
Line 1	4	1.33	0.33	3.00	0.93	1.07	1.50
Line 3	6	2.00	1.00	1.00	2.80	0.35	0.50
Line 5	4	1.33	0.33	3.00	0.93	1.07	1.50
Line 8	6	2.00	1.00	1.00	2.80	0.35	0.50
Mean	5.00	1.66	0.66	2.00	1.86	0.71	1.00
H							1.01
H*							0.78

Table 3.19 *Villa Zeta*, axial line results

$V\zeta$	*TD*	*MD*	*RA*	i_{RA}	*RRA*	i_{RRA}	*CV*
Line 1	9	2.25	0.83	1.20	2.36	0.42	0.50
Line 3	6	1.50	0.33	3.00	0.94	1.06	1.33
Line 4	5	1.25	0.16	6.00	0.47	2.12	2.50
Line 8	8	2.00	0.66	1.50	1.89	0.52	0.33
Line 9	8	2.00	0.66	1.50	1.89	0.52	0.33
Mean	7.20	1.80	0.53	2.64	1.51	0.92	1.00
H							0.94
H*							0.60

Table 3.20 *Villa Eta*, axial line results

$V\eta$	*TD*	*MD*	*RA*	i_{RA}	*RRA*	i_{RRA}	*CV*
Line 1	5	1.25	0.16	6.00	0.47	2.12	1.50
Line 3	5	1.25	0.16	6.00	0.47	2.12	1.50
Line 4	6	1.50	0.33	3.00	0.94	1.06	0.66
Line 8	6	1.50	0.33	3.00	0.94	1.06	0.66
Line 9	6	1.50	0.33	3.00	0.94	1.06	0.66
Mean	5.60	1.40	0.26	4.20	0.75	1.48	1.00
H							1.06
H*							0.90

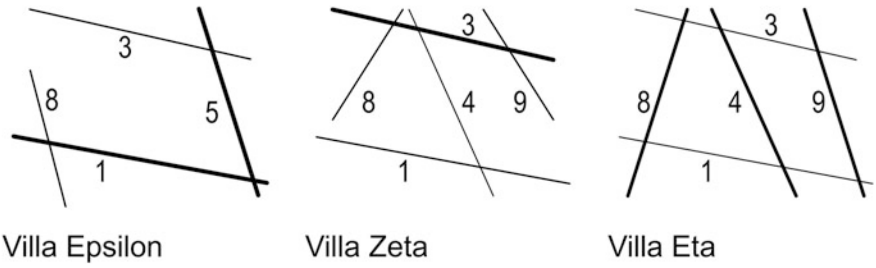


Fig. 3.24 Axial maps weighted for integration, thicker lines equal higher integration

In the case of the three villas, it is possible to identify the paths through space that most rapidly provide visual cohesion to a plan. That is, the most efficient way for a visitor to develop an understanding of a set of spaces is to follow the path with the highest integration values. Alternatively, the line with the highest integration value is also the most efficient path that allows for a security patrol, or a docent in a gallery, to survey the maximum amount of space in the plan. For the *Villa Epsilon*, lines 1 and 5 are equal in integration potential, but they are only marginally higher than the values for lines 3 and 8. The *Villa Eta* results are also relatively undifferentiated. However, for the *Villa Zeta*, line 4 is the most significant in terms of integration, and its entire map displays a wide range of results.

Despite the simplicity of their plans, it is possible to use the axial map s to differentiate between the three villas. For example, the *Villa Epsilon* has a mostly linear structure where, with one exception, there is only a single path that can be taken to experience the majority of the plan. The *Villa Zeta* has a planning pattern where every room opens from a single, central space and adjacent corridor, while the *Villa Eta* has a complex, rhizomorphous plan, with many possible connecting paths. These qualities are readily apparent in a visual examination of the axial line maps for each villa and their implications for inhabitation are also reasonably straightforward. For example, a plan organized with a linear hierarchy suggests a significant degree of privacy is provided to inhabitants, with access to the deepest spaces only afforded to a select few. At the other end of the spectrum, a rhizomorphous spatial structure suggests a high degree of adaptability allowing inhabitants to follow multiple paths through the plan. Beyond these general observations, our three examples are too limited to develop further conclusions. Indeed, for an analysis of architecture to have sufficient data to be statistically relevant, it should either focus on large buildings, such as prisons or museums, or it must consider sets of small buildings with similar properties.

3.4 Intersection Point Analysis

The intersection point map could be conceptualised as an inversion of the axial line map, which shifts the emphasis from paths to the connections between them. The set of intersections incorporated in a map are of two types: i-nodes, which occur when one path intersects another path, and s-nodes which are intersections between paths and walls, also called ‘stubs’. The first of these types of intersections are, by virtue of their extrapolation from an axial line map, an efficient and minimal set of pause-points in space, where optimal decisions about navigation and movement can be made. However, in addition to being an efficient set of decision points, a map must also provide, within the limits of the technique, a complete coverage of the plan. To achieve a comprehensive coverage of a plan requires the selected inclusion of the second type of intersection, those between paths and walls.

The process for inverting an axial line map is described in Chap. 2, which also includes a discussion of the different methods for deciding which stubs or end nodes to include in the map. The manual process for determining which stubs provide unique surveillance properties in a plan commences by adding a potential node (p-node) to the end of every stub then determining if each p-node surveils a portion of the plan that no i-node surveils. Surveillance is determined by drawing a straight ‘check line’ from each p-node to each visible surface vertex (Fig. 3.25). If an adjacent i-node can be used to draw similar check lines to each surface vertex associated with the p-node, then that p-node does not to contribute to plan surveillance. Nodes that provide unique surveillance properties are retained while those that do not are removed. The retained nodes are relabelled as stub nodes (s-nodes). It is also possible for multiple p-nodes to provide coverage of spaces with no i-node surveillance; in such a case all p-nodes are retained. The order of p-node assessment does not affect the outcome of this procedure. The resultant intersection graph is then analysed using standard Space Syntax procedure.

Stage 1, Abstraction Process
The abstraction process is demonstrated in this section using the plans of the villas *Epsilon, Eta* and *Zeta* and the axial maps developed in the previous section as a starting point. Five steps are then required to abstract the intersection point map.

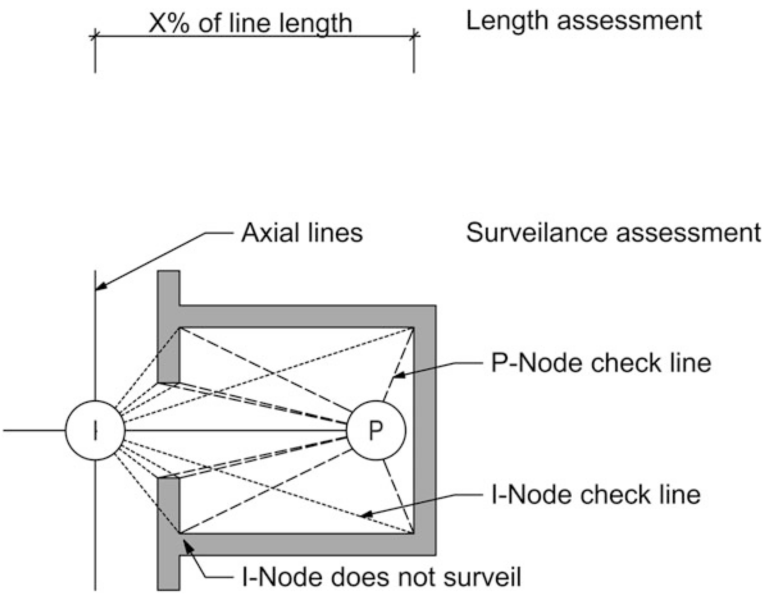


Fig. 3.25 Checking procedure to determine if line stubs possess unique surveillance properties. p-node check lines show the space surveilled, i-node check lines pass through walls to meet the same surface vertex points thus the p-node provides unique surveillance properties

Step 1. Commence with the axial map for the selected spatial configuration (Fig. 3.26).
Step 2. Identify all axial line intersection point s within the map, add an intersection node (i-node) to these points, and assign each a unique identifier, in this case a numbered index (Fig. 3.27).
Step 3. Identify potential nodes (p-nodes) at the end of every stub and assign a unique identifier to each (Fig. 3.28). Determine if the p-nodes surveil a portion of the plan that no i-node surveils. Remove p-nodes that do not contribute to plan surveillance. Re-label retained p-nodes as s-nodes (Fig. 3.29).

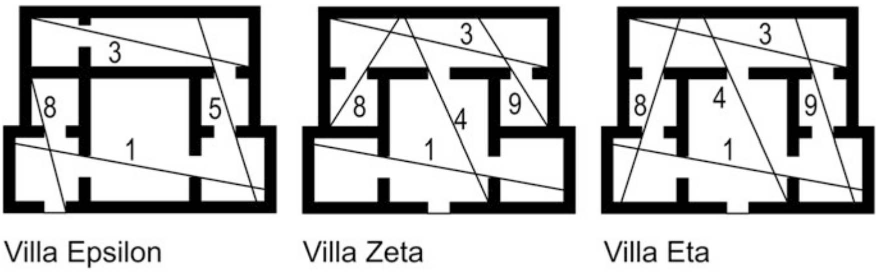


Fig. 3.26 Axial maps for the villas *Epsilon*, *Zeta* and *Eta*

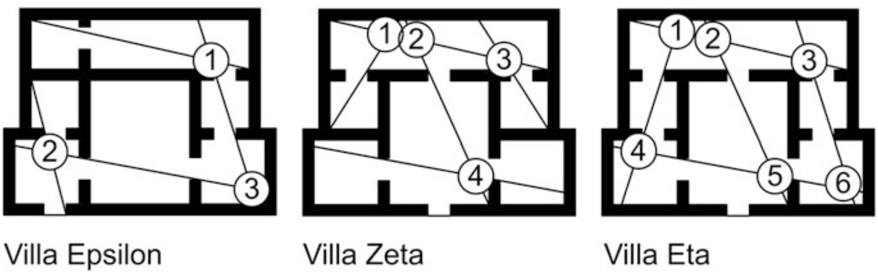


Fig. 3.27 Identification of intersection points and allocation of intersection-nodes (i-nodes)

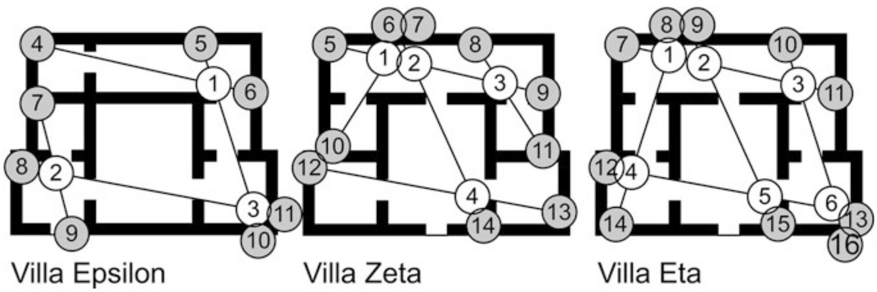


Fig. 3.28 Potential-nodes (p-nodes) assigned to all stubs (shown shaded)

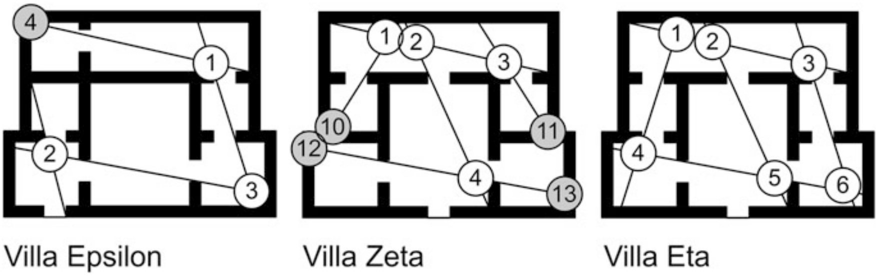


Fig. 3.29 Removal of p-nodes possessing no unique surveillance properties; remaining p-nodes become s-nodes. Note that *Villa Eta* does not require s-nodes because no stubs satisfy length or surveillance criteria

Step 4. In this step the axial map is inverted to produce the intersection graph by linking i-nodes and s-nodes in a way that reflects the properties of the axial map. This commences by directly linking each node associated with an axial line to each other node associated with that axial line. s-nodes will only ever be associated with a single axial line whereas i-nodes are always associated with two or more axial lines. The links ensure a graph step distance of 1 exists between every node located on a single axial line (Fig. 3.30).
Step 5. Once the intersection graph has been produced, the underlying axial map is removed (Fig. 3.31) and, if desired, the intersection graph may be redrawn to clarify the topological relations although this has no impact on the mathematical analysis (Fig. 3.32).

Stage 2, Configurational Analysis
Once completed the intersection map is analysed mathematically using the same procedure and formulas used in the previous sections to derive graph measures for the convex space and axial line maps. Tables 3.21, 3.22 and 3.23, respectively, contain the results for the villas *Epsilon*, *Zeta* and *Eta.*

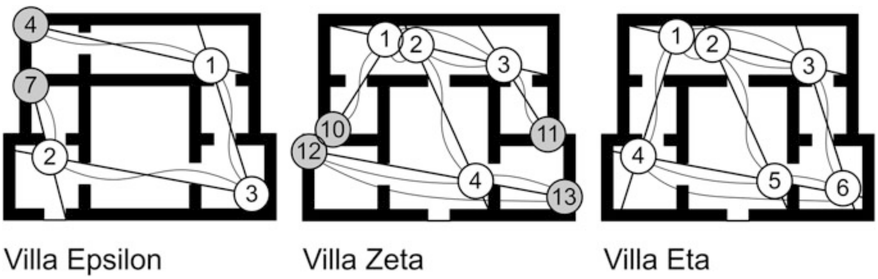


Fig. 3.30 Addition of links (shown curved) to maintain character of axial map

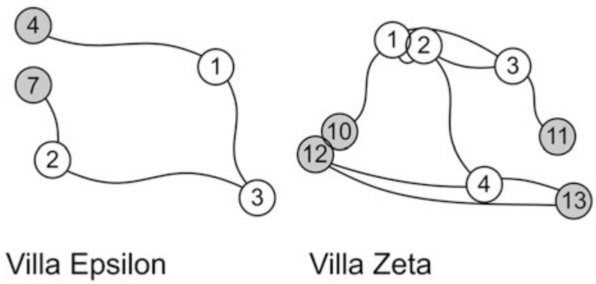


Fig. 3.31 Intersection graphs of the villas *Epsilon*, *Zeta* and *Eta*

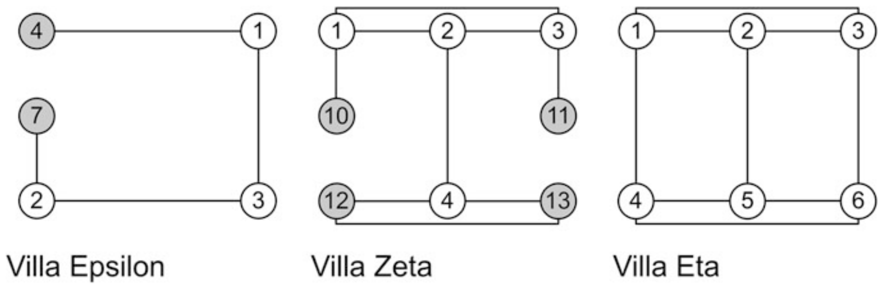


Fig. 3.32 Intersection graphs redrawn for clarity

Table 3.21 *Villa Epsilon*, intersection point results

Vγ	*TD*	*MD*	*RA*	*i*	*RRA*	*CV*
Point 1	7	1.75	0.50	2.00	1.42	1.50
Point 2	7	1.75	0.50	2.00	1.42	1.50
Point 3	6	1.50	0.33	3.00	0.94	1.50
Point 4	10	2.50	1.00	1.00	2.84	0.50
Point 7	10	2.50	1.00	1.00	2.84	0.50
Mean	8	2.00	0.66	1.80	1.89	1.10
H						1.00
H*						0.77

Stage 3, Interpretation

The interpretation of the intersection point results for the villas *Epsilon*, *Zeta* and *Eta* is most significant when considered in parallel with their equivalent axial line results. For example, consider the experience of a person traversing line 3 in the *Villa Epsilon*, moving from left to right. This is the path taken by a person who is moving from the most isolated space in the plan to the second most isolated. In the axial map, all locations along line 3 have results of $MD = 2$ and $i = 1$. Instead, in the intersection map, it can be seen that at the start of the path (point 4) $MD = 2.5$ and $i = 1$, and by the time a person has traversed the path and reached the turning

Table 3.22 *Villa Zeta*, intersection point results

Vζ	*TD*	*MD*	*RA*	*i*	*RRA*	*CV*
Point 1	13	1.86	0.29	3.45	0.88	1.66
Point 2	11	1.57	0.19	5.26	0.58	1.00
Point 3	13	1.86	0.29	3.45	0.88	1.66
Point 4	13	1.86	0.29	3.45	0.88	1.33
Point 10	19	2.71	0.57	1.75	1.74	0.33
Point 11	19	2.71	0.57	1.75	1.74	0.33
Point 12	18	2.57	0.52	1.92	1.59	0.83
Point 14	18	2.57	0.52	1.92	1.59	0.83
Mean	15.50	2.21	0.41	2.87	1.23	1.00
H						1.01
H*						0.78

Table 3.23 *Villa Eta*, intersection point results

Vη	*TD*	*MD*	*RA*	*i*	*RRA*	*CV*
Point 1	7	1.40	0.20	5.00	0.57	9.00
Point 2	7	1.40	0.20	5.00	0.57	9.00
Point 3	7	1.40	0.20	5.00	0.57	9.00
Point 4	7	1.40	0.20	5.00	0.57	9.00
Point 5	7	1.40	0.20	5.00	0.57	9.00
Point 6	7	1.40	0.20	5.00	0.57	9.00
Mean	7.00	1.40	0.20	5.00	0.57	9.00
H						1.09
H*						1.00

point towards the room to the central-right of the plan (point 1), this has changed to $MD = 1.75$ and $i = 2.00$. This suggests that while moving along this path the depth of the spatial position is gradually reduced, and its centrality is heightened.

Consider the example of a person moving along line 1 in the *Villa Zeta* axial map, passing from left to right. This path is through the front three rooms in the plan, which are the entry hall, and the left and right vestibules on either side of it. This path starts at point 12 ($MD = 2.57$, $i = 1.92$), then moves through point 4 ($MD = 1.86$, $i = 3.45$) in the entry hall, before reaching its conclusion at point 14 ($MD = 2.57$, $i = 1.92$). The first and last parts of this path are deeper and less integrated than average, whereas the central location, as indicated by high integration and low Mean Depth values, is more pivotal to passage through the plan. The axial line result, which encapsulates the entire path, is deeper than the mean ($2.25 > 1.80$) and less integrated ($1.20 < 2.64$). This combination of results allows us to see that line 1 is more complex than the axial map suggests, shifting in character (relative to the mean) at multiple points along its path, and especially adjacent to the entry.

Whereas the comparative analysis of the *Villa Epsilon* and *Villa Zeta* axial and intersection maps is informative, this is not the case for the *Villa Eta*. Because in the *Villa Eta* map, every intersection connects to three other intersections, the results are not differentiated. Thus, in terms of intersection points, every space has the same *TD*, *MD*, and *i* results. The problem is that the plan is made up of two symmetrical halves with a single loop that passes through each half. Such a situation would be rare in most plans, which are both more complex in terms of number of spaces and the connections between them. Nevertheless, it signals that both the axial line and intersection point techniques have limits. For example, being an inversion of the axial map, the intersection graph is unable to capture information that has already been 'lost', through abstraction during the axial mapping process. Thus, the axial map is unable to differentiate between the spatial experience of a long uninterrupted corridor (a single large space) and of an enfilade of connected spaces (a series of spaces with their doors aligned along the one axis), both of which are traversed by a single path. Without intersection points along this line, it is not possible for the intersection graph to differentiate between the experience of these very different spaces. This does not constitute a weakness in the intersection technique because it is a means of assessing locations that the axial map identifies as significant. In contrast, a convex space analysis might be more informative in this context, or an alternative method, such as the visibility graph approach, which is the subject of Chap. 4, may be more appropriate.

3.5 Conclusion

Variations of the three techniques introduced in this chapter are used in Part II of this book to analyse questions about Modern architecture. Starting with the architecture of Mies van der Rohe in Chap. 5, convex space and intersection point analysis techniques are used to investigate the changing social and spatial properties of four of Mies's early designs which were important precursors to his canonical *Farnsworth House*. The *Farnsworth House* is typically regarded as the ultimate, minimalist glass and steel residence, the apogee of domestic Modernism. In Chap. 6, Richard Neutra's theories about modern space and its psychological impact on visitors and inhabitants are investigated using axial line analysis and intelligibility calculations. Functional space analysis, a variation of the convex space technique, is used in Chap. 7 to examine the relationship between the minimal, Phileban forms of Modernist design and the social structure of spaces contained within them. Chap. 7 uses ten of Glenn Murcutt's Late Modern regionalist works as a sample to test just how closely related formal expression is to social function.

Chapter 4
Isovist Analysis, Theories and Methods

Isovist analysis offers a way of geometrically describing the spaces and forms of a building which can be seen from a particular position. As such, it combines a consideration of both fixed, building-related factors, such as space and form, and temporal, experiential ones, such as visibility and the impact of movement. Isovists are part of a larger field of study known as visibility analysis, which is concerned with quantifying the relationship between vision and behaviour. As the previous chapters have demonstrated, several of the Space Syntax methods connect human vision to spatial cognition and intelligibility, that is, the capacity to understand and then navigate through a building. It will also be remembered that convex maps comprise the set of visually defined zones, and axial maps represent an optimal system of movement and surveillance paths in a building or city. In both of these methods, the visual properties of space are highly generalised or abstracted. In contrast, isovists have the potential to mimic, and thereby be used to examine, the visual experience of a building from a particular point in space, and even take into consideration specific human features such as eye height and stride length while moving. In a sense, this technique begins to model the way space is perceived and experienced, whereas the earlier methods were concerned with spatial structure, hierarchy, permeability and intelligibility. In combination, all of these factors—the social, cognitive and perceptual—are at the core of arguments that historians, critics and architects use to explain the successes and failures of Modernism.

4.1 Introduction

An isovist is ‘the set of all points visible from a single vantage point in space with respect to an environment’ (Benedikt 1979: 47). In an architectural plan an isovist is usually represented as a two-dimensional polygon, drawn on a floor plan, defining the portion of space which can be seen from a particular static position. This polygon provides a useful graphic representation of spatial visibility, but it is also,

M. J. Ostwald and M. J. Dawes, *The Mathematics of the Modernist Villa*,
Mathematics and the Built Environment 3,
https://doi.org/10.1007/978-3-319-71647-3_4

more importantly, a shape that has specific, measurable, and therefore comparable, geometric characteristics. These measurable and comparable attributes have led to isovist analysis becoming an accepted technique for architectural and urban research, providing a rigorous and repeatable method for the analysis of the visual qualities of an environment. However, isovist analysis is also a poorly understood technique, with very few practicing architects and a relatively small group of academics possessing a detailed knowledge of its importance, processes and legitimate applications. Further complicating this situation is the fact that isovist analysis is almost always undertaken using software. Such software automates the process, liberating the researcher from the highly repetitive parts of the method and, in doing so, allowing for large studies to be undertaken in an efficient manner (Penn et al. 1997). However, the disadvantage of this is that the software obscures many of the processes and considerations that provide the foundation for the technique, generating results without providing the user with any sense of their limitations or usefulness. In addition, there are multiple alternative ways of producing and working with isovists, not all of which are suitable for every application.

Given this context, in which the strengths and limitations of this method are not well understood, the present chapter describes and demonstrates three related approaches to the analysis of spatial visibility. The first of these is the standard 'isovist', that is the area seen in any direction from a single position in a building or space. The second, the 'isovist field', involves the construction of a comprehensive set of regularly located isovists in a building or space. The final approach is concerned with measuring 'global visibility', a determination of the visual significance of a point in an isovist field relative to the entire building or space. To illustrate these approaches, this chapter uses a detailed worked example of a manual application of visibility analysis to a hypothetical architectural plan. These worked examples include an explanation of two alternative approaches to constructing isovists, along with mathematical and diagrammatical methods for producing local and global visibility measures. In this way, the chapter first presents a detailed introduction and background to isovist analysis and an explanation of its methodological features, including a consideration of the accuracy, consistency and repeatability of the method. This is followed by a series of examples, including all of the major formulae required for its application, and a discussion of the way in which these values might be used to gain an insight into an architectural plan.

4.2 Background to Visibility Analysis

Researchers in the disciplines of architecture and urban design typically credit Michael Benedikt (1979) with being the first author to use isovists and, whilst working with Larry Davis, for developing the first rigorous method for isovist construction (Davis and Benedikt 1979). While Benedikt and Davis may have offered the first serious formulation of this concept for an architectural readership, as Turner et al. (2001) observe there are precedents in the fields of urban and landscape geography (Tandy 1967) including the concepts of the 'viewshed' (Amidon and Elsner 1968; Lynch 1976) and 'intervisibility' (Gallagher 1972). Nevertheless, the origin of isovist analysis resides in the model of visual perception called the 'ambient optic array' first proposed by the environmental psychologist James Gibson (1966, 1979).

The ambient optic array consists of three concepts. First, 'to be ambient at a point means to surround a position in the environment that could be occupied by an observer' (Gibson 1979: 65). Second, being optical indicates that the ambient array of interest relates to the mechanics of vision—the light entering the eye to strike the retina. Finally, 'to be an array means to have an arrangement' (Gibson 1979: 65). This property of 'arrangement' is achieved by the process of reflecting light off the surfaces of an environment, an interaction that provides the light rays with geometrically and spatially structured information which is conveyed to the observer. Thus a light ray no longer simply represents energy and the path of photons; rather, it transmits information about the environment. Where diagrammatic representations of previous models of visual perception documented the subtended angles (silhouettes) of objects in an observer's field of vision, the optic array represents the information carried by light reflected from environmental surfaces that converge on the observation point. Gibson's 'ecological approach' to visual perception has parallels to the phenomenological assumptions implicit in 'naive realism'; the proposition that vision provides the observer with a direct and measurable understanding of the world.

Movement is usually considered critical to visual perception, as it is only through movement that we are able to perceive the environment that lies beyond the surfaces that are visible in our current position. As the observer changes positions the ambient array also changes to reveal previously hidden surfaces and to obscure previously visible surfaces. Gibson (1979) illustrates this concept using a diagrammatic analysis of movement along a disjointed corridor (Fig. 4.1). In this example, movement through space causes wall surfaces to leave the optic array behind, while new surfaces emerge from previously occluded, areas. Thus, each step produces a different optic array, each of which reflects the visual properties of the environment from a particular position.

While Gibson's illustration of the changing visibility states associated with movement may simulate a human gaze which is fixed in a single forward direction, the optic array actually incorporates all light rays accessible to an observer's eye, from *any* direction. Gibson (1979) notes that an observer occupying a single location may still move their eyes and head, thereby changing the ambient optic array. As Smardon et al. confirm, the 'eyes, head and body can all move' and 'under normal conditions, a viewer is continuously sampling a much broader portion of the environment even though at any one instant the new stimuli are limited' (1986: 41). Rotating the head and eyes, for example, allows observers to align the 124° high acuity region of the macular field to any portion of the environment (Schiffman 1982). Thus, the practice of viewing the isovist as a 360° field of view simulates this type of detailed and methodical scanning. Nevertheless, it is also possible to simulate the visual qualities of an immobile observer. For example, partial isovists

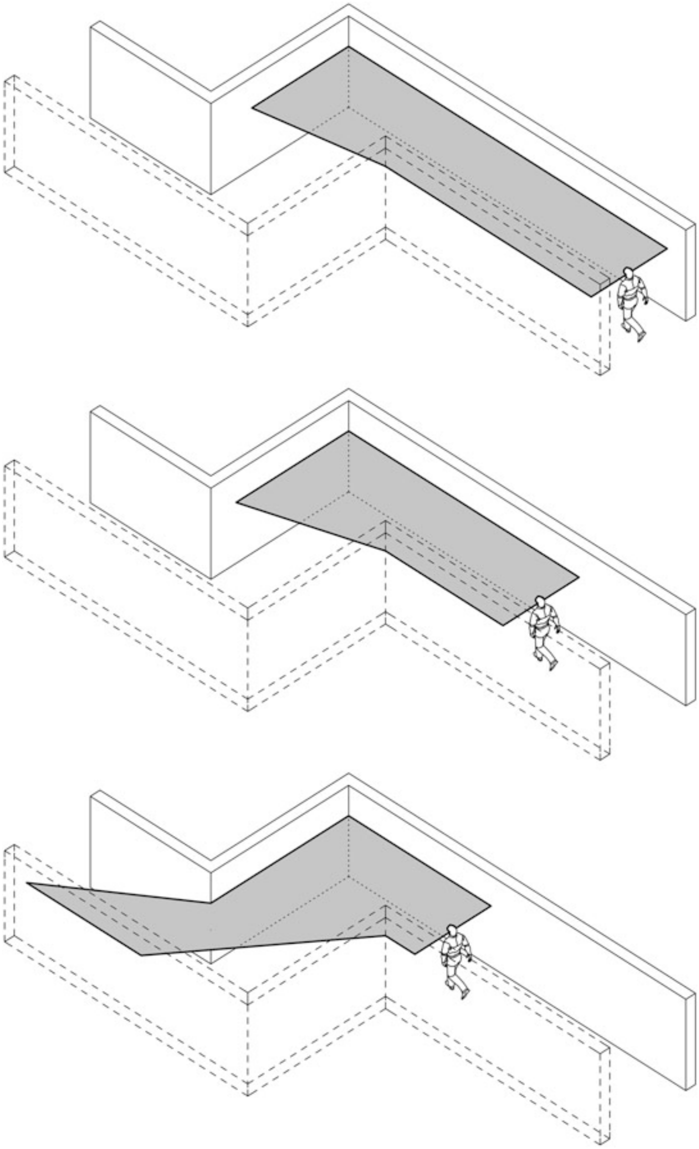


Fig. 4.1 Visible space recorded at three stages during the movement of a person along a corridor. The visible area is shaded

can be used to 'consider only a restricted part of the theoretically available visual field (for example, 90° instead of 360°)' (Meilinger et al. 2009: 2). Thus, a partial isovist can represent the limited field of view that is perceived without rotating the eyes, head or body (such as those seen in Fig. 4.1). Indeed, past research has shown that in simulations of human movement using automated agents, the best approximation of human behaviour occurs when agents possess a cone of vision of around 170° (Turner and Penn 1999). However, it is important to distinguish between research which attempts to recreate isolated or specific human behavioural characteristics and that which seeks to capture the visibility characteristics of an environment. In the latter case, which is the most common in architectural analysis, a full 360° isovist provides the most efficient and consistent method of capturing and comparing data. The 360° isovist is also the most common type because it can be used to construct an isovist view field.

An isovist 'view field' is the set of all possible isovists generated using a predetermined selection of viewing points. In practice, the construction of such a view field commences by placing a regular grid over the chosen environment and generating an isovist at the centre point of each square in the grid. The benefit of the view field is that, whereas an isovist captures the view of space from a single static location, the view field provides measures of visibility characteristics across an entire environment. While it is theoretically possible to create an isovist view field consisting of partial isovists, the standard practice is to use full 360° isovists.

Benedikt (1979) originally presented isovist field data as a scalar map allowing for intuitive analyses of changing visibility characteristics throughout the environment. However, the multiple observation points of the isovist field also provide the basis for the application of graph theory mathematics to investigate the relationships between each. When applying graph theory to the isovist field, the isovist field becomes a 'visibility graph' that allows for the calculation of global visibility measures in addition to the local measures of individual isovists (Turner et al. 2001).

Since first being proposed in the late 1960s and being adopted by architectural researchers a decade later, isovists and isovist view fields have been used for a range of purposes, including studies of spatial cognition (Meilinger et al. 2009), wayfinding (Conroy 2001), phenomenology (Wong 2012), social structure (Markhede and Koch 2007), spatial structure (Tzortzi 2004; Psarra 2005, 2009b; Zamani and Peponis 2013) and object display (Stavroulaki and Peponis 2003, 2005; Antonakaki 2007). The method is useful for supporting the systematic identification of characteristic spaces, including the 'most visible' and 'most hidden' locations in a building (Conroy-Dalton and Bafna 2003; Wiener and Franz 2005).

Past research using isovist view fields and visibility graphs also identifies a close correlation between the mathematical data and observed behaviour of people. In particular, global visibility measures, derived from visibility graphs have proved useful for the analysis of pedestrian movement rates and appear to be superior to axial line maps for predicting pedestrian behaviour (Turner and Penn 1999; Desyllas and Duxbury 2001; Turner et al. 2001). Such findings are significant because, in the context of Hillier's (1996) theory of the 'movement economy', the relationship between pedestrian behaviour and space has an impact on the prediction of a wide range of factors including crime rates and location (Hillier and Shu 2000) and rental returns (Desyllas 2000). With current computational power it is technically feasible to undertake three-dimensional isovist analyses (Morello and Ratti 2009; Indraprastha and Shinozaki 2011; Bhatia et al. 2013), but the lack of standard methodologies for constructing and using such three-dimensional isovists, coupled with limited evidence of their correlation to human behavioural patterns, means that most practical applications of the theory still focus only on two dimensions. Thus, the two-dimensional qualities of vision are not only more readily comprehensible but they are more amenable to mathematical analysis.

4.3 Methodological Considerations

In architectural and design research, an isovist is diagrammatically depicted as a shaded polygon drawn on a plan. This polygon represents a two-dimensional, horizontal plane of vision, generated at eye level and capturing the extent of space visible from a specific observation point. Therefore, only information contained within this plane is included in the isovist, with forms and objects above or below this plane being ignored (Fig. 4.2). There are occasional exceptions to this standard practice, including isovists constructed using a vertical visual plane drawn over a section through a building. It is also possible to generate and compare the impact of different eye heights on visual experience. This latter consideration would, for example, account for differences in visual fields generated from standing and seated observers. For example, one variant is the 'kneesovist', which depicts a plane drawn close to knee height to represent movement capacity of an observer in an environment. This is useful because the movement and vision potential of an environment are often different (Koch 2012). Some other disciplines have also developed particular versions of isovist or visibility analysis that are more suitable to the issues they are testing. For example, landscape geographers often include three-dimensional data and present visibility diagrams that contain a number of discontinuous polygons, or polygons that contain holes related to obscured areas, potentially produced by peaks blocking views of adjacent valleys (Llobera 2003) (Fig. 4.2). The remainder of this chapter focuses exclusively on horizontal, two-dimensional isovists generated at eye level, although it is worth remembering that the same techniques can be modified to suit specific circumstances and research questions.

Whereas the 360° vision cone and two-dimensional planar representation are the most common applications of isovist analysis, a bigger issue, potentially affecting the repeatability of particular experiments, is that there are large numbers of possible variations in the application of this technique. Subtle, but still significant, variations arise from the existence of three different approaches to locating isovist observation points. The first suggests utilising regular grids (Benedikt 1979) or regular and/or distorted grids (Turner et al. 2001) for locating observation points. Both of these variations typically then proceed to generate an isovist field and use visibility graph analysis techniques. The second approach to isovist location uses a series of points in space which have been selected for their relevance to a particular hypothesis. Some examples of this approach which relate to patterns of human behaviour include points along specific paths (Benedikt 1979; Penn et al. 1997),

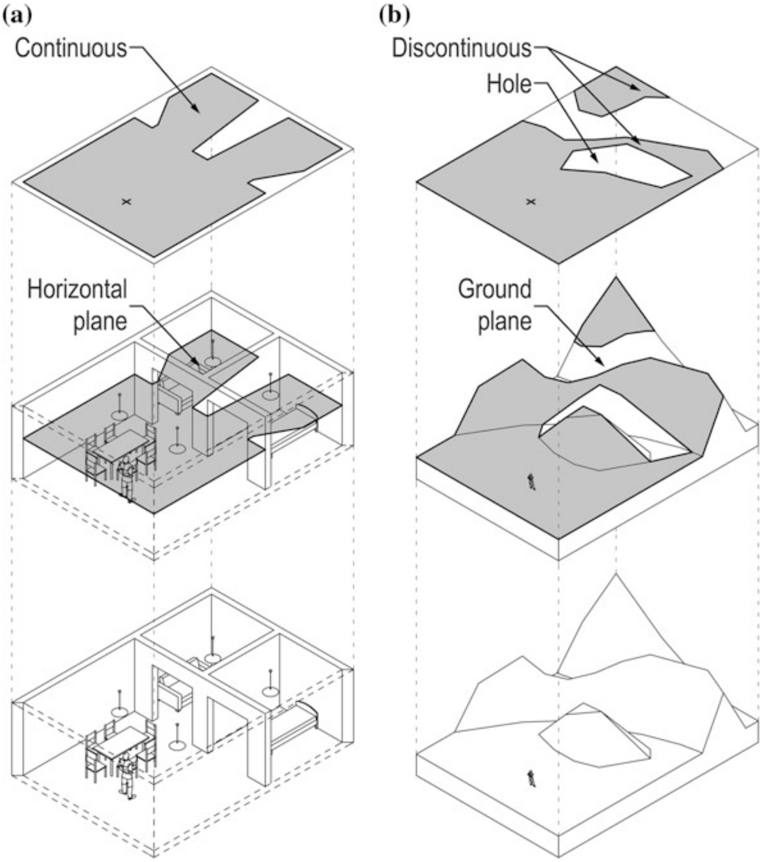


Fig. 4.2 **a** An isovist is a single plane polygonal representation, often ignoring transient features (such as furniture) or those above or below the chosen sight plane; **b** A 'geographic' isovist demonstrating polygons containing holes and discontinuous polygons

observed pause points in environments (Conroy 2001), product placements in stores (Markhede and Koch 2007), viewing locations for museum displays (Peponis et al. 2004), and contemplation sites for statues or religious icons (Stavroulaki and Peponis 2003; 2005; Antonakaki 2007). It is also possible to locate isovists in 'informationally stable' spaces or 'e-spaces' (Peponis et al. 1997b)—that is, areas from which the same wall surfaces remain visible (Turner 2003)—and 'Kernels' of star-shaped buildings (O'Rourke 1987), which are essentially a specialised type of e-space. At an urban scale, researchers may also use nodes in GIS databases to locate isovists (Jiang and Claramunt 2002).

A common factor linking the majority of these examples is that the system has both relevance to the particular case or theory and potential transferability to other similar cases. A variation of this approach uses a system or formula to locate observation points consistently. For example, such systems might include central points in rooms and halls (Hanson 1998) or intersection points on axial line maps (Ostwald and Dawes 2012). However, such approaches often utilise information unique to a particular environment and may be difficult to transfer to other cases. Sophia Psarra's (2009a) analysis of Mies van der Rohe's *Barcelona Pavilion* is an example of one such approach ideally developed for the analysis of a specific case.

The third and final approach to selecting points for isovist generation uses a singular, non-repeatable system. The main use of this approach is in research demonstrating a methodology, rather than offering interpretations based on it (Davis and Benedikt 1979). For example, an observation point (see Fig. 4.2) may be used to illustrate an isovist polygon expanding through a door to an adjacent room. Any location in the simple building can demonstrate this; the selection of such an observation point may be due to the aesthetic properties of the resultant isovist polygon rather than any rigorous procedure.

Of these three approaches, the first is the most common in architectural research. In this approach, the size and position of the grid that locates the observation points affects the consistency and repeatability of the research. In early research using this method computational processing power determined the grid size, and the results were typically reported in only approximate terms (Batty 2001; Turner et al. 2001). Current research provides exact dimensions for such grids, but only a minority provide a detailed rationale for the selection of the grid size (Franz and Wiener 2008). The ideal grid size is typically related to the scope of the study, with the majority of researchers stating that, where possible, smaller grids are superior to larger grids. In contrast, Alasdair Turner (2003) suggests focusing only on the geometry of a space that is accessible to a human body. This involves setting the grid size for analysis to the minimum space a human can comfortably occupy, with smaller spaces not requiring analysis.

After determining the ideal size, the grid must then be located within an environment. It is extremely rare for researchers to specify if the grid aligns to the centre of the environment, to a major element within the environment or to one of its corners. Researchers also rarely state if it is the intersection of grid lines or a grid centroid that is the location of the isovist observation point. This is especially problematic when calculating global measures using graph theory mathematics. Where the grid does not align exactly with the built components of the environment, the difference between choosing grid intersections and grid centroids can introduce or eliminate observation points from individual spaces, thus changing the calculated result. A similar problem exists in studies which calculate global measures using only a limited number of points (say, derived from a large grid) because every added or subtracted point has a potentially substantial impact on the calculations. In such a case the result may not be compromised, but the repeatability of the study will be adversely affected.

Another set of factors limiting the isovist's capacity to describe actual spatial experience relates to the properties of some surfaces and boundaries along with particular atmospheric conditions. Benedikt, for example, 'disqualifies the sky, glass, mirrors, mist and perfectly black surfaces from being real surfaces' (1979: 49) for the purposes of generating an isovist. Thus, he decides that such items should not define the isovist polygon. This position is central to the majority of architectural applications of isovist analysis which treat the environment as a static, closed system, bounded by the exterior surfaces of the building, treating glass and mirrors as opaque and non-reflective. Isovist analysis is also inherently geometric and, as such, it excludes consideration of surface colours and textures. Benedikt's 'perfectly black surface' is an idealised, hypothetical material that absorbs all light, thus preventing the information-laden light rays from being reflected back to the observer's eye.

The case of transparent and reflective surfaces is both more common and potentially more problematic and thus, despite most studies treating these surfaces as opaque, there are exceptions. For example, Turner et al. (2001) consider glass as a transparent surface in their analysis of Mies van der Rohe's *Farnsworth House*, but only when the observation point is beyond the exterior of the building. Choudhary et al. (2007) treat glazed surfaces as transparent in their analysis of Mies's courtyard houses, using the courtyard walls to define the extent of the environment. Psarra's (2009a) analysis of the *Barcelona Pavilion* treats transparent and reflective surfaces as they appear; thus, isovists reflect from some surfaces and pass through others. Psarra's particular research focus allows her to limit isovists to the footprint of the pavilion but such a decision also raises the important question of isovist boundaries. If transparent surfaces do not affect the isovist, where does the isovist end? An isovist analysis examining an important spatio-behavioural issue, such as the relationship between a room and its exterior view, will ideally consider distant elements as part of an architectural space. There are several potential approaches to this issue of the limits of the isovist.

Multiple types of 'edge conditions' can potentially define the limit or extent of an isovist. Fixed surfaces are the most basic edge condition, but additional practical boundaries include a fixed distance from the observation point (the 'visibility boundary'), global perimeters surrounding the environment (the 'global boundary') and dynamic or transient edges (Fig. 4.3). Gibson (1947), for example, differentiates two types of space: 'local', where the horizon is hidden by other surfaces, and 'aerial' which is limited by the earth's surface, horizon and sky. Thiel (1961) further suggests that local space extends to around 60 metres while aerial space is beyond around 140 metres. The space in between these limits is a 'transitional area', which Camillo Sitte (1945) notes also corresponds to the size of most successful European piazzas and, as Kevin Lynch and Gary Hack (1984) observe, is the distance at which a human face may be distinguished. Conversely, Benedikt (1979) limits the extent of an isovist to the edge of the environment, defined by an artificial and seemingly arbitrary global boundary. An alternative approach is to designate a uniform maximum visible distance, or visibility boundary, for each observation location.

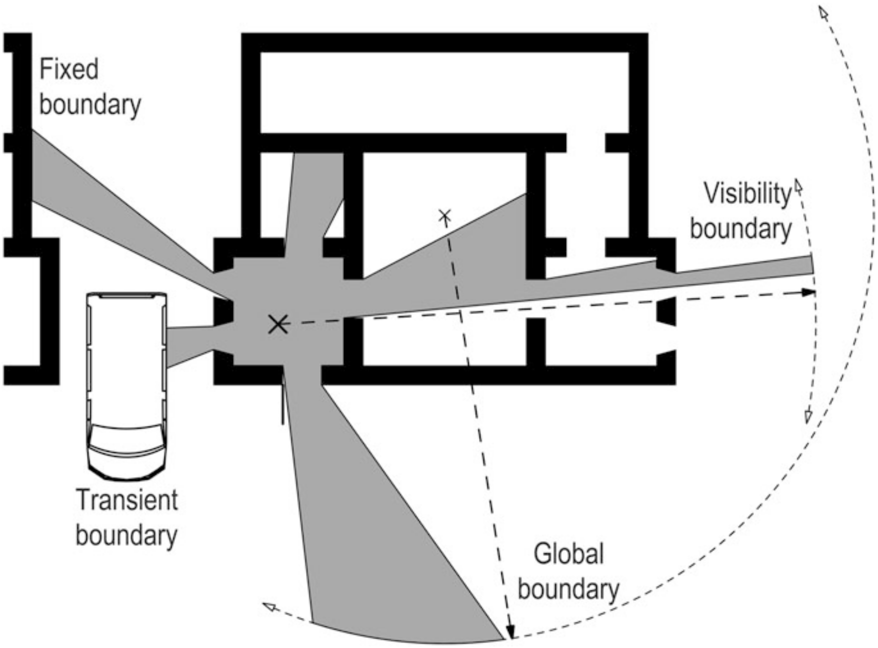


Fig. 4.3 Different types of isovist boundary conditions

Davies et al. discuss this problem and observe that '[o]pen spaces, when considered treeless, are transformed into near-infinite isovists, although this is far from true in the real world' (2006: 11). They conclude that 'isovist analysis requires well-defined borders in order to be realistic' (2006: 11) and propose setting a visibility limit of 200 metres. Weitkamp et al. (2007) utilise a similar approach to studying landscape visibility with the view distance set to the much higher limit of 1200 metres.

Relatively little research in architecture considers the impact of dynamic isovist boundaries, the most obvious example of this being the differing visual impacts of a door that is open, partially open or closed. Peponis et al. (2003) are a notable exception, exploring changing spatial awareness which results from differing door positions and reflective surfaces. Benedikt (1979) alludes to another dynamic condition which has a potential impact on isovist limits when, as previously noted, he disqualifies 'mist' from consideration. Marcos Llobera argues that 'atmospheric conditions may render an unobstructed object invisible' (2003: 29) and observes that too often in visibility analysis, little attention is given to such considerations, which shape 'whether a location, or an object on it, can be distinguished or identified' (2003: 29). In practical terms, atmospheric conditions including mist and fog can seriously limit visibility and conversely, clear night skies can allow for views of distant stars. The same space may have a very different isovist during the day or night depending on levels of natural and artificial illumination, and careful decisions must be made about how to approach these issues (Stavroulaki and Peponis 2005; Choudhary et al. 2007; Antonakaki 2007).

A final consideration when determining isovist boundaries relates to the impact of these decisions on later mathematical analysis and, in particular, the problems of the ‘edge effect’ (Hillier 1996). As noted previously in Chap. 2, some graph measures are sensitive to the relationship between the proximity of an observation point and the boundary of the environment. Visual integration, the measure most frequently associated with movement patterns, is one major example. To counter the influence of the edge effect, researchers recommend expanding the region covered by the study well beyond the particular area of interest or alternatively, adjusting the calculations to counter this effect (Hillier 1996).

While the large number of different approaches outlined in this section may be problematic in terms of their impact on the repeatability of isovist-based experiments, the flexibility of the method allows researchers using isovist analysis to evaluate many specific spatial properties. Also, despite the range of alternative positioning strategies for isovist locations, three options are typically used, depending on whether the aim is to arrive at a holistic value (leading to the use of regular grid positions), to test a particular condition (leading to a location-specific strategy) or to analyse a methodology. The flexibility of the isovist approach to the analysis of space allows researchers to focus on specific factors that other spatial analysis systems are less able to capture.

4.4 Manual Isovist Construction

There are two major variations of the process of constructing an isovist polygon. The first of these follows the original procedure of Davis and Benedikt (1977) and provides a stable approach to producing consistent results in any simple, enclosed environment. It operates by tracing lines from surface vertices or corners in the plan of an environment to the observation point, much like rays of light approaching the eye in Gibson’s (1947) ambient optic array or Aristotle’s model of vision. If such a line does not pass through another surface, then it identifies a visible point on the isovist perimeter. If any of these lines pass through a surface, then their generating vertex is not visible from the observation point.

Lines drawn from reflex vertices are also extended beyond their vertex to intersect another surface whenever this is possible. These extensions are described as an ‘occluded boundary’, ‘occluding line’ or ‘occluding radial’. The point where the extended line strikes another surface is then also defined as a visible point. The isovist polygon is thus the smallest area defined by the combination of occluding lines and surfaces of an environment which contains the observation point. That is, its vertices are defined by the set of visible points, and its edges by the set of either surfaces or occluded boundaries which connect them. This method is both straightforward and efficient for environments with a small number of surface vertices (Figs. 4.4 and 4.5).

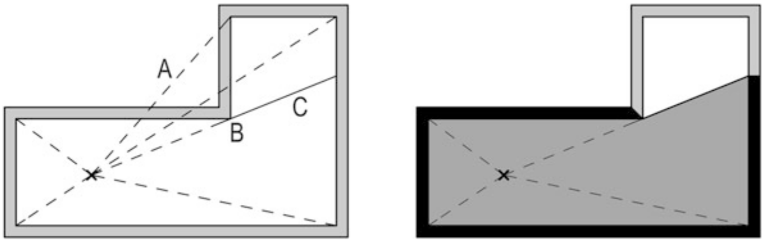


Fig. 4.4 Isovist construction, classical process: vertex line A passes through a surface, thereby confirming that its generating vertex is not part of the isovist. A reflex vertex B (reflex angle) may produce an occluding radial C. Only reflex vertices will produce occluding radials. Adapted from Davis and Benedikt (1979). Hidden walls shown Grey

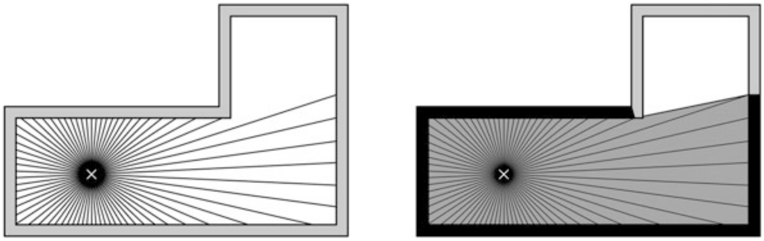


Fig. 4.5 Isovist construction, modern process: vertex lines that pass through a surface do not constitute part of the isovist polygon. Vertex lines that can be extended beyond their vertex become occluding lines. Radial lines end when intersecting a solid surface. Joining the ends of these lines creates the isovist polygon

The second method is more common in contemporary, computational variations of the isovist construction process. Whereas the first traced a limited set of lines from the environment to the eye, the second generates a more extensive set of lines drawn from the eye to the environment. These lines radiate out from the viewing position with an equal angular distribution and are known as 'radial lines' or 'radials'. If, for example, a full isovist contains 360 lines, the angular displacement between each is 1°. Similarly, a full isovist constructed with 72 lines will have an angular displacement of 5°. Each radial line extends until intersecting with a surface and denotes this intersection location as being visible from the observation point. The sequential linking of these visible points (that is, the ends of the radial lines) will create the perimeter of the isovist polygon. This approach is analogous to Benedikt's (1979) example of placing a light source in a model to generate isovists. Mike Christenson (2010) demonstrates a simple computational method for the generation of isovists using this approach, which has some similarities to Michael Batty's (2001) demonstration using virtual agents walking on an angular displacement from the observation point until meeting a surface.

Given the same observation position and context, both the first, surface vertices technique, and the second, radial line method, will, if rigorously executed produce similar isovists. The surface vertex method is highly efficient in a small environment where only a limited number of vertices exist. However, for a large building, the vertex method may require far more lines to generate an isovist compared with the radial line approach. Researchers should, however, be able to use a combination of logic and intuition to limit the number of lines required for surface vertex isovist generation. All other things being equal, a surface vertex isovist offers superior accuracy to that of the radial line method. This is because the surface vertex method will always identify the exact position of surface vertices whereas the radial line approach can only precisely locate a vertex that is intercepted by a radial line. If the angle between radial lines is too large, then this second method swiftly loses accuracy.

In order to understand this issue of accuracy, consider that a 1° increment produces 360 radial lines and a seemingly accurate result, whereas a 5° increment produces only 72 lines, and a relatively poor isovist. Compounding this problem is the fact that the human eye is capable of recognising a much higher resolution of radial lines than most computational analyses utilise. Physiologically, humans 'can detect, under ideal conditions, objects intercepting 0.5 seconds of arc' and under perfect circumstances can detect 'objects intercepting 30 seconds of arc' (Smardon et al. 1986: 45). Replicating the ability to detect objects intercepting 0.5 seconds of arc requires generating an isovist with over 2.5 million radial lines. Replicating the ability to recognise an object intercepting 30 seconds of arc ($1/120^{th}$ of one degree) requires generating an isovist with 43,200 radial lines. What is conventionally called '20/20 vision' requires visual acuity of the equivalent of 21,600 radials in a two-dimensional plane. These figures are important because they give a sense of the practical upper limit for the required number of radial lines (or their angular increment) to create an isovist which replicates human visual acuity. This is because there is little practical need to analyse an environment in a greater level of detail than our visual perception allows. However, this information does not establish a useful minimum number of radial lines required for an accurate analysis. Many applications of isovist construction use 360 radial lines, seemingly accepting this as a reasonable compromise, although it is more likely to be a practical solution rather than a logical one. However, anything below this level offers only a crude simulation of human sight, although there may be reasons to use such a simulation for simple calculations.

A related problem is that the metric distance between radial lines increases with distance from the observation point while angular displacement remains constant. Thus, it becomes more difficult to see objects as the distance to these objects increases. In practice, for a person with 20/20 vision, this decrease has minimal impact. However, for an analysis of only 360 radial lines (that is, a 1° increment), the decrease in accuracy is far more pronounced in longer distance views. Such a property may result in the omission of significant, distant spatial features from subsequent analysis, such as those viewed through the gaps in a colonnade. Nevertheless, despite these challenges, the radial line method is still used because it has a superior capacity to generate a range of mathematical values for describing and comparing isovists.

A single isovist is only capable of defining the visibility characteristics from a single location, and thus in many instances a system of isovists is required to document an entire building. An isovist field is a comprehensive set of isovists generated at regular points within an environment, usually the interior of a building, and as such, all of the previous issues raised in this chapter are also applicable to isovist field analysis. This form of visibility analysis still treats isovists as independent entities, capable of describing only the spatial characteristics from their observation point. However, the value of the isovist field extends beyond its capacity to compare independent isovists, into the consideration of the mathematical relationship between each isovist in the set (Turner and Penn 1999; Turner et al. 2001). This later consideration involves viewing the set of isovists as a network.

In this type of analysis, each isovist observation point in the field becomes a graph node, and a graph edge links any pair of mutually visible nodes. Nodes are mutually visible when each node is located inside the isovist polygon of the other node's observation point, allowing them to be connected by a single straight line. A single node may possess edge connections to any number of other nodes. Researchers then use graph mathematics to describe the relationship between each node relative to the entire network or graph. Thus, this type of analysis of an isovist field can provide a measure of the visual properties of an entire environment (known as a 'global' visibility measure), whereas an individual isovist can only provide information about a specific point in space (known as a 'local' visibility measure). While manual graph theory analysis of the isovist view field is possible (and demonstrated in the following section), the number of calculations required for a large building means that it is usually undertaken with software such as UCL Depthmap.

4.5 Worked Example

The remainder of this chapter contains a detailed example that demonstrates the construction of isovists using both the vertex tracing method and the radial projection method, and various approaches to documenting the resultant data. The demonstration uses a hypothetical house, the *Villa Alpha* (Fig. 4.6). The villa has no windows, one external, closed and opaque door and uniform ceiling heights. In the following examples of visibility analysis, all observation points are located at the intersections of regular grid lines which are scaled to give a manageable number of observation points. Furthermore, all isovists depict a horizontal plane at an observer's eye level. Finally, CAD software is used to eliminate inaccuracies resulting from variations in levels of manual dexterity that may occur in 'hand' constructions of isovists.

The locating grid is aligned to the villa's geometry (the centre-lines of walls) and scale and has an alphanumeric labelling system (A–P on the vertical axis and 1–20 on the horizontal axis). As all possible observation points in this analysis are located at the intersections of the grid lines they can be described using a coordinate

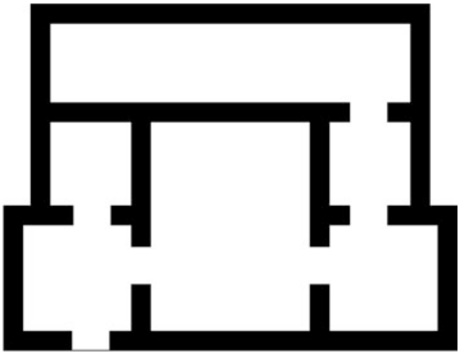


Fig. 4.6 *Villa Alpha* plan

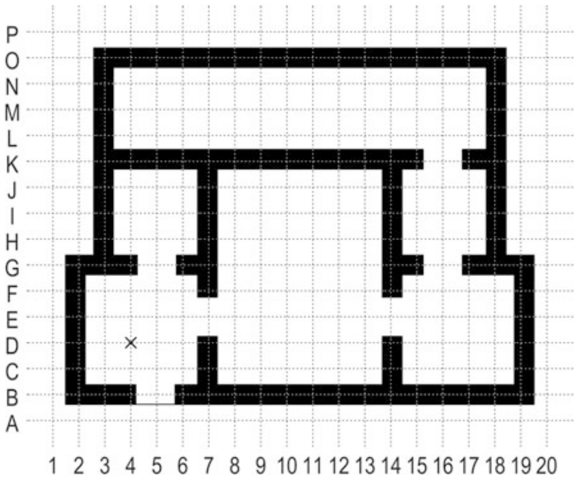


Fig. 4.7 Isovist locating grid with observation point D-4 marked

system. For example, the following demonstration of isovist construction uses coordinate D-4—marked with a cross (Fig. 4.7)—as the observation point.

4.5.1 Surface Vertex Method

Step 1a. To commence isovist construction using the surface vertex method, first identify the closest surface vertex to the observation point D-4 (Fig. 4.8). Draw a straight line from this vertex to the observation point and then extend the line away from the vertex until it intersects a surface of the environment. Drawing a line from a vertex *through* a surface to the observation point indicates that the vertex is not visible from the observation point. Drawing a line from the vertex *to* the observation point (which does not pass through another surface) indicates that the vertex lies on the perimeter of the isovist. In practice, if it is obvious to the researcher that a vertex is not visible from the observation point (for example, the vertex at O-3), there is no need to draw that line. However, to be completely rigorous, every line should be drawn then the superfluous ones eliminated. While this may seem unnecessary for vertices that are 'clearly' part of the isovist, in practice it can be easy to overlook critical vertices.

Step 2a. Identify subsequent vertices, commencing with the second closest, then the third closest and so on, repeating, in each case, the line drawing process in the previous stage (Figs. 4.9 and 4.10). An isovist polygon has two edge types, boundaries and occluding radials. A vertex does not inform isovist construction if an agent walking from the observation point would cross an occluding radial to reach the vertex. Thus, drawing the occluding line from vertex F-7 immediately excludes vertices at K-7 and K-14 from being seen (Fig. 4.11). However it is recommended to draw lines to every vertex. Continue this process, drawing vertex lines to identify all vertices forming the isovist polygon.

Step 3a. The process of drawing in all vertex lines is then complete. Remove all vertex lines leaving only occluding lines and surfaces. The isovist, which is normally shaded to distinguish it graphically, is the smallest consisting of occluding radials and isovist boundaries that contains the observation point (Figs. 4.12 and 4.13).

4.5.2 Radial Projection Method

Step 1b. The radial line approach to constructing an isovist commences with the selection of the resolution of the radial lines, that is, the incremental angle between adjacent radial lines. In this demonstration, the angular increment of 5° was chosen. Thus, 72 lines complete a 360° isovist (this particular increment is chosen for graphic clarity for the demonstration, rather than as an ideal resolution).

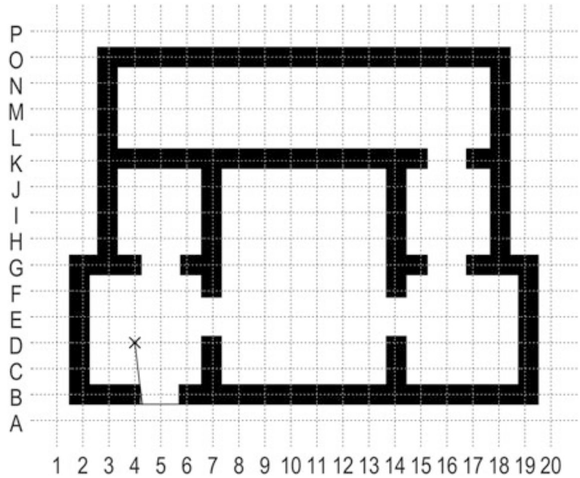


Fig. 4.8 Identify the closest surface vertex and draw a vertex line to the observation point. Though difficult to see in this image, the vertex line extends beyond the vertex to intersect the external door

Fig. 4.9 Draw a second vertex line from second closest vertex. Note that this line cannot extend beyond the surface at B-2

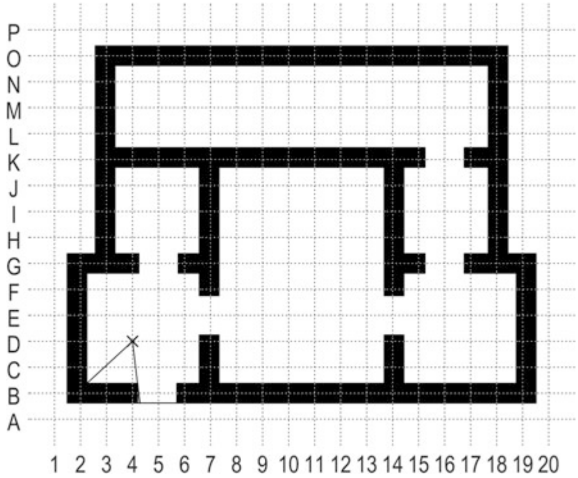
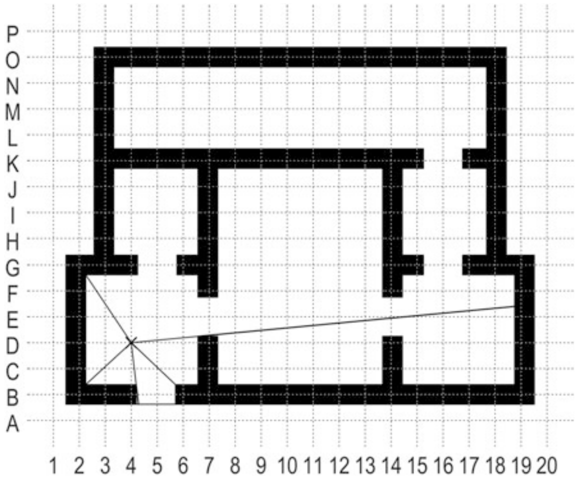


Fig. 4.10 Complete subsequent vertex lines commencing with the next closest vertex



The process commences by drawing a radial line from the isovist to intersect with a boundary. In this case, the first line is vertical. Consistent analytical results require that the first radial line be drawn in the same direction from the observation point for all studies (Fig. 4.14).

Step 2b. Select a direction of rotation (clockwise in this example) and draw the second radial line at the selected angle of resolution (5° in this case) until it intersects a boundary. Thereafter, draw the third line, and so on (Figs. 4.15).

Step 3b. When all radial lines are complete, draw lines linking the end of each radial line to the end of the adjacent radial line to form the perimeter of the isovist polygon (Figs. 4.16 and 4.17). While this isovist differs from that constructed using the

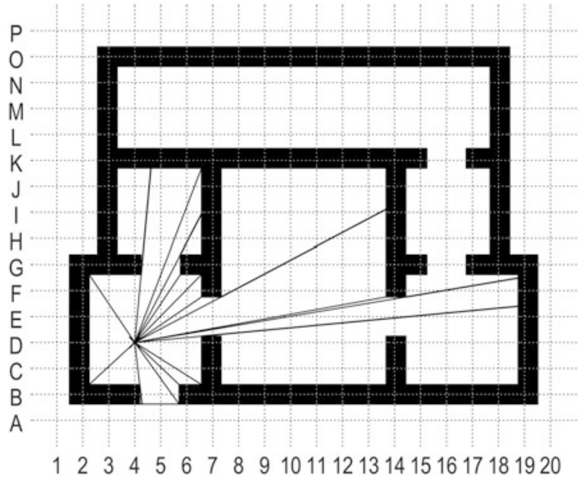


Fig. 4.11 Continue drawing all vertex lines that define the perimeter of the isovist

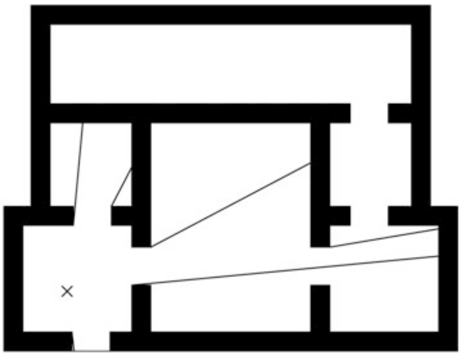


Fig. 4.12 Remove all vertex lines leaving only occluding lines

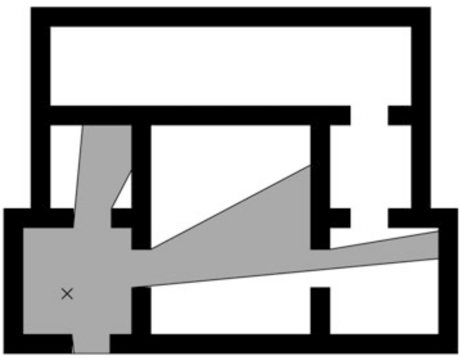


Fig. 4.13 Shade the isovist polygon to allow for graphic clarity

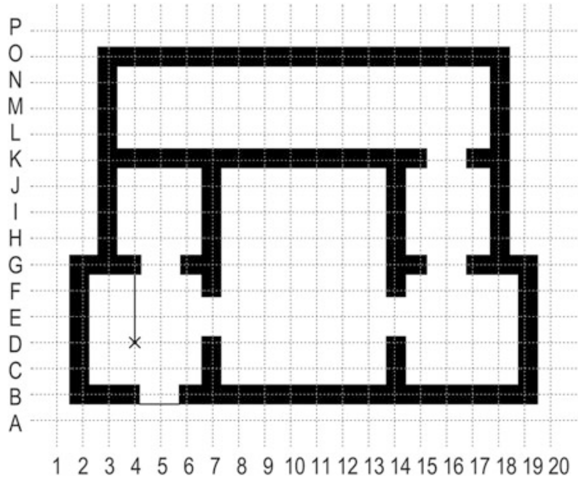


Fig. 4.14 Draw the first radial line at the selected orientation

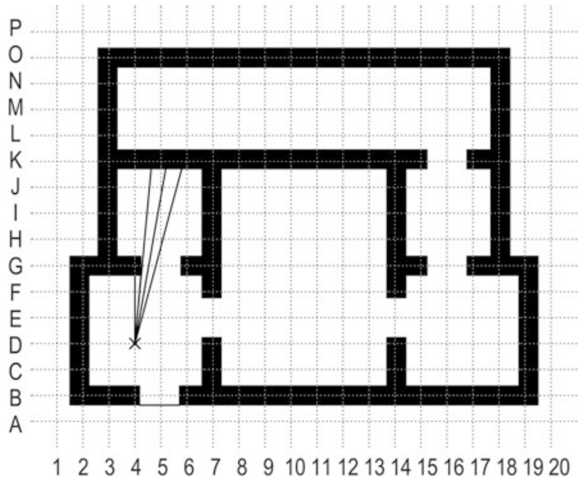


Fig. 4.15 Draw additional radial lines at the selected angular increment

surface vertex method, increasing the radial resolution (that is, decreasing the angular increment) will reduce discrepancies.

4.6 Deriving Quantitative Measures

There are multiple ways of measuring isovists for analysis. For example, Arthur Stamps reviewed twenty-five possible measures, noting that 'isovists can be distinguished [using from] two to perhaps six properties' and concluding that the 'most plausible properties are Size and Concavity' (Stamps 2005: 753). Isovist size, measured as the square metre area of the isovist polygon, is also the first of the

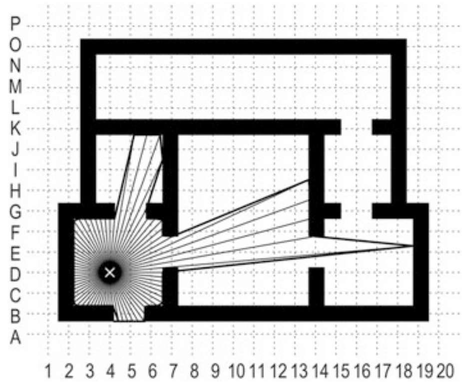


Fig. 4.16 Draw lines linking the ends of adjacent radial lines to define the isovist polygon perimeter

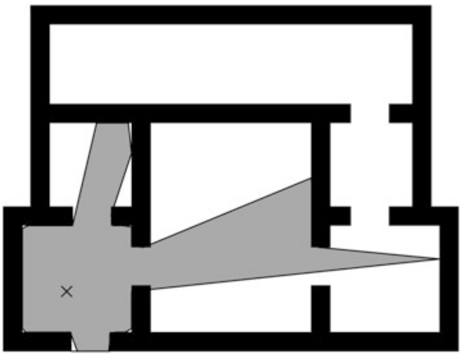


Fig. 4.17 Remove radial lines and shade the isovist polygon for graphic clarity

measures proposed by Benedikt (1979). The process for calculating isovist area commences with breaking the isovist into a number of simpler shapes, using a method such as polygon triangulation. The sum of the area of these simple shapes gives the area of the isovist. One advantage of the radial line method is that two adjacent radial lines and the isovist boundary between them form a triangle, thus removing the need to decide on the best method of dividing the isovist. CAD software will also readily calculate the area of even the most complex isovists. However, while the area is relatively straightforward to calculate, it provides no information about the shape or complexity of the view. To gain a more detailed understanding of the isovist requires more sophisticated measures, including concavity, radial line lengths and their statistical distributions and occlusivity.

The process of calculating concavity commences with determining the perimeter length of the isovist. The isovist perimeter is the combined length of the occluding radials and boundaries that define the isovist polygon. Benedikt (1979) measures real surfaces and occluding radial lengths independently, classing each as a separate measure. While Stamps (2005) develops his own measure of concavity (called Convex Deficiency) based on the concave hull of polygons, he notes that a suitable alternative is another measure proposed by Benedikt (1979) called Circularity. Circularity is a comparison of the area of the isovist to the perimeter of the isovist, calculated as:

$$Circularity = \frac{Isovist\ Perimeter^2}{(4 \times \pi \times isovist\ area)}$$

Ruth Conroy (2001) also proposes a comparison of the perimeter and area of the isovist in an Area Perimeter Ratio using a different formula:

$$Area\ perimeter\ ratio = \left(\frac{isovist\ area}{isovist\ perimeter}\right)$$

Several additional measurements of isovists rely on the fact that the radial line method allows for the measurement and comparison of the length of individual radials (longest, shortest, etc.) and a calculation of the average length of all radials. These values allow for the derivation of several secondary measures from the set of the radials, including Standard Deviation (σ), Variance (the second moment about the mean of the radials, M_2) and Skewness (the third moment about the mean of the radials, M_3).

Benedikt (1979) claims that the measures Variance and Skewness can be used to quantify the dispersion of the perimeter around the observation point and the asymmetry of the isovist polygon. Standard Deviation is the square root of Variance, where Variance is calculated by subtracting the mean radial length μ, from the length of each radial r, and squaring the difference, then finding the average of these differences:

$$M_2 = \left(\left(\frac{1}{N}\right)\sum_{i=1}^{N}(r_i - \mu)^2\right)$$

A calculation of the Variance of the first three radial lines in the *Villa Alpha* follows, although for a complete calculation, all 72 radial lengths would have to be processed in this way:

$$M_2 = \frac{\left((2.305 - 2.868)^2 + (2.287 - 2.868)^2 + (5.985 - 2.868)^2 + \ \ldots(r_{72} - \mu)^2\right)}{72}$$

$$M_2 = \frac{\left((-0.563)^2 + (-0.581)^2 + (3.117)^2 + \ldots\right)}{72}$$

$$M_2 = \frac{(0.317 + 0.338 + 9.716 + \ldots)}{72}$$

$$M_2 = 4.773$$

$$\sigma = \sqrt{M_2}$$

Skewness relies on a formula similar to Variance, although the radial difference calculations are cubed rather than squared:

$$M_3 = \left(\left(\frac{1}{N} \right) \sum_{i=1}^{N} (r_i - \mu)^3 \right)$$

Another important measure, Drift, is the distance of the observation point *d* from the 'centre of gravity' *c* of the isovist polygon, where the centre of the isovist is calculated as a 'polygonal lamina' (Conroy 2001: 154). Conroy calculates the distances between observation point and centre of gravity in the *x* and *y* planes individually and the square root of the sum of the square of the planar differences is the magnitude of the isovist drift:

$$Drift = \sqrt{(d_x - c_x)^2 + (d_y - c_y)^2}$$

For example, an observation point located at *x*, *y* coordinates 15, 6 and with a centre of gravity located at coordinates 9, 12 is calculated as follows:

$$\begin{aligned}
Drift &= \sqrt{(15 - 9)^2 + (6 - 12)^2} \\
Drift &= \sqrt{(6)^2 + (-6)^2} \\
Drift &= \sqrt{36 + 36} \\
Drift &= \sqrt{72} \\
Drift &= 8.485
\end{aligned}$$

Researchers use the visibility graph to calculate global visibility measures. As previously stated, each isovist observation point becomes a node in the graph linked by edges to every other node that is directly visible from the observation point. Guaranteeing accuracy of manual calculations is impossible in all but the simplest of cases. This is because the visibility graph quickly becomes too complex to work with. However, drawing the isovist field of a building in a CAD program offers an alternative approach for calculating global measures. Such an approach replicates the results of the visibility graph method—for individual observation points—without needing to construct the full visibility graph. This method allows for the calculation of global measures such as integration, using standard graph theory formulas (see Chap. 3).

Multiple authors describe the application of graph theory mathematics to the analysis of architecture (Hillier and Hanson 1984; Hillier 1996; Ostwald 2011a). The first stage in developing global measures is calculating the Total Depth (*TD*) of the isovists. For an isovist field, Total Depth relies on determining the distance, measured as visibility levels (in a graph sense) or steps, between each node and the observation point. The observation point is located at a depth of 0. Every point directly visible from the observation point is located 1 visibility level from the observation point. These are first-order (depth 1) points (Fig. 4.18). Every point, excluding the original or first-order points, visible from any first-order point are second-order (depth 2) points (Fig. 4.20). Total Depth is the number of points (n_x) at each visibility depth multiplied by their depth from the original point.

$$TD = (Depth\ 0 \times n_x) + (Depth\ 1 \times n_x) + (Depth\ 2 \times n_x) + \ldots (Depth\ X \times n_x)$$
$$TD = (0 \times n_x) + (1 \times n_x) + (2 \times n_x) + \ldots (X \times n_x)$$

Displaying the first isovist in a CAD program immediately shows the number of observation points that are directly visible, thus giving the number of first-order (depth 1) points. Displaying the isovists for all first-order points immediately shows the number of second-order points, and so on. This allows easy calculation of Total Depth for individual observation points without resorting to the construction of a complete visibility graph. Total Depth for observation point D-4 is shown below.

In the *Villa Alpha*, there are 46 first-order points directly visible to the point of origin (D-4) (Fig. 4.19). Displaying all first-order isovists shows there are 62 second-order points, directly visible from first-order points (Fig. 4.19). Finally, there are 37 third-order points, which make up, along with all of the previous orders, the complete visual extent of the plan (Fig. 4.20). Thus, the Total Depth of the *Villa Alpha*, relative to the starting position D4, is:

$$TD = (0 \times 1) + (1 \times 46) + (2 \times 62) + (3 \times 37)$$
$$TD = (0) + (46) + (124) + (111)$$
$$TD = 281$$

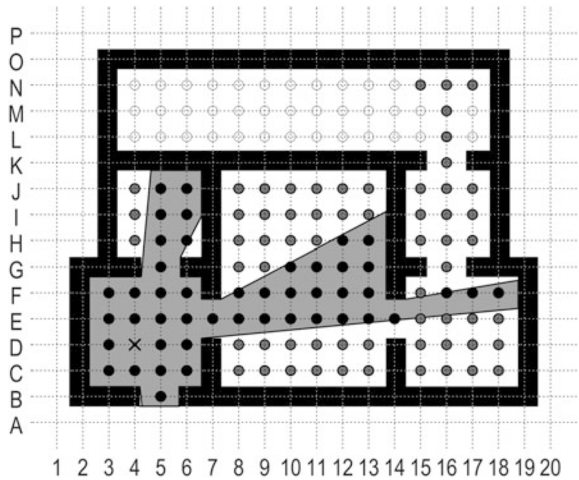


Fig. 4.18 The set of 46 first-order points (for location D-4)

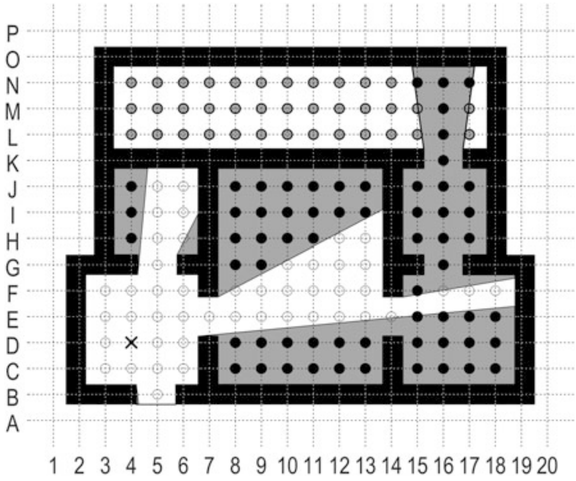


Fig. 4.19 The set of 62 second-order points

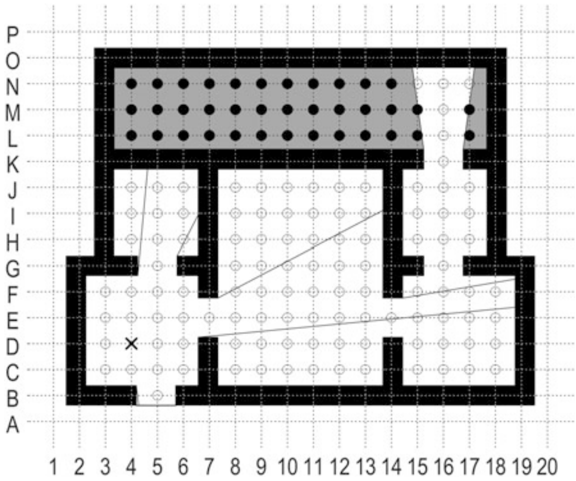


Fig. 4.20 The set of 37 third-order points

Completing this procedure for each isovist observation point on the grid yields a complete set of results for the entire plan. The effect is the same as constructing a visibility graph and counting the depth of each observation point, but is much more manageable to complete manually.

Total Depth also forms the basis for a range of additional visibility graph measures including Mean Depth (*MD*). In calculating Mean Depth, *K* is the number of observation points in the analysis.

$$MD = \frac{TD}{(K-1)}$$

In the case of the *Villa Alpha*, where K equals 146, the Mean Depth of D-4 is 1.93. Mean Depth then forms the basis of the Relative Asymmetry (RA) calculation, which in turn enables the calculation of visual integration (i):

$$RA = \frac{2(MD - 1)}{(K - 1)}$$

$$i = \frac{1}{RA}$$

Calculations for RA and i for point D-4 in the *Villa Alpha* produce results of $RA = 0.01$ and $i = 76.92$.

4.7 Isovist Representation

It is possible to represent the majority of visibility measures both graphically and numerically. The simplest representation used in isovist analysis is a depiction of the isovist itself—as a polygon on a plan—possibly accompanied by a qualitative discussion of its characteristics. One variation on this approach, adopted by Christenson (2010), is to represent all isovists of a view field in miniature at their observation point (Figs. 4.21 and 4.22). The advantage of this system is that, at a glance, it is possible for the trained eye to pick moments in space where new vistas come into view, or where ‘stable’ spaces suddenly become rich in visual information. As might be anticipated, the majority of these moments occur at the intersections between major lines of sight or room thresholds.

It is also possible to attach numerical values to isovists, giving a fuller account of visibility properties. Nonetheless, data matrices are the most common way of presenting the numerical qualities of isovists. However, while the numerical accuracy of this approach is often desirable for statistical analysis, the density of data produced in this way can be difficult to understand, leading to systems like

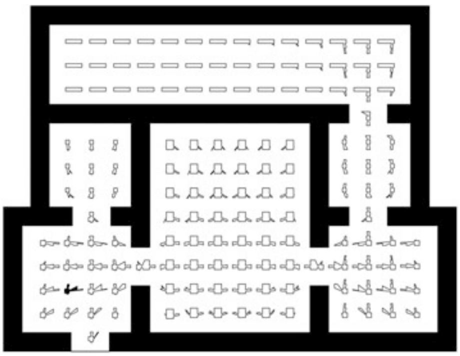


Fig. 4.21 Drawing the isovists of the *Villa Alpha* in miniature on the plan allows an overview of changing visibility characteristics. Point D-4 is shaded

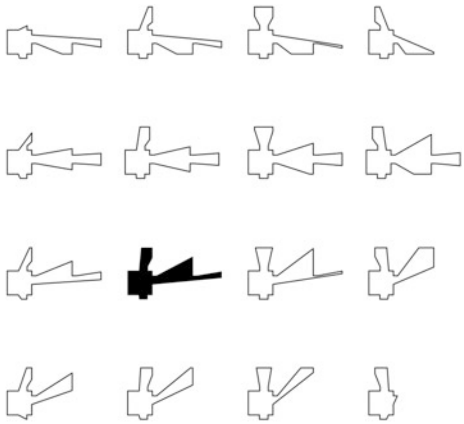


Fig. 4.22 The set of isovists in the same room as point D-4

Christenson's (2010) for graphically representing isovist information. In any case, there are several additional techniques for graphically representing visibility information. For example, Benedikt (1979) uses a scalar field to show the value of a single measure for every isovist in an environment. Despite the apparent ease of reading this data, locating gradient thresholds for such a map requires interpolating the raw data, which is too prohibitively labour-intensive to calculate manually.

The introduction of graph theoretic mathematics to visibility analysis brings a similar but simplified system of visual representation to isovist field data. This data representation system uses the isovist location grid to define pixels on the plan and applies a colour code to each pixel that represents the value of the measure at each observation point (Fig. 4.23). This representation is coarse when compared to a scalar map, but eliminates the need to interpolate data; thus additional resources may be allocated to data collection and the use of a smaller grid somewhat

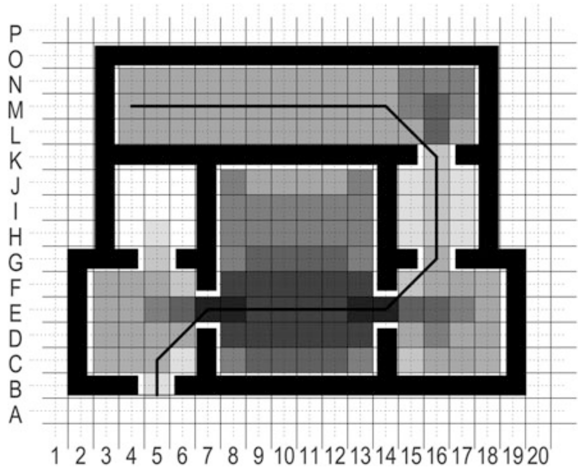


Fig. 4.23 Shading pixels allows for easy visual analysis of particular measures. In this example, the original isovist grid is dotted while the secondary grid is used for defining pixels for data coding. Lighter colours depict smaller isovist areas. The black line through the villa represents a hypothetical path taken by an occupant

compensates for the coarse representation. An example of this approach for the *Villa Alpha* is as follows.

The graphic representation procedure commences by creating the isovist field and calculating the measures of each of the 146 isovists. However, these results are for points in the grid rather than spatial zones or regions. Creating pixels to code the values present in the plan requires a second grid of identical size, offset by one-half of one grid module in the *x* and *y* planes to create a perimeter around each isovist point. Colour coding each of these grid cells allows the graphic representation of the isovist data; in this case the measure shown is the area of each isovist and dark colours represent larger areas (Fig. 4.23). The isovists with the largest areas in *Villa Alpha* (the points from which the largest volume of the interior may be viewed) are near two doorways (grid points E-7 and E-13). The smallest isovists (the most visually constrained spaces in the house) are in the single room, adjacent to the entry (I-5). A review of the graphic representation of the isovist data (Fig. 4.21) confirms this. The shaded, 'pixel' diagram can offer easier comprehension of the data compared to a matrix of numeric data. The shaded plan presents a clear overview of information pertaining to the visual qualities of the entire villa, allowing researchers to infer the spatial experience of an occupant traversing a path, for example, from the front door to the rear of a villa (Fig. 4.22).

Transferring data to a pixel representation also presents one disadvantage, in that the representation is only as detailed as the number of colours or shades used. An alternative representation avoids this problem by creating graphs of particular isovist measures along defined paths (Conroy-Dalton 2001; Weitkamp et al. 2007; Yang et al. 2007). Such an approach allows for greater accuracy in the reporting of that data, even if it is limited to only a selection of routes through space. For example, while the relative visual experience of a person walking through the *Villa Alpha* from the entry to the end of the rear room may be represented in the pixel plan, the actual variation, complete with numerical values, may also be graphed (Fig. 4.24). This approach develops Benedikt's (1979) representation of the changing isovist areas as an observer approaches a street corner. The *y*-axis of this particular graph represents the area of the isovist and the *x*-axis represents each pixel step along the path commencing from the door—effectively creating a pseudo time scale. Thus, in the example, the volume of visible space grows swiftly over the

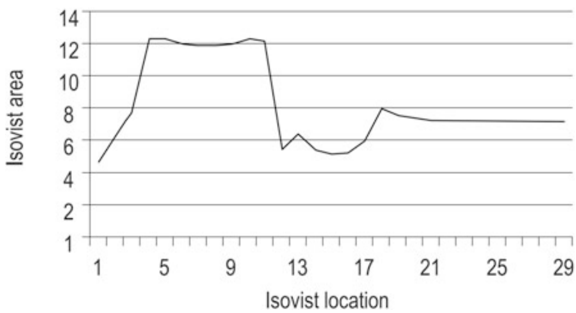


Fig. 4.24 A graph representing changing isovist area with progression along a path from the front door into and through the *Villa Alpha*

first four steps along the path and is then stable until step 11, with an isovist area of around 12 units^2 (the villa is based on a regular but not necessarily defined unit). The isovist area drops again after step 11, to around 6 units^2 before rising to a regular area of view, from around step 18 to 29, of around 7 units^2. Representing data as a graph in this way can lead to a greater understanding of an environment than may be achieved from an intuitive reading of a path delineated by coloured or shaded cells. This approach also allows representation of multiple data sets, for example, overlaying circularity data and area data into a single graph providing a basis for comparison.

4.8 Using Isovists for Analysis

While the simplest representation of an isovist is as a polygon on a plan, the simplest analytical use of an isovist is to determine if a location, or object, significant to a hypothesis is visible from a particular observation point. If the object is inside the isovist polygon generated from the observation point the object will be visible. Another practical application of isovist analysis is to determine the impact of certain spatial changes on the isovist view field. For example, the same space could be analysed with opaque windows and closed doors, and again with open windows and doors, thereby representing the extent of the external environment that is visible. For instance, the interior isovist generated from D-4 in the *Villa Alpha* (Fig. 4.13), is 65.15% smaller than the isovist (Fig. 4.3) which accommodates the exterior environmental views from the same position. Benedikt (1979) also uses isovists to demonstrate that different paths through the same environment produce different spatial experiences.

Comparative analyses between multiple environments are also possible using isovist methods. For this example, we compare the isovist results for the villas *Epsilon*, *Zeta* and *Eta*. Shading each of these plans to indicate isovist area, at the centre of each pixel, allows for intuitive visual comparisons by using an identical colour scale (Fig. 4.25). A darker colour indicates a larger visible area. From this representation, it is clear that the *Villa Zeta* contains both the largest isovists (darkest pixels) and the greatest number of large isovists. This means that the *Villa*

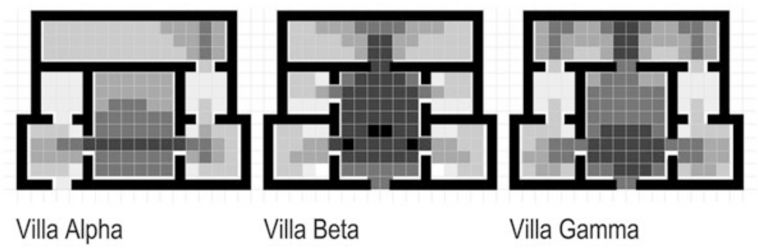


Fig. 4.25 Shading the plan for the villas *Epsilon*, *Zeta* and *Eta*, with an identical scale allows easy visual comparison of visibility characteristics associated with isovist area

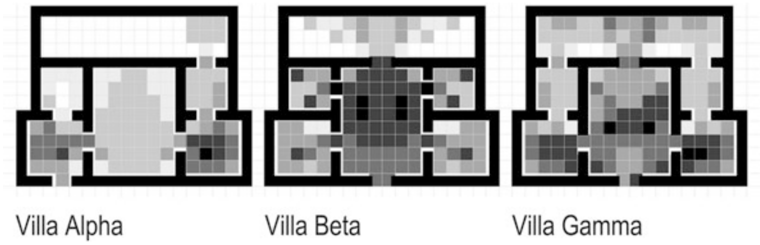


Fig. 4.26 Shading the plans of villas *Epsilon*, *Zeta* and *Eta* to depict occlusivity allows comparisons of glimpsed views in the villas

Zeta allows occupants to view a greater portion of the villa than is possible in the villas *Epsilon* and *Eta*. The occlusivity of the isovists (Fig. 4.26), that is, the length of the occluding radial lines, further indicates that the *Villa Zeta* offers more locations with glimpsed views to adjacent rooms where space is obscured by built surfaces. In contrast, the limited occlusivity of the *Villa Epsilon* means that its spaces are more concave, enclosing or private than those of the *Villa Zeta*. These two measures indicate that a better awareness of the entire layout of the *Villa Zeta* is available to the occupant compared to the *Villa Epsilon*. Availability of high levels of global spatial information to an occupant within the building is an indicator that the environment is more intelligible than one where only limited whole-environment information is available.

4.9 Conclusion

Isovist analysis traditionally focuses on determining the volume of space seen from a specific location in an environment, or the degree of variability in visible distance from this point. However, the flexibility of isovist analysis allows researchers to adapt existing methods and measures, as well as developing entirely new ones, to test unique hypotheses. This flexibility has resulted in a growing number of distinctive applications of these approaches to analysing aspects of spatial experience and social structure that are not captured by other techniques. Despite this flexibility, there is a relatively small body of literature directly correlating observed human behaviour to visibility measures. In addition, researchers give little consideration to variable environmental qualities that may have a significant impact on the spatial experience of the occupant.

Ultimately, comparative visibility analyses provide insights into differences in spatial experiences at various locations in a single environment or between multiple environments. For example, the *Villa Epsilon* contains relatively few locations from which large volumes of space are visible. This suggests that the experience of the *Villa Epsilon* is more cellular and contained. In contrast, the *Villa Zeta*, a design with the same floor area, is much more open and more readily understood.

Similarly, the spaces in the *Villa Epsilon* are more often constrained by surfaces, whereas the *Villa Zeta* plan offers greater opportunity for glimpsed views to distant rooms. Beyond these observations, the hypothetical villas are too simple to develop further conclusions.

The purpose of this chapter is not to offer evidence of the efficacy of visibility analysis but to provide an explanation and critique of some aspects of it which are rarely discussed in the literature, and to demonstrate how it may be applied. This chapter also demonstrates that complex visibility graphs are not required for calculating global visibility measures manually. The procedure described in this chapter replicates the logic and results of visibility graph analysis through a more user-friendly process than constructing a full visibility graph. Isovists and visibility graphs are used in Chaps. 8, 9 and 10 in this book for the analysis of Frank Lloyd Wright's domestic architecture.

Part II
Mies, Neutra and Murcutt

Chapter 5
Mies van der Rohe: Characteristics of the Free Plan

This chapter investigates three spatial properties in the domestic architecture of Mies van der Rohe. All three are associated with Mies's rejection of the type of cellular, hierarchically-structured planning found in traditional and pre-Modern housing. In its stead, Mies proposed a 'free' or 'open' plan, with only a minimum of physical divisions, as a sign of his abandonment of historic social structures. However, the traditional division of the plan into functionally-defined rooms responded to and shaped the way spaces were inhabited, moved through and viewed. Regardless of whether this cellular planning structure is retained or removed, people still need to use, change position within and survey their spaces, which raises the question; how do these three socio-spatial properties differ in the cellular and the free plans?

Mies's 1951 *Farnsworth House* is often heralded as being the first open-planned domestic design of the Modern era and historians and critics have identified three distinct socio-spatial changes it demonstrated or encouraged. First, it provided a previously unavailable freedom for new social structures to evolve. Second, it heightened the possibilities for inhabitation and movement to occur in the same space. Third, it emphasised the importance of static observation points. In contrast, the cellular planning found in more traditional domestic designs was thought to constrain social structures, isolate inhabitation from movement and provide few significant observation positions. As is often the case when examining architectural arguments, one side of this position is relatively clear, the properties of the *Farnsworth House* are fixed and measureable. However, the properties of the 'traditional house' are more diverse and it is difficult to even identify a reasonable sample to represent such a house, let alone to measure it. But this question about the relationship between the free plan and the cellular plan does have an intriguing corollary in Mies's own architecture.

The *Farnsworth House* was not only praised for changing the way domestic space is used, traversed and surveyed, but was also positioned as signalling a shift

M. J. Ostwald and M. J. Dawes, *The Mathematics of the Modernist Villa*, Mathematics and the Built Environment 3,
https://doi.org/10.1007/978-3-319-71647-3_5

in Mies's own architecture. Mies's early domestic architecture of the 1920s and 1930s was seemingly more cellular and traditional in its planning and thus, almost two decades later when he produced the *Farnsworth House*, it appeared to signal a dramatic change. But did it? Combining three syntactical approaches, this chapter compares the spatial properties of the *Farnsworth House* with those of four earlier domestic works by Mies, in order to determine whether the *Farnsworth* plan is especially different from the seemingly more traditional plans found in Mies's earlier architecture.

5.1 Introduction

Historians have described Mies's most famous domestic work, the *Farnsworth House*, as the epitome of the minimalist, monumental tradition in Modern architecture (Cohen 1996; Blaser 1999). The *Farnsworth House* has been praised for its uncompromising, stark geometric form, its brazen transparency and its almost classical relationship with its site (Goldberger et al. 2010; Krohn 2014). The many published photographs of this design celebrate its thin, white-painted steel structure and the way it seems to float above the ground on a pair of raised platforms within a wooded glade (Futagawa 1974; Vandenberg 2003). However, while its exterior presence and setting are noteworthy, it is arguably more famous for its interior.

The plan of the *Farnsworth House* is, with the exception of a single partitioned zone, entirely open. Rather than having distinct, functionally-defined rooms, it has a single large space that is partially divided by a freestanding thickened wall containing the bathroom, kitchen bench-top and services. Carefully placed items of furniture subdivide the remainder of the open plan, identifying potential sites for inhabitation and signifying the function of each area. The voids around the furniture provide spaces for movement and social interaction. The periphery of the plan, defined by glass walls and curtains, is not so much a space of passage, but of its termination. This last zone contains locations where specific vistas are framed through the interior (Frampton 1985).

These properties of the *Farnsworth House*—the free plan allowing for the creation of a new social structure, its blurring of the distinction between inhabitation and movement spaces and the creation of static viewing locations—suggest the presence of a series of social, cognitive and experiential qualities that were possibly unique in domestic architecture at the time (Blaser 1999; Samson 2015). But did Mies develop these properties exclusively in the *Farnsworth House*, or is there evidence that he had been experimenting with them in his earlier domestic works? Scholars and critics remain divided over this issue, with some arguing that Mies gradually developed these strategies throughout his career (Frampton 1985; Colomina 2009), and others suggesting that the *Farnsworth House* represents a more substantial paradigm shift in design (Vandenberg 2003; Bradbury and Powers 2009; Wilkinson 2010).

To investigate this issue, this chapter combines different syntactical maps to compare three properties of Mies's *Farnsworth House* with the same properties in four of his earlier domestic works. The three properties are concerned with the social structures implicit in the spatial and functional planning of these houses, the relationship between habitable spaces and movement, and the significance of terminal viewing positions in these designs. The first of these three is analysed using convex space mapping to identify and compare various indicators about the social structures in the five houses. The second uses intersection point mapping to examine the relationships between sites of inhabitation and pause points along movement paths to see if there is an increased correlation of these in the *Farnsworth House*. The third uses a variation of the intersection technique that includes end-nodes, to examine those locations in the plan that are experientially significant, but are not critical to its circulation. The inclusion of such locations has the potential to shift the social structure of the house away from its centre, and notions of inhabitation and movement, and towards its periphery, where view framing is potentially more important.

This chapter commences with a brief background to Mies van der Rohe's architecture, focussing on several aspects of his spatial planning which were to reach their apogee in the *Farnsworth House*. Thereafter, the methods used to analyse the five houses are described. The methods generally conform to the procedures and standards described in Chap. 3, although some specific variants are articulated in the present chapter. However, a particular property of the methods used in this chapter is that they derive mathematical and statistical data from the three syntactical maps we produce for each house, not from their graph-based measures. This is an unusual approach because the chapter's focus is on examining the relationship between three different spatial systems in each house; visually defined areas of inhabitation, choice or pause points in the network of paths, and terminal or viewing positions as an extension of this network.

In addition to the *Farnsworth House*, the four designs that are analysed in this chapter are the 1927 *Wolf House*, the *Esters* and *Lange* houses which were completed in 1927 and 1930, and the *Lemke House* from 1933. Mies did not have the opportunity to construct many stand-alone domestic works prior to the *Farnsworth House*, and these four are amongst the earliest of his rectilinear, Modernist-style designs. Significantly, the first of these was designed at a time when Kenneth Frampton (1985) argues Mies was first developing the strategies he would later refine in the *Farnsworth House*. The fourth, the *Lemke House*, was also the last completed design Mies produced before the *Farnsworth House*. The four early designs were also completed in a relatively short time period, almost two decades prior to Mies's commission for Edith Farnsworth. As such, they are not necessarily expected to show the gradual evolution of Mies's ideas, rather they are positioned collectively in juxtaposition to his later masterwork.

5.2 Mies van der Rohe

Ludwig Mies Van Der Rohe was born in Germany in 1886 and grew up in a period of intense social, political and economic change (Frampton 1985; Risebero 1982). After working as an unpaid bricklayer's labourer, an experience he would later describe as invaluable, he took up an apprenticeship manufacturing decorative plaster mouldings and it was through this work that he developed a talent for drafting (Cohen 1996). By 1906 Mies was working for architect Bruno Paul and specializing in furniture design while studying architecture at the Museum of Arts and Crafts and the Institute of Fine Arts. In the same year Mies secured his first private commission, a house for Alois and Sophie Riehl. Following subsequent periods of employment with Peter Behrens and Hendrick Berlage, Mies established an independent practice, producing a series of conservatively styled houses. These works are in stark contrast to the designs he submitted for competitions, exhibitions and publications. The unbuilt projects were influenced by both the flourishing expressionist movement and Mies's awareness of the potential for new technologies and materials (De Witt and De Witt 1987).

By 1921, the influx of Russian émigrés into Germany brought with them a new artistic and architectural avant-garde in the form of Constructivism and a revived enthusiasm for industrial technology. This dual influence—which was especially visible at the 1922 Constructivist exhibition in Berlin—is also apparent in Mies's 1923 Burohaus design, an office building with a strong structural expression. During this period Mies began to produce his concrete-and-brick, country house designs, including the *Wolf House*. This design was the first of a series of Modernist villas that some scholars argue demonstrates a partial dissolution of the cellular planning structures found in most housing of that era (Tegethoff 1985). Other works in this sequence include the *Lange*, *Esters* and *Lemke* houses. Along with Mies's *Villa Tugendhat*, completed in 1930, these houses feature plans that combine traditional room arrangements alongside more open living areas. It is these works which some historians identify as an important step for Mies towards the production of the free plan.

While these buildings allowed Mies an opportunity to translate his new conceptual thinking into reality, he soon became better known for designing exhibition architecture, and in particular for his ground-breaking German Pavilion at the Barcelona Exhibition of 1929 (Blake 1966; Blaser 1965). It could even be argued that the *Barcelona Pavilion* was a special type of house, albeit one that wasn't burdened with a specific function (Pevsner 1964). In place of functionally delineated spaces, the *Barcelona Pavilion* offers a sequence of interconnecting paths, punctuated with static viewing positions, each framing an exquisite artificial vista. Robin Evans (1997) observes that the plan of the pavilion encourages certain behaviours including a tendency to turn the spaces that would normally be used for circulation into places of inhabitation and viewing. In particular, in the *Barcelona Pavilion* there is a tension between the apparent freedom of movement the design offers to visitors and the static, two-dimensional way it frames views of itself from various peripheral locations in the plan. Evans (1997) describes the quality of these framed views as ‘painterly’, in that they are reminiscent of the properties of Renaissance perspective drawings, with their planar compositions, fixed viewpoints along axes and strong horizon lines. While the particular spatial properties of the *Barcelona Pavilion* are beyond the scope of the present chapter, what is notable in Evans’ analysis is that he identifies as already present, several of the experiential qualities later identified in the *Farnsworth House*.

In 1937 Mies relocated to America to become head of the architecture school at the Armour Institute in Chicago, and in 1945 he received a commission to design a weekend house for Edith Farnsworth. It was in the *Farnsworth House* that Mies was able to crystallize his conceptual values and experience with exhibition design into a single residence. In this design, the dominant asymmetry found in his early plans was largely replaced with a type of overlapping symmetrical composition, comprising the juxtaposition of two forms: the pavilion itself and the intermediate patio form, sited just above the ground plane. However, from the outside, viewed through its full-height windows on all sides, Mies’s most famous free plan was revealed. Mies described the free plan as ‘a new conception’ of space, which ‘has its own grammar, like a new language’ (qtd. in Norberg-Schulz 1965: 152). The free plan effectively negates the power of traditional social structures and offers inhabitants a new level of flexibility. But this flexibility has limits, as Mies explains, the free plan relies on a series of ‘inner laws’ for its order. These laws define how the space is occupied, moved around and viewed. The new grammar of the free plan is a function of both its physical limits and of the social and experiential relations it structures. As Christian Norberg-Schulz notes, the free plan requires ‘a strong means of organisation (such as a visible coordinate system) or it will end in chaos’ (1965: 152). Therefore, the elements of the free plan must be controlled and ‘emphasised through isolation and by framing’ (Norberg-Schulz 1965: 153). As a result of this, unlike in the conventional domestic plan, in the *Farnsworth House* people are not treated as inhabitants, but as visitors to a gallery, where their interactions with objects are formalised and specific viewpoints are emphasised (Baird 1995). When all of these properties of the plan are brought together the effect is to strip the design of its domesticity, and elevate it ‘to the status of monument’ (Frampton 1985: 235).

The sense of monumentality found in the *Farnsworth House* arises in part from the particular relationship between the viewer and the object that the free plan creates. Unlike many Modernist architects, including Le Corbusier, Richard Neutra and Frank Lloyd Wright, who conceptualised the experience of their work as being reliant on movement—offering people, respectively, spatial choices, controlled experiences or paths of discovery—Mies’s architecture was typically understood in more static and transcendent terms (Giedion 1961). In particular, it is often described as being experienced though a sequence of controlled, flat-planed views from various terminal-positions at the periphery of circulation paths (Bonta 1979; Evans 1997). It is this framing of space and form that has led to Mies’s architecture being repeatedly described as 'monumental' (Pevsner 1964, 1984; Frampton 1985; Scully 2003; Krohn 2014).

A monument is an object that marks something of significance, commemorating or celebrating a person, place, event or time in order to trigger memories of that subject. In architecture, monuments are intended to be solemn, enduring or timeless. 'Genuine monumentality is understood as being indifferent to its own time' and as such, monumental buildings are typically designed using a language of 'durability, solidity and dignity' (Curtis 2008: 61). Monumentality implies both a distinct way of viewing architecture and of responding to it (Sert et al. 1993). Spatially and formally, a monument functions by controlling or shaping specific views and experiences for the purpose of connecting the viewer to the object and then the past (that which is being memorialised) to the present (the mind of the observer). Thus, it must capture a person's attention first and, rather than encouraging this person to physically move and explore, lead their mind to make certain connections or evoke particular memories associated with the subject of the monument. In a sense, the monument relies on locking the viewer in space, fixing the relationship between the viewer's body and the design, for the purpose of triggering a dynamic mental response (Sert et al. 1993; Ostwald 2002; Curtis 2008). Hence, the classical architectural experience of the monument, like that of a Renaissance palace, involves viewing it from a tightly controlled vista, most often a position at the end of a network of linear paths (Wölfflin 1964).

Norberg-Schulz (1980) notes this property in his analysis of Baroque monuments, where distinct viewing positions, usually located along axial paths, are intended to engage the mind in divine contemplation (Ostwald 2006). This effect is similar to that achieved in Neo-Rationalist architecture, which employed simple and timeless geometric forms, often in tightly controlled settings, to raise the viewer's mind to the contemplation of supposedly higher ideals (Colquhoun, 2002; Pérez-Gómez 1983). Rowe's (1976) 'ideal villa' has similarly pure, geometric and formal characteristics that evoke a consideration of rational, or more specifically, mathematical insights. A monument's ideal form, combined with its placement in the landscape, emphasises key static relationships between the viewer and the building. Moreover, the viewpoints that frame these scenes are often situated at terminal locations, at the beginning or end of paths to and from the monument. In this way the paths signal the locations that are significant for contemplation, appreciation and understanding.

The sense of monumentality evoked by Mies's architecture arises in part from his use of simple geometric forms, which combined 'sparseness and extreme precision' alongside a 'sense of cubic proportions' (Pevsner 1984: 206). However, there is a lack of agreement about when the monumental impulse first began to characterise Mies's work. His 1926 *Memorial to Rosa Luxemburg and Karl Liebknecht* has several of the abstract, geometric properties which were to later characterise his architecture, but it is also finished in a raw, proto-Brutalist aesthetic with elaborate, cantilevered masonry forms. Perhaps, for this reason, Frampton

(1985) ignores this memorial, and traces the beginning of Mies's engagement with monumentality to the 1933 *Reichsbank* competition, suggesting that this design was the first that developed monolithic, timeless and thereby contemplative properties. Certainly, by the end of his career, Mies's architecture relied on the 'suppression of all that was programmatically incompatible with the monumental' (Frampton 1985: 237). However, even Mies's earliest houses, such as the 1912 *Kroller House*, have what Nikolaus Pevsner describes as a 'convincing monumentality' about them (1984: 206). In these early projects Mies effectively proved that monumentality was achievable in a Modern house through the careful manipulation of simple forms. Yet, it was not enough to achieve this simplicity and minimalism in the plan; Mies set out to express its social and experiential implications. Wolf Tegethoff argues that Mies achieved this outcome through 'the breakdown of room boundaries, the opening of the structure, the separation of supports and walls, the flat roof, projecting terraces and radiating lines', all of which 'organise, open and relate the space to the landscape' (Tegethoff 1985, 13). In this quote, as in the previous descriptions from Frampton and Evans, the three spatial strategies which are at the core of this chapter come together: the new social structure of the plan, the merging of movement and inhabitation functions, and the need to visually organise the design through its framing from terminal locations.

5.3 Method

5.3.1 Hypotheses

One of the challenges with examining the various claims that have been made about Mies's planning strategies is that few of them are described in a way that is readily testable. For example, much has been written about Mies's free plan, and the way it merges living, circulation and viewing locations into a single space. However, we do not know if these factors are causal or responsive. That is, the various spatial properties may provide a rationale for the free plan, but they are also a practical necessity arising from it. Similarly, all three properties we have discussed so far in this chapter have been linked to the sense of monumentality found in Mies's mid-career architecture, but whether they are the cause of this monumentality, or arise from it has never been adequately explained. For example, the feeling of monumentality may result from the process of forcing an observer to stand still and contemplate a form or, conversely from the form's power to stop a person in their tracks, and encourage them to contemplate its majesty. Such questions about Mies's free plan have been alluded to in the past, but they have largely resisted any deeper consideration because there are too many factors involved to formulate a simple or absolute answer.

Instead of trying to define Mies's three spatial properties in absolute terms, in this chapter they are approached in a more holistic and relative manner. For example, in this context what is important is simply whether these spatial properties are more or less pronounced in the *Farnsworth House* than in Mies's earlier domestic architecture. This way of looking at the problem shifts the emphasis away from specific arguments about, for instance, doorway widths, furniture locations and viewpoints and towards measurable spatial, social and cognitive patterns. Such generalised, or statistical patterns are more amenable to investigation using quantitative methods. Using this reasoning, a series of hypotheses can be framed for testing the three spatial properties, as they are measured in Mies's *Farnsworth House* and relative to his four earlier works. Each hypothesis is then aligned to a method for investigating its particular properties, and an indicator of the conditions required in the results for the hypothesis to be proven (Table 5.1).

All of the testing undertaken in this chapter uses convex spaces for constructing comparisons, not functionally defined rooms. This is because the visual coherence of each space is a critical part of the character of the free plan. In addition to this general principle, because the houses differ in terms of size and program (the *Lange House* has 70 convex spaces and seven bedrooms, while the *Farnsworth House* has eight convex spaces and one bedroom), two further processes are used for the analysis. First, ratios and percentages are employed to construct the majority of the comparisons. These are normalised relative to the number of convex spaces in each design. Second, to compare the programs, convex spaces are grouped into four categories which suggest how public or private they are. This process follows Christopher Alexander's et al. (1977) theory of intimacy levels or privacy gradients.

The first of the three spatial properties examined in this chapter is associated with the open plan's capacity to shape, accommodate and reveal new social patterns. This property isn't so much about new spatial properties in isolation, but rather about the relationship between social structure and visually defined units of space. This is because the free plan both accommodates and expresses social patterns. For the purposes of this chapter, the hypothesis argues that *both the spatial structure and the relationship between this structure and visual partitioning in the Farnsworth House are different from the equivalent properties in Mies's earlier domestic architecture*. The most obvious approach to testing a hypothesis about social structure is to use inequality genotypes, but past research into Mies's domestic architecture has demonstrated that it is surprisingly inconsistent (Bafna 1999). Sonit Bafna's not unreasonable starting assumption was that there would be a 'genotypical consistency in these houses' that could be used 'as a basis upon which to study their phenotypical differences' (2001: 20.3). This implies that the order of rooms in the inequality genotype would reflect the architect's ideal (itself a manifestation of social conditions) and that small differences in the results would be caused by particular site, context and program conditions. Unfortunately, the inequality genotypes were more diverse than anticipated and even simplifying the method to consider functionally defined spaces did not produce a clear result. To

Table 5.1 Spatial properties mapped to specific hypotheses, analytical methods and result indicators

	Property	Hypothesis	Method	Indicator of a positive result
1	Social structure of space	Both the spatial structure and the relationship between this structure and visual partitioning in the *Farnsworth House* are different from the equivalent properties in Mies's earlier domestic architecture	Convex space analysis producing (i) justified plan graphs, and proportional analysis of spatial types relative to (ii) occupation and (iii) privacy zones	(i) The justified plan graph for the *Farnsworth House* will not conform to the general structure found in the earlier works (ii) The ratio of spaces to occupants will be lower for the *Farnsworth House* than in the earlier works (iii) The division of the plan by privacy zoning will reveal a substantial (>10%) difference between the *Farnsworth House* and the earlier works
2	Relationship between inhabitation and movement	Inhabitation and movement patterns in the *Farnsworth House* are more clustered than in Mies's earlier domestic architecture	Intersection point analysis correlated to convex spaces	(i) The proportion of each house's complete set of intersections found in a single convex space in that house, will be higher in the *Farnsworth* than in the earlier houses (ii) The proportion of each house's complete set of intersections found in the 10% of spaces in that house with the highest number of intersections, will be higher in the *Farnsworth* than in the earlier houses
3	Significance of terminal viewpoints	Static viewing positions in the *Farnsworth House* are more critical for experiencing the totality of its plan than in Mies's earlier domestic architecture	End-node point analysis, correlated to convex spaces	(i) The proportion of convex spaces featuring only end-nodes (not intersections) will be higher in the *Farnsworth House* than in any of the earlier houses (ii) The proportion of each house's complete set of end-nodes found in the 10% of spaces in that house with the highest number of end-nodes, will be higher in the *Farnsworth* than in the earlier houses

further complicate matters, the free plan is particularly resistant to this type of analysis, as most spaces are not functionally defined or isolated. This has led to the present approach, which examines the structure of plan graphs and then compares the number of visually coherent spaces (convex spaces) with their occupant numbers and social groupings. Occupant numbers are determined, for consistency, by assuming that every bedroom has a single inhabitant.

The second spatial property being tested is a consequence of the flexible spatial structure in the free plan. It proposes that the free plan encourages or allows for closer relationships to occur between movement and inhabitation. This is reframed as the hypothesis that *inhabitation and movement patterns in the Farnsworth House are more clustered than in Mies's earlier domestic architecture*. This hypothesis is tested by comparing the percentage of convex spaces (places of inhabitation) in each house that contain intersection points (key moments in the circulation routes of the design). If the hypothesis is true, then the most intersection-rich portions of the *Farnsworth House* plan should feature a higher proportion of the set of intersection points in that house than in any of the others. Two variations of this test are required. First, a comparison of the single space with the highest proportion of each house's complete set of intersections. Second, because of the differences in house size, a comparison of the proportion of each house's complete set of intersections found in the 10% of spaces in that house with the highest number of intersections. Thus, for this second approach, a house with 70 spaces will combine the highest seven. For a design with fewer than 10 spaces, the space with the highest proportion is used for the analysis.

The third hypothesis holds that *static viewing positions in the Farnsworth House are more critical for experiencing the totality of its plan than in Mies's earlier domestic architecture*. Note that this hypothesis is not about intelligibility, it is about coverage. Thus it assumes that the proportion of convex space s featuring only end-nodes (not intersection point s) will be higher in the *Farnsworth House* than in any of the earlier houses. In a similar way to the previous test, because the houses differ in size, the proportion of each house's complete set of end-nodes found in the 10% of spaces in that house with the highest number of end-nodes are also examined.

The analytical methods used in this chapter are chosen primarily because they provide a consistent way of extracting various measures from different plans, thereby creating a reasonable basis for comparison. Convex space analysis has been chosen to examine social structures, intersection point analysis for comparing inhabitation and movement-related structures and end-node analysis for examining the influence of static viewing locations.

5.3.2 Approach

For the purposes of this analysis, new three-dimensional CAD models were produced for each house, based on Mies's construction drawings (Schink 2009).

These CAD models are used for all of the analysis. Only internal, habitable spaces and fixed furniture and screens in these houses are included in this analysis. Because several of the houses are multi-level, different plans are manually linked through staircase zones to enable simultaneous analysis of the entire building. Connections between levels are annotated (S1, S2, S3 …) on the axial plans and an arrow is included to demonstrate the connection. The particular differences between the standard versions of the convex space and intersection point methods (see Chap. 3) used for this research are described hereafter.

For the present analysis, convex spaces with one dimension smaller than 300 mm, such as those found in doorways or between columns, are incorporated into the largest adjacent space. In addition, convex spaces associated with stairs may extend linearly beyond the end of a staircase where movement potential exists, but are not extended wider than the stair, where an occupant would be required to climb or jump between levels. Beyond these general principles, two additional processes informed the creation of a convex plan for each house. For non-convex, L-shaped or T-shaped rooms, where only a limited number of alternative ‘convex decompositions’ (ways of dividing non-convex spaces into convex spaces) exist, the rooms were partitioned using the primary function of the room to determine the location of the largest convex space. Where spaces do not possess a primary functional zone to guide the process, they were divided such that the convex spaces possess the lowest perimeter-to-area ratio for the room. When these processes are applied, the convex map is produced and the connections between spaces identified using functional adjacency (the capacity to walk between spaces) as the primary determinant. Where three mutually adjacent spaces suggest the presence of a circulation loop, the following logic is applied to analyse whether it should be retained or not in the graph analysis. If a central wall or pillar that is larger than 300 mm must be circled around to pass between the three spaces, it is classed as a non-trivial loop and it is retained in the analysis. If passage between the three spaces does not require moving around such a column or wall, and the face-to-face contact area between the convex spaces is larger than 300 mm in each case, it is classed as a trivial loop. However, if the face-to-face contact area between two of the three spaces is less than 300 mm, they are classed as not linked for the purposes of this analysis (Fig. 5.1). All convex spaces are coded to identify their stated functional purpose, and zones in open-planned spaces are similarly coded using named spaces on plans.

The procedure employed hereafter for generating an axial map follows the standard version, with the only minor modification being to accommodate the linking of axial maps across multiple levels of a building. Axial lines are treated here as lines of straight movement rather than lines of sight. As such, a line may originate at one point on a floor, and travel horizontally across the floor before ascending stairs and continuing to its termination at a higher level. This is a line of straight movement, but not, in the case of stairs at least, a direct visual connection between the ends of the line. The axial map is then inverted to produce the first version of the intersection map used in this chapter. The production of the end-node

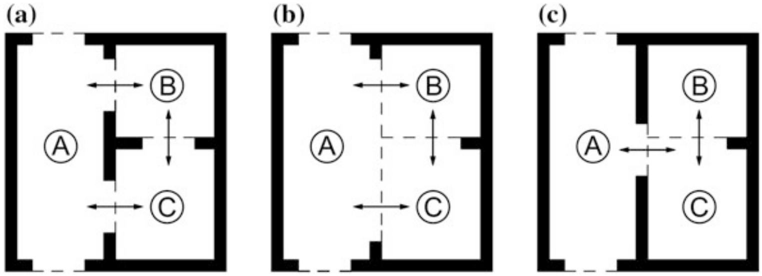


Fig. 5.1 **a** A non-trivial circulation loop, **b** a trivial circulation loop and **c** a situation where the face-to-face adjacency of convex spaces is too small for an occupant to move from A to B without experiencing C as an intermediate space

variation of this map requires examining the end of each axial line stub to determine if it possesses unique surveillance properties (that is, it is located in a convex space which would not otherwise be represented in the larger set). End-nodes are included in the intersection map if they possess unique surveillance properties.

Table 5.2 contains a list of the different room types, and the number of convex spaces which make up these rooms in each house. The room titles are all determined using the labels on Mies's final design drawings. Some of these are translated and updated from the historic drawings, because they reflect uses that are uncommon in contemporary society. For example, there are multiple types of servant quarters (for cooks, maids and grooms) all of which are treated under the same heading here. Similarly, there are multiple types of 'men's sitting rooms' and again, all are grouped into a single heading here. Table 5.2 also divides the rooms into four privacy zones. It could be argued that some of these divisions are arbitrary. For example, all halls are classed as 'semi-public', even though some connect only multiple bedrooms and bathrooms, and are not readily accessible to visitors. Similarly, the nursery is classed as 'semi-private', but in some houses this evidently functioned as a children's playroom, while in others it was reserved for a wet-nurse and baby. Rather than attempting to judge the actual use of each room in its original condition, a simple grouping by name was used for consistency.

5.4 Results

5.4.1 Wolf House, Guben, Poland (1927)

Designed for Erich Wolf, an executive in the textile industry, the *Wolf House* was Mies's first completed modern house. The building occupies the crest of a hill on the long, narrow site and it is designed around a courtyard with views over the Neisse River (Fig. 5.2). The ground floor contains service areas and larger,

Table 5.2 Convex spaces key and their presence in each house. Note that where multiple variations of rooms exist they are numbered in the graphs and plans

Privacy Zoning	Key	Function	*Wolf*	*Lange*	*Esters*	*Lemke*	*Farnsworth*
Semi-Public	E	Entry	3	3	1	1	
	H	Hall	11	14	13		
Semi-Private	S	Stairs	5	3	2		
	ST	Study	1			1	2
	L	Living room	2	3	2	1	
	mR	Music room	2				
	MR	Men's sitting/Billiards Room		3	2		
	Wr	Women's sitting	1	1	1		
	AG	Art gallery		1		1	
	D	Dining room	1	1	2		1
	N	Nursery			2		
Service	K	Kitchen	1	2	1	2	1
	G	General use	4	3	7		
	ld	Laundry		1	1		
	Dr	Drying room		1	3		
	Sr	Sewing room	1	1			
	DK	Dark room		1	2		
Private	SV	Servant room	2	3	2		
	A	Antechamber	2	7		1	
	GR	Guest bedroom	2	1	2		2
	B	Bedroom	5	9	14	1	
	d	Dressing room	3				2
	b	Bathroom	7	12	8	2	
Totals			53	70	65	10	8

open-planned living rooms while the upper floors retain a more traditional cellular planning structure for the private spaces (Figs. 5.3, 5.4 and 5.5). In total there are 53 convex spaces in the *Wolf House*, and seven bedrooms (including servant rooms) giving a ratio of spaces to inhabitants of 7.5714:1. This means that there are approximately seven and a half visually coherent spaces for every person living in the house (Figs. 5.6, 5.7 and 5.8).

The justified graph of the convex spaces features two major circulation loops, the largest of which has eight spaces and includes all living areas, while the smaller consists of the five most integrated spaces in the design and requires traversing both staircases (Fig. 5.9). Two additional minor circulation loops include the kitchen (five spaces) on the ground floor and servant areas (four spaces) on the first floor. These loops provide the occupants with some flexibility in the way they move through the design, although the planning in the upper levels is more hierarchically

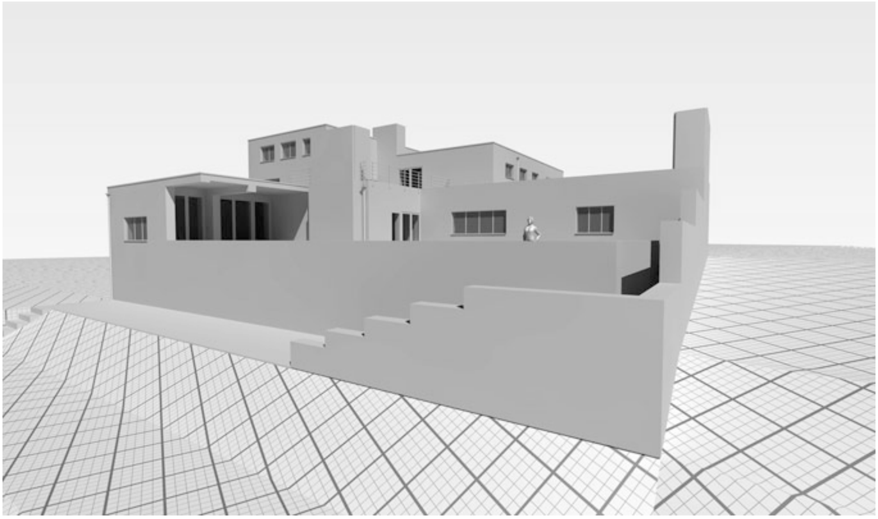


Fig. 5.2 External view of the *Wolf House*

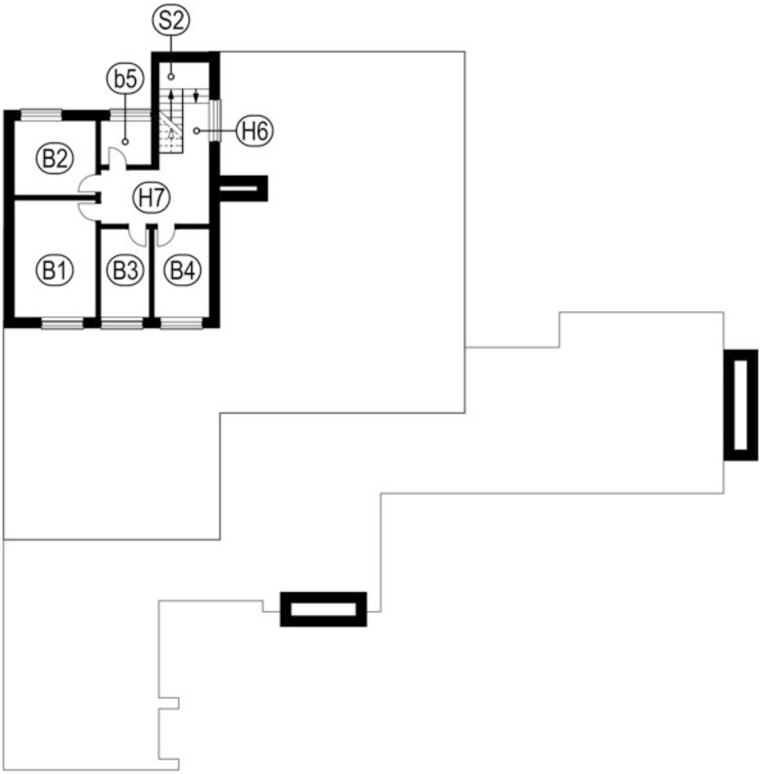


Fig. 5.3 Annotated second floor plan of the *Wolf House*

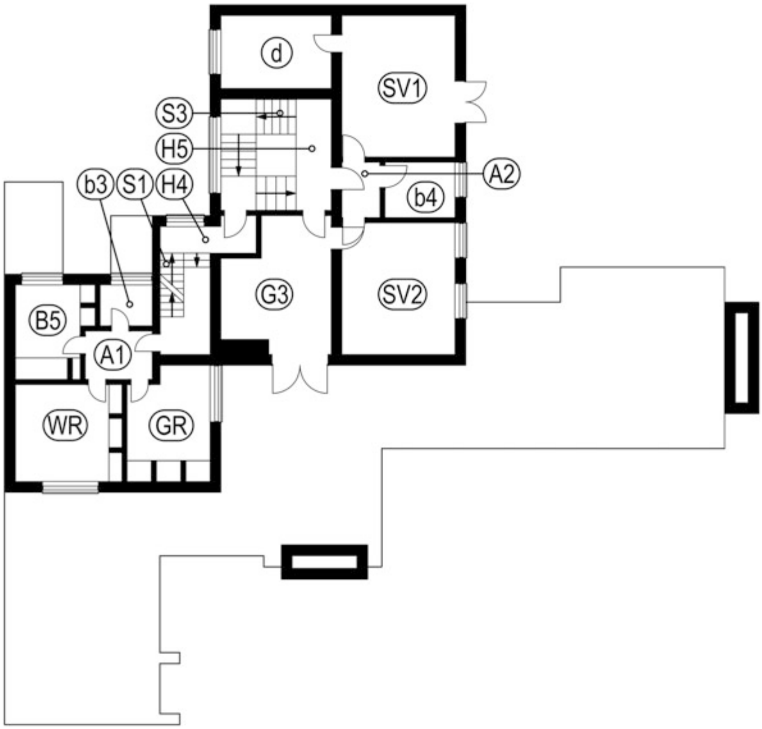


Fig. 5.4 Annotated first floor plan of the *Wolf House*

organised. When the convex spaces in the *Wolf House* are divided in accordance with privacy zones, 26% of these spaces are semi-public, 23% semi-private, 11% are service related and 40% are private (Table 5.3). In combination, the structural (justified graph) and social zoning (privacy level) results describe a plan that is split between a relatively flexible and open public side and a more rigid and controlled private zone.

For comparative purposes, six measures of the spatial properties of the *Wolf House*, relative to the location, number and proportion of intersection and end-nodes, are useful (Figs. 5.10, 5.11 and 5.12, Table 5.4). For the first, there are 53 convex spaces in the *Wolf House,* 43 of which contain either intersection or end points. Thus, 81% of spaces have either decision points or termination points. Of the convex spaces, 25 (47%) have intersection points, 18 (33%) have end points, and one space has both an intersection and an end point. These results indicate that almost half of the spaces of the plan are not part of the general network of decision points, and that one third of all spaces only function as destination points. The 10% of convex spaces in the plan with the highest proportion of intersection points account for 32% of the complete set of intersection points. The 10% of convex spaces with the highest proportion of end-nodes account for 27% of the complete

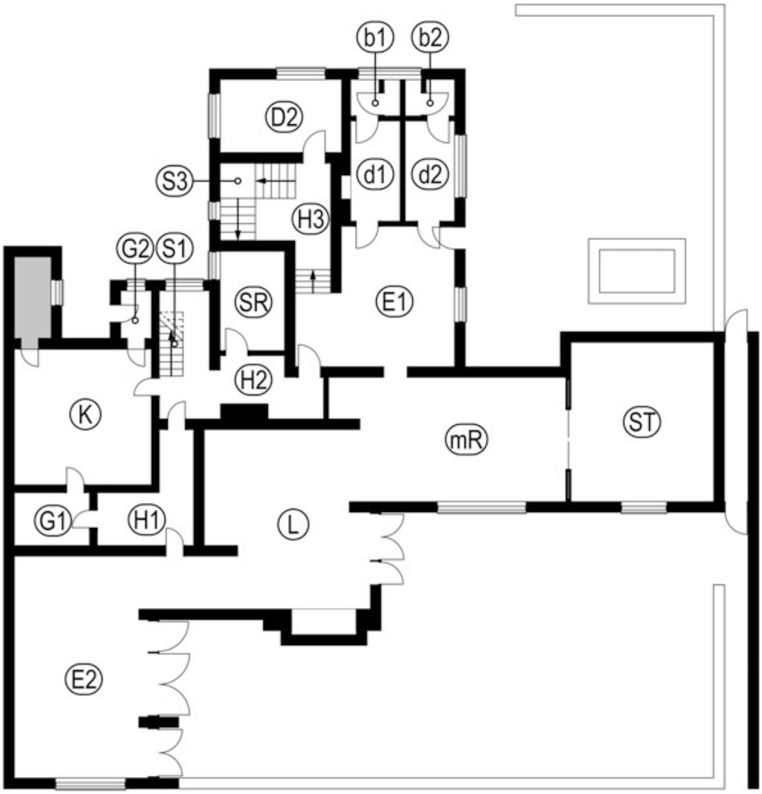


Fig. 5.5 Annotated ground floor plan of the *Wolf House* (shaded areas indicate non-habitable spaces)

set of end-nodes. The ratio of convex spaces to intersection points is 1.0566:1 and of convex spaces to end-nodes is 0.3396:1.

5.4.2 Lange House, Krefeld, Germany (1930)

The *Lange House* is one of two villas on adjacent properties in the industrial town of Krefeld (Fig. 5.13). The design and construction processes for these two villas occurred in parallel and each utilized the same materials and structural systems. The first of the two houses, designed for Hermann Lange, an executive in the textile industry, occupies three floors with bedrooms on the top floor, living areas on the central floor and service areas in the basement (Figs. 5.14, 5.15 and 5.16). Like the *Wolf House* the primary service areas are located towards the northern façade,

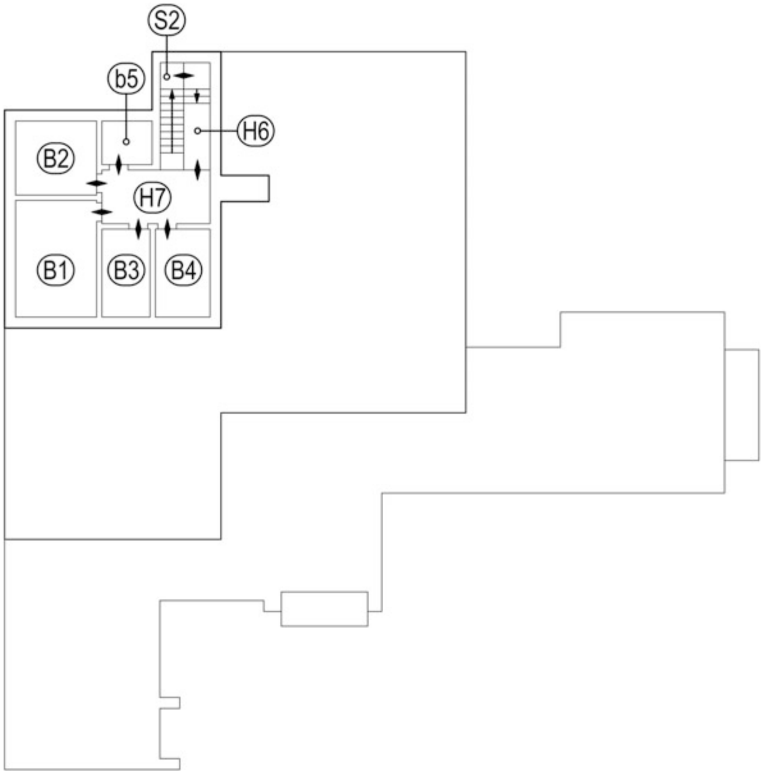


Fig. 5.6 Convex spaces in the second floor of the *Wolf House*

allowing open-plan living and cellular bedrooms to articulate the more desirable southern aspect. There are 70 convex spaces in the plan and seven bedrooms (including servant rooms) leading to a ratio of 10:1 visually coherent spaces to inhabitants (Figs. 5.17, 5.18 and 5.19).

The justified graph displays several internal circulation loops on the ground floor, including one that traverses eight spaces. The basement level contains one circulation loop, and the top floor features minor circulation loops associated with the 'girl's' bedroom and the master bedroom suites, but otherwise follows a more arborescent spatial structure (Fig. 5.20). The semi-public areas lie on dedicated public loops that only interact with the semi-private or private loops where necessary. When the convex spaces in the *Lange House* are divided in accordance with privacy zones, 24% of these spaces are semi-public, 17% semi-private, 13% are service related and 46% are private (Table 5.5). This result differs from that of the *Wolf House* in relatively minor ways, with a slightly higher proportion of private (6%) and service spaces (2%) and a commensurately lower proportion for semi-private (6%) and semi-public (2%) spaces.

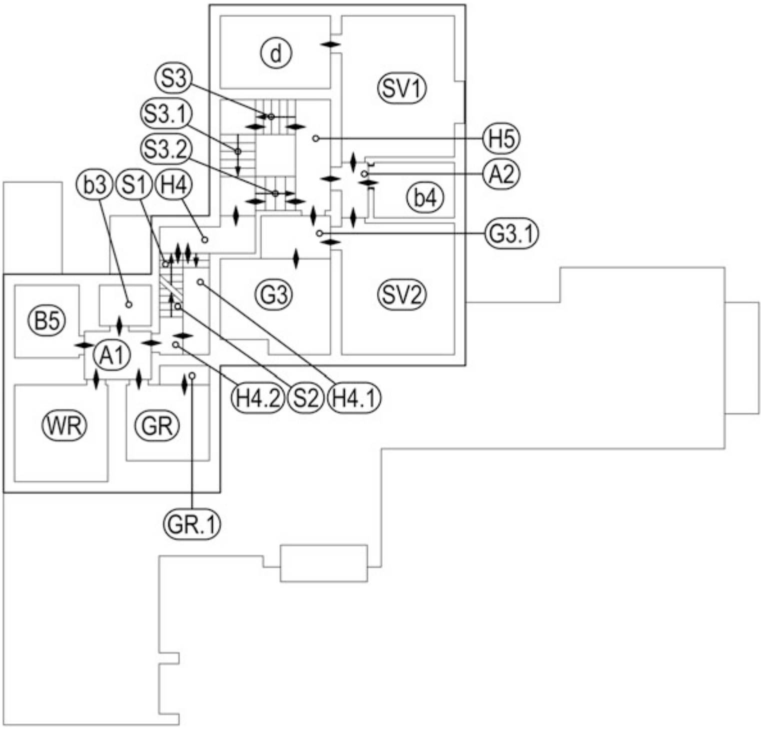


Fig. 5.7 Convex spaces in the first floor of the *Wolf House*

For comparative purposes, six measures of the spatial properties of the *Lange House*, relative to the location, number and proportion of intersection and end-nodes, are useful (Figs. 5.21, 5.22 and 5.23, Table 5.6). For the first, there are 70 convex spaces in the *Lange House,* 51 (73%) of which have either intersection points or end-nodes and 19 (27%) of which have neither. Of these convex spaces, 34 (48%) have intersection points, 20 (28%) have end-nodes and 3 have both. These results indicate that more than half of the spaces of the plan are not part of the general network of decision points, and that just less than a third of all spaces only function as destination points. The 10% of convex spaces in the plan with the highest proportion of intersection points account for 47% of the complete set of intersection points. The 10% of convex spaces in the plan with the highest proportion of end-nodes account for 35% of the complete set of end-nodes. The ratio of convex spaces to intersection points in the *Lange House* is 1.1142:1 and of convex spaces to end-nodes is 0.3570:1.

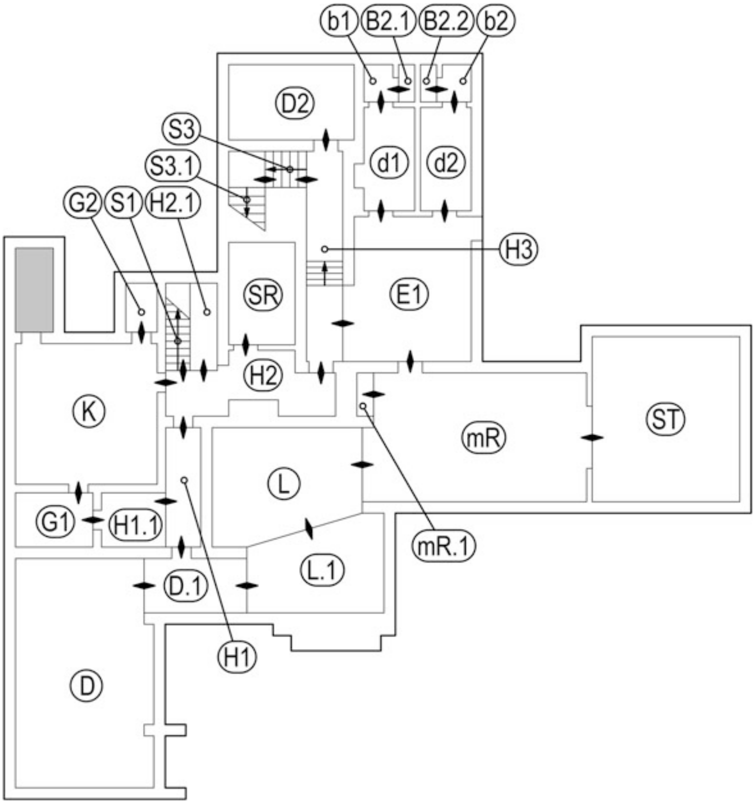


Fig. 5.8 Convex spaces in the ground floor of the *Wolf House* (shaded areas indicate non-habitable spaces)

5.4.3 Esters House, Krefeld, Germany (1930)

The *Esters House* was designed for the plot adjacent to the *Lange House* after Herman Lange referred Josef Esters, also a textile industry executive, to Mies (Fig. 5.24). 'The most important difference vis-à-vis the *Lange House* consists in the fact that thanks to a less dominant positioning of the main lounge in terms of the other rooms, the circulations on the ground floor are richer and more complex', featuring rooms with multiple entrances, which 'also function as the house's internal circulation spaces' (Schink 2009: 98) (Figs. 5.25, 5.26 and 5.27). In total, there are 65 convex spaces in the house and ten bedrooms (including the servant room) leading to a ratio of 6.5:1 visually defined spaces to inhabitants (Figs. 5.28, 5.29 and 5.30).

The justified graph of the *Esters House* plan confirms the presence of only three circulation loops, the largest of which has six spaces (Fig. 5.31). This number is

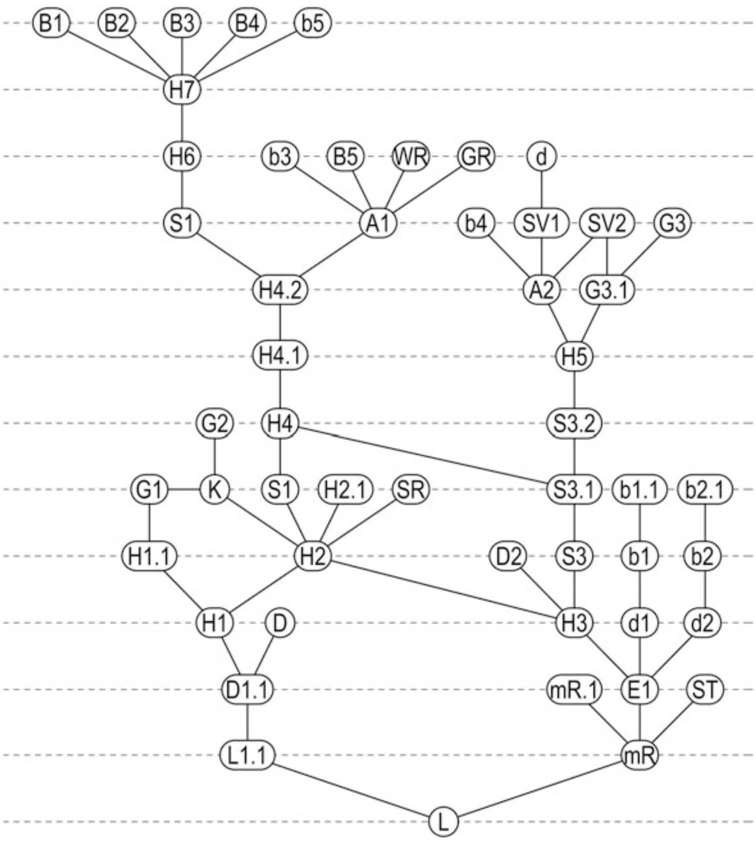


Fig. 5.9 Justified plan graph of the convex spaces in the *Wolf House*

Table 5.3 Division of convex spaces by proportion relative to privacy zones, in the *Wolf House*

Spatial Type	*Wolf House*	
	#	%
Semi-Public	14	26
Semi-Private	12	23
Service	6	11
Private	21	40
Totals	53	100

notably smaller than the number present in the *Lange House*, although it does exclude a trivial loop involving the kitchen and entrance space. The top floor contains several circulation loops that incorporate bedrooms, antechambers and corridors. The top floor also contains minor branching structures incorporating

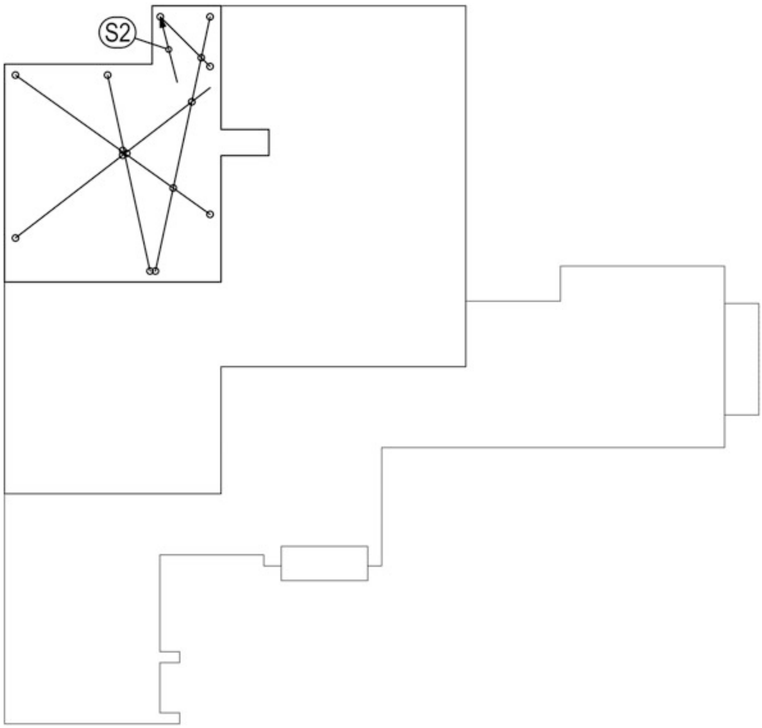


Fig. 5.10 Intersection points and end-nodes in the second floor of the *Wolf House*

fourteen spaces of which eight are one step from a circulation loop, and six belong to one branching structure. This spatial organization differs from those found in both the *Lange* and *Wolf* houses. By dividing the convex spaces of the *Esters House* in accordance with privacy zones it is revealed that 22% of these spaces are semi-public, 18% semi-private, 19% are service related and 41% are private (Table 5.7). This is not dissimilar to the results for the previous two houses, with only an increase in the proportion of service space (up 8% over the *Wolf* and 5% over the *Lange*) being notable.

Six measures of the spatial properties of the *Esters House*, relative to the location, number and proportion of intersection and end-nodes, provide a further basis for comparison (Figs. 5.32, 5.33 and 5.34, Table 5.8). There are 65 convex spaces in the *Esters House,* 48 (74%) of which feature either intersection points or end-nodes and 17 (26%) of which have neither. This can be compared to 27% of the spaces in the *Lange House* which had neither and 19% of those in the *Wolf House*. Of the convex spaces in the *Esters House*, 33 (50%) have intersection points, 13 (20%) have end-nodes and none have both. These suggest that half of the spaces of the plan are not part of the general network of decision points, and around one in five spaces only

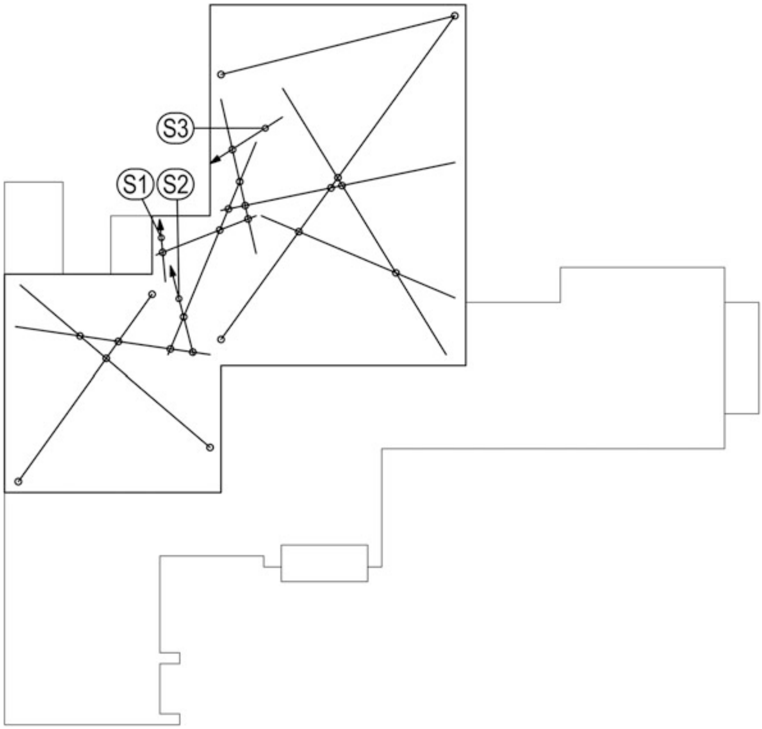


Fig. 5.11 Intersection points and end-nodes in the first floor of the *Wolf House*

function as destination points in the movement network of the plan. The 10% of convex spaces in the plan with the highest proportion of intersection points account for 36% of the complete set of intersection points. The 10% of convex spaces with the highest proportion of end-nodes account for 48% of the complete set of end-nodes. The ratio of convex spaces to intersection points in the *Esters House* is 1.1076:1 and of convex spaces to end-nodes is 0.2615:1.

5.4.4 Lemke House, Berlin, Germany (1933)

The *Lemke House* was Mies's final constructed residential commission before he immigrated to the United States. This modest home, on the shore of a Berlin lake, was designed for the printer Karl Lemke (Fig. 5.35). The house has an L-shaped form, wrapping around a courtyard that is oriented to the lake (Fig. 5.36). One wing of the plan contains living and service areas, while the other contains a gallery and bedroom. There are ten convex spaces in the plan and a single bedroom, giving a

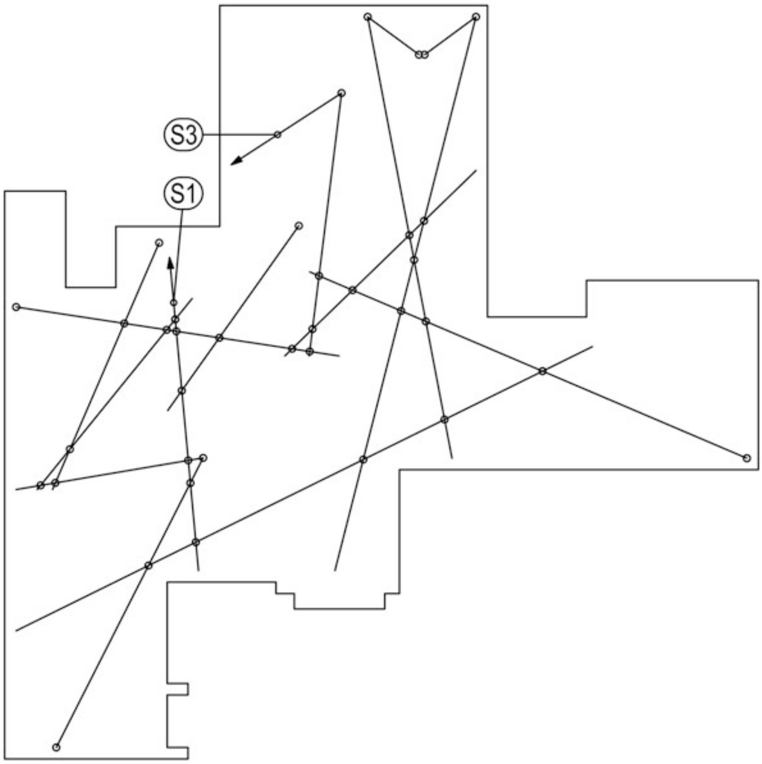


Fig. 5.12 Intersection points and end-nodes in the ground floor of the *Wolf House*

ratio of 10:1 visually coherent spaces to inhabitants (Fig. 5.37). This result is interesting because, despite being a much smaller house than the previous three, the ratio is identical to that of the *Lange House* and slightly higher than the *Wolf* (7.5714:1) and *Esters* (6.5000:1) houses.

The justified graph of the convex spaces contains a single circulation loop incorporating the living room, office, kitchen and entry (Fig. 5.38). This loop provides only minimal opportunities for occupants to vary their movement paths, as only the bedroom and its bathroom are not directly connected to the loop. This spatial structure is a further break from the divided structures (half relatively flexible, the other very controlled) found in the previous houses. Furthermore, just as the plan graph begins to suggest a change in Mies's approach to domestic design, so too does the division of the spaces of the *Lemke House* in accordance with privacy zones. Only 10% of these spaces are semi-public, 30% semi-private, 20% service related and 40% are private (Table 5.9).

Six measures of the spatial properties of the *Lemke House*, relative to the location, number and proportion of intersection and end-nodes, are developed for

Table 5.4 Convex spaces tabulated against intersection and end-point results for the *Wolf House*. Convex spaces with neither intersection nor end points are deleted from the table. For the *Wolf House* there are ten of these spaces: E2, E3, H1.1, H2.1, H5, S3, S3.2, L.1, mR.1 and GR.1

	Nodes			**Proportions %**				
Space	**Inter.**	**End**	**Total**	**Inter/Inter**	**Inter/Total**	**End/End**	**End/Total**	**Total**
H1	4	0	4	7.1429	5.4054	0	0	5.4054
H2	4	0	4	7.1429	5.4054	0	0	5.4054
H3	3	0	3	5.3571	4.0541	0	0	4.0541
H4	2	0	2	3.5714	2.7027	0	0	2.7027
H4.1	2	0	2	3.5714	2.7027	0	0	2.7027
H4.2	1	0	1	1.7857	1.3514	0	0	1.3514
H6	2	0	2	3.5714	2.7027	0	0	2.7027
H7	3	0	3	5.3571	4.0541	0	0	4.0541
S1	2	0	2	3.5714	2.7027	0	0	2.7027
S2	1	0	1	1.7857	1.3514	0	0	1.3514
S3.1	4	0	4	7.1429	5.4054	0	0	5.4054
ST	0	1	1	0	0	5.5556	1.3514	1.3514
L	1	0	1	1.7857	1.3514	0	0	1.3514
mR	3	0	3	5.3571	4.0541	0	0	4.0541
WR	0	1	1	0	0	5.5556	1.3514	1.3514
D1	0	1	1	0	0	5.5556	1.3514	1.3514
D1.1	2	0	2	3.5714	2.7027	0	0	2.7027
D2	0	1	1	0	0	5.5556	1.3514	1.3514
K	3	1	4	5.3571	4.0541	5.5556	1.3514	5.4054
G1	2	0	2	3.5714	2.7027	0	0	2.7027
G2	0	1	1	0	0	5.5556	1.3514	1.3514
G3	0	1	1	0	0	5.5556	1.3514	1.3514
G3.1	1	0	1	1.7857	1.3514	0	0	1.3514
Sr	0	1	1	0	0	5.5556	1.3514	1.3514
SV1	1	0	1	1.7857	1.3514	0	0	1.3514
SV2	1	0	1	1.7857	1.3514	0	0	1.3514
A1	2	0	2	3.5714	2.7027	0	0	2.7027
A2	3	0	3	5.3571	4.0541	0	0	4.0541
GR	0	1	1	0	0	5.5556	1.3514	1.3514
B1	0	1	1	0	0	5.5556	1.3514	1.3514
B2	0	1	1	0	0	5.5556	1.3514	1.3514
B3	0	1	1	0	0	5.5556	1.3514	1.3514
B4	1	0	1	1.7857	1.3514	0	0	1.3514
B5	1	0	1	1.7857	1.3514	0	0	1.3514
d	0	1	1	0	0	5.5556	1.3514	1.3514
b1	1	0	1	1.7857	1.3514	0	0	1.3514
b1.1	0	1	1	0	0	5.5556	1.3514	1.3514
b2	1	0	1	1.7857	1.3514	0	0	1.3514

(continued)

Table 5.4 (continued)

	Nodes			Proportions %				
Space	**Inter.**	**End**	**Total**	**Inter/Inter**	**Inter/Total**	**End/End**	**End/Total**	**Total**
b2.1	0	1	1	0	0	5.5556	1.3514	1.3514
b3	0	1	1	0	0	5.5556	1.3514	1.3514
b4	0	1	1	0	0	5.5556	1.3514	1.3514
b5	0	1	1	0	0	5.5556	1.3514	1.3514
Totals	56	18	74					

Table key: *Inter* intersection point; *End* end-node point

Fig. 5.13 External view of the *Lange House*

comparative purposes (Fig. 5.39, Table 5.10). First, there are ten convex spaces in the *Lemke House*, eight (80%) of which have either intersection points or end-nodes and two (20%) of which have neither. Second, of the convex spaces, four (40%) have intersection points, four (40%) have end-nodes and one has both. These results indicate that less than half of the spaces of the plan are part of the general network of decision points, and an equivalent proportion only function as destination points. The convex space in the plan with the highest proportion of intersection points accounts for 40% of the complete set of intersection points. The convex space in the plan with the highest proportion of end-nodes accounts for 10% of the complete set of end-nodes. For the last two measures, the ratio of convex spaces to intersection points in the *Lemke House* is 0.5000:1 and of convex spaces to end-nodes is 0.4000:1.

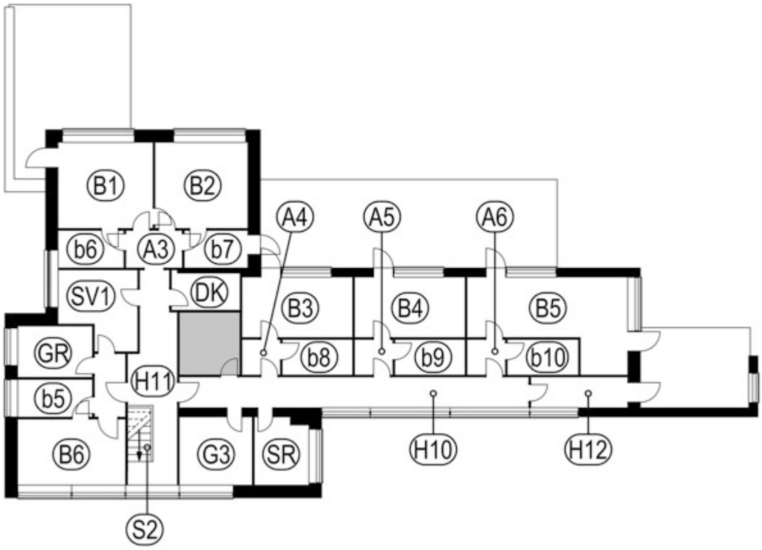


Fig. 5.14 Annotated plan of the first floor of the *Lange House* (shaded areas indicate non-habitable spaces)

The small scale and programmatic simplicity of this building are insufficient to generate high numbers of axial lines and intersection points. The highest concentration of intersection points occurs at the formal entrance to the building. In this instance, the concentration of intersection points is also related to the convex space adjacent to the antechamber (gallery) of the master bedroom and follows the pattern established in earlier designs, where these spaces contain a relatively high number of intersections.

5.4.5 *Farnsworth House, Plano, Illinois, USA (1951)*

The *Farnsworth House*, designed as a weekend retreat for Edith Farnsworth, is an icon of Modernist residential design. The seemingly simple building consists of a single, glass-walled rectangular form and an adjacent rectangular patio (Fig. 5.40). Internal divisions are limited to an offset plywood service core and a teak wardrobe (Fig. 5.41). The minimal internal divisions produce an open plan with only the bathrooms having a cellular quality. In total, the ratio of convex spaces in the *Farnsworth House* to bedrooms is 8:1, or eight visually coherent spaces per inhabitant. This result is within the range established for the previous four houses (Fig. 5.42).

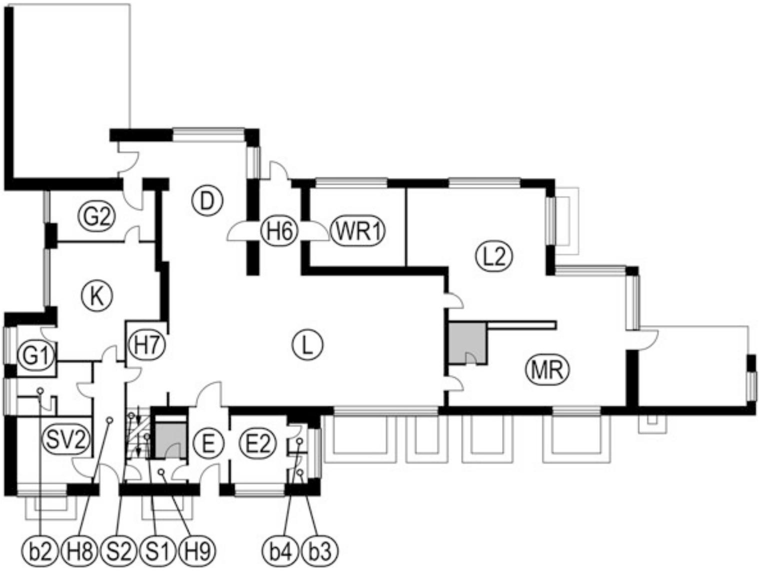


Fig. 5.15 Annotated plan of the ground floor of the *Lange House* (shaded areas indicate non-habitable spaces)

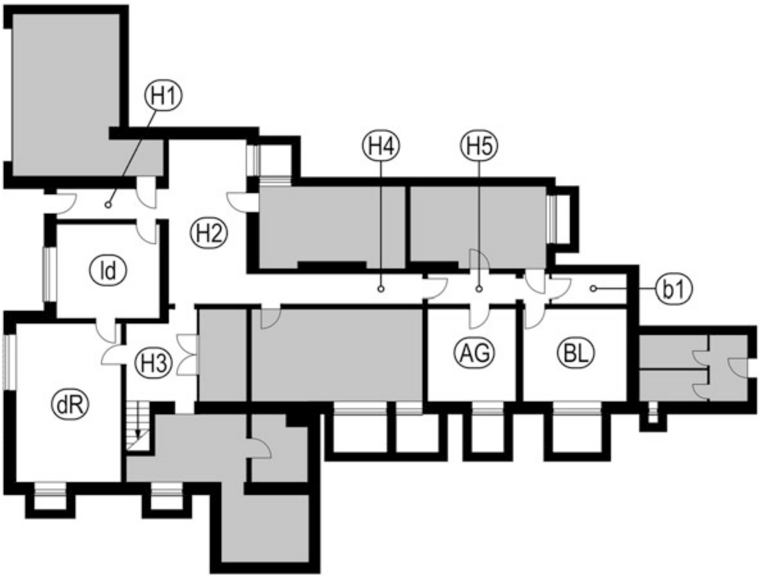


Fig. 5.16 Annotated plan of the basement of the *Lange House* (shaded areas indicate non-habitable spaces)

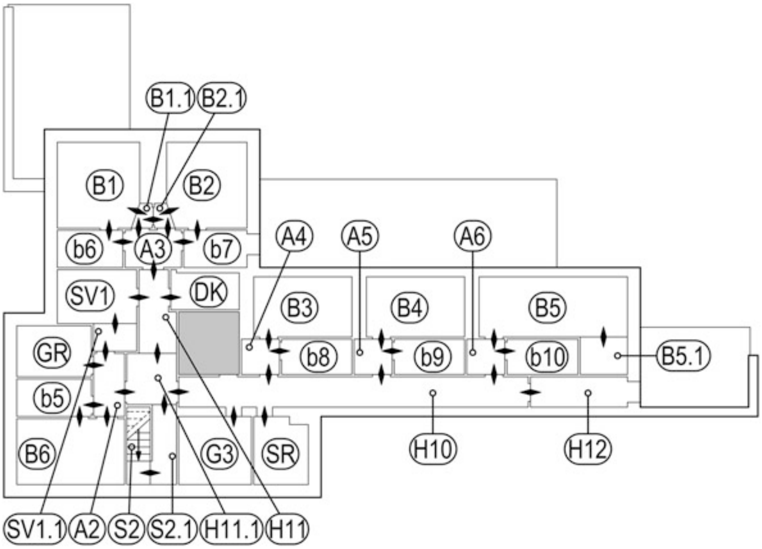


Fig. 5.17 Convex spaces in the first floor of the *Lange House* (shaded areas indicate non-habitable spaces)

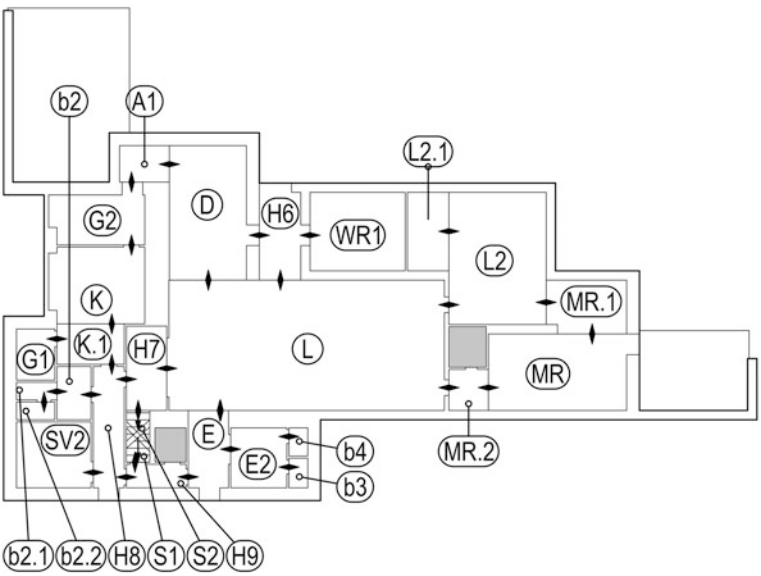


Fig. 5.18 Convex spaces in the ground floor of the *Lange House* (shaded areas indicate non-habitable spaces)

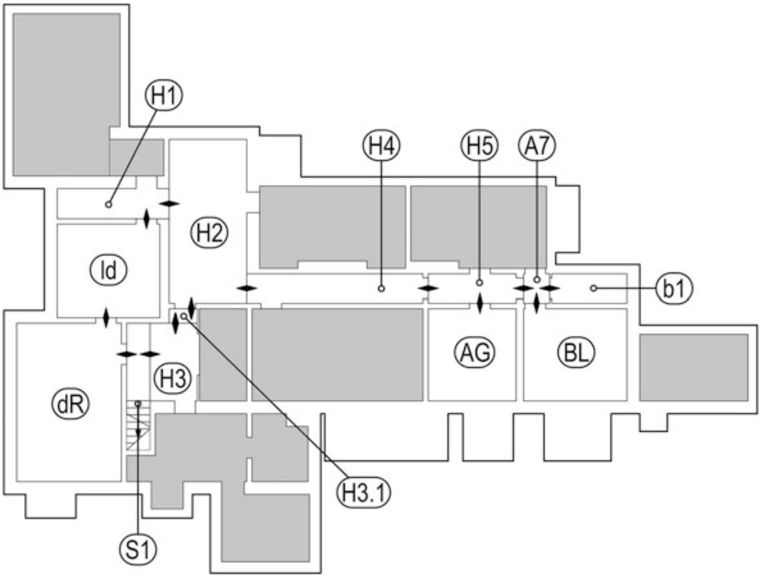


Fig. 5.19 Convex spaces in the basement of the *Lange House* (shaded areas indicate non-habitable spaces)

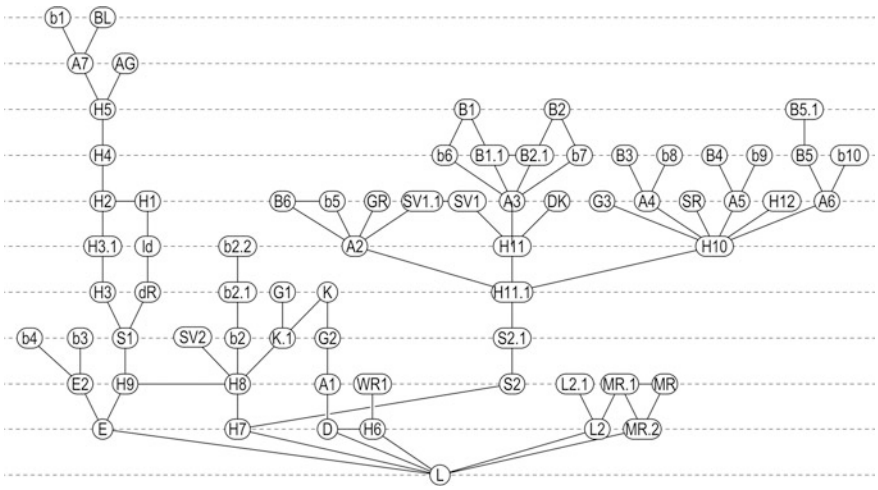


Fig. 5.20 Justified plan graph of the convex spaces in the *Lange House*

Table 5.5 Division of convex spaces by proportion relative to each privacy zones, in the *Lange House*

Spatial Type	***Lange House***	
	#	%
Semi-Public	17	24
Semi-Private	12	17
Service	9	13
Private	32	46
Totals	70	100

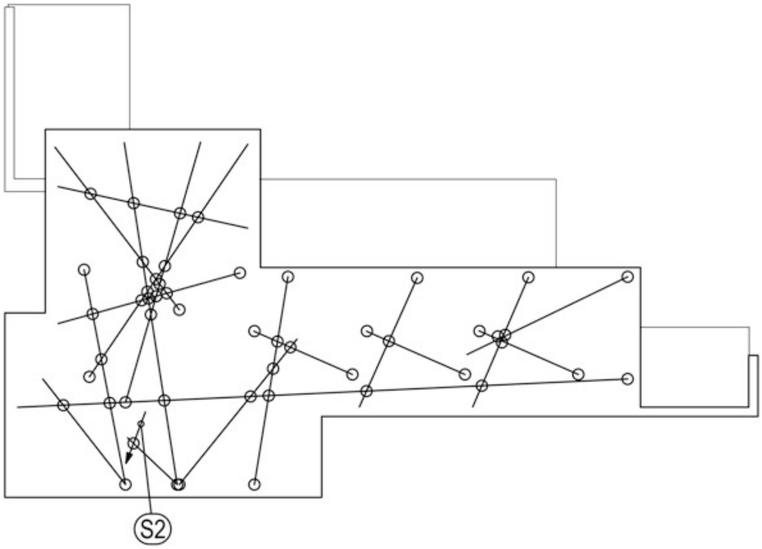


Fig. 5.21 Intersection points and end-nodes in the first floor of the *Lange House*

The convex map of the *Farnsworth House* shows that in essence, the house consists of one major and one minor circulation loop, with only the bathrooms not being part of a loop structure (Fig. 5.43). A slightly different definition of convex spaces would lead to a situation where the owner's bathroom is accessible by way of the living room nook, rather than the bedroom; or from both bedroom and nook, creating a trivial loop. Mies's planning arrangement allows alternative routes through the building, however, due to its programmatic simplicity, these routes are virtually limited to the choice of direction taken by the occupant around the main circulation loop.

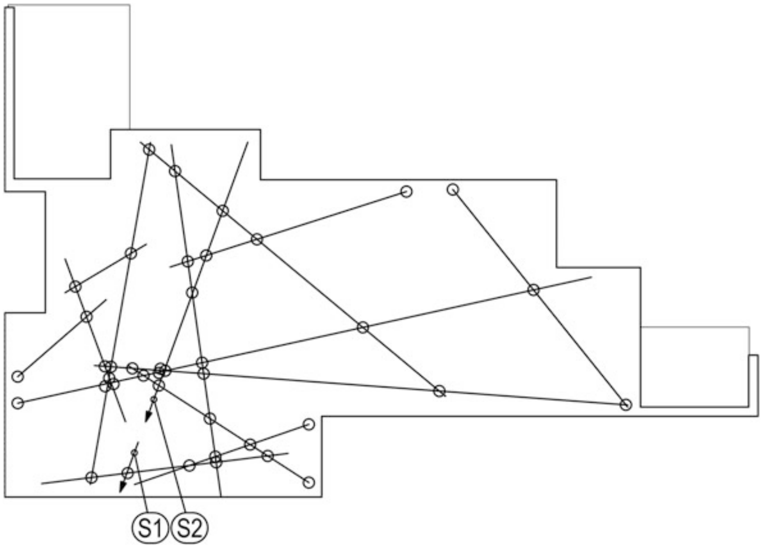


Fig. 5.22 Intersection points and end-nodes in the ground floor of the *Lange House*

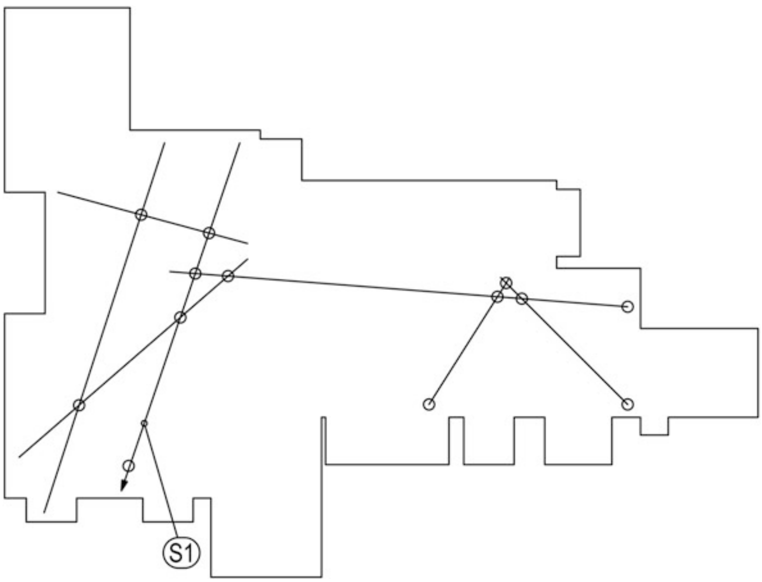


Fig. 5.23 Intersection points and end-nodes in the basement of the *Lange House*

Table 5.6 Convex spaces tabulated against intersection and end-point results for the *Lange House*. Convex spaces with neither intersection nor end points are deleted from the table. For the *Lange House* there are 19 of these spaces: H3, H4, H6, S1, L2.1, MR.1, MR.2, K.1, G2, ld, SV1.1, A7, B1.1, B2.1, B5.1, b2, b2.1, b6 and b7

	Nodes			Proportions %				
Space	**Inter.**	**End**	**Total**	**Inter/ Inter**	**Inter/ Total**	**End/ End**	**End/ Total**	**Combined**
E	3	0	3	3.8462	2.9126	0	0	2.9126
E2	2	0	2	2.5641	1.9417	0	0	1.9417
H1	1	0	1	1.2821	0.9709	0	0	0.9709
H2	3	0	3	3.8462	2.9126	0	0	2.9126
H3.1	1	0	1	1.2821	0.9709	0	0	0.9709
H5	3	0	3	3.8462	2.9126	0	0	2.9126
H7	6	0	6	7.6923	5.8252	0	0	5.8252
H8	6	0	6	7.6923	5.8252	0	0	5.8252
H9	1	0	1	1.2821	0.9709	0	0	0.9709
H10	4	0	4	5.1282	3.8835	0	0	3.8835
H11	8	0	8	10.2564	7.7670	0	0	7.7670
H11.1	2	0	2	2.5641	1.9417	0	0	1.9417
H12	0	1	1	0	0	4.0000	0.9709	0.9709
S2	1	0	1	1.2821	0.9709	0	0	0.9709
S2.1	1	0	1	1.2821	0.9709	0	0	0.9709
L	5	0	5	6.4103	4.8544	0	0	4.8544
L2	1	1	2	1.2821	0.9709	4.0000	0.9709	1.9417
MR	1	0	1	1.2821	0.9709	0	0	0.9709
Billiard	0	1	1	0	0	4.0000	0.9709	0.9709
Wr1	1	0	1	1.2821	0.9709	0	0	0.9709
Wr2	0	1	1	0	0	4.0000	0.9709	0.9709
AG	0	1	1	0	0	4.0000	0.9709	0.9709
D	5	0	5	6.4103	4.8544	0	0	4.8544
K	3	0	3	3.8462	2.9126	0	0	2.9126
G1	0	1	1	0	0	4.0000	0.9709	0.9709
G3	0	1	1	0	0	4.0000	0.9709	0.9709
Dr	1	0	1	1.2821	0.9709	0	0	0.9709
Sr	0	1	1	0	0	4.0000	0.9709	0.9709
DK	0	2	2	0	0	8.0000	1.9417	1.9417
SV1	1	0	1	1.2821	0.9709	0	0	0.9709
SV2	1	0	1	1.2821	0.9709	0	0	0.9709
A1	1	0	1	1.2821	0.9709	0	0	0.9709
A2	2	0	2	2.5641	1.9417	0	0	1.9417
A3	2	0	2	2.5641	1.9417	0	0	1.9417
A4	2	0	2	2.5641	1.9417	0	0	1.9417
A5	1	0	1	1.2821	0.9709	0	0	0.9709

(continued)

Table 5.6 (continued)

	Nodes			Proportions %				
Space	**Inter.**	**End**	**Total**	**Inter/ Inter**	**Inter/ Total**	**End/ End**	**End/ Total**	**Combined**
A6	1	0	1	1.2821	0.9709	0	0	0.9709
GR	0	1	1	0	0	4.0000	0.9709	0.9709
B1	2	0	2	2.5641	1.9417	0	0	1.9417
B2	2	0	2	2.5641	1.9417	0	0	1.9417
B3	0	2	2	0	0	8.0000	1.9417	1.9417
B4	0	2	2	0	0	8.0000	1.9417	1.9417
B5	2	3	5	2.5641	1.9417	12.0000	2.9126	4.8544
b1	0	1	1	0	0	4.0000	0.9709	0.9709
b2.2	0	1	1	0	0	4.0000	0.9709	0.9709
b3	0	1	1	0	0	4.0000	0.9709	0.9709
b4	0	1	1	0	0	4.0000	0.9709	0.9709
b5	1	0	1	1.2821	0.9709	0	0	0.9709
b8	1	1	2	1.2821	0.9709	4.0000	0.9709	1.9417
b9	0	1	1	0	0	4.0000	0.9709	0.9709
b10	0	1	1	0	0	4.0000	0.9709	0.9709
Totals	78	25	103					

Table key: *Inter* intersection point; *End* end-node point

Fig. 5.24 External view of the *Esters House*

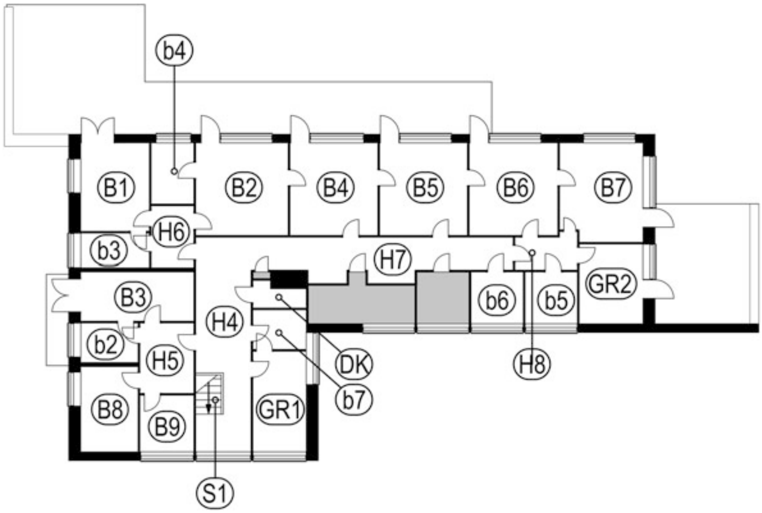


Fig. 5.25 Annotated plan of the first floor of the *Esters House* (shaded areas indicate non-habitable spaces)

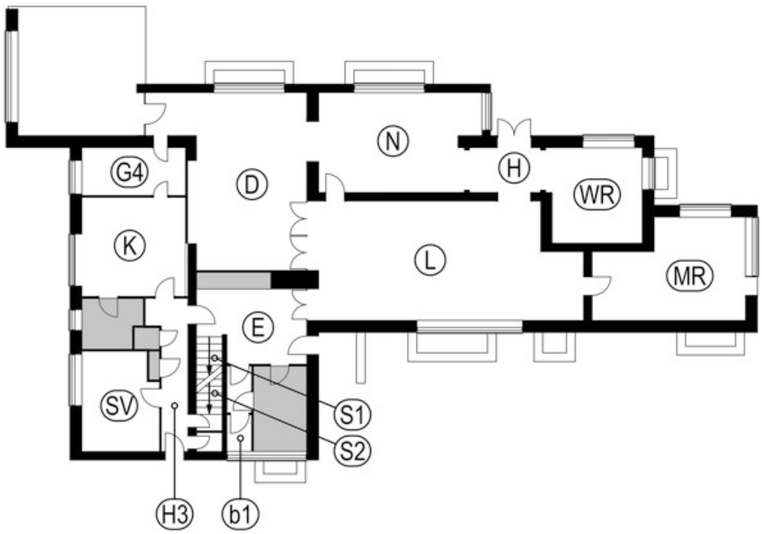


Fig. 5.26 Annotated plan of the ground floor of the *Esters House* (shaded areas indicate non-habitable spaces)

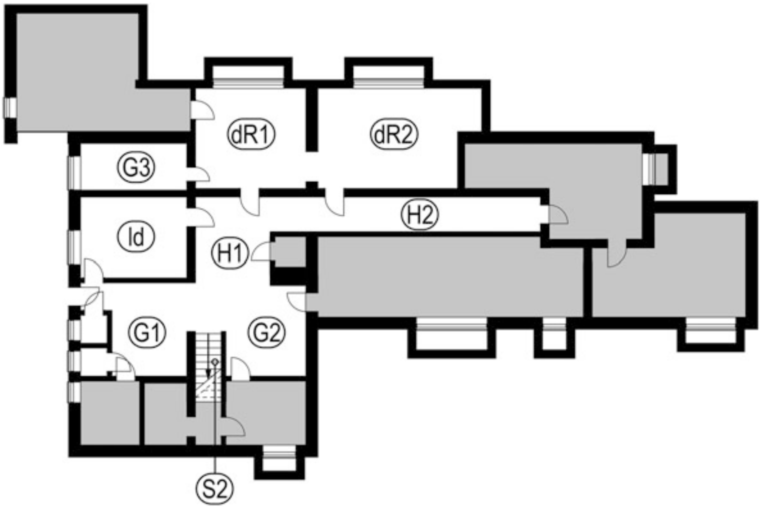


Fig. 5.27 Annotated plan of the basement of the *Esters House* (shaded areas indicate non-habitable spaces)

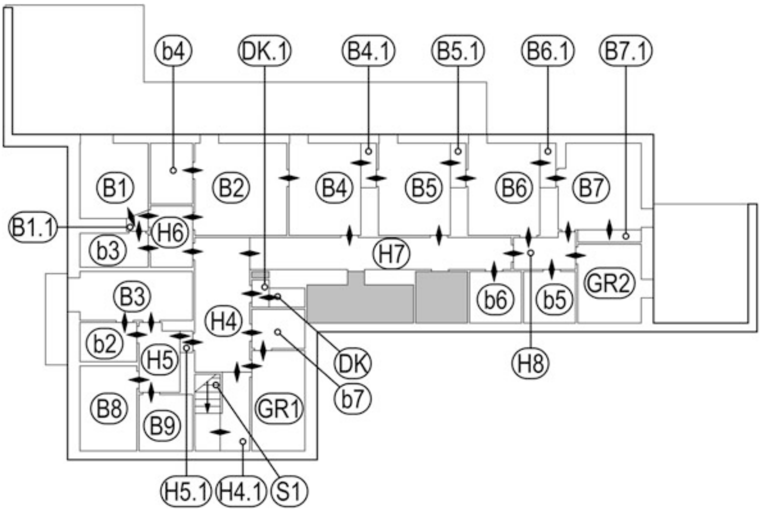


Fig. 5.28 Convex spaces in the first floor of the *Esters House* (shaded areas indicate non-habitable spaces)

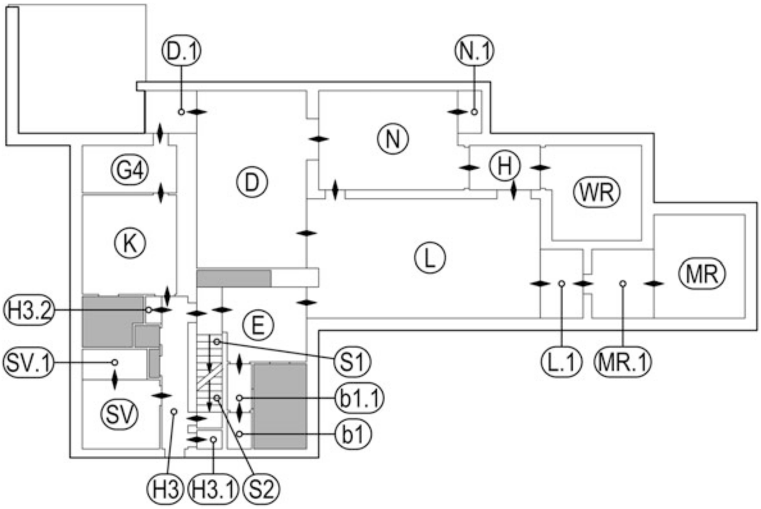


Fig. 5.29 Convex spaces in the ground floor of the *Esters House* (shaded areas indicate non-habitable spaces)

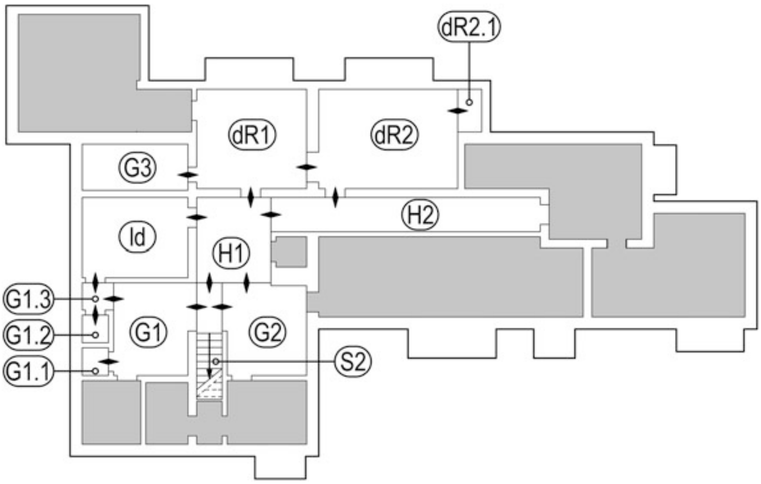


Fig. 5.30 Convex spaces in the basement of the *Esters House* (shaded areas indicate non-habitable spaces)

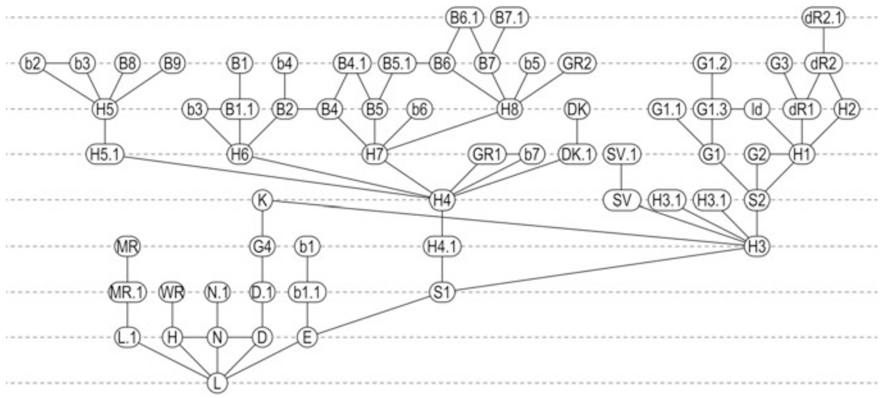


Fig. 5.31 Justified plan graph of the convex spaces in the *Esters House*

Table 5.7 Division of convex spaces by proportion relative to intimacy level, in the *Esters House*

Spatial Type	***Esters House***	
	#	%
Semi-Public	14	22
Semi-Private	11	18
Service	12	19
Private	26	41
Totals	65	100

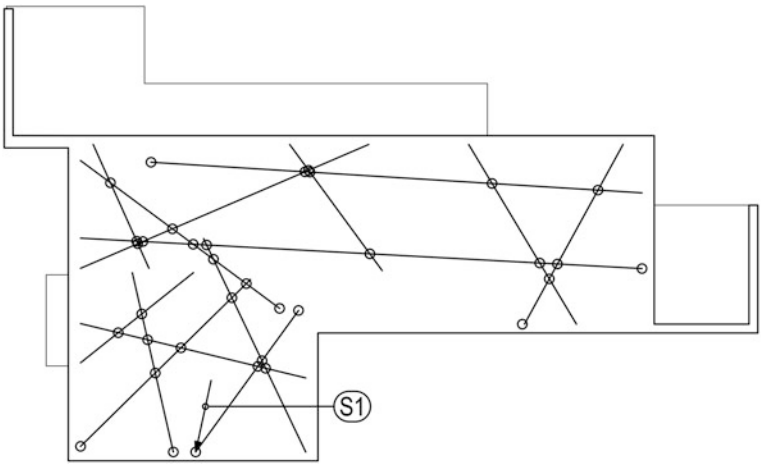


Fig. 5.32 Intersection points and end-nodes in the first floor of the *Esters House*

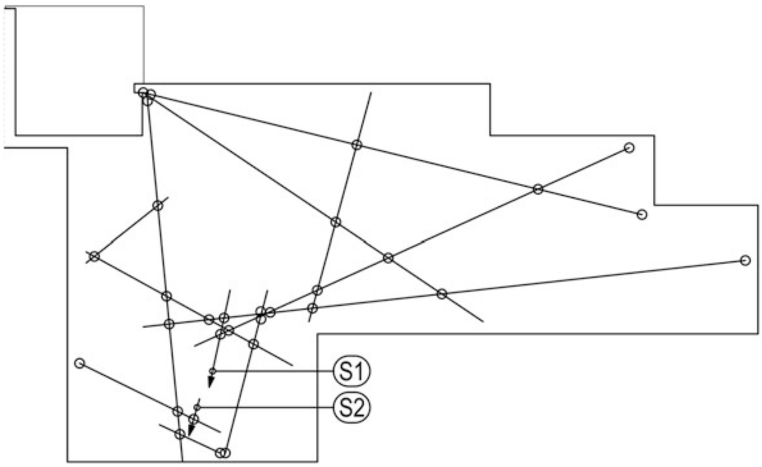


Fig. 5.33 Intersection points and end-nodes in the ground floor of the *Esters House*

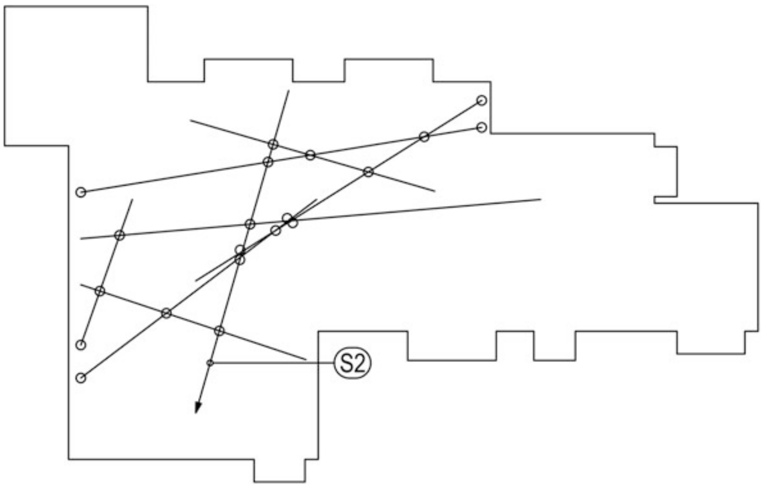


Fig. 5.34 Intersection points and end-nodes in the basement of the *Esters House*

Dividing the spaces in the *Farnsworth House* in accordance with privacy zones reveals that there are 0% semi-public spaces, 37% semi-private, 13% are service related and 50% are private (Table 5.11). Thus, in terms of general spatial types as a proportion of the complete set of visually coherent areas in a plan, the *Farnsworth House* only differs from the early works in one particular way, the complete lack of

Table 5.8 Convex spaces tabulated against intersection and end-point results for the *Esters House*. Convex spaces with neither intersection nor end points are deleted from the table. For the *Esters House* there are 17 of these spaces: H3, H4.1, L.1, MR.1, D, N.1, G2, G4, DK1.1, SV, B1.1, B3.1, B4.1, B5, B6, B7 and b1.1

	Nodes			Proportions %				
Space	**Inter.**	**End**	**Total**	**Inter/ Inter**	**Inter/ Total**	**End/ End**	**End/ Total**	**Combined**
E	8	0	8	11.1111	8.9888	0	0	8.9888
H	1	0	1	1.3889	1.1236	0	0	1.1236
H1	3	0	3	4.1667	3.3708	0	0	3.3708
H2	3	0	3	4.1667	3.3708	0	0	3.3708
H3.1	0	1	1	0	0	5.8824	1.1236	1.1236
H3.2	3	0	3	4.1667	3.3708	0	0	3.3708
H4	4	0	4	5.5556	4.4944	0	0	4.4944
H5	2	0	2	2.7778	2.2472	0	0	2.2472
H5.1	1	0	1	1.3889	1.1236	0	0	1.1236
H6	2	0	2	2.7778	2.2472	0	0	2.2472
H7	2	0	2	2.7778	2.2472	0	0	2.2472
H8	2	0	2	2.7778	2.2472	0	0	2.2472
S1	1	0	1	1.3889	1.1236	0	0	1.1236
S2	2	0	2	2.7778	2.2472	0	0	2.2472
L	5	0	5	6.9444	5.6180	0	0	5.6180
MR	1	0	1	1.3889	1.1236	0	0	1.1236
Wr	0	2	2	0	0	11.7647	2.2472	2.2472
D.1	3	0	3	4.1667	3.3708	0	0	3.3708
N	1	0	1	1.3889	1.1236	0	0	1.1236
K	3	0	3	4.1667	3.3708	0	0	3.3708
G1	1	0	1	1.3889	1.1236	0	0	1.1236
G1.1	0	1	1	0	0	5.8824	1.1236	1.1236
G1.2	0	1	1	0	0	5.8824	1.1236	1.1236
G1.3	1	0	1	1.3889	1.1236	0	0	1.1236
G3	0	1	1	0	0	5.8824	1.1236	1.1236
ld	1	0	1	1.3889	1.1236	0	0	1.1236
Dr1	2	0	2	2.7778	2.2472	0	0	2.2472
Dr2	3	0	3	4.1667	3.3708	0	0	3.3708
Dr2.1	0	2	2	0	0	11.7647	2.2472	2.2472
DK1	0	1	1	0	0	5.8824	1.1236	1.1236
SV.1	0	1	1	0	0	5.8824	1.1236	1.1236
GR1	3	0	3	4.1667	3.3708	0	0	3.3708
GR2	0	1	1	0	0	5.8824	1.1236	1.1236

(continued)

Table 5.8 (continued)

	Nodes			Proportions %				
Space	**Inter.**	**End**	**Total**	**Inter/ Inter**	**Inter/ Total**	**End/ End**	**End/ Total**	**Combined**
B1	1	0	1	1.3889	1.1236	0	0	1.1236
B2	1	0	1	1.3889	1.1236	0	0	1.1236
B3	4	0	4	5.5556	4.4944	0	0	4.4944
B4	1	0	1	1.3889	1.1236	0	0	1.1236
B5.1	1	0	1	1.3889	1.1236	0	0	1.1236
B6.1	1	0	1	1.3889	1.1236	0	0	1.1236
B8	0	1	1	0	0	5.8824	1.1236	1.1236
B9	0	1	1	0	0	5.8824	1.1236	1.1236
b1	0	1	1	0	0	5.8824	1.1236	1.1236
b2	1	0	1	1.3889	1.1236	0	0	1.1236
b3	3	0	3	4.1667	3.3708	0	0	3.3708
b4	0	1	1	0	0	5.8824	1.1236	1.1236
b5	1	0	1	1.3889	1.1236	0	0	1.1236
b6	0	1	1	0	0	5.8824	1.1236	1.1236
b7	0	1	1	0	0	5.8824	1.1236	1.1236
Totals	72	17	89					

Table key: *Inter* intersection point; *End* end-node point

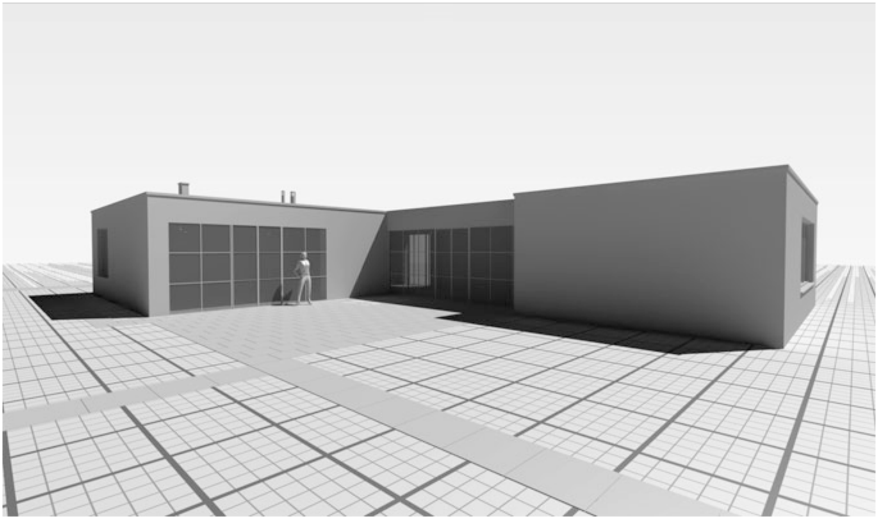


Fig. 5.35 External view of the *Lemke House*

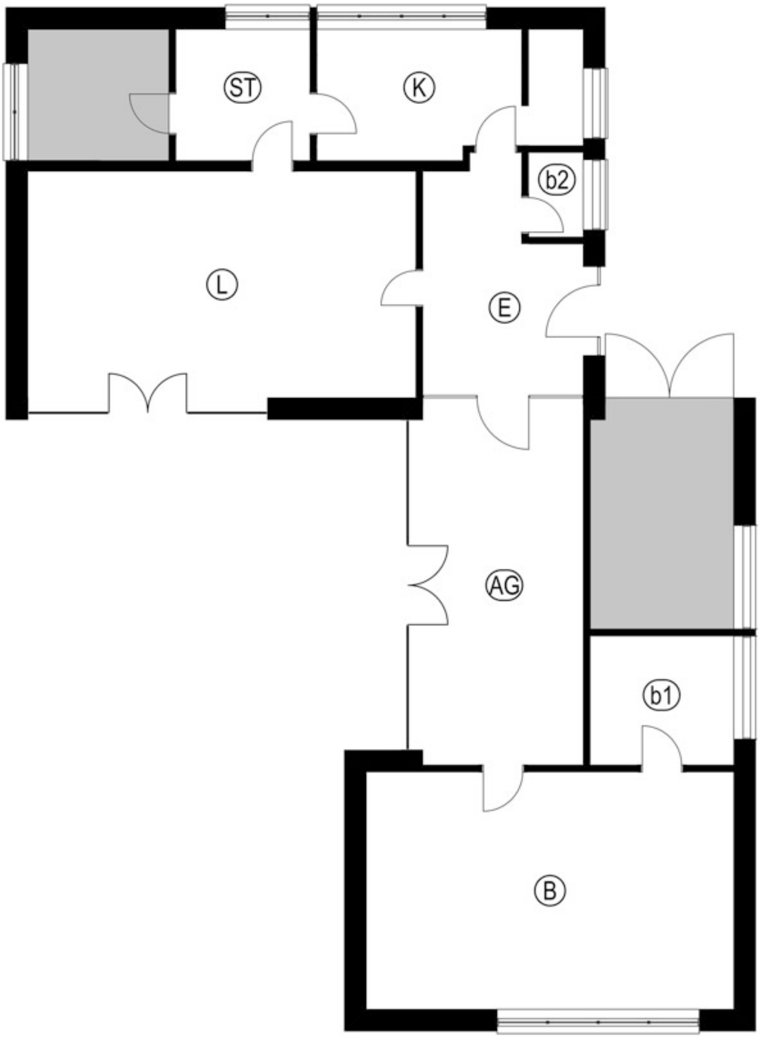


Fig. 5.36 Annotated plan of the *Lemke House* (shaded areas indicate non-habitable spaces)

semi-public space. As such spaces, like entry halls and lobbies, are for receiving visitors, and the *Farnsworth* is both isolated and largely transparent, they are not needed. Furthermore, the shift from a European clientele in need of large family homes, to an American woman in need of a private retreat, could also explain this shift. But in most other ways, the broad social groupings in the *Farnsworth House*,

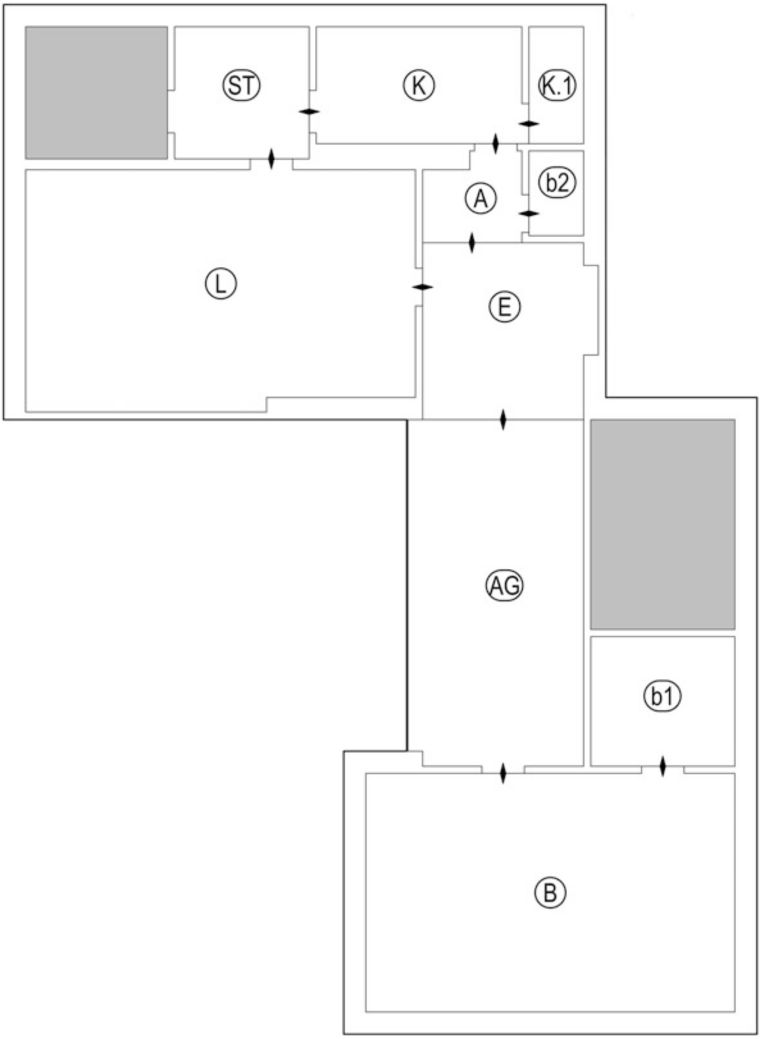


Fig. 5.37 Convex spaces in the *Lemke House* (shaded areas indicate non-habitable spaces)

relative to the openness of the space, are not especially different from those in the earlier works.

For comparative purposes, consider the following six spatial characteristics of the *Farnsworth House*, which combine convex spaces and intersection points and end-nodes (Fig. 5.44, Table 5.12) There are eight convex spaces in the *Farnsworth*

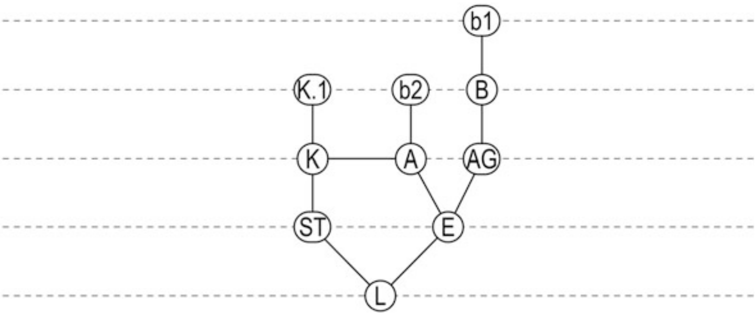


Fig. 5.38 Justified plan graph of the convex spaces in the *Lemke House*

Table 5.9 Division of convex spaces, by proportion relative to privacy zones, in the *Lemke House*

Spatial Type	***Lemke house***	
	#	%
Semi-Public	1	10
Semi-Private	3	30
Service	2	20
Private	4	40
Totals	10	100

House, six (75%) of which have either intersection points or end-nodes and two (25%) of which have neither. Of the convex spaces, four (50%) have intersection points, two (25%) have end-nodes and none have both. These results confirm that half of the spaces of the plan are part of the general network of decision points, and only a quarter function solely as destination points in the movement network. The convex space with the highest proportion of intersection points accounts for 45% of the complete set of intersection points. The convex space with the highest proportion of end-nodes accounts for 8% of the complete set of end-nodes. The ratio of convex spaces to intersections for the *Farnsworth House* is 1.3750:1, and of convex spaces to end nodes is 4.0000:1.

5.5 Discussion

A summary of the results is presented in Table 5.13. Before revisiting the three hypotheses, a simple review of the data for the *Farnsworth House*, relative to the mean for the set of houses, is informative for examining the larger question about the degree to which it represents a paradigm shift in Mies's planning.

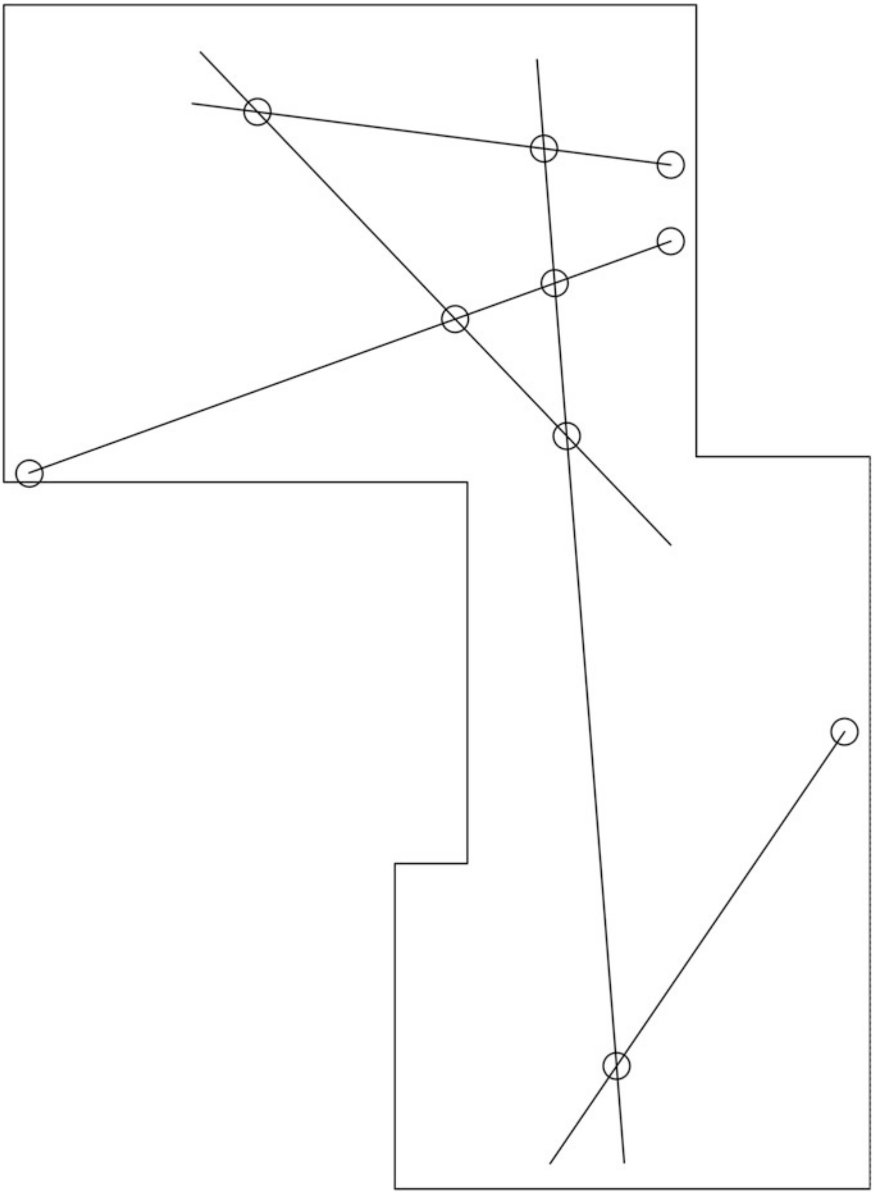


Fig. 5.39 Intersection points and end-nodes in the *Lemke House*

In terms of the ratio of convex spaces to occupants, the *Farnsworth* result is below the Mean, but not especially so, and it is actually higher than the results for the *Wolf* and *Lemke* houses. If a single person inhabited just one free-planned space,

Table 5.10 Convex spaces tabulated against intersection and end-point results for the *Lemke House*. Convex spaces with neither intersection nor end points are deleted from the table. For the *Lemke House* there are two of these spaces: ST and AG

	Nodes			**Proportions %**				
Space	**Inter.**	**End**	**Total**	**Inter/ Inter**	**Inter/ Total**	**End/ End**	**End/ Total**	**Combined**
E	2	0	2	40	22.2222	0	0	22.2222
L	1	1	2	20	11.1111	25.0000	11.1111	22.2222
K	1	0	1	20	11.1111	0	0	11.1111
K.1	0	1	1	0	0	25.0000	11.1111	11.1111
A	0	0	0	0	0	0	0	0
B	1	0	1	20	11.1111	0	0	11.1111
b1	0	1	1	0	0	25.0000	11.1111	11.1111
b2	0	1	1	0	0	25.0000	11.1111	11.1111
Totals	5	4	9					

Table key: *Inter* intersection point; *End* end-node point

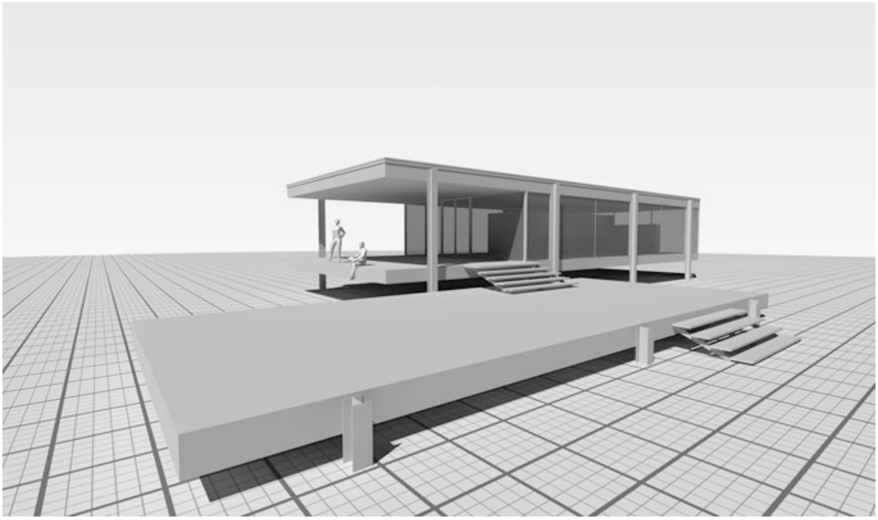


Fig. 5.40 External view of the *Farnsworth House*

then the ratio would be 1:1. Thus the lower the ratio, the more free or open the plan. In this context, the *Farnsworth House* is not remarkably open, it just has fewer occupants and is a much smaller house. As noted in the previous section, the division of convex spaces relative to privacy zones shows that the *Farnsworth House* is only below the mean for semi-public and service areas, neither of which

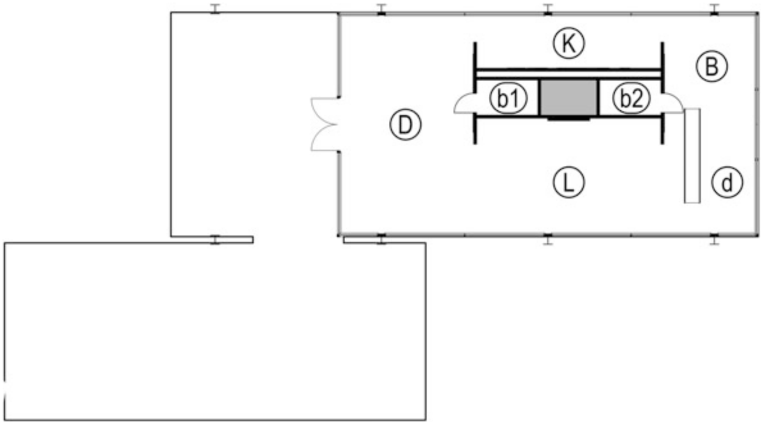


Fig. 5.41 Annotated plan of the *Farnsworth House* (shaded areas indicate non-habitable spaces)

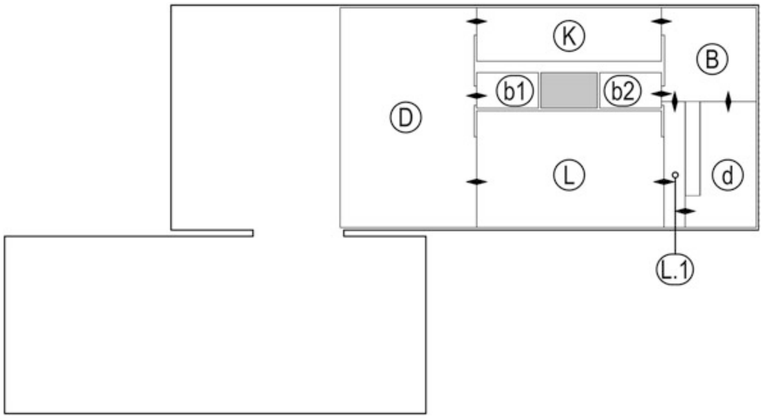


Fig. 5.42 Convex spaces in the *Farnsworth House* (shaded areas indicate non-habitable spaces)

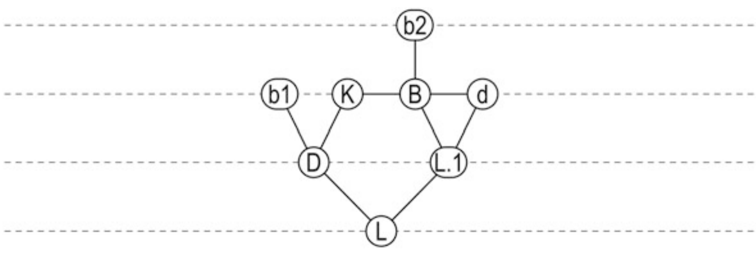


Fig. 5.43 Justified plan graph of the convex spaces in the *Farnsworth House*

Table 5.11 Division of convex spaces by proportion relative to privacy zones, in the *Farnsworth House*

Spatial Type	*Farnsworth House*	
	#	%
Semi-Public	0	0
Semi-Private	3	37
Service	1	13
Private	4	50
Totals	8	100

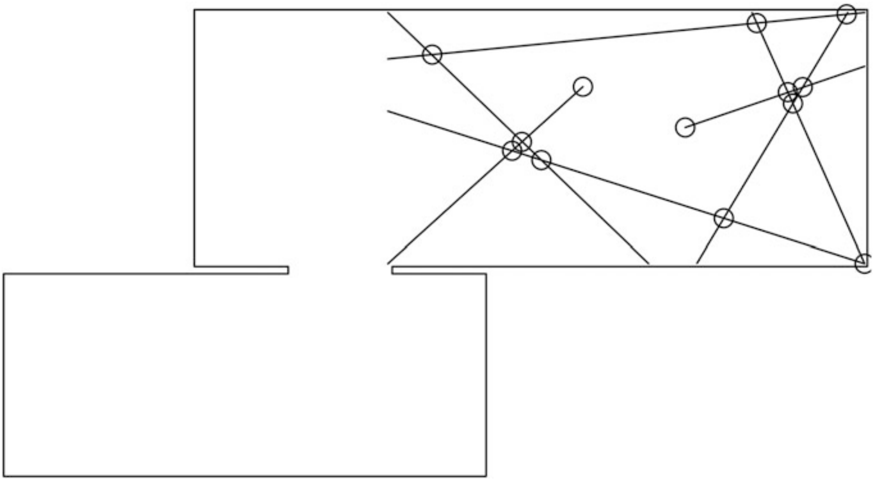


Fig. 5.44 Intersection points in the *Farnsworth House*

Table 5.12 Convex spaces tabulated against intersection and end-point results for the *Farnsworth House*. Convex spaces with neither intersection nor end points are deleted from the table. For the *Farnsworth House* there are two of these spaces: L and b1

	Nodes			**Proportions %**				
Space	**Inter.**	**End**	**Total**	**Inter/ Inter**	**Inter/ Total**	**End/ End**	**End/ Total**	**Combined**
L.1	5	0	5	45.4545	0	0	0	38.4615
D	4	0	4	36.3636	0	0	0	30.7692
K	0	1	1	0	7.6923	50	7.6923	7.6923
B	1	0	1	9.0909	0	0	0	7.6923
B.1	1	0	1	9.0909	0	0	0	7.6923
b2	0	1	1	0	7.6923	50	7.6923	7.6923
Totals	11	2	13					

Table key: *Inter* intersection point; *End* end-node point

Table 5.13 Comparative results. Note that percentages are rounded to the nearest whole number and ratios are reported to four decimal places

Measure		*Wolf*	*Lange*	*Esters*	*Lemke*	*Farnsworth*	Mean
Occupation rate (x:1)							
	Convex space: occupant ratio	7.5714	10.0000	6.5000	10.0000	8.0000	8.4143
Privacy zones (%)							
	Semi-Public	26	24	22	10	0	16
	Semi-Private	23	17	18	30	37	25
	Service	11	13	19	20	13	15
	Private	40	46	41	40	50	43
Convex spaces containing (%)							
	Any points	81	73	74	80	75	77
	Intersections	47	48	50	40	50	47
	End-nodes	33	28	20	40	25	29
Points relative to space (x:1)							
	Intersection: convex space ratio	1.0566	1.1142	1.1076	0.5000	1.3750	1.0307
	End-node: convex space ratio	0.3396	0.3570	0.2615	0.4000	0.2500	0.3216
Top 10% of spaces (%)							
	Containing proportion of intersections	32	47	36	40	45	40
	Containing proportion of end-nodes	28	35	48	10	8	26

are necessary for a country retreat for just one or two people. This isn't a change in domestic social structure, it is a reflection of a different program.

The mean proportion of the set of convex spaces in each house containing any points is 77%, and the means for intersection and endnotes are 47% and 29%, respectively. The *Farnsworth House* results are within 4% of these and are equal highest for the intersection proportion (with the *Wolf House*), but are not otherwise notable. However, the results for the ratio of node types to convex spaces presents some of the few outcomes which differentiate the *Farnsworth House* from the other designs. For example, the *Farnsworth House* has the highest intersection to convex space ratio and the lowest end-node to convex space ratio. Thus, there are more choice points or pause points in the *Farnsworth House*, per visually defined space, than in any of the other designs. Conversely, there are fewer terminal positions relative to the number of visually defined spaces, than in any of the designs. This pattern is reinforced by the final pair of results, which determine the proportion of the complete set of intersection and end-node points in each house, which are most clustered. The *Farnsworth House* has the second highest proportion of clustered intersections (after the *Lange House*), and the lowest proportion of end-nodes.

5.6 Conclusion

Hans Rudolf Morgenthaler's perceptual analysis of Modernism notes that Mies's *Lange House* 'is very poor in providing clues that influence the user's movements' and its 'interior is laid out so that there are multiple paths to get from one area to another' (2015: 139). As a result of this, there are few 'instinctual' cues found in the spatial relationships in this house, and the building benefits more from 'an intellectual analysis' than one of 'perceptual sensations' (2015: 139). A side affect of the lack of strong perceptual cues is that that the building excites the mind in a way which is 'similar to the intellectual enjoyment one receives from a Greek Temple' (Morgenthaler 2015: 139). Morgenthaler's description captures three of the themes that are developed in the present chapter.

Mies's architecture possesses neither a strong sense of direction, nor clear cues about patterns of inhabitation. Instead, the experience of Mies's architecture is a largely cognitive, rational or intellectual one. It does not offer a sensual or emotional appeal like that of Wright's architecture (see Chaps. 8 and 9). Instead, as a result of its appeal to the mind rather than the body, Mies's architecture evokes the timeless attraction of the classical temple, the prototype for Rowe's original 'ideal' villa. Here, the themes of space, cognition and experience come together around the concepts of the free plan and the power of monumentality.

The first hypothesis in this chapter holds that *both the spatial structure and the relationship between this structure and visual partitioning in the Farnsworth House are different from the equivalent properties in Mies's earlier domestic architecture.* This hypothesis is tested using three methods: plan graphs, space to occupant ratio, and spatial division by privacy zoning. In the first instance, the plan graphs show a partial evolution in Mies's planning from the first design through the fourth, with the prevalence of branching structures gradually reducing over time and being replaced by loops. However, both the *Lemke* and *Farnsworth* houses have similar social structures embedded in their plans, in terms of spatial adjacency and permeability, although different spaces are included in each of their loops. For the former, the loop includes the living room, entrance, alcove, kitchen and study. For the latter, it includes the living room, dining room, kitchen and bedroom. Setting aside the alcove and entrance in the *Lemke House*, the only difference is that the *Lemke* includes the study in the loop, while the *Farnsworth* includes the bedroom. However, the results for the ratio of spaces to inhabitants and the division of spaces by privacy zones do not identify the *Farnsworth House* as being especially different from the earlier ones. What has changed in the *Farnsworth* is simply that Mies's early houses were for large families, with quarters for servants and visitors, whereas his last two houses were designed for individuals or couples. Thus, the change in the social structure of the *Farnsworth House* is not especially significant in terms of its free plan, which means that the first hypothesis is false. Certainly there are differences between, say, the social structures in the *Lange* and *Farnsworth* houses, but far fewer between the *Lemke* and *Farnsworth*.

The second hypothesis proposes that *inhabitation and movement patterns in the Farnsworth House are more clustered than in Mies's earlier domestic architecture*. That is, the proportion of intersection points, representing choice locations in a defined group of convex spaces, will be higher in the *Farnsworth House* than in any of the previous houses. Comparing just the highest 10% of convex spaces in each house, the *Farnsworth House* has the highest intersection to convex space ratio. Furthermore, the single most important convex space in any house, in terms of choice points for movement, is the living room of the *Farnsworth House,* which contains 45% of the complete set of intersection points in that house. This can be compared with the equivalent results for the *Wolf*, *Lange*, *Esters* and *Lemke* houses which have, respectively, 9%, 10%, 11% and 33%. Collectively, these results demonstrate that Mies's early domestic architecture tends to isolate living and circulation paths, whereas in the *Farnsworth House* they are, as theorised, much more closely related. Thus, this second hypothesis is true.

The final hypothesis argues that *static viewing positions in the Farnsworth House are more critical for experiencing the totality of its plan than in Mies's earlier domestic architecture*. For the results to confirm this, the proportion of convex spaces featuring only end-nodes (not intersection points) will be higher in the *Farnsworth House* than in any of the earlier houses. The results for this test are negative. End points are vital for ensuring surveillance in the *Lemke House*, with 40% of spaces containing only end points. However, for the rest of the houses the results are more similar: Wolf, 32%; Lange 29%; Esters 23%; Farnsworth 25%. Indeed, the *Farnsworth House* has the second lowest result, completely undermining the validity of the hypothesis as it is stated. However, another way of viewing this claim involves considering the 10% of spaces in each plan that feature the largest proportion of the set of end-nodes. For this measure, the *Farnsworth House* has the lowest result. That is, the end-nodes are more dispersed in the open plan, even though they are only required to surveil 25% of spaces. On balance, this final hypothesis must be rejected, although an alternative interpretation of the importance of terminal positions in the plan is raised by this study. Potentially, the reason that such locations (in this instance, as defined by the end points of axial lines) are seemingly so important in the movement networks in Mies's open plan may be that they are rare and it is this property that makes them more notable. It may be that the relative paucity of terminal locations, coupled with their distribution in the plan, makes them ideal locations to encourage visitors to stop and contemplate the spaces and views framed through the design. The accounts provided by historians and critics are not detailed enough to determine if this is the case, but the data certainly indicates that end-points might be significant in the *Farnsworth House* because they offer unusual views which are more dispersed.

Finally, it is clear that the planning of the *Farnsworth House* is not such a dramatic departure from Mies's early strategies as many have suggested. Not only is there a tendency to create open-plan, flexible living spaces in even his earliest works, but the planning of the *Lemke House* has much in common with that of the *Farnsworth House*, even though the former didn't arrive at such a refined or minimal state. From these results it might even be said that Mies is being true to his own dictum. That is, in the *Farnsworth House* he is effectively doing more (or at least as much) with less.

Chapter 6
Richard Neutra: Spatial Theory and Practice

While Richard Neutra is conventionally celebrated as the archetypal Modernist architect, his designs were only superficially indebted to the tenets of European Functionalism and the aesthetic values of the International Style. He was instead profoundly influenced by scientific theories that sought to measure and predict the way the human body would react to space and form. These theories led him to design buildings in such a way as to choreograph people's emotional and physical responses through a process called 'visual excitation'. For Neutra, visual excitation is triggered by controlling the way people see, move through and comprehend space.

Neutra's (1962, 1971) argument is founded in two major beliefs; that vision leads to movement and experience leads to understanding. In practical terms, the first position maintains that long, controlled vistas in a design stimulate a person's visual senses, drawing them through the building and making them aware of its larger context. The second belief holds that this experience of movement provides each person with a strong sense of where they are in space (within both the building and its larger context) and in time (being aware of diurnal and seasonal changes). This last property has also been linked to an additional proposition from Neutra, concerning the ontological importance of the direct experience of nature.

This chapter uses syntactical analysis to investigate whether Neutra designed in accordance with these three theories about the relationship between vision and movement, cognition and experience, and interior and exterior. Focussing on Neutra's Californian houses, the chapter uses axial line analysis to search for evidence of this connection between spatial theory and practice.

6.1 Introduction

Austrian-born American architect Richard Joseph Neutra produced designs that are typically interpreted as using technology and industrial materials to express their functional properties and the spirit of their era (Boesiger 1964; Hines 1982;

M. J. Ostwald and M. J. Dawes, *The Mathematics of the Modernist Villa*,
Mathematics and the Built Environment 3,
https://doi.org/10.1007/978-3-319-71647-3_6

Sack 1992). He has been described as one of 'the most celebrated of the founders of Modern architecture' and as a designer 'who managed to capture the spirit of Modernism in a powerful and memorable way' (Sennott 2004: 917). However, despite his reputation for producing white, geometric designs, which otherwise appear to conform to early twentieth century Modernist ideals, Neutra repeatedly claimed that his primary purpose as a designer was to shape the sensory and cognitive responses of the human body (Neutra 1962, 1971).

Long before other architects were attracted to phenomenological reasoning, Neutra argued that architecture's *raison d'être* is to provide a type of sensory and physical framing to assist each person to understand and appreciate their position in the world (Neutra 1951, 1956). While his position has parallels with those of later phenomenological thinkers in architecture, it also departs from the then more recent tradition privileging science over philosophy. Fundamentally, the intellectual lineage of the majority of contemporary architects who are working in the phenomenological tradition can be traced to philosophers Edmund Husserl and Martin Heidegger, whereas the origins of Neutra's theory are found in the work of experimental psychologist Wilhelm Maximilian Wundt.

Both the scientific and philosophical traditions of twentieth century thinking about the senses have their origins in Germany in the late nineteenth century. At that time Wundt began formulating a way of isolating and measuring bodily reactions to external stimuli, including heat, sound or smell. Wundt believed that by understanding the senses and their impact on behaviour, human responses could be modified or even, for clinical purposes, controlled. Husserl (1982) strongly rejected this approach, calling for the primacy and irreducibility of human experience to be recognised. Heidegger (1962) developed this argument to support an inquiry into the nature of being and existence, and in the hands of late twentieth century architects (including Peter Zumthor, Steven Holl and Juhani Pallasmaa), the spiritual dimension of Heidegger's philosophy was translated into an argument for the transcendent quality of certain places and buildings (Norberg-Schulz 1979). These architects maintain that great design evokes a deep, sensory appreciation of place, space or tectonics and that it is only through the search for authenticity and truth that this can be achieved (Pérez-Gómez 1983; Pallasmaa 1996).

The division between contemporary architectural phenomenology and Neutra's theory of sensory choreography is essentially one between, respectively, poetry and science. This is not to say that Neutra's ideas lack poetry, nor that the architectural phenomenologists reject science. Instead, Neutra's ideas emphasise a particular empirical mindset and a clinical foundation for his design theory, while those of the architectural phenomenologists tend to valorise the metaphysical. In much the same way that Wundt and Husserl were both fascinated with the role played by the human senses in understanding the world, but resorted to different ways of achieving their ontological goals, so too Neutra cannot be so easily detached from the more recent phenomenological tradition.

These characteristics of Neutra's architecture begin to explain the contradictory place he occupies in the history of Modernism (Hines 1982; Lamprecht 2000). On the one hand, his work appears to embody all of the values of the Modern movement, but the theories he used to explain his designs do not repeat the classic Modernist tropes of functionalism and the *zeitgeist*. Further exacerbating this problem, Neutra's theory has rightly been described as structurally 'unsystematic' and his prose as 'hard to read' and 'repetitive' (Kruft 1994: 432). Thus, while Neutra offered lengthy, detailed descriptions of his design process, their complexity and opacity led many historians and critics to ignore his theories altogether and interpret his architecture as a type of socially-informed, technologically-enabled response to the era (McCoy 1960; Boesiger 1964).

It has only been in the last few decades that researchers have begun to take Neutra's claims about his design process and representational practices more seriously (Lavin 1999, 2000, 2004; Lamprecht 2000; Ostwald 2014b). For example, Neutra preferred to describe his architecture using a combination of perspective views and plans—his dislike of elevations setting him apart from his Modernist contemporaries. But where this attitude was once dismissed as a symptom of Neutra's obsession with the image, more recently scholars have asked whether his rejection of the elevation might be integral to the way he visualised people's experience of space (Niedenthal 1993; Lamprecht 2000; Ostwald and Henderson 2012). Collectively, the resurgence of interest in Neutra is partly associated with a simple question, is there evidence that he applied his theory in his architecture?

This question is the catalyst for the present chapter, which proposes a syntactical analysis of the planning of five of Neutra's Californian houses: the canonical *Kaufmann Desert House* from 1947, and the *Tremaine*, *Moore*, *Kramer* and *Oxley* houses from, respectively, 1948, 1952, 1953 and 1958. The purpose of this research is to examine three related characteristics of Neutra's design theory: the use of long sight-lines to control the way movement occurs; the use of visual and movement patterns to support or enhance spatial cognition; and the role of the exterior in the social and experiential function of the home.

For the first of the three characteristics, which is associated with Neutra's argument that vision leads to movement, axial line analysis is used to examine the topological significance of sight lines and paths in Neutra's architecture. Combining measured values (depth and integration) alongside a review of the spaces surveyed and passed through as part of the structure of the house (its non-trivial loops and hierarchies), the chapter examines whether long sight and movement lines are especially significant in these plans. For the second characteristic being analysed, which arises from Neutra's claim that experience leads to understanding, a correlation is constructed between integration and connectivity measures to calculate the relative intelligibility of each plan. This process identifies the degree to which paths and vistas in the house allow a visitor to efficiently experience and thereby comprehend a design.

The third characteristic of Neutra's theory examined in this chapter is also associated with the argument that experience leads to understanding, because Neutra maintained that it is critical for people to appreciate not only their domestic environment, but also the context in which it is situated. In practical terms, Neutra proposed that people should experience the passing seasons, and changes in temperature and weather, using all of their senses (Neutra 1956, 1962). He had two strategies for achieving this outcome. First, people in the interior of a house, regardless of the social function of the space they are inhabiting, should not only be able to see outside, but move outside with relative ease. Second, people should be encouraged (or even required) to move outside as part of their quotidian occupation of the house. In this chapter, the first of these is examined by determining the step distance of each plan, that is the number of turns required to navigate the 'shortest path from the formal entrance (most public space) to the main bedroom (most private space) of each dwelling' (Hanson 1998: 243). For the second, the extent to which exterior connections are necessary for the social functions of the house is determined through a qualitative review of the axial maps.

Importantly, this chapter does not test if Neutra's theory of visual excitation actually works. That is, this chapter does not examine whether people's emotional and physical responses can be choreographed in any methodical or consistent manner by architecture. While this proposition is inherently seductive for many architects, there is little or no empirical evidence that supports the validity of determinism of this kind. Certainly some behavioural and environmental preference research suggests that people are statistically likely to experience mild positive emotional responses to certain spatial, formal or symbolic stimuli (Stamps 2000). For example, people do tend to prefer views of natural settings over views of urban settings or spaces with no outlook at all. People also tend to be happier if they have access to natural light and ventilation (see Chaps. 8 and 9 for a more detailed discussion of this issue). Such findings have been used to support the 'biophilia hypothesis' which claims that humans have an innate affinity to natural forms and environments (Kellert and Wilson 1993). This idea would have resonated with Neutra, who called his own theory of architecture 'Biorealism', and who used views of nature, typically framed and controlled by architectural form, as a means of assisting his clients to locate themselves in space and time. However, the efficacy of Neutra's theory is not the subject of this chapter, which is instead concerned with investigating whether the spatial strategies espoused by Neutra are actually present in his designs.

6.2 Neutra and Biorealism

In his 1956 book *Life and Human Habitat*, Neutra outlined his theory of Biorealism, which called for architecture to strive to achieve three interconnected goals. The first is to support the human body to reconnect with nature; the second is to limit the impact of chaotic environments that would otherwise distract the mind. The third is to address the sensory needs of the human body in such a way that it can better understand the environment. While the underlying anthropological rationale for this theory is beyond the scope of this chapter, what is more interesting in the present context is how Neutra set about achieving this outcome in his architecture.

The essence of Neutra's design strategy can be traced to the results of Wundt's nineteenth century experimental research, which uncovered a series of relationships between human perceptions and reactions. In particular, Wundt observed that 'the reflex to the muscles that move the eye-ball is connected … with contraction of the corresponding muscles for movement of the head' (1969: 294). This finding suggests that vision (as translated through the musculature surrounding the eye) has a direct connection to bodily responses (the movement of the head). Neutra was fascinated by this idea and extrapolated it to claim that if the eye is drawn to a particular vista, then the head will turn towards that view, which in turn will be the catalyst for the entire body to move in that direction. This led to the formulation of Neutra's famous maxim; 'we "see not merely to see" but see in order to act upon vision' (Neutra 1956: 13). Vision, he argues, activates 'a person's locomotor urges' (Neutra 1956: 14), causing them to respond physically, and through this movement, to learn about the spaces and environments they are inhabiting. Furthermore, if this relationship between vision and action, or sense and response, is universal, then architectural form (what Neutra called 'shape') can be used to trigger and control these urges, causing a person to look in a certain direction and follow a particular path. Neutra summarised this idea as being that human response is a 'consequence of shape' (1956: 20).

Neutra developed and presented this theory about sensory response and its choreography through design, using his residential works of the late 1940s and early 1950s as examples. He did this because he believed that the home is the single place on 'the surface of the globe which we get to know intimately' (Neutra 1956: 21). Yet the home is also, paradoxically, the site of much of the 'optical litter' and 'visual conflict' that prevents the body connecting with and appreciating its environment (Neutra 1956: 166). The architect's role is therefore to minimise the chaotic or random distractions of the home, using a limited palette of forms (flat roofs, orthogonal walls and planes of glass) to shape the way the eye is captured, the body is inspired to move, and the mind is led to understand its environment.

While Neutra repeated this argument throughout much of his career, the biggest impediment to accepting it as a true account of his practical approach is that he rarely provided any direct evidence of how he applied it in his designs. At best, there are multiple clues in Neutra's books that reveal how he might have designed to achieve these outcomes. For example, his tendency to imagine and depict spatial affects using perspectives sketches, sometimes keyed to specific locations in a plan, reinforces the notion that he designed to achieve particular visual effects. He also went to great pains to minimise visual distractions in some parts of his design, but not in others, which suggests a deliberate strategy at work. For example, he sometimes minimised the division between the interior and the surrounding landscape by using corner glazing (without mullions) and emphasises the connection using continuous ceiling-eaves and reflecting pools. But more importantly, he occasionally used silver paint on structurally indispensable elements in an attempt to 'dematerialise' them, so as not to distract the eye from the vistas and paths he wished to emphasise. As Lamprecht observes, the silver finish 'appears only in those places where the sightline is affected' (2000: 34). Thus, for some vistas, there was a conscious decision to minimise distractions, while for others this was deemed relatively unimportant.

Another example of how Neutra worked is found in his various imagined accounts of people experiencing, reacting to and understanding architecture

(Ostwald and Henderson 2012). For example, as mentioned in Chap. 1, he describes the experience of a person approaching a house as follows. ‘As we approach we raise our head to recognize the house number [and as] we tilt our head upward, the equilibrium or inner ear organ immediately functions and combines the manifold record of our body position with pure vision and its ever-changing perspectives’ (Neutra 1956: 13). This quote is notable for a number of reasons, not the least of which is the way it has been constructed using the first-person, collective pronoun ‘we’. As Neutra’s account progresses, the clear inference is that a universal perspective is being presented and that the human eye—indeed any human eye—is inexorably drawn to the house number, then the angle of the head is inclined to take in the entire house and its natural context. Neutra’s description continues in this vein, stating that we then ‘roll our eyes by means of that ingenious muscle cluster around our eyeballs which is intricately and neurally tied up with those tools which we use unconsciously for turning and tilting the head’ (Neutra 1956: 13). Here, once again, Neutra stresses the involuntary response of the body to stimuli in general, and architectural form in particular. Before we know it, we have ‘our hand touching the knob of the entrance door, tactile and thermal experience of conductive and polished metal comes to us through the fingers and palms of the hands, while at the same time the muscle senses faithfully report from below about the rubber mat on which we have stepped’ (Neutra 1956: 13). In this example, architectural form stimulates the senses in such a way as to lead the body from the street to the front door, providing the mind with a subconscious understanding of the spatial approach to the house. Furthermore, while we have remarked on the first-person framing of Neutra’s narrative, its present tense is also notable because it emphasises the immediacy of the reactions; they are subconscious responses to the controlled use of architectural form.

Ultimately, the success of Neutra’s theory of Biorealism rests on his capacity to achieve three properties in a design. First, the creation of long, distinct vistas, to draw the eye and the body through space. Second, the creation of plans with improved connectivity to support increased cognitive clarity. Third, to ensure that the exterior environment is part of the experience of the house. Through the application of these strategies, his architecture was intended to promote heightened sensory appeal, reduce distractions and increase awareness of nature. These strategies are the subject of the remainder of the chapter, insofar as evidence of their application can or cannot be found in five of Neutra’s most important designs of the era.

6.3 Method

6.3.1 Hypotheses

Without a mathematical basis to directly compare Neutra’s houses with other designs, the three hypothesises which drive this chapter are formulated more to guide the discussion and conclusion than as definitive results (Table 6.1). In all

Table 6.1 Spatial properties mapped to specific hypotheses, analytical methods and result indicators

	Property	Hypothesis	Method	Indicator of a positive result
1	Vision leads to movement	Long sight lines will dominate the network of vistas and paths in each plan	Axial line analysis	The most integrated line(s) should encompass a large proportion of each plan's functional zones and participate in their major circulation loops
2	Movement leads to understanding	Plans will possess a high level of cognitive clarity	Intelligibility comparison	$R^2 > 0.75$ in at least four cases
3	Experience of the exterior is integral	(i) The most private spaces will be topologically close to the exterior (ii) The structure of the plan will require exterior connections	Step distance and structural comparison	(i) Step distance will be less than 2 in at least four cases (ii) Exterior spaces will be integral to the social structure of at least four cases

cases, the test is framed as evidence being found in at least four of the five cases, because these are all houses that Neutra used to support his argument, and so a greater than average number of positive results should be anticipated. The results for two of the three hypotheses also combine quantitative and qualitative indicators.

To assess the first hypothesis, Total Depth (*TD*) and Mean Depth (*MD*) are employed to classify and differentiate those spaces that are shallow or deep relative to the entire building, and integration (*i*) is calculated to investigate how accessible a line is to every other line in the system. Integration was calculated from Real Relative Asymmetry (*RRA*), which means that the results are relativised for direct comparison between the differently sized houses (Turner 2004).

For the second hypothesis, Intelligibility (*I*) is used as the mathematical basis to construct a comparison (see Chap. 2). Intelligibility is a measure of how efficiently the configuration of a space can be understood by traversing its component parts (Peponis et al. 1990; Hillier 1996; Haq and Girotto 2003). In early Space Syntax research intelligibility was often represented as a scatter graph of the connection and integration values of each line; if the axes are balanced, then the closer the angle of the line is to 45° the more intelligible the plan. The logic behind this process is that integration represents a global measure of the connectivity of a given space to all other spaces in the system. The number of connections the line makes represents how much of a configuration can be seen from each line and therefore the relationship between these measures suggests how intelligible a plan is. The higher the mathematical correlation of points ($R^2 \rightarrow 1$) the more intelligible the system. A benchmark for intelligibility values is found in the mean intelligibility of a sample of 75 urban environments: $R^2 = 0.68$ (Hillier et al. 1987). Urban environments with R^2 values greater than 0.68 exhibit above average intelligibility. However, for relatively spatially simple environments, like houses, a higher result would be anticipated to indicate above average intelligibility, say $R^2 > 0.75$.

The third hypothesis is tested using step distance, being the minimum number of direction changes encountered along a path between the most public and most private spaces in a design. Hanson (1998) uses step distance as a comparative measure of social separation between visitors and inhabitants, but in our case it serves as the topological distance between inhabitants and the environment.

6.3.2 Approach

As a starting point for the analysis, new CAD models of each of the five houses were prepared using Neutra's original working drawings along with published plans and photographs of the completed houses. The process used to develop the axial maps from these plans conforms to the general principles described previously (see Chap. 3), where axial lines represent visibility and movement. Not only is the relationship between sight and access pivotal to Neutra's argument that vision leads to movement, it is 'one of the most pervasive, effective, and powerful means through which architecture formulates social significance and social meaning is through the separation of accessibility and visibility' (Koch 2010: 13).

To construct the axial maps, the boundaries of each plan are 'cropped' close to the house to maintain the analytical focus on habitable spaces. This means that while exterior paths and driveways in Neutra's designs can often extend a substantial distance from the house, only those close to the buildings, and clearly 'spatially defined', are included. In this case—and because of the importance of outdoor 'rooms' and 'corridors'—'spatially defined' is taken to mean any hard-paved area that connects physically separate wings of the design or is required to complete internal circulation loops. Some of these hard-paved areas are also defined by garden or retaining walls, and a few are roofed, providing a stronger sense of these spaces as outdoor rooms.

Spaces that do not contribute to the social function of a building are excluded from the analysis. These include dumbwaiters, plant rooms and storage areas that are either too small for human inhabitation or not designed for any social use. Similarly, built-in furniture is treated as unnavigable obstacles, while all doors are assumed to be open. Following the principle that an axial line represents both vision and access, glazed walls are treated as obstructions to movement, as are pools and water features.

Stairs in the five houses are divided into two categories: those which do not interrupt the spatial cognition of a user and those that do. In the first category are small sets of stairs, with four or fewer risers, that are part of a larger space and do not unduly disrupt the direct visual and physical connection across that space. In the second category are stairs with five or more risers, which are treated as separate spatial units requiring dedicated axial lines. Landings are considered part of any stair set connected to them; thus a single landing could be simultaneously considered as part of both types of stair under the additional selection logic applied. Where a dedicated line is required to connect multiple levels, this section of the plan is split as necessary. Where no axial lines exist that run the entire length of a stair, one is added to complete the circulation paths and a line connecting it to the remainder of the network is also included. These lines are annotated (‘A’ and ‘B’) on the axial plans of the *Kaufmann* and *Tremaine* houses, and an arrow included demonstrating the connection.

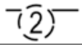
For each house a perspective view is provided along with an annotated plan identifying the original functional uses of the spaces (Table 6.2). The first numbered bedroom in each plan is the master bedroom. Maid’s and chauffeur’s bedrooms, guest bedrooms and servant spaces (including small living rooms for servants) are differentiated from the main family spaces in the text, but not in the annotations, which are simply numbered in accordance with their base function.

For the axial map of each house, the lines are differentiated to show the top third (most integrated), the middle third, and the lowest third (least integrated). The most integrated line is numbered, along with the line that is closest to the mean and the one that is least integrated in the plan (Table 6.3). If two or more of these lines have equal i values, then they are all signified in this way. Rather than providing a complete table of results for every line in each house, only the top three, middle three and lowest three lines, based on integration values, are inserted in a table. However, because multiple lines may have identical i values, several of the tables contain more than these nine results. The high, mean and low results, at the base of

Table 6.2 Key to plan annotations

Abbreviation	Room
C	Courtyard
CP	Car parking
T	Terrace
GL	Gloriette
E	Entry
H	Hallway
P	Porch
K	Kitchen
L	Living
D	Dining
G	Gallery
ST	Studio
LB	Library
B1	Master bedroom
B2, B3, …	Secondary bedrooms
b1, b2, …	Bathrooms
DR	Dressing
S	Storage
LD	Laundry
SV	Service area
CR	Change rooms

Table 6.3 Key to axial maps

Category	Type	Key
High integration	Most integrated line(s)	
	Top third of integrated lines	———
Middle integration	Mean integrated line(s)	
	Middle third of integrated lines	– – –
Low integration	Least integrated line(s)	
	Lowest third of integrated lines	---------

each column in the tables, are for the complete set of lines. Each table also includes the total number of lines in the map and the step distance between the master bedroom and the entry space in the house.

6.4 Results

6.4.1 *Kaufmann Desert House, Palm Springs, California, USA (1947)*

The *Kaufmann Desert House* is sited at the base of Mount San Jacinto in Palm Springs, California. Described by Barbara Lamprecht as both Palm Springs' 'first Modernist grand villa' and a 'social extrovert' (2000: 179), the house 'subsequently became the *chief d'oeuvre* [of the] suburban townscape' (Hines 1982: 201). The plan of the *Kaufmann Desert House* features a central living area from which four major functional wings radiate. This pinwheel configuration situates more public spaces closer to the core and more private or functional zones (such as the garage) to the wings (Fig. 6.1). Significantly, the rooms in three of the wings are only accessible by way of external circulation paths. The *Kaufmann Desert House* also possesses two prominent orthogonal axes that bisect the plan: the first links the garage and entry to the guest rooms and the second links the maid's room and the bedrooms. Finally, centred over the living area is an upper level *gloriette* (from the French word *gloire*, meaning 'little room'), a semi-external living space (Fig. 6.2). The reliance on external paths and spaces for its basic functional operation is a feature of this design.

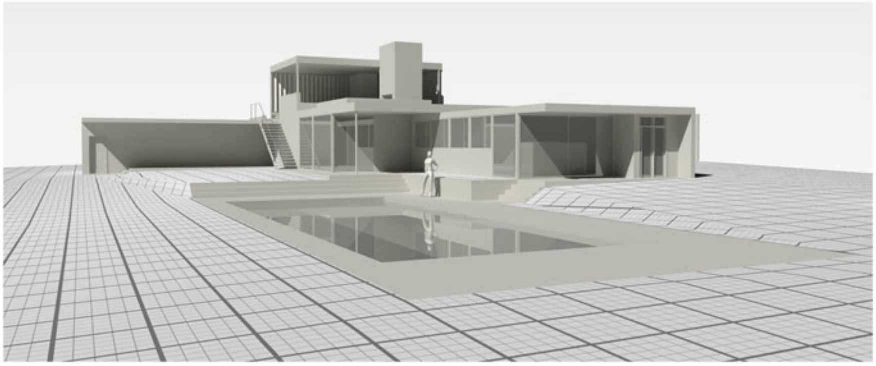


Fig. 6.1 *Kaufmann Desert House,* perspective view

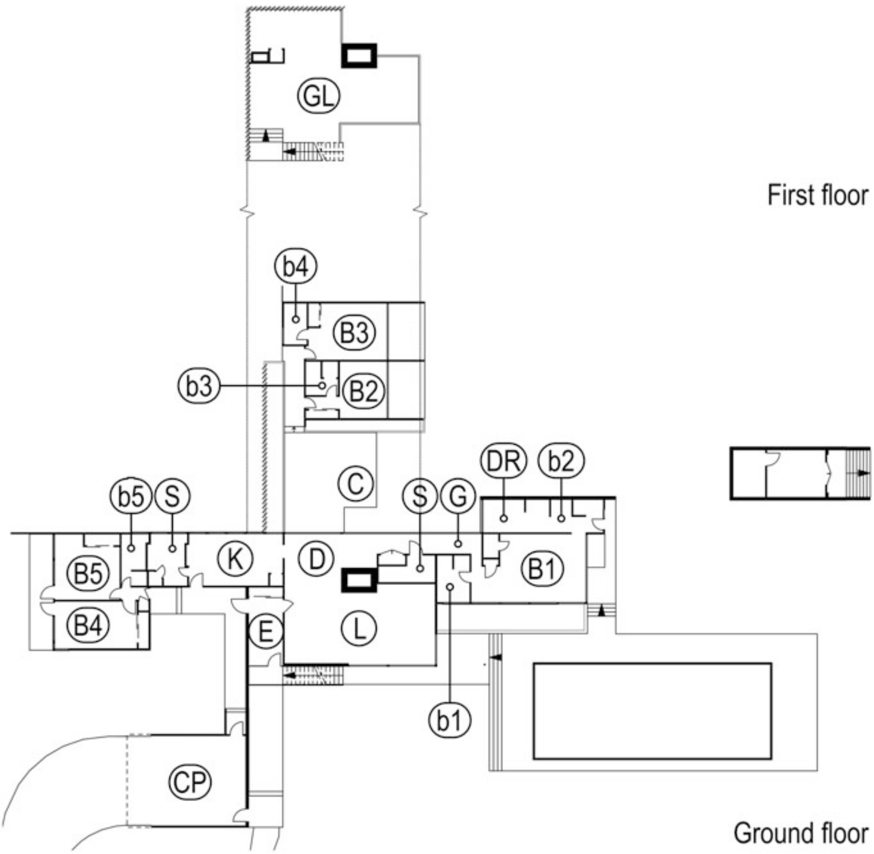


Fig. 6.2 *Kaufmann Desert House*, annotated plan

The axial map for the *Kaufmann House* identifies thirty-three lines, the longest and most integrated of which cross in the living room (Fig. 6.3, Table 6.4). The most integrated line (i = 3.27) runs from the second maid's bedroom (B5), along an exterior corridor, through the entry foyer and the living room to the pool. The line with the integration value closest to the mean commences in the first maid's bedroom (B4) before passing along an exterior corridor to the dining room. The *gloriette*—which is connected to the house by way of a single set of external stairs that are accessed from the pool area—contains the most segregated line in the design (i = 0.68). The complete set of results confirms that the *Kaufmann Desert House* is flexible and adaptive when external circulation connections are included and highly inflexible, and indeed non-functional, when they are excluded.

Only two changes of direction are required to progress from the formal entrance to the master bedroom, a result which is also the same for three of the four remaining bedrooms. The second maid's bedroom requires only a single change in

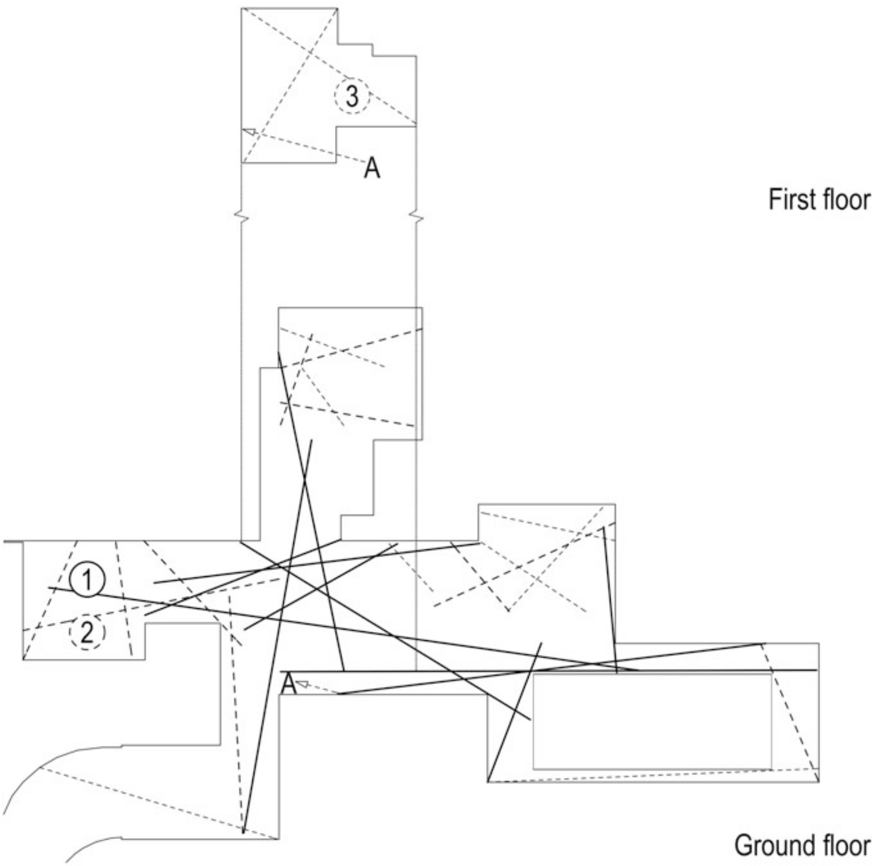


Fig. 6.3 *Kaufmann Desert House*, axial map

Table 6.4 *Kaufmann Desert House*, results

	MD	*RA*	*RRA*	*i*	Line length	Connectivity
Lowest three *i* values	4.9062	0.2520	1.4712	0.6797	13,217.8010	1
	3.9375	0.1895	1.1063	0.9038	11468.7530	2
	3.8750	0.1854	1.0828	0.9235	4547.7354	1
Median three *i* values	2.8750	0.1209	0.7061	1.4160	5721.0405	3
	2.8750	0.1209	0.7061	1.4160	9628.5596	3
	2.8750	0.1209	0.7061	1.4160	6052.4800	4
	2.7500	0.1129	0.6591	1.5171	7499.2041	2
	2.7500	0.1129	0.6591	1.5171	8289.5205	2
Highest three *i* values	2.0625	0.0685	0.4001	2.4988	21077.9380	10
	2.0312	0.0665	0.3884	2.5746	21867.7210	9
	1.8125	0.0524	0.3060	3.2677	38547.8590	14
Min	1.8125	0.0524	0.3060	0.6797	4081.13960	1
Mean	2.8446	0.1190	0.6947	1.6279	13669.5777	4.4242
Max	4.9062	0.2520	1.4712	3.2677	38547.8590	14
Step distance (E → B1)						2
Total lines in map						33

direction from the entry. This means that each of the deeper bedrooms is at least partially visible with only a single direction change after entering the house. This implies either a relatively low privacy threshold in the house or a high degree of connection to the exterior. The data also indicates that the *Kaufmann Desert House* is very intelligible or has a high level of cognitive clarity about it: $R^2 = 0.8764$ (Fig. 6.4). This result occurs for two reasons: there are several highly integrated, long lines that pass through the centre of the plan, and the overall planning strategy for the house is relatively shallow ($MD = 2.8$).

6.4.2 *Tremaine House, Montecito, California, USA (1948)*

While Neutra was working on the *Kaufmann Desert House*, he was also designing the *Tremaine House*, and the two share several features. For example, both have pinwheel plans, centrally located social spaces and masonry walls grounding their structures, visually at least, in the landscape (Fig. 6.5). The *Tremaine House* was designed as a permanent residence for a couple and their three children. It has more than thirty rooms, including a basement level (Fig. 6.6). As is the case with the *Kaufmann Desert House*, in the *Tremaine House* a small number of long vistas and associated paths bisect the centre of the elongated pinwheel plan, forming connections between the different wings and many of the spaces in between. However, in the *Tremaine House* there are non-trivial circulation loops which do not require external circulation, offering a greater degree of flexibility in the way the space is inhabited and used at any time of the year and under any weather conditions.

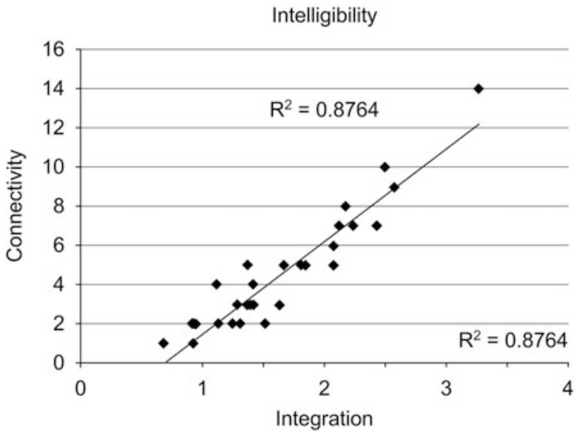


Fig. 6.4 *Kaufmann Desert House*, intelligibility graph

The axial analysis of the *Tremaine House* reveals that fifty-six lines are required to produce a valid map (Fig. 6.7, Table 6.5). The data from the map identifies that the longer lines crossing the central living spaces are the most integrated ($2.11 < i < 2.30$) and the third highest integration value is for a line crossing the formal entrance. Conversely, the lines in the basement level are amongst the least integrated in the design ($0.58 < i < 1.0$). The line with the highest integration value passes through the terrace, the living room, the kitchen and the exterior circulation.

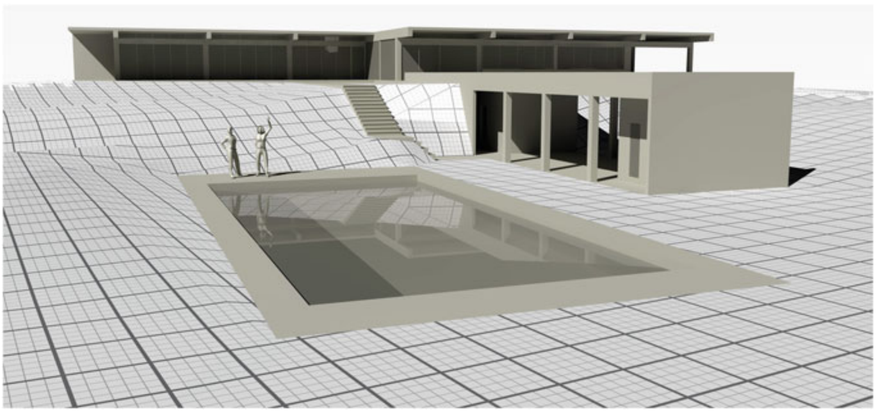


Fig. 6.5 *Tremaine House*, perspective view

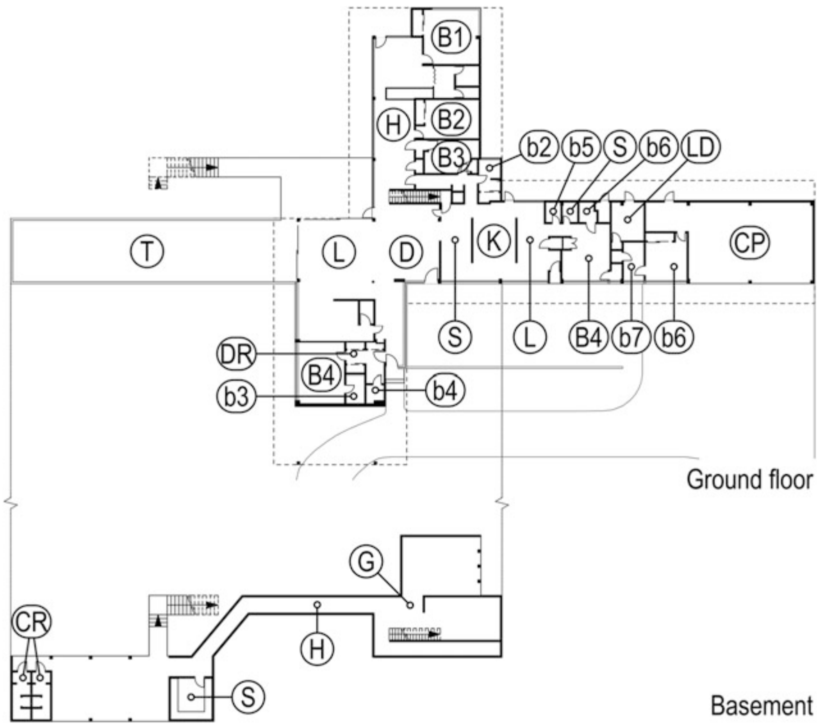


Fig. 6.6 *Tremaine House*, annotated plan

The lines that are closest to the mean for integration pass through, respectively, the hall and bedroom 2, and the library and the filing room. The lines with the lowest integration values are found in the change rooms in the basement level (which were intended for a pool that was never built).

A straight line of sight from the entry looks across the living spaces into the vestibule of the master bedroom and, with a single turn, the bedroom itself is visible, meaning that this plan has a step distance of one. Despite this seemingly shallow social depth, the *Tremaine House* is actually the least intelligible of the five Neutra houses analysed in this chapter (R^2 = 0.54921), having both the weakest correlation between line connectivity and integration and the least balanced (or furthest from 45°) trend-line where the axis is scaled to give a square graph (Fig. 6.8).

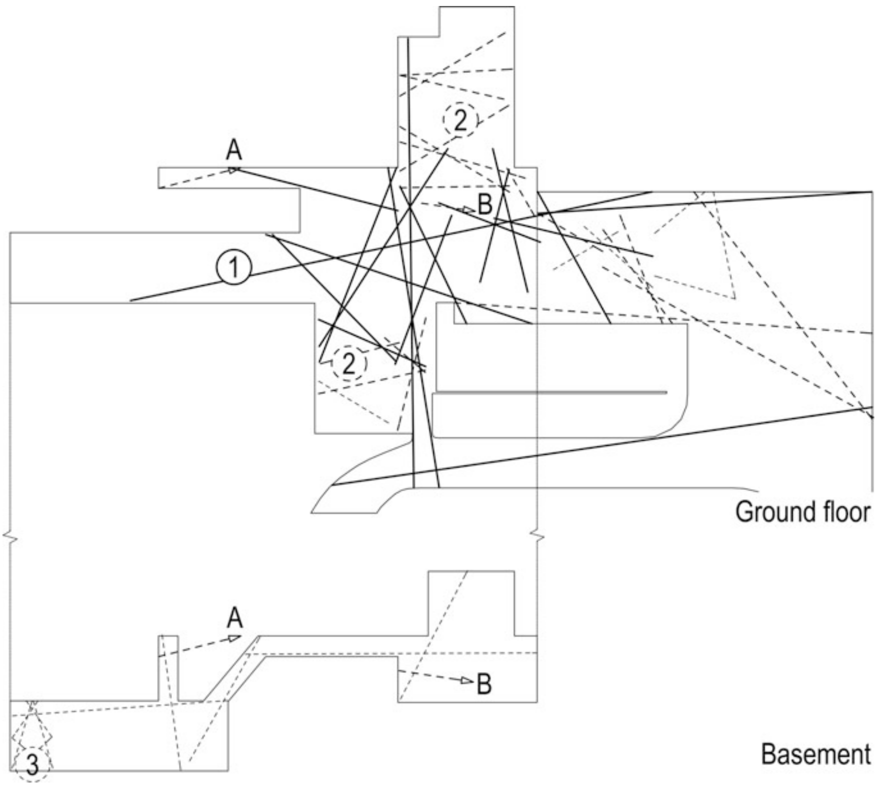


Fig. 6.7 *Tremaine House*, axial map

Table 6.5 *Tremaine House*, results

	MD	*RA*	*RRA*	*i*	Line length	Connectivity
Lowest three *i* values	6.7090	0.2114	1.7038	0.5869	1992.0631	2
	6.7090	0.2114	1.7038	0.5869	1993.1252	2
	5.7636	0.1764	1.4216	0.7033	5314.2666	4
	5.7636	0.1764	1.4216	0.7033	5314.2012	4
Median three *i* values	3.5090	0.0929	0.7488	1.3354	23184.8200	5
	3.4727	0.0915	0.7379	1.3550	9551.1729	3
	3.4727	0.0915	0.7379	1.3550	6084.0195	4
Highest three *i* values	2.5818	0.0585	0.4720	2.1182	33713.6410	18
	2.5272	0.0565	0.4558	2.1939	24324.9860	12
	2.4545	0.0538	0.4341	2.3036	40290.1450	16
Min	2.4545	0.0538	1.7038	0.5869	1992.0631	1
Mean	3.7409	0.1015	0.8180	1.3597	11828.1753	5.3214
Max	6.7090	0.2114	0.4341	2.3036	41127.5200	18
Step distance (E → B1)						1
Total lines in map						56

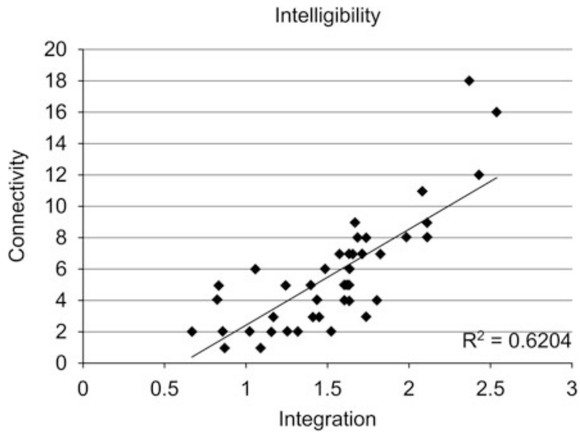


Fig. 6.8 *Tremaine House*, intelligibility graph

6.4.3 Moore House, Ojai California, USA (1952)

The *Moore House* deviates from Neutra's typical pinwheel planning arrangement of the era, having a more linear, dual pavilion *parti*, with all of its communal spaces to the north (Fig. 6.9). Like the *Kaufmann Desert House*, the guest wing and parking areas are accessible only by way of external circulation routes. A corridor connects the communal, private and service spaces and is extended to become the path to the guest wing. The linearity of the plan led Sylvia Lavin to observe that experientially, 'the architecture and the views it offers … are captured through peripheral vision' (2004: 109). With twenty-three defined spaces, the *Moore House* is also much smaller than the *Tremaine House* and about the same size as the *Kaufmann Desert House* (Fig. 6.10).

The axial map for the *Moore House* reveals that two long perpendicular axes form the central connections within the main house (Fig. 6.11). In this sense, the *Moore House* has a similar visual structure to the previous two, despite not having the same planning strategy. The map also reveals that three non-trivial internal circulation loops exist, including, surprisingly, two involving the master bedroom and bathrooms 3 and 4. The third loop encompasses all the house's major living areas. This property of the plan suggests that the owners have been provided with a much higher degree of flexibility than their guests and, like the *Tremaine House*, the master bedroom is directly accessible from the formal entrance. Only two circulation loops which involve external connections exist, both of which include the hallway.

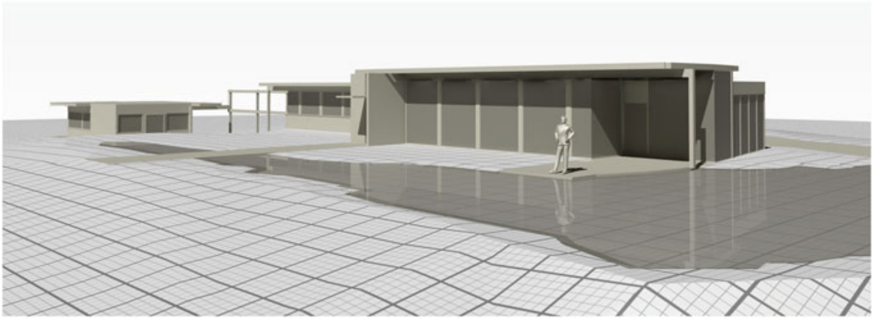


Fig. 6.9 *Moore House*, perspective view

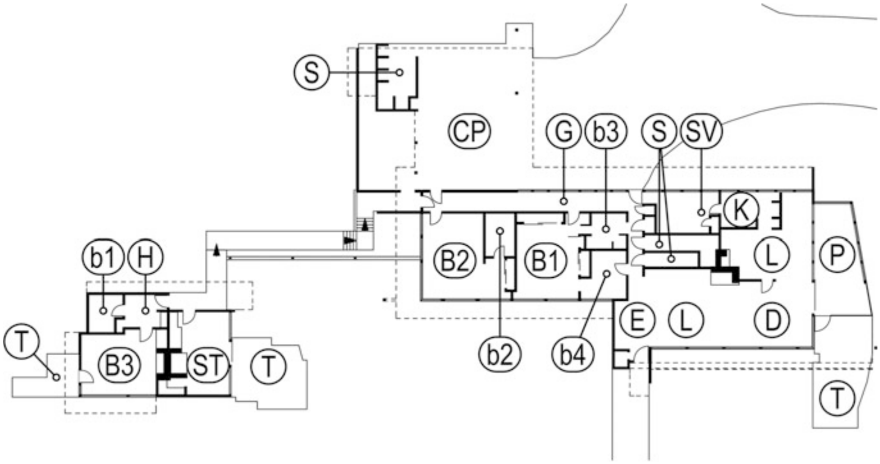


Fig. 6.10 *Moore House*, annotated plan

The most integrated line in the map passes from the exterior circulation area, through the hall, to the service area and the kitchen (Table 6.6). This path effectively functions as the service backbone of the house; this strategy differentiates this design from the previous two, in which the most highly integrated lines were associated with living spaces. The mean integrated line commences in the master bedroom (B1) and progresses through the bathroom (b4) and into the hall. The least integrated vistas and paths are those from the studio to the patio, and from the patio to the guest bedroom (B3). Curiously, the formal entrance is on the third most integrated line. The most and second most integrated lines intersect at a shallow angle above the upper level external stair. Bedrooms in the main house are of approximately average integration ($0.79 < i < 1.20$) and the living areas fall into a similar range. Like the *Tremaine House*, this design requires only a single direction

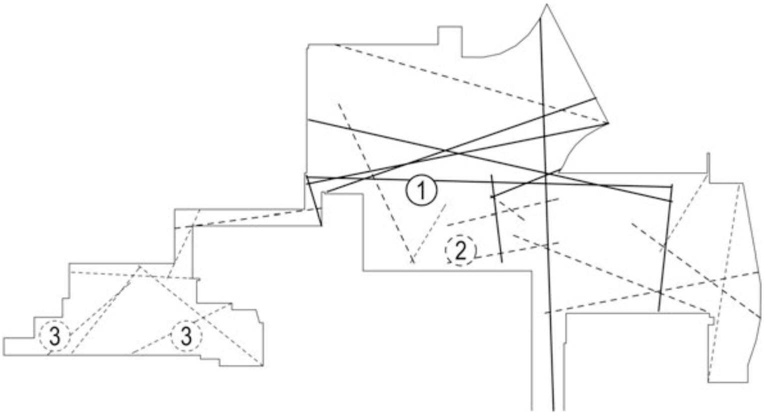


Fig. 6.11 *Moore House*, axial map

Table 6.6 *Moore House*, results

	MD	*RA*	*RRA*	*i*	Line length	Connectivity
Lowest three *i* values	6.1923	0.4153	2.1644	0.4620	8102.5996	1
	6.1923	0.4153	2.1644	0.4620	7977.4438	1
	5.2307	0.3384	1.7636	0.5670	11600.3780	3
	5.2307	0.3384	1.7636	0.5670	8147.4399	3
Median three *i* values	3.3461	0.1876	0.9780	1.0224	8152.3281	3
	3.2307	0.1784	0.9299	1.0753	15731.9580	5
	3.2307	0.1784	0.9299	1.0753	14989.4880	4
Highest three *i* values	2.6153	0.1292	0.6733	1.4850	30626.2990	10
	2.5384	0.1230	0.6413	1.5592	22358.2300	7
	2.3461	0.1076	0.5611	1.7820	26545.8610	9
Min	2.3461	0.1076	0.5611	0.4620	2964.9650	1
Mean	3.6011	0.2080	1.0843	1.0436	12294.4870	4
Max	6.1923	0.4153	2.1644	1.7820	30626.3000	10
Step distance (E → B1)						1
Total lines in map						27

change between the formal entrance and the master bedroom (B1). This result supports the general reading of the plan as containing a strangely centrally located master bedroom, with three alternative entry paths into it.

The intelligibility graph for the *Moore House* has an R^2 value of 0.6783, which confirms a moderate to low level of correlation between integration and connectivity (Fig. 6.12). The angle of the balanced trend-line also supports the idea that the *Moore House* is at best modestly intelligible. However, despite this general trend, a small number of scores show a large divergence between connectivity values for similarly integrated lines (especially $i \approx 1.5$).

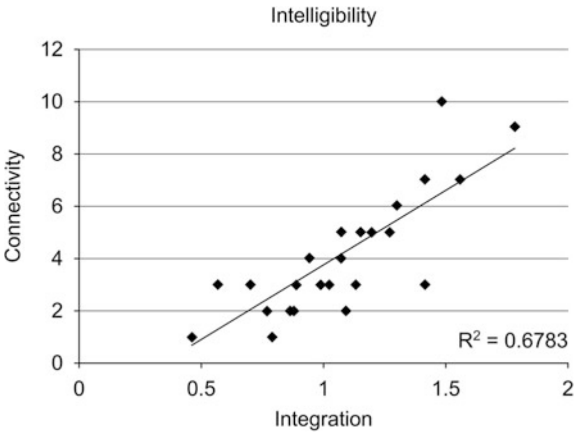


Fig. 6.12 *Moore House*, intelligibility graph

6.4.4 Kramer House, Norco, California, USA (1953)

The *Kramer House*, which was designed for a physician and his family, is approached from the south side and the entry is through a landscaped garden alongside the carport (Fig. 6.13). This southern side of the house was designed to accommodate a guest room that was deliberately isolated from the main bedroom. This guest room was intended to serve the doctor as a second bedroom so that he would not disturb his wife when he made night calls to patients (Lamprecht 2000). The house retains some of the pinwheel properties of the earlier plans, including a centrally located communal space, even though it is not as extensively developed as the plans of the earlier designs (Fig. 6.14). With only fifteen defined spaces, the *Kramer House* is one of Neutra's smaller designs of the era.

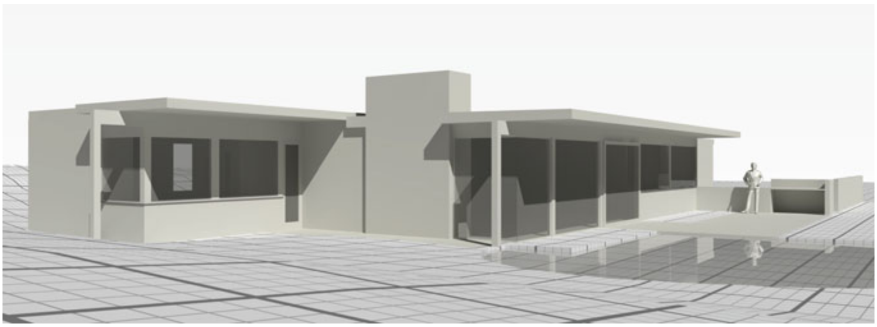


Fig. 6.13 *Kramer House*, perspective view

The *Kramer House* axial map—much like that of the *Moore House*—reveals the longest and most integrated lines intersect at shallow angles in a dedicated circulation space (Fig. 6.15). Also, like the *Moore House*, one of these lines passes through the main living spaces at the extreme edge of the area, rather than centrally, as it does in the *Kaufmann* and *Tremaine* houses. In the *Kramer House* the main functional spaces are sited to the side of the circulation core and provide a degree of flexibility by accommodating a secondary circulation system. Indeed, the house features separate public and private flexible zones with the main functional areas located on two of the circulation loops. The master bedroom contains the remaining loop, which is linked by only a single connection to the rest of the house.

The axial map for the *Kramer House* features only twenty-two lines (Table 6.7). Significantly, the top third most integrated lines all converge into the same hallway zone. Furthermore, the most integrated line forms the only connection between the master bedroom circulation loop and the remainder of the house (i = 3.75). The second most integrated line (i = 3.46) runs the length of the central hallway from the living room through to the garage. Conversely, the least integrated paths include those to the dressing room or walk-in-wardrobe (i = 1.00) and the courtyard (i = 0.703). In an interesting reflection of the brief, the same line integrates both the master bedroom (B1) and the guest bedroom (B3), separating the two, but keeping them both attached to the house in a similar social structure. This could well reflect the client's stated desire to use the guest bedroom when he was 'on-call'. From the formal entrance only a single direction change is required to reach the master or guest bedrooms. While there is geographic or dimensional distance between the entry and the bedrooms, several long, clear vistas and paths connect these spaces.

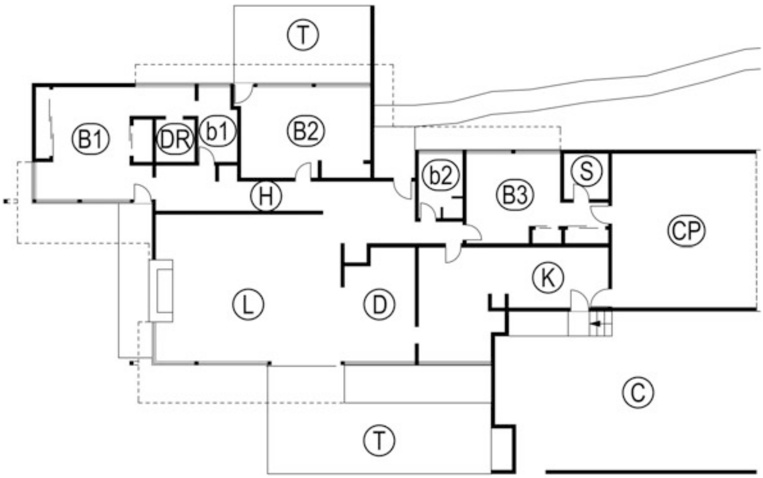


Fig. 6.14 *Kramer House*, annotated plan

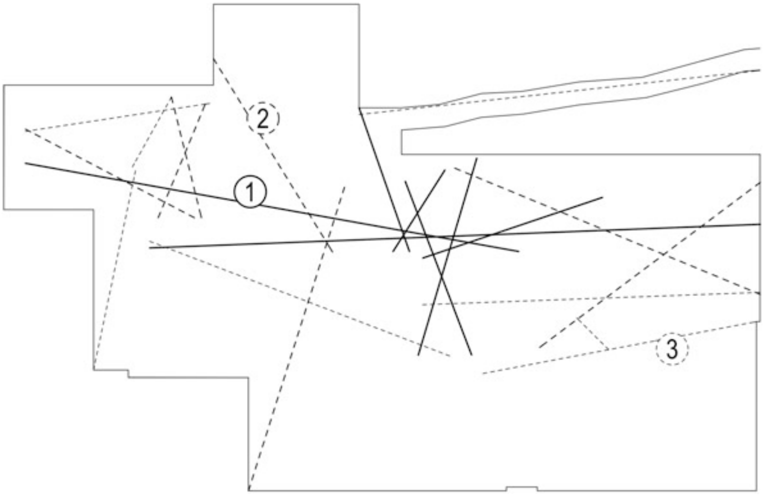


Fig. 6.15 *Kramer House*, axial map

Table 6.7 *Kramer House*, results

	MD	***RA***	***RRA***	***i***	**Line length**	**Connectivity**
Lowest three *i* values	4.0476	0.3047	1.4222	0.7031	10898.2800	1
	3.1428	0.2142	1.0000	1.0000	3219.5430	2
	3.0952	0.2095	0.9777	1.0227	1753.6630	2
Median three *i* values	2.2380	0.1238	0.5777	1.7307	13187.5000	4
	2.2380	0.1238	0.5777	1.7307	15063.5200	5
	2.1904	0.1190	0.5555	1.8000	9005.9490	3
Highest three *i* values	1.9523	0.0952	0.4444	2.2500	8140.2310	7
	1.6190	0.0619	0.2888	3.4615	25993.3100	11
	1.5714	0.0571	0.2666	3.7500	19800.3100	12
Min	1.5714	0.0571	0.2666	0.7031	1753.6630	1
Mean	2.3939	0.1393	0.6505	1.7765	10121.1200	4.3636
Max	4.0475	0.3047	1.4222	3.7500	25993.3100	12
Steps distance (E → B1)						1
Total lines in map						22

An R^2 value of 0.8965 confirms that the *Kramer House* is highly intelligible (Fig. 6.16). Thus, it is possible to develop a spatial awareness of the majority of this plan by passing along a relatively small number of paths. This supports Neutra's general principle of strong spatial orientation; a quality associated with the efficient discovery of the inhabitable spaces in a plan.

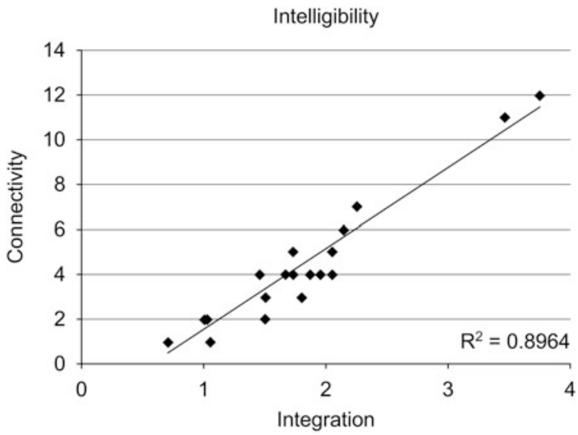


Fig. 6.16 *Kramer House*, intelligibility graph

6.4.5 Oxley House, La Jolla, California, USA (1958)

Neutra described the *Oxley House* as a 'modest home' (1971: 38), with only fifteen defined spaces including several exterior areas. Designed for the family of a physicist, the house is located on a site overlooking the Pacific Ocean in La Jolla (Fig. 6.17). Originally intended to be a pinwheel plan, one wing, containing the pool and a terrace, was never constructed, leaving the house midway between the radiating and linear strategies Neutra typically employed. The entrance is by way of a stepping, angled path that connects to a covered terrace (Fig. 6.18). Once within the entry hall, the visitor is within a space with an angled axis made up of a sequence of doorways which separate five pairs of spaces: bedroom 1 and dining room, dining room and living room, living room and hall, hall and bedroom 2, and bedroom 2 and courtyard. This intricately planned vista (which deliberately angles across the otherwise orthogonal space of the house) is identified by the axial map as the most integrated, and longest, vista and path in the design; a finding which perfectly aligns Neutra's intentions with the results of this analysis.

The axial map displays the dominance of two almost parallel lines, one through the centre of the configuration (as previously noted) and the other connecting an external circulation zone (Fig. 6.19). A single perpendicular line crosses these two, along with three angled ones. The intersection zone between the lines, which generally corresponds to the living, dining and terrace areas, also corresponds to the set of the most integrated lines in the house. Functional spaces supporting the living areas lie on two of the three loops, offering flexibility of use for daily activities. The third loop includes the guest room and garage. Each of these circulation loops requires a degree of external passage in much the same fashion as the *Kaufmann Desert House*. The master bedroom, living room, hall and guest room all lie on the most integrated line (i = 5.38) (Table 6.8). This line is at the core of the circulation structure of the house, forming part of all of the non-trivial loops. From the formal

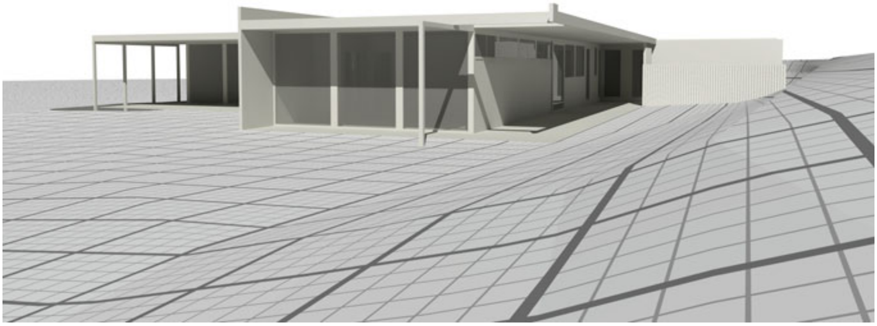


Fig. 6.17 *Oxley House*, perspective view

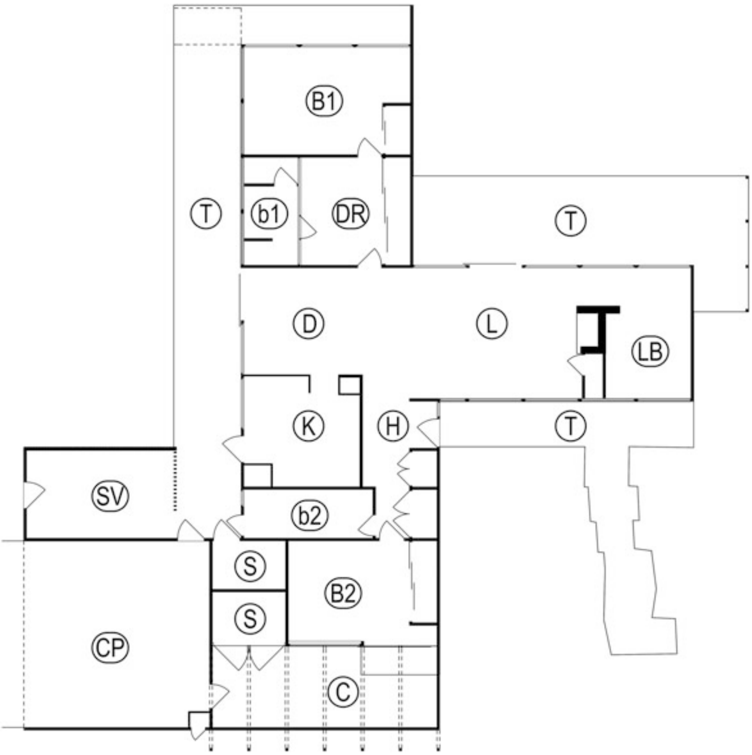


Fig. 6.18 *Oxley House*, annotated plan

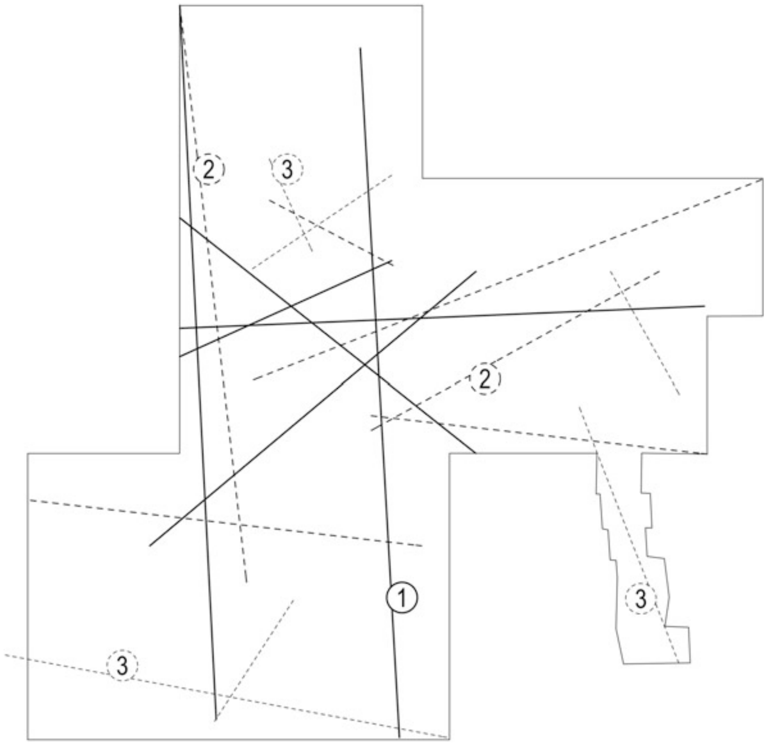


Fig. 6.19 *Oxley House*, axial map

Table 6.8 *Oxley House*, results

	MD	***RA***	***RRA***	***i***	**Line length**	**Connectivity**
Lowest three *i* values	2.8235	0.2279	0.9607	1.0408	8934.4736	1
	2.8235	0.2279	0.9607	1.0408	3260.4805	2
	2.4705	0.1838	0.7748	1.2906	4693.9688	2
Median three *i* values	1.8823	0.1102	0.4648	2.1510	10852.956	4
	1.8235	0.1029	0.4339	2.3046	10653.231	5
	1.8235	0.1029	0.4339	2.3046	19355.965	6
Highest three *i* values	1.5882	0.0735	0.3099	3.2265	17029.711	9
	1.5294	0.0661	0.2789	3.5850	12304.671	9
	1.3529	0.0441	0.1859	5.3775	22429.455	11
Min	1.3529	0.04411	0.1859	1.0440	2360.481	1
Mean	1.9738	0.1217	0.5131	2.3020	12181.9776	5
Max	2.8235	0.2279	0.9607	5.3775	23281.6500	11
Steps distance (E → B1)						1
Total lines in map						18

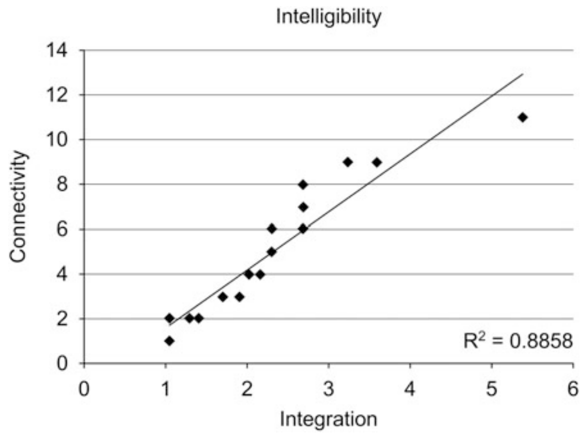


Fig. 6.20 *Oxley House*, intelligibility graph

entrance only a single direction change is required to traverse the most integrated line to either of the bedrooms. Conversely, the least integrated lines are found in the master bedroom en-suite (i = 1.04).

An R^2 value of 0.8858 confirms that the *Oxley House* is also highly intelligible (Fig. 6.20). However the graph is deceptive in that the high integration of the central line would suggest that a greater number of connections are required to more closely match the trend-line. Nevertheless, a review of the design data and map reveals that the majority of internal spaces are directly observable when traversing this line, a quality which in itself would make the house intelligible.

6.5 Conclusion

The first hypothesis outlined in this chapter holds that long sight lines will dominate the network of vistas and paths in each of Neutra's plans. The five axial maps demonstrate that this is true, with a small number of long sightlines shaping and controlling the planning and social structures in all of the designs. These lines typically bisect the heart of the plan and incorporate, or are adjacent to, most of the major functional spaces. Furthermore, when traversing the paths defined by these lines, peripheral vision would allow a person to gain a large amount of information about any remaining parts of the plan. Mathematically, Neutra's most integrated lines often cross the geometric cores of their plans, and if his architecture is dominated by long vistas as the theory suggests, then a relatively tight integration range along with a low mean result might be evidence for this. Of the five houses, the larger ones typically possess the smallest range of integration values, with the smallest house (*Oxley*) having the widest range. Only the *Moore House*, which is separated into two pavilions, is the exception to this rule. However, overall the mean integration values are all low compared to the maximum score in each house. An examination of the full mathematical results confirms that in each design there are a small number of highly integrated paths or vistas, and a large number of lines with significantly lesser values. Overall, the combined quantitative and qualitative data tends to support the first hypothesis.

The second hypothesis holds that Neutra's plans will possess a high level of cognitive clarity and therefore, that intelligibility results in at least four of the five houses will be greater than $R^2 = 0.75$. The *Kramer* ($R^2 = 0.90$), *Oxley* ($R^2 = 0.89$) and *Kaufmann* ($R^2 = 0.88$) designs all posses very high intelligibility scores but the *Moore* ($R^2 = 0.6783$) and *Tremaine* ($R^2 = 0.55$) houses fall below the $R^2 = 0.75$ benchmark. Therefore three of these houses possess a strong sense of orientation and spatial clarity but the other two do not. Interestingly, past research has demonstrated that Neutra's 1929 *Lovell 'Health' House* has a particularly labyrinthine plan with a commensurately low level of intelligibility, $R^2 = 0.2124$ (Ostwald and Dawes 2012). Thus, as logic dictates, just because a design has a similar aesthetic expression, it does not mean that its planning is also consistent. Because the second hypothesis was framed as an expectation that at least four of the houses would demonstrate this property, it is disproved. Nevertheless, there is some support for this property in the data.

The third hypothesis has two parts. First, it suggests that even the most private spaces in the plan will be topologically close to the exterior. The shortest path from the most public space to the most private averages only 1.2 direction changes across the five designs. Four of the five houses have a step distance of one! This confirms that the houses are topologically shallow, a finding that is supported by the mean depth results, $1.9 < MD < 3.7$. The second part of this hypothesis holds that the structure of the plan will require exterior connections. All five houses have similar planning and circulation strategies, with Neutra consistently including kitchen, living, dining and garage areas on major circulation loops. With the exception of the *Kramer House*, all of these loops also include external spaces. Moreover, in the case of the *Kaufmann* and *Oxley* houses, all loops require external circulation and for the former, three of the four wings are only accessible by way of external paths. On balance, both parts of this hypothesis are confirmed by these results.

If we view the complete set of results, they provide a level of evidence that Neutra created spaces where vision leads to movement and where close proximity to the environment is emphasised and even celebrated. However, despite his stated intentions, experience does not necessarily lead to understanding in Neutra's planning, with only three of the five cases supporting this contention. Overall, despite not emphatically supporting all three hypotheses, this chapter has uncovered several important traits of Neutra's architecture that have rarely been taken seriously in the past, but may begin to explain why designers and historians continue to be fascinated by it to the present day.

Chapter 7
Glenn Murcutt: Form and Social Function

The famous Modernist axiom, 'form follows function', suggests that the programmatic needs of a design, its function, should both precede and take precedence over decisions about its aesthetic expression or form. In practice though, early Modernists repeatedly failed to live up to this ambition and the relationship between form and function in architecture remains contentious to the present day (Brolin 1976; Bonta 1979; Evans 1997; Ellin 1999). However, the strand of Modernism known as Critical Regionalism revisited this axiom in the late twentieth century offering an alternative: form follows context (Kalay 2004; Hyde et al. 2007). This position holds that a considered response to the natural environment, along with a careful selection of local materials and tectonic approaches, should lead to the production of an appropriate architectural form. What is unclear in this new variation is whether context has simply supplanted function in the Regionalist credo, or been included as an additional factor. Certainly writers who examine Regionalism only rarely mention planning or social structures, focussing instead on tectonics and form (Lefaivre et al. 2001; Lefaivre and Tzonis 2003; Canizaro 2007). It is this lacuna—the absence of commentary on the social properties of the plan and its implications—that is the catalyst of the present chapter.

Focussing on Murcutt's canonical rural domestic type—the freestanding linear pavilion in the landscape—this chapter examines two arguments about their planning. These arguments arise from the assumption that, just as Murcutt's architecture repeats a distinct formal type and response to contextual and tectonic issues, so too it must have a similarly consistent and considered underlying social structure. In this chapter we analyse the social and spatial structure of Murcutt's architecture to determine if it indeed is, as suggested, both consistent and deliberate. If it is, then this might imply that form arises in Murcutt's architecture from a consideration of both function and context. If not, then perhaps the social structure of the plan has been sacrificed to the gods of form and context.

M. J. Ostwald and M. J. Dawes, *The Mathematics of the Modernist Villa*,
Mathematics and the Built Environment 3,
https://doi.org/10.1007/978-3-319-71647-3_7

7.1 Introduction

For the majority of architectural writers, design analysis involves interpreting the formal and tectonic properties of a building (Gelernter 1995; Frampton 1995; Baker 1995). Indeed, interpreters of the canonical works of architectural history remain steadfastly focussed on these properties, repeatedly revisiting the key volumetric and material characteristics of a building until, over time, the essence of an architect's work has been distilled for widespread consumption. For example, the work of the Australian architect Glenn Murcutt has, over the last few decades, begun to be described in a highly consistent manner. Murcutt's rural pavilions are accepted as being 'linear', 'lightweight', 'minimal', 'symmetrical', 'elegant' and 'economical' (Drew 1985; Fromonot 1995; MacMahon 2001; Frampton 2006). The way they are positioned in the landscape evokes visions of classical temples, simple, geometric forms surrounded by nature. Indeed, across the many accounts of Murcutt's architecture, a recurring theme is the way his rural houses rekindle myths of the primitive hut (Drew 1985; Frampton 2002).

The primitive hut of the ancients is an 'origin myth' in architecture, which is repeated in many treatises as an imagined account of the creation of the first building (Rykwert 1981). While there are multiple variations of the myth, the first building is typically valorised for being unadorned and unpretentious; it is constructed using local materials and labour, thereby providing a direct physical and symbolic connection between its form, site and inhabitants (Kruft 1994; Ostwald and Williams 2015). The primitive hut is both timeless and universal, at home in its context and era, offering its inhabitants a physical and spiritual connection to the world.

Murcutt's rural architecture evokes the primitive hut through its siting and use of repetitive forms and materials that recall simple vernacular dwellings and lifestyles. For example, Françoise Fromonot argues that Murcutt's houses have a universality and timeless appeal about them. They are 'variations on the same theme', an 'analysis of [which] reveals a number of constants which could be called *characteristic*, analogous to those identifiable in specimens which illustrate a *species*' (2006: 60). Rory Spence describes Murcutt's houses as constituting a unwavering formal type: 'the long thin open pavilion' (1986: 72) and Philip Drew argues that Murcutt's talent is his capacity to shape 'a minimalism that is austere and tough so that all that remains is an irreducible core' (1986: 60). Fromonot, Spence, Drew and Frampton are not alone in identifying each of Murcutt's rural houses as a local variant of a universal type. Yet, despite this apparent accord concerning their formal, contextual and phenomenal qualities, relatively little has been said about Murcutt's architecture in terms of its spatial structure.

In this chapter, syntactical analysis is used to investigate the spatial and social structures of the plans of ten of Murcutt's most famous rural houses. The goal of this analysis is to test two assumptions about Murcutt's planning. The origins of both assumptions can be traced to the way historians and critics have lauded the apparent consistency of his designs in terms of their formal expressions, contextual responses and tectonic approaches. The first of these assumptions holds that

Murcutt's planning is as consistent as the other features of his buildings. The second is that Murcutt's planning is as deeply considered as the other characteristics of his architecture. The first of these effectively asks, is there a pattern in Murcutt's social planning? The second asks, is there evidence that this pattern is deliberate? These assumptions are framed as two hypotheses in the following section, and then tested in this chapter using connectivity plan graphs of functionally defined spaces.

The ten houses used to examine these hypotheses are all sited in rural parts of New South Wales, on Australia's east coast. They are freestanding dwellings on isolated sites, with often dramatic views over the surrounding landscape or through adjacent bushland. The majority of these sites are also exposed to extreme weather conditions and high diurnal temperature ranges. Historians and critics have tended to categorise these ten houses into two groups. The first group includes five works completed between 1975 and 1982, which are mostly small, single or dual pavilion structures with symmetrical roofs. The designs in this group are the *Marie Short*, *Nicholas*, *Carruthers*, *Fredericks* and *Ball-Eastaway* houses. The first four of these designs are typically identified as a distinct subset of Murcutt's early domestic architecture, whereas the *Ball-Eastaway House*, despite obvious similarities, is regarded as a transitional work. The second group of houses tend to be larger, have asymmetrical roof-lines and feature multiple zones within linearly extended volumes, akin to having multiple pavilions under the same roof. These houses, which were constructed between 1984 and 2005, are the *Magney*, *Simpson-Lee*, *Fletcher-Page*, *Southern Highlands* and *Walsh* houses.

Notably, historians and critics differentiate these two groups of houses either chronologically ('early' and 'late') or formally (for example, symmetrical verses asymmetrical rooflines), and differences in planning are never mentioned. However, it might be assumed that just as there is a subtle shift in expression and scale between the first and second groups, so too there might be a similar change in spatial planning and social structure. Thus, while the hypotheses that are tested in this chapter are framed around the search for evidence of consistency and determination across the ten designs, if the data identifies two patterns that correspond to the two groups, that too would be a valuable outcome.

7.2 Spatial Structure

Perhaps because Murcutt's architecture appears both highly consistent and deeply considered it has been the subject of multiple attempts to uncover the properties that make his buildings so distinctive. For example, research into Murcutt's early rural housing using shape grammar analysis uncovered a distinct environmentally-derived rule set, which seems to shape the form taken by his architecture (Hanson and Radford 1986a; 1986b). Fractal analysis of the formal properties of Murcutt's architecture also reveals a high level of consistency, but it does question the importance of transparency in the experience of these works (Vaughan and Ostwald 2014; Ostwald and Vaughan 2016). Syntactical analysis of various designs by

Murcutt has identified the existence of some statistical patterns in his planning (Ostwald 2011b; 2011c) and additional studies have successfully connected spatial zones in Murcutt's architecture with their formal expressions (Lee et al. 2013, 2015a, 2015b, 2016). Significantly, the form-based studies have been able to identify simple rule sets (an architectural grammar) that can explain Murcutt's architecture or evolve new instances of it, but the spatial studies have been less successful.

There is something about the way Murcutt structures space that has, thus far, defied easy categorisation. This may explain why space, in a topological sense, is rarely mentioned in the context of Murcutt's architecture; if it is, it tends to be for the purpose of commenting on geometry rather than topology. For example, multiple writers have noted that the geometry of the planning of Murcutt's *Marie Short House* is reminiscent of Mies van der Rohe's *Farnsworth House*. Philip Drew describes the *Marie Short House* as featuring a pair of pavilions that merge 'Mies van der Rohe's single storey glass pavilion type' with the 'primitive hut archetype' (1985: 74). Kenneth Frampton echoes this when he argues that the planning and expression of the *Marie Short House* combines the essence of the primitive hut 'with the tectonic refinement of Mies' *Farnsworth House*' (2002: 1). Haig Beck and Jackie Cooper also note the geometry of the plan of the *Marie Short House* is similar to that 'of Mies's *Farnsworth House* with its staggered deck' and 'layered zones of public and private' space (2002: 48). However, this last quote from Beck and Cooper is the only one which acknowledges that the interior of the *Marie Short House* has a function. Indeed, the view that, like Louis Kahn, Murcutt tends to separate served and service zones, is one of the few recurring observations about Murcutt's planning (Drew 1985, 2001; Beck and Cooper 2002; Frampton 2006). More often, writers provide poetic accounts of their experience of moving through Murcutt's interiors, emphasising their transparency and connections to nature, but not commenting on their planning. For example, Drew (1985) likens the experience of moving through one of Murcutt's interiors as being both complex and distracting, an unexpected reaction given the otherwise minimal, formal expression of the architecture.

Most often, if interior space is mentioned at all in the context of Murcutt's architecture, it is simply accepted as a minimal, appropriate response to the client's brief. For instance, Juhani Pallasmaa asserts that for Murcutt, order in form is as important as order in 'organising and structuring' space (2006: 19). Pallasmaa reinforces this point by arguing that Murcutt 'doesn't merely aestheticise the human domicile', he structures his designs to support 'a humanised reading and meaning to the human condition itself' (2006: 17). Pallasmaa's claim is broadly that the rigour and simplicity of Murcutt's architectural expression is reflected in a similarly exacting and refined spatial structure, which in turn supports a more transcendent human condition. While this argument is rarely stated so clearly in this way, it is apparent that critics accept that the interiors of Murcutt's rural domestic architecture are as consistent and refined as his exterior forms. Certainly his approach to the siting of his architecture is highly consistent, as too are his client's social (cultural and familial) needs, so surely his interiors must follow a similar, consistent and considered approach?

7.3 Method

7.3.1 Hypotheses

Two hypotheses are examined in this chapter (Table 7.1). The first is concerned with the consistency of the social structures embedded in Murcutt's planning and the second with how deliberate or determined these are. The hypotheses are tested using observations and measures derived from connectivity plan graphs of functionally defined spaces (see Chap. 3).

The first hypothesis maintains that *the spatial configuration of Murcutt's rural domestic architecture has a consistent underlying social pattern*. This claim is tested in three ways, first through visual analysis of the plan graphs, second through statistical review of the role of substructural types in these graphs, and finally, through a comparison of inequality genotypes. The visual analysis is used to reveal the extent to which each house's spatial configuration is shallow or deep, permeable and rhizomorphous or hierarchical and arborescent. Non-trivial circulation loops are identified as part of this process and examined to determine which parts of the plan they access. Any patterns revealed in this analysis are discussed and compared. The plan graphs are then divided into three substructural types (non-trivial loops, bushes and enfilade branches) and both their number and proportional representation compared against equivalent indicators from a normally distributed set of data. Thereafter, the plan graph is analysed mathematically, and from this data an

Table 7.1 Spatial properties mapped to hypotheses, analytical methods and result indicators

	Property	Hypothesis	Method	Indicator of a positive result
1	Consistency of spatial structure	The spatial configuration of Murcutt's rural domestic architecture has a consistent underlying social pattern	Connectivity graph analysis and statistical analysis	(i) Plan graphs display a consistent configurational structure (ii) The substructures and nodes in the plan graphs are more clustered than those in a normally distributed set of data (iii) Inequality genotypes possess a consistent ordering and grouping of areas
2	Determination of spatial structure	The spatial configuration of Murcutt's rural domestic architecture has a deliberate underlying social pattern	Difference Factor comparison	H^* will be less than 0.5 in 60% of cases

inequality genotype is developed for each house. This is a sequence of functionally defined spaces, ranked in accordance with their integration values. It is the relative gap between the precedence accorded to various spaces (their inequality) that expresses the social pattern. An inequality genotype can be used to demonstrate how a 'culture manifests itself in the layout of space by forming a spatial pattern in which activities are integrated and segregated to different degrees' (Hillier and Tzortzi 2006: 285). However, inequality genotypes have proven particularly difficult to compare in architect-designed homes (Bafna 1999; 2001), and statistical genotypes, while useful, have their own challenges (Ostwald 2011b; 2011c; Lee et al. 2015a; 2015b). Instead of following either of these approaches, we examine the integration ranges of key spaces in each design, relative to their minimum, maximum and mean values. Through this process we can compare where in the genotype these spaces are most commonly found. By combing the results of the three approaches—visual analysis, statistical analysis of substructural types and simplified genotype comparison—we can draw a conclusion about the level of consistency in Murcutt's configurational planning.

The second hypothesis holds that *the spatial configuration of Murcutt's rural domestic architecture has a deliberate underlying social pattern*. This question is important because it is possible that any pattern uncovered in the analysis of a set of domestic designs might be either unintended or so commonplace as to be unremarkable. Thus, this hypothesis is concerned with testing whether the graphs of the ten houses are differentiable from a graph with a general distribution of spaces. If they are, then this might suggest they are the result of a distinct effort to achieve a unique or original spatial configuration. Difference Factor is used to measure the strength or weakness of the inequality in a genotype, which could be regarded as the degree of deliberation represented in its configuration (see Chap. 3). When using the Relative Difference Factor, an H^* value close to 0 is regarded as a 'strong' genotype, while a value close to 1 is a 'weak' genotype. A weak genotype ($H^* > 0.5$) is one that is more homogenised, with only limited configurational differences, while a strong genotype ($H^* < 0.5$) has a higher level of dispersal of spaces, implying a more distinct topological configuration has been produced (Hanson 1998; Zako 2006; Ostwald 2011c). Certainly a distinct configuration in an individual case can be either random or deliberate, so in order to confirm which of these it is, a majority of cases are required to confirm a level of determination. Therefore, for the second hypothesis to be supported, we must find $H^* < 0.5$ in 60% of the cases examined.

7.3.2 Approach

For the analysis, new CAD models of each of the ten houses were prepared in accordance with Murcutt's final construction drawings, including any 'on-site' variations that were incorporated prior to 'practical completion'. Later additions and modifications to the designs are excluded and the original naming of each house is retained. All plans and graphs are annotated in accordance with the original functional labels on Murcutt's drawings (Table 7.2).

The principle adopted in this chapter is that graph nodes represent named or programmatically defined spaces. In most cases it is a straightforward process to identify these nodes, as the majority occupy isolated, rectilinear rooms with clear functional purposes. However, Murcutt's houses also feature semi-open planned areas, where different functional uses are signalled only by a combination of the furniture within them and changes in floor finishes. In this chapter, a set of threshold conditions are used to determine how these spaces are classified. Specifically, for a space to be subdivided, at least two of the following four conditions must be fulfilled: a physical barrier is present within the space, even if it does not block vision (for example, an island kitchen bench which partitions a space); a change in floor finishing (say, from polished timber to carpet); a change in level; and a combination of forms that suggest a spatial enclosure even if it is not completely physically controlled (for example, a pair of columns with an exposed arch or beam above them). All of these conditions suggest a division of space—although typically, at least two are required to strongly imply such a division—while still being part of an open plan. Where no clear threshold conditions exist, the space is counted as a single node. Because spaces in several of Murcutt's houses fall into this category, some combined labels are used (for example, KLD, means an

Table 7.2 Key to plan and graph annotations

Zoning	Key	Function
Public	⊕	Exterior
Semi-Public	V	Veranda
	LBY	Lobby
	C	Court
	H	Hall
	G	Garage
	U	Utility Room
Semi-Private	L	Living Area
	F	Family Room
	D	Dining
	ST	Studio
	M	Music Room
	K	Kitchen
Service	l	Laundry
	A	Alcove
	S	Store
Private	B	Bedroom
	WIR	Walk-in-wardrobe
	b	Bathroom
	WC	Toilet

open plan kitchen, living and dining space). To complete the mapping process, utility zones, which often encompass several cupboards and racks for hanging clothing, are merged into single areas and bathrooms with internal partial partitions are also treated as one space. Accessible, multi-purpose storage spaces are included in the analysis, but rainwater collection tanks and wood stores are excluded.

Spaces are regarded as connected if they have operable doors between them or adjacent boundaries that are large enough to accommodate human movement. ‘French windows’ are treated as a single connection and the trivial loops associated with them are excluded from the analysis. There are a small number of sliding walls in Murcutt’s architecture that allow entire spaces to be opened-up and rooms to be transformed into verandas. None of these operable walls change the permeability graphs; they change the level of environmental control, allowing or restricting access to sunlight and air.

To assist with visually interpreting the graphs, some conventions that do not affect the calculations are used. For example, large open-plan spaces have elongated oval nodes rather than circular ones and a jagged section in a graph edge indicates a change in level.

7.4 Results

7.4.1 Marie Short House, Kempsey, New South Wales, Australia (1975)

The *Marie Short House* is the first of Murcutt’s famous rural houses and it is credited as both heralding a new Australian style and with being a key example of critical regionalist architecture (MacMahon 2001; Frampton 2006). The house consists of two, similarly sized, pitched-roofed pavilions that are placed side-by-side and then slid apart along a centreline (Fig. 7.1). One pavilion contains living spaces, the other, sleeping quarters; a corridor connects the two (Fig. 7.2).

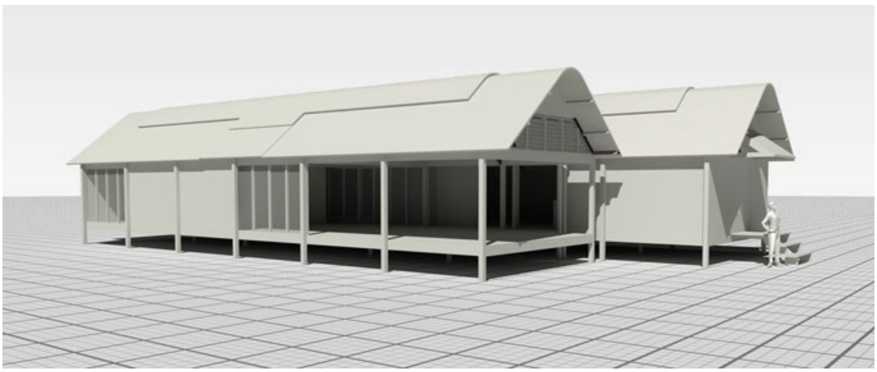


Fig. 7.1 *Marie Short House*, perspective view

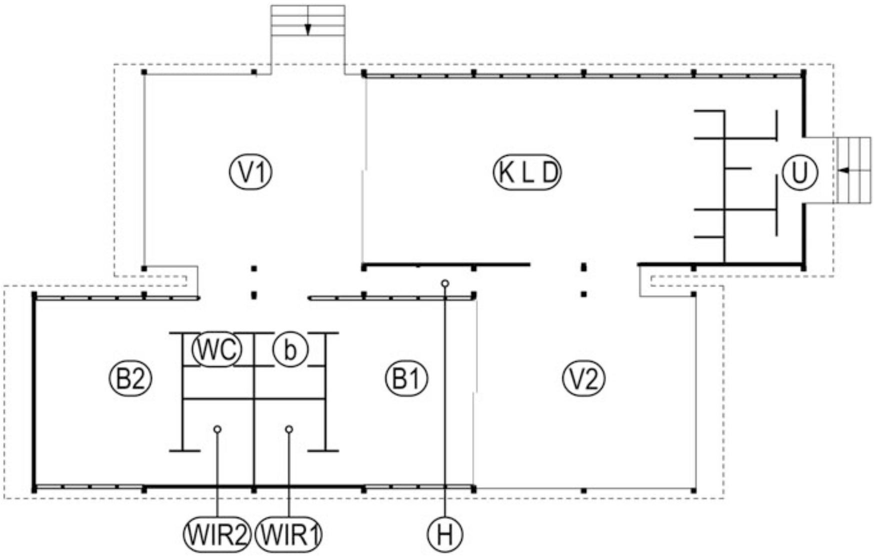


Fig. 7.2 *Marie Short House*, annotated plan

The plan graph of the *Marie Short House* (Fig. 7.3) reveals an unexpectedly complex, dual structure, with a circulation loop dominating the living pavilion and a bush-like section, rooted in the hallway, in the more private pavilion. Between these two, the hall provides a constant point of connection. While both more complex and structurally deep than might be anticipated from its exterior form, this spatial configuration is a reflection of two pavilions with different functions; a more flexible one for living and a more compartmentalised or cellular one for sleeping and bathing.

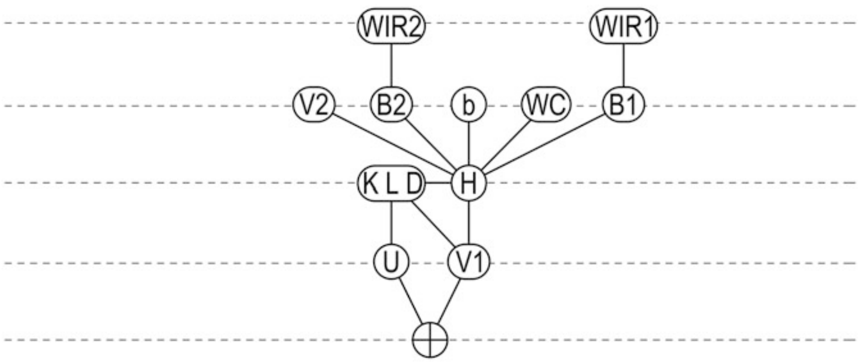


Fig. 7.3 *Marie Short House,* plan graph

Table 7.3 Marie Short House, data

Space	TD_n	MD_n	*RA*	*RRA*	i_{RRA}	*CV*
⊕	29	2.6364	0.3273	1.1488	0.8705	0.8333
V1	21	1.9091	0.1818	0.6382	1.5669	0.9762
K,L,D	21	1.9091	0.1818	0.6382	1.5669	0.9762
H	15	1.3636	0.0727	0.2553	3.9172	4.0000
U	29	2.6364	0.3273	1.1488	0.8705	0.8333
V2	23	2.0909	0.2182	0.7659	1.3057	0.4762
B2	22	2.0000	0.2000	0.7020	1.4244	1.6429
b	25	2.2727	0.2545	0.8935	1.1192	0.1429
WC	25	2.2727	0.2545	0.8935	1.1192	0.1429
B1	23	2.0909	0.2182	0.7659	1.3057	1.1429
WIR2	32	2.9091	0.3818	1.3403	0.7461	0.3333
WIR1	33	3.0000	0.4000	1.4041	0.7122	0.5000
Minimum	15	1.3636	0.0727	0.2553	0.7122	0.1400
Mean	24.8300	2.2576	0.2515	0.8829	1.3770	1.0000
Maximum	33	3.0000	0.4000	1.4041	3.9172	4.0000
H						0.9258
*H**						0.5738

The inequality genotype of the *Marie Short House* is: hallway (3.9172) > veranda 1 (1.5669) > combined kitchen, living, dining (1.5669) > bedroom 2 (1.4244) > veranda 2 (1.3057), bedroom 1 (1.3057) > bathroom and toilet (both 1.1192) > exterior and utility room (both 0.8705) > walk-in-wardrobe 2 (0.7461) > walk-in-wardrobe 1 (0.7122) (Table 7.3). What is notable in this inequality genotype is that the exterior is very low in the hierarchy, equal to the utility room and just above the two walk-in-wardrobes in terms of its role in the social structure of the house. This design may emphasise views to the exterior (visual connections) and a capacity to control some environmental conditions (breezes), but direct physical access is less important. An *H** measure of 0.5738 is in the middle range.

7.4.2 *Nicholas House, Blue Mountains, New South Wales, Australia (1980)*

Located in the Blue Mountains west of Sydney, the *Nicholas House* was designed as a country retreat. Like the *Marie Short House*, the *Nicholas House* has a two-pavilion *parti*, but the pavilions in the *Nicholas House* are unequally sized (Fig. 7.4). A semi-open plan living and eating area, as well as two ground floor bedrooms, dominate the larger, northern pavilion. A loft space, accessed by a narrow ladder, functions as a third bedroom. This living pavilion, like several of Murcutt's early rural houses, is slightly raised above the ground and is clad in

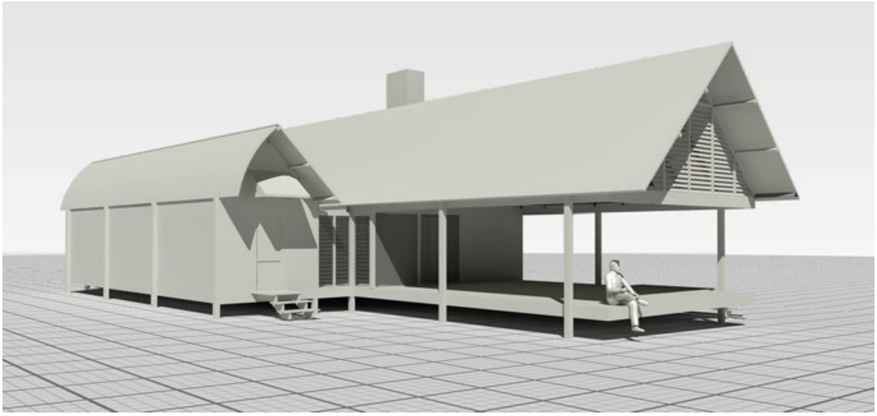


Fig. 7.4 *Nicholas House*, perspective view

timber and lined with glass louvres and cedar external blinds. The smaller, service pavilion includes the kitchen, bathroom and storage areas, and its south edge has a distinctive wall clad in corrugated iron and with a curved roof above. Whereas in the *Marie Short House* a defined corridor separates the two pavilions, in the *Nicholas House* the same zone (between the pavilions) is largely incorporated into the adjacent spaces, meaning that it does not function as a dedicated circulation area, but rather borrows from the surrounding spaces for this purpose (Fig. 7.5).

The *Nicholas House* poses several challenges for creating a functionally-defined plan graph, because of the lack of differentiation between the main semi-open areas. A previous attempt to produce a plan graph for this design merged the living and dining rooms into a single area, because both are visually connected (Ostwald 2011b). However, for this chapter we have taken into account the impact of the service wall and the adjacent columns and determined that the two should be separated, because these features effectively divide the space. The new plan graph of the *Nicholas House* is a shallow, loose structure with five loops, four of which involve only three spaces, the minimum number for a non-trivial loop (Fig. 7.6). Only the entry loop—encompassing the entrance, veranda, kitchen and living spaces—plays a more significant role. The lack of a functional corridor (akin to the one at the core of the *Marie Short House*) is responsible for the shallow depth and network of connections, including those between all three bedrooms and the dining room.

The inequality genotype of the *Nicholas House* is: dining (5.5000) > living and kitchen (both, 2.2000) > bathroom (1.8333) > alcove (1.3750) > exterior, bedroom 1, bedroom 2 and bedroom 3 (all, 1.1000) (Table 7.4). Significantly, the exterior is as isolated from the social functions of the house as the bedrooms, while the dining, living and kitchen spaces are at the core of the house's social structure. The H^* measure of 0.6180 is marginally towards the undifferentiated ($H^* > 0.5$) spectrum of indictors.

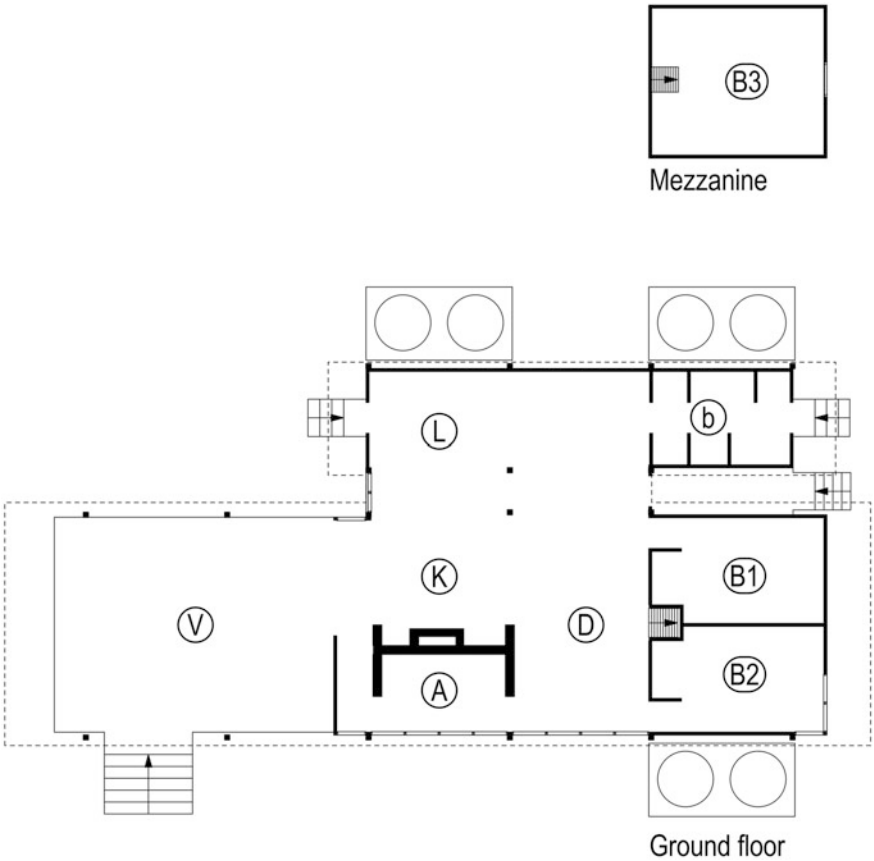


Fig. 7.5 *Nicholas House*, annotated plan

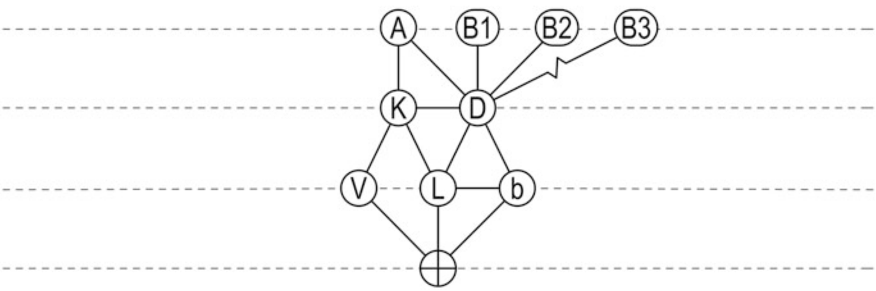


Fig. 7.6 *Nicholas House*, plan graph

Table 7.4 *Nicholas House*, data

Space	TD_n	MD_n	*RA*	*RRA*	i_{RRA}	*CV*
⊕	19	2.1111	0.2778	0.9091	1.1000	1.0833
V	19	2.1111	0.2778	0.9091	1.1000	0.5833
L	14	1.5556	0.1389	0.4545	2.2000	1.0595
b	15	1.6667	0.1667	0.5455	1.8333	0.7262
K	14	1.5556	0.1389	0.4545	2.2000	1.3929
D	11	1.2222	0.0556	0.1818	5.5000	4.3333
A	17	1.8889	0.2222	0.7273	1.3750	0.3929
B1	19	2.1111	0.2778	0.9091	1.1000	0.1429
B2	19	2.1111	0.2778	0.9091	1.1000	0.1429
B3	19	2.1111	0.2778	0.9091	1.1000	0.1429
Minimum	11	1.2222	0.0556	0.1818	1.1000	0.1429
Mean	16.600	1.8445	0.2111	0.6909	1.8608	1.0000
Maximum	19	2.1111	0.2778	0.9091	5.5000	4.3333
H						0.9437
*H**						0.6180

7.4.3 Carruthers House, Blue Mountains, New South Wales, Australia (1980)

Located on the site adjacent to the *Nicholas House*, the *Carruthers House* is, at first glance, even more straightforward in its formal expression and planning (Fig. 7.7). Fromonot describes it as a 'simple timber barn roofed with corrugated iron' (2006: 112). With the exception of its chimney, the single pavilion is elevated on posts above the ground plane. Internally it is divided into two sections, the north edge, which contains the main circulation space and a sitting room open to the landscape, and the south edge, where bedrooms, a bathroom and a kitchen are located. At one end of the pavilion there is a loft bedroom while at the other, the living area has a

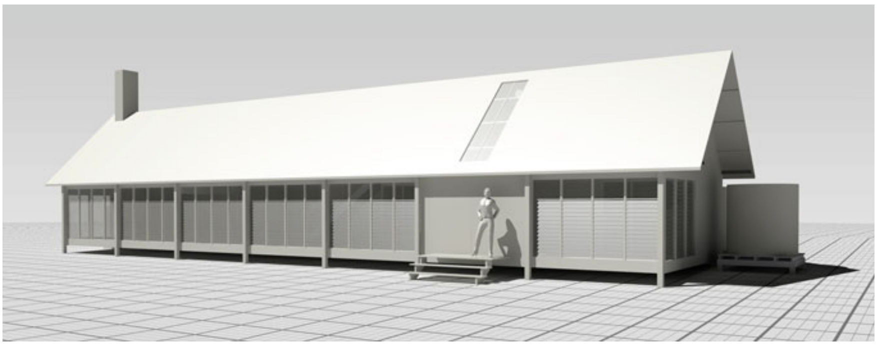


Fig. 7.7 *Carruthers House*, perspective view

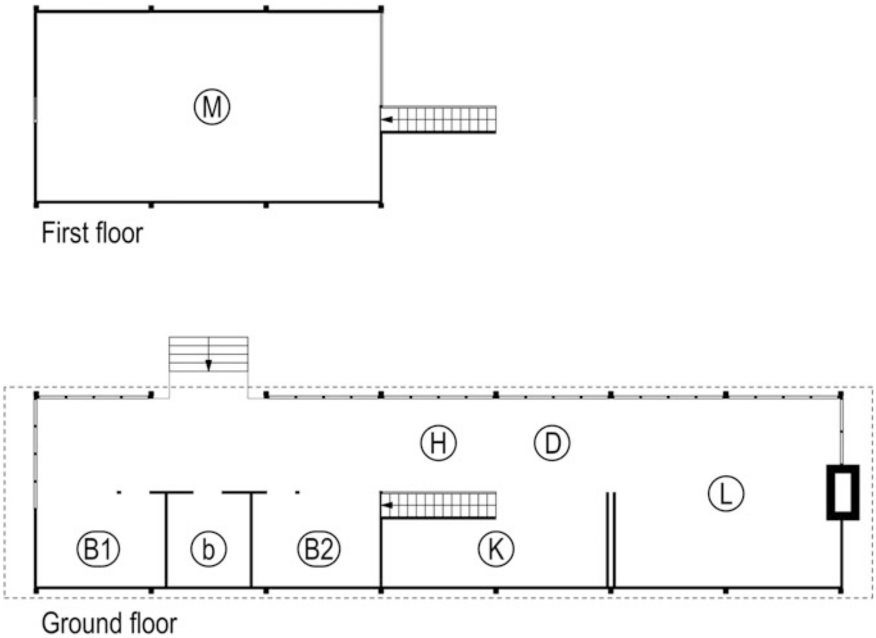


Fig. 7.8 *Carruthers House*, annotated plan

large, double height space (Fig. 7.8). Externally, the south wall is largely without openings, protecting the interior from winter winds, and there are four elevated rainwater collection tanks.

A visual analysis of the plan graph of the *Carruthers House* reveals a shallow, nested 'bush-like" structure with its primary 'root' in the hallway and its secondary 'root' in the dining room (which is really an extension of the hallway spatially, but because of the placement of furniture and the mezzanine above, operates as a separate zone). This is the only one of the houses analysed in the present chapter where there are no loops in the graph (Fig. 7.9).

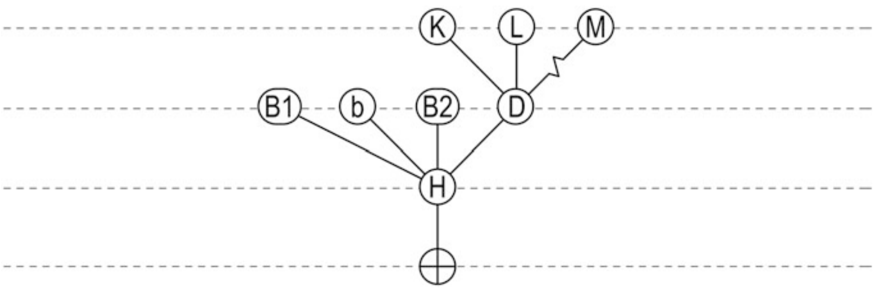


Fig. 7.9 *Carruthers House*, plan graph

Table 7.5 *Carruthers House*, data

Space	TD_n	MD_n	*RA*	*RRA*	i_{RRA}	*CV*
⊕	18	2.2500	0.3571	1.1274	0.8870	0.2000
H	11	1.3750	0.1071	0.3382	2.9567	4.2500
B1	18	2.2500	0.3571	1.1274	0.8870	0.2000
b	18	2.2500	0.3571	1.1274	0.8870	0.2000
B2	18	2.2500	0.3571	1.1274	0.8870	0.2000
D	12	1.5000	0.1429	0.4509	2.2176	3.2000
K	19	2.3750	0.3929	1.2401	0.8064	0.2500
L	19	2.3750	0.3929	1.2401	0.8064	0.2500
M	19	2.3750	0.3929	1.2401	0.8064	0.2500
Minimum	11	1.3750	0.1071	0.3382	0.8064	0.2000
Mean	16.8900	2.1111	0.3175	1.0021	1.2379	1.0000
Maximum	19	2.3750	0.3929	1.1274	2.9567	4.2500
H						0.9857
*H**						0.7216

The inequality genotype of the *Carruthers House* is: hallway (2.9567) > dining room (2.2176) > exterior, bedroom 1, bathroom, bedroom 2 (all, 0.8870) > kitchen, living room and music room (all, 0.8064) (Table 7.5). With seven of the nine spaces in this house being grouped into just two levels of integration, only the hallway and dining spaces are especially significant in the social structure of the plan. These are also the only spaces with integration levels higher than the mean (1.2379). The high *H** measure, 0.7216, confirms the undifferentiated quality of the plan.

There is an interesting phenomenological account of the experience of this house that reflects some of these results. Drew observes that upon entry to the house, the visitor is drawn into the 'the pine tube' of the primary volume, which is interrupted by three inserted planes; 'one which separates the living room from the kitchen … one on the left of the stair, and another, below the left floor deck in line with the bedrooms, run parallel with the axis of the pavilion' (1985: 96). The impact of these three spatial dividers is to lead the visitor to the sense that the space is 'surge[ing] back and forth like a stream encountering boulders in its course' (1985: 96). The high control values for the hallway (*CV* = 4.2500) and the dining room (*CV* = 3.2000) suggest a strong linear 'pull' through the plan that is interrupted by a series of side rooms, some irregularly placed, with much lower control values.

7.4.4 *Fredericks House, Jambaroo, New South Wales, Australia (1982)*

The *Fredericks House* is located south of Sydney and slightly inland from the coast. While the design has a twin-pavilion cross-section reminiscent of that of the *Marie Short House*, in this case the pavilions have different floor areas (Fig. 7.10). Both

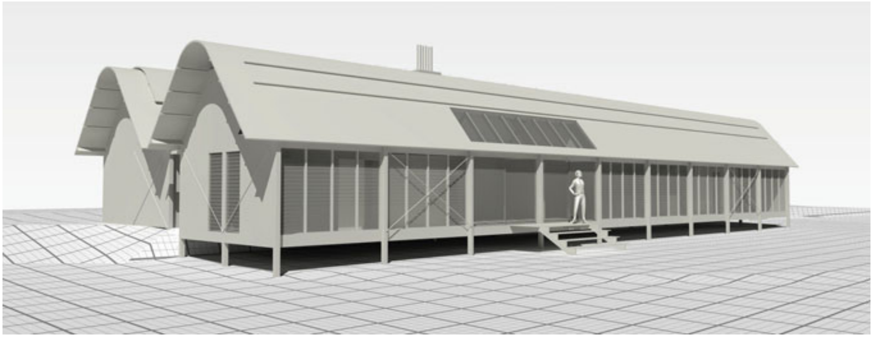


Fig. 7.10 *Fredericks House*, perspective view

pavilions are timber, post and beam structures, with external western red cedar cladding. Murcutt describes the house as having 'a very ordinary plan … like a railway carriage' (qtd. in Beck and Cooper 2002: 77). A pre-existing chimney structure anchors one side of the plan to the site, with its central kitchen, dining and living spaces, while at the two ends of the pavilion there are bedroom, bathroom and service spaces (Fig. 7.11). Significantly, this house has two loft-bedrooms that are rarely depicted in photographs or plans. Beck and Cooper argue that Murcutt's reluctance to acknowledge these spaces may be because they introduce a 'dynamic spatial condition' into the plan that 'disturbs [its] serenity' (2002: 76). Drew describes the *Fredericks House* as 'the finest of Murcutt's series of long houses' (1985: 121).

The *Fredericks House* plan graph reveals a pair of loops at the base, leading to three 'bush-like' zones, centred on the living room, hallway 2 and the garage (Fig. 7.12). This is the third of Murcutt's houses to feature a combination of a flexible public space configuration leading to more hierarchically planned, private spaces.

The inequality genotype of the *Fredericks House* is: hallway 2 (1.5692) > living room (1.3846) > exterior (1.3076) > garage (1.1208) > combined kitchen, living and dining spaces (1.0699) > bedroom 2, studio 1 and bedroom 3 (all 0.8406) > hallways 1 (0.8116) > laundry, study 2 and bedroom 4 (all 0.6923) > bedroom 1, walk-in-wardrobe and bathroom (all 0.5604). Only five of the fifteen spaces are above the mean integration measure, which confirms that there are a small number of highly connected spaces skewing the mean (Table 7.6). Notably, this is the first of the Murcutt houses considered thus far wherein the exterior is amongst the group of most integrated spaces. With $H^* = 0.8087$, the plan graph has only a low level of spatial differentiation.

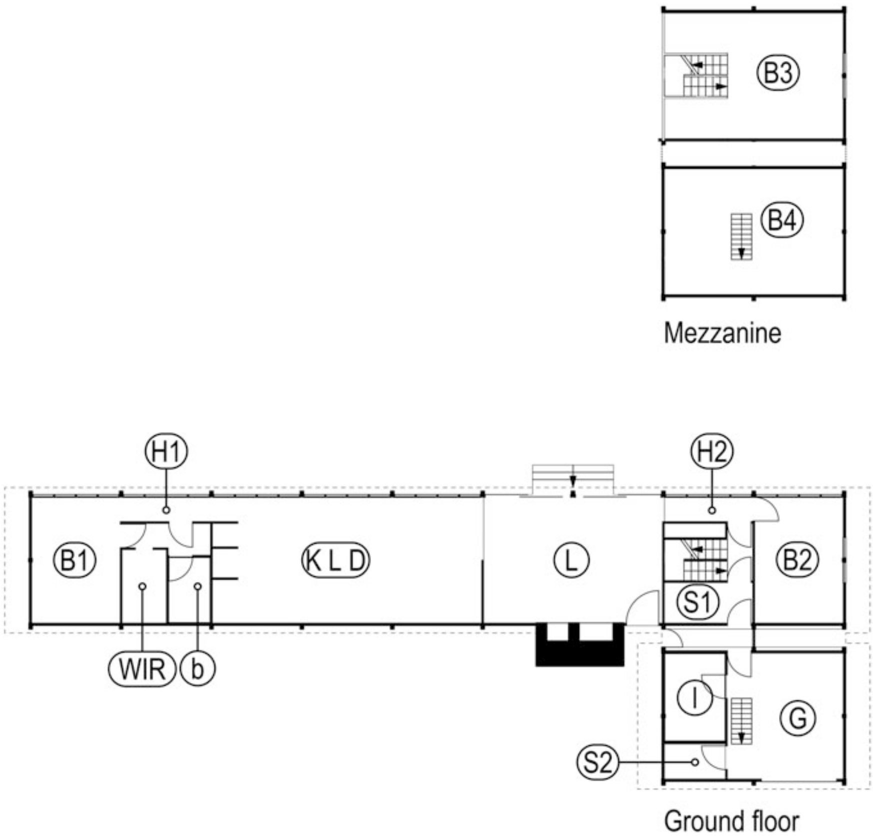


Fig. 7.11 *Fredericks House*, annotated plan

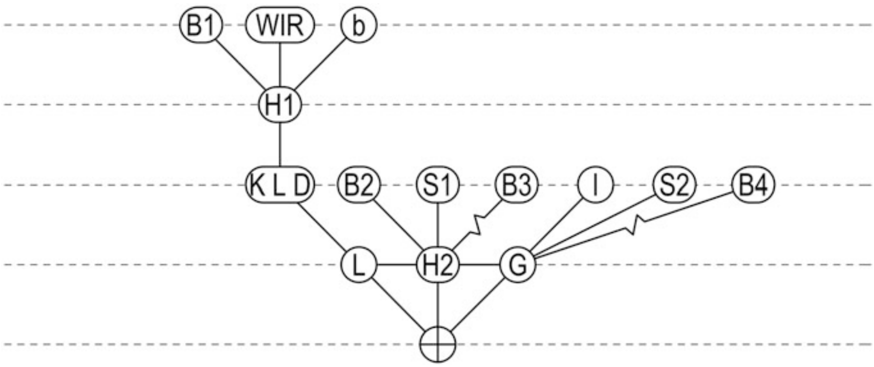


Fig. 7.12 *Fredericks House*, plan graph

Table 7.6 *Fredericks House*, data

Space	TD_n	MD_n	*RA*	*RRA*	i_{RRA}	*CV*
⊕	32	2.2857	0.1978	0.7647	1.3076	0.7000
L	31	2.2143	0.1868	0.7223	1.3846	1.0000
K,L,D	36	2.5714	0.2418	0.9347	1.0699	0.5833
H1	43	3.0714	0.3187	1.2321	0.8116	3.5000
B1	56	4.0000	0.4615	1.7844	0.5604	0.2500
WIR	56	4.0000	0.4615	1.7844	0.5604	0.2500
b	56	4.0000	0.4615	1.7844	0.5604	0.2500
H2	29	2.0714	0.1648	0.6373	1.5692	3.8667
B2	42	3.0000	0.3077	1.1896	0.8406	0.1667
S1	42	3.0000	0.3077	1.1896	0.8406	0.1667
B3	42	3.0000	0.3077	1.1896	0.8406	0.1667
G	35	2.5000	0.2308	0.8922	1.1208	3.5000
l	48	3.4286	0.3736	1.4445	0.6923	0.2000
S2	48	3.4286	0.3736	1.4445	0.6923	0.2000
B4	48	3.4286	0.3736	1.4445	0.6923	0.2000
Minimum	29	2.0714	0.1648	0.6373	0.5604	0.1667
Mean	42.9300	3.0667	0.3179	1.2293	0.9029	1.0000
Maximum	56	4.0000	0.4615	1.7844	1.5692	3.8667
H						1.0210
*H**						0.8087

7.4.5 Ball-Eastaway House, Glenorie, New South Wales, Australia (1982)

Designed as a home and private gallery for the artists Syd Ball and Lyn Eastaway, this house is sited on a series of sandstone ledges near a wooded reserve to the northwest of Sydney. The house has a distinct, 'train carriage' plan with 'a simple arrangement of rooms located beneath the gentle barrel-vaulted ceiling' (MacMahon 2001: 122). The train carriage analogy is emphasised externally by the fact that the building sits above the ground, as if raised on wheels, and is clad in corrugated steel, with exposed industrial detailing (Fig. 7.13). Elizabeth Farrelly describes this design, which is visually '[o]pen at both ends', as having an 'extruded form' which is 'emphatically directional' (1993: 21). While this building is a departure from Murcutt's previous aesthetic and tectonic practices, in planning terms it has some similarities to the previous four works (Fig. 7.14). Furthermore, despite often being left out of recent publications on Murcutt's architecture—perhaps because it is less easy to categorise it as a regionalist design—Fromonot describes the house as 'one of Murcutt's most successful buildings' (1995: 84).

The plan graph of the house has only one non-trivial loop: from the hallway to the dining room, living room, kitchen and back again. This loop is also situated deeper in the plan than might be anticipated from a review of the spatial configurations of the previous houses. Furthermore, eight of the eleven spaces in the graph are connected to the hallway. In combination, these features suggest a social structure that has some similarities to the *Carruthers House*, but more substantial differences with the other early works (Fig. 7.15).

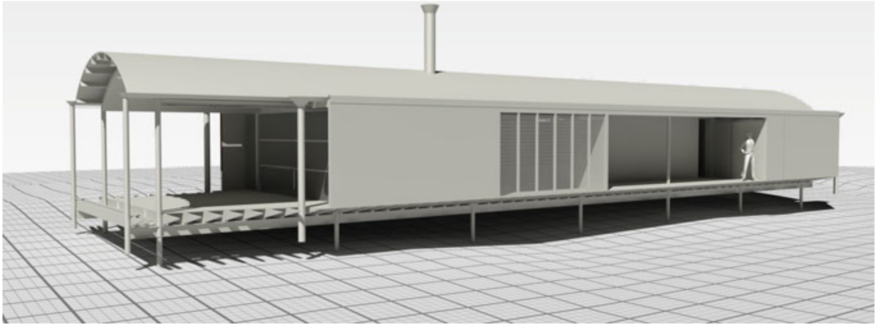


Fig. 7.13 *Ball-Eastaway House*, perspective view

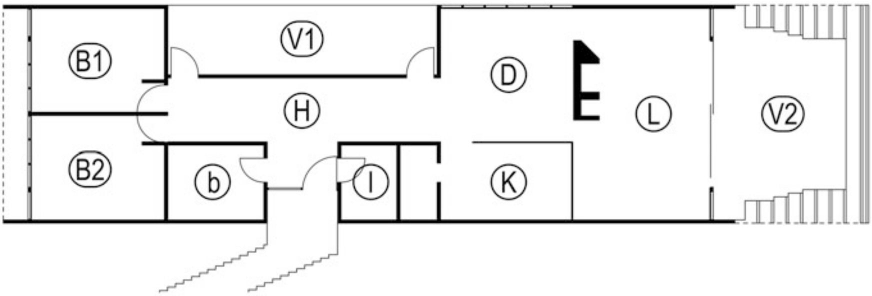


Fig. 7.14 *Ball-Eastaway House*, annotated plan

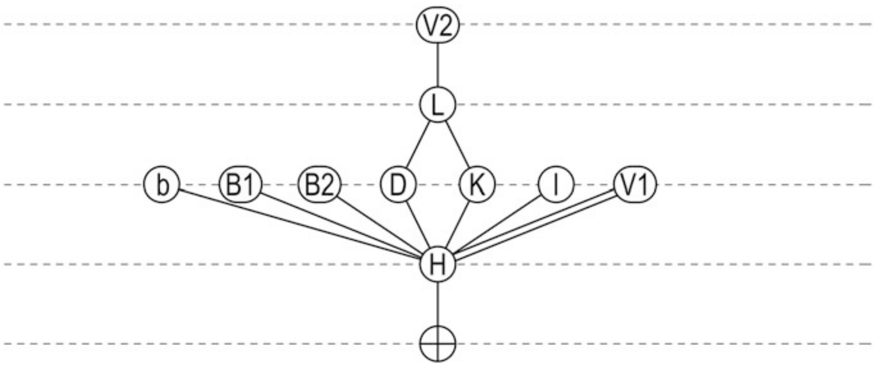


Fig. 7.15 *Ball-Eastaway House*, plan graph

Table 7.7 *Ball-Eastaway House*, data

Space	TD_n	MD_n	*RA*	*RRA*	i_{RRA}	*CV*
⊕	22	2.2000	0.2667	0.9043	1.1059	0.1250
H	13	1.3000	0.0667	0.2261	4.4234	7.0000
b	22	2.2000	0.2667	0.9043	1.1059	0.1250
B1	22	2.2000	0.2667	0.9043	1.1059	0.1250
B2	22	2.2000	0.2667	0.9043	1.1059	0.1250
V1	22	2.2000	0.2667	0.9043	1.1059	0.1250
l	22	2.2000	0.2667	0.9043	1.1059	0.1250
D	18	1.8000	0.1778	0.6029	1.6588	0.4583
K	18	1.8000	0.1778	0.6029	1.6588	0.4583
L	23	2.3000	0.2889	0.9796	1.0208	2.0000
V2	32	3.2000	0.4889	1.6578	0.6032	0.3333
Minimum	13	1.3000	0.0667	0.2261	0.6032	0.1250
Mean	21.45	2.1455	0.2546	0.8632	1.4546	1.0000
Maximum	32	3.2000	0.4889	1.6578	4.4234	7.0000
H						0.8739
*H**						0.4459

The inequality genotype for the *Ball-Eastaway House* is: hallway (4.4234) > dining room and kitchen (both 1.6588) > exterior, bedroom 1, bedroom 2, veranda 1, bathroom and laundry (all 1.1059) > living room (1.0208) > veranda 2 (0.6032). Only three of the eleven spaces in this house have integration levels above the mean (1.4546) and the living room and veranda 2 are isolated from the remainder of the house (Table 7.7). The control value of the hallway (*CV* = 7.0000) emphasises just how important it is in the structure of the house, with the living space being the next most significant (*CV* = 2.00) and the remainder having negligible influence (0.4583 > *CV* > 0.1250). The *H** measure of 0.4459 for the plan graph is marginally less then 0.5, suggesting that the graph is both slightly more deliberate in its structure than a generic graph of a similar size, and confirming that it is the most differentiated of any of the early Murcutt houses.

7.4.6 Magney House, Bingie Bingie, New South Wales, Australia (1984)

The *Magney House* is located on an isolated site on the plains south of Sydney, with the ocean to the east and distant mountain views to the west (Fig. 7.16). With its linear pavilion form and asymmetrical, butterfly roof, the design has 'a peculiarly aeronautic character' (Frampton 2006: 68). Planned according to Murcutt's 'protective back and open front organisational strategy' (Gusheh et al. 2008: 147), the house is more visually open to the north, whereas the south elevation is enclosed to protect it from winter winds. A wide service wall runs the length of the south side of the plan, which is coupled with an adjoining access corridor connecting the entire house (Fig. 7.17).

Fig. 7.16 *Magney House*, perspective view

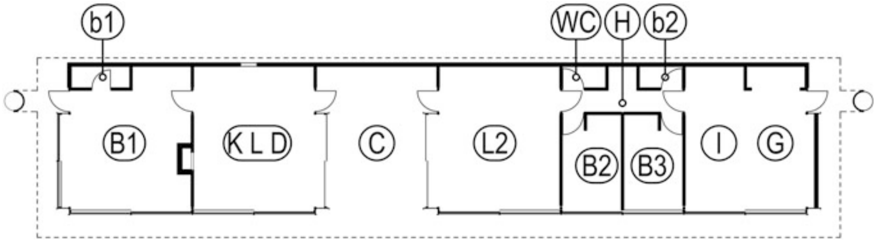


Fig. 7.17 *Magney House*, annotated plan

The *Magney House* plan graph has three loops embedded in an otherwise arborescent schema, the first connecting the exterior to the courtyard, then to the kitchen-living-dining area, then to bedroom 1 and finally back to the exterior. The second also commences with the exterior and the courtyard, then living room 2, hallway and laundry before returning to the exterior. The final loop connects the exterior to the garage, laundry, and then back to the exterior. All three could also be described as 'partial' or 'artificial' loops because, despite the strict nomenclature of the method wherein all exteriors are treated as the same, the exterior spaces where these loops start are often in the middle of the plan, while the ones that complete the loops are at the ends. Within the overall plan, there is also a sub-instance of 'bush-like' structure where living room 2 enters a hall, which controls access to two bedrooms and a bathroom. Overall, the planning diagram could be said to reveal the vestigial planning of two partial houses, one nested within the other (Fig. 7.18).

The inequality genotype for the *Magney House* is: exterior and laundry (both 1.5154) > hallway (1.2123) > garage (1.0697) > bedroom 1 and C (both 0.9571) > combined kitchen, dining living, and bedroom 2, and bedroom 3, bathroom 2, toilet, (all 0.6994), > bedroom 1 and living 2 (both 0.6062). This is the first of Murcutt's houses where the exterior is equally high in terms of its social

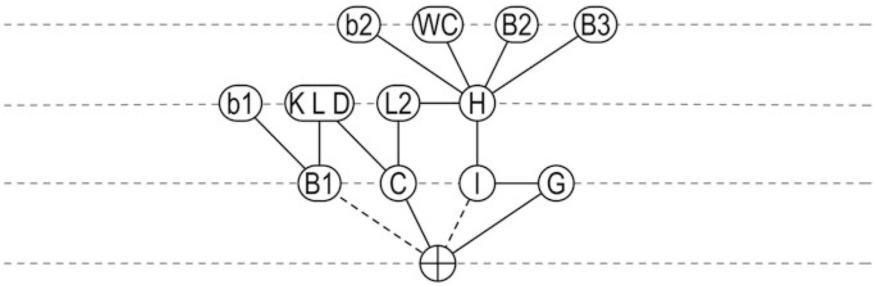


Fig. 7.18 *Magney House*, plan graph

Table 7.8 *Magney House*, data

Space	TD_n	MD_n	*RA*	*RRA*	i_{RRA}	*CV*
⊕	24	2.0000	0.1818	0.6599	1.5154	1.5000
B1	31	2.5833	0.2879	1.0448	0.9571	1.7500
b1	42	3.5000	0.4545	1.6497	0.6062	0.3333
K,L,D	38	3.1667	0.3939	1.4297	0.6994	0.6667
C	31	2.5833	0.2879	1.0448	0.9571	1.7500
L2	42	3.5000	0.4545	1.6497	0.6062	0.3333
l	24	2.0000	0.1818	0.6599	1.5154	0.9500
H	27	2.2500	0.2273	0.8249	1.2123	4.3333
WC	38	3.1667	0.3939	1.4297	0.6994	0.2000
b2	38	3.1667	0.3939	1.4297	0.6994	0.2000
B2	38	3.1667	0.3939	1.4297	0.6994	0.2000
B3	38	3.1667	0.3939	1.4297	0.6994	0.2000
G	29	2.4167	0.2576	0.9348	1.0697	0.5833
Minimum	24	2.0000	0.1818	0.6599	0.6062	0.2000
Mean	33.8462	2.8205	0.3310	1.2013	0.9182	1.0000
Maximum	42	3.5000	0.4545	1.6497	1.5154	3.8333
H						1.0360
*H**						0.8456

significance in the plan. However, an H^* result of 0.8456 signifies a plan with a high degree of homogeneity, which also suggests a low level of determination or deliberation (Table 7.8).

7.4.7 *Simpson-Lee House, Mount Wilson, New South Wales, Australia (1994)*

The *Simpson-Lee House* is a double pavilion residence, sited on a rock ledge overlooking an escarpment of the Blue Mountains, northwest of Sydney (Fig. 7.19).

According to Fromonot, the client brief was for ‘a sanctuary for a retired couple’ (1995: 206). Orientated to the east, the larger of the pavilions contains two bedrooms that are separated by a central living area (Fig. 7.20). The smaller pavilion, which angles in plan around the rock ledge towards the northeast, combines a garage with a pottery studio. As both pavilions are linear and have mono-pitch roofs that rise up in the direction of the primary views, the house corresponds to what Drew describes as ‘Murcutt’s development of an essentially linear typology where the chief variable is the section and roof profile’ (1985: 150).

A visual analysis of the plan graph of the *Simpson-Lee House* reveals a largely arborescent structure, with two loops. The first starts with the exterior, which connects, in turn, through hallway 1, living, dining and hallway 2 before returning to the exterior. The second connects the living, dining and kitchen spaces. Once again, the first of these loops does not passes through the same exterior door, so the ‘ringiness’ in the plan could be regarded as an artefact of the method, whereas the ‘lived’ structure of the house is a tree with a network of cross-connected branches (Fig. 7.21).

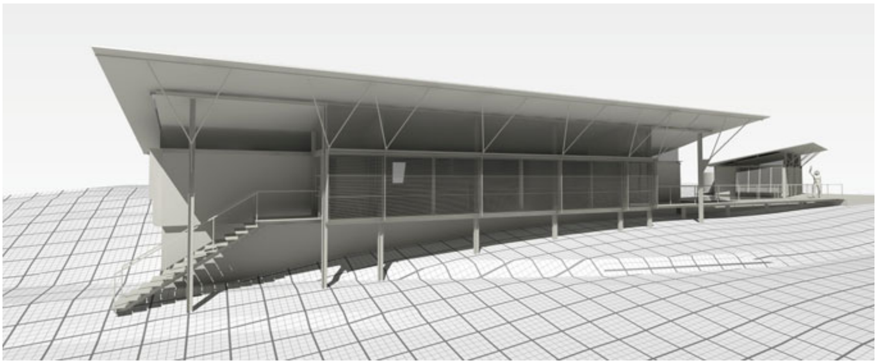


Fig. 7.19 *Simpson-Lee House*, perspective view

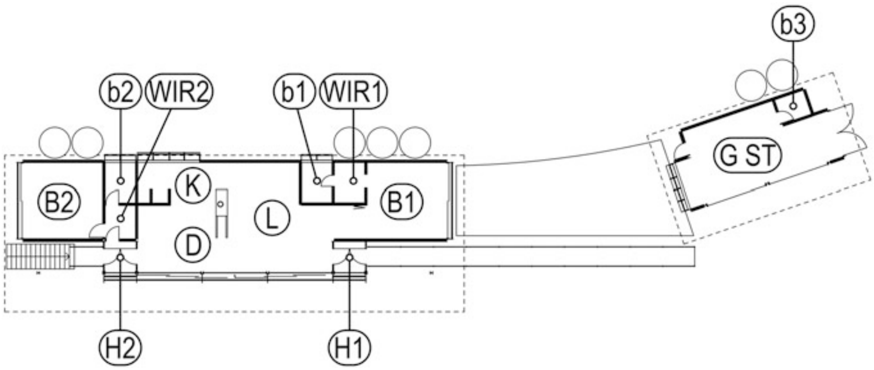


Fig. 7.20 *Simpson-Lee House*, annotated plan

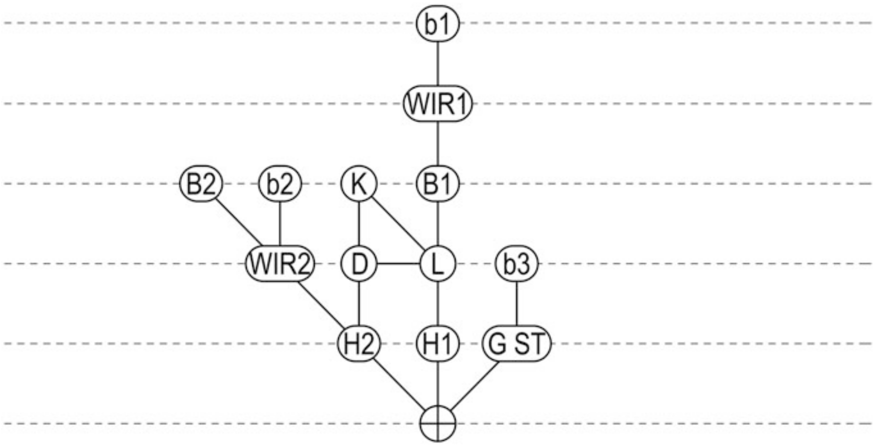


Fig. 7.21 *Simpson-Lee House*, plan graph

For the *Simpson-Lee House*, the inequality genotype is: hallway 2 (1.2241) > living and dining (both 1.1561) > the exterior (1.0953) > hallway 1 (1.0405) > kitchen and walk-in-wardrobe 2 (both 0.8324) > bedroom 1 (0.8004) > the combined garage and studio (0.7176) > walk-in-wardrobe 1 (0.5781) > bedroom 2 and bathroom 2 (both 0.5624) > bathroom 3 (0.5076 > and bathroom 1 (0.4336).

Seven of these spaces are above the mean integration measure (0.8214) and seven below, which implies that this design is more balanced in its distribution than the earlier Murcutt houses. Notably, the exterior is highly integrated, and given that a person has to move outside to pass between the two pavilions that make up this plan, and each pavilion has alternative routes to the exterior, this result is not surprising. Some of the minor anomalies in this set of results include the relatively high level for bedroom 1 (i = 0.8004) and a result for the second walk-in-robe (i = 0.8324), which is matches the kitchen and exceeds the mean (i = 0.8214). An H* value of 0.7986 suggests a looseness or weakness in the planning structure (Table 7.9).

7.4.8 *Fletcher-Page House, Kangaroo Valley, New South Wales, Australia (1998)*

The *Fletcher-Page House* is another linear design, this time on sloping grassland in the hills of Kangaroo Valley, south of Sydney (Fig. 7.22). This house is slightly smaller than the *Simpson-Lee House*, having only nine habitable zones in comparison with the latter's thirteen. However, the house is unusual in this sequence, as its roof is tilted upwards to the north (parallel to the slope of the hillside), which

Table 7.9 *Simpson-Lee House*, data

Space	TD_n	MD_n	*RA*	*RRA*	i_{RRA}	*CV*
⊕	32	2.4615	0.2436	0.9130	1.0953	1.3333
H2	30	2.3077	0.2179	0.8169	1.2241	1.0000
WIR2	38	2.9231	0.3205	1.2013	0.8324	2.3333
B2	50	3.8462	0.4744	1.7779	0.5624	0.3333
b2	50	3.8462	0.4744	1.7779	0.5624	0.3333
H1	33	2.5385	0.2564	0.9611	1.0405	0.5833
L	31	2.3846	0.2308	0.8649	1.1561	1.8333
D	31	2.3846	0.2308	0.8649	1.1561	1.0833
K	38	2.9231	0.3205	1.2013	0.8324	0.5833
B1	39	3.0000	0.3333	1.2494	0.8004	0.7500
WIR1	49	3.7692	0.4615	1.7299	0.5781	1.5000
b1	61	4.6923	0.6154	2.3065	0.4336	0.5000
G ST	42	3.2308	0.3718	1.3935	0.7176	1.3333
b3	54	4.1538	0.5256	1.9702	0.5076	0.5000
Minimum	30	2.3077	0.2179	0.8169	0.4336	0.3333
Mean	41.2857	3.1758	0.3626	1.3592	0.8214	1.0000
Maximum	61	4.6923	0.6154	2.3065	1.2241	2.3333
H						1.0169
*H**						0.7986

Fig. 7.22 *Fletcher-Page House*, perspective view

leaves the northern elevation partly hidden by the slope. In response to this, on the southern side of the house, large openings are positioned toward the primary views. This tension between the desire to capture views and the need to control sunlight access gives this house an unusual spatial quality, in the context of the remainder of Murcutt's rural works. Frampton also observes that 'long views through the house … impart a sense of grandeur that totally belies its restricted dimensions' (2006: 86). In this design, Murcutt also replaces his typical corridor planning strategy with a series of connecting doors along the southern length of the plan, to enclose each

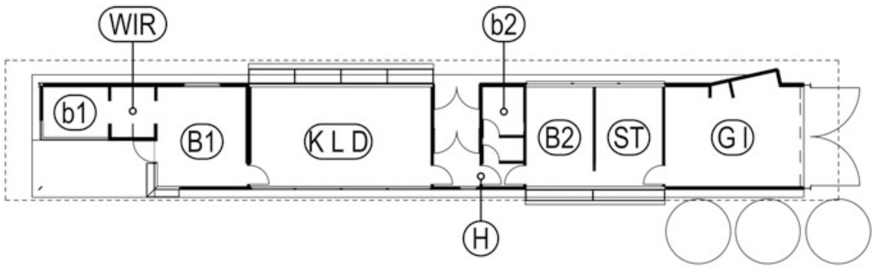


Fig. 7.23 *Fletcher-Page House*, annotated plan

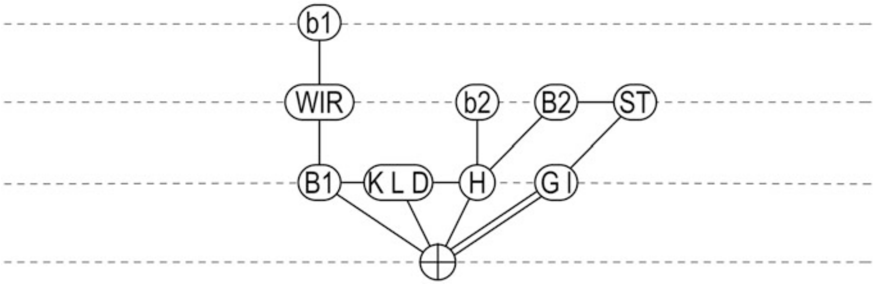


Fig. 7.24 *Fletcher-Page House*, plan graph

room. A deep entry space in the middle divides the house into two zones, creating west and east sides. To the east are the garage, study and bedroom 2, whilst to the west are the kitchen, the main bedroom with en-suite and a private veranda (Fig. 7.23).

The plan graph for the *Fletcher-Page House* reveals a partial tree structure with three loops, all of which are reliant on exterior connections (Fig. 7.24). With four exterior doors (including the garage), these loops are relatively consistent with the pattern established across the previous three houses. However, unlike the *Magney* and *Simpson-Lee* houses, this one has two relatively straightforward sides to the configuration—rather than the more complex, nested topology of the previous two—reflecting the dominant east-west division in the plan.

The inequality genotype for the *Fletcher-Page House* is: exterior (1.8333) > combined kitchen, living and dining room and the hallway (both 1.3750) > bedroom 1 (1.2222) > combined garage and laundry (1.0000) > bedroom 2 (0.8462) > studio and walk-in-wardrobe (both 0.7333) > bathroom 2 (0.6875) > bathroom 1 (0.4783). This is the first of the Murcutt genotypes where the exterior is the sole highest result (Table 7.10). The H^* measure of 0.6764 is slightly more balanced than the results for the previous two houses, although it still indicates a lack of configurational determination.

Table 7.10 *Fletcher-Page House*, data

Space	TD_n	MD_n	*RA*	*RRA*	i_{RRA}	*CV*
⊕	15	1.6667	0.1667	0.5455	1.8333	1.4167
B1	18	2.0000	0.2500	0.8182	1.2222	1.0833
WIR1	24	2.6667	0.4167	1.3636	0.7333	1.3333
b1	32	3.5556	0.6389	2.0909	0.4783	0.5000
K,L,D	17	1.8889	0.2222	0.7273	1.3750	0.8333
H	17	1.8889	0.2222	0.7273	1.3750	2.0833
b2	25	2.7778	0.4444	1.4545	0.6875	0.2500
G 1	20	2.2222	0.3056	1.0000	1.0000	0.7500
ST	24	2.6667	0.4167	1.3636	0.7333	1.0000
B2	22	2.4444	0.3611	1.1818	0.8462	0.7500
Minimum	15	1.6667	0.1667	0.5455	0.4783	0.2500
Mean	21.4	2.3778	0.3445	1.1273	1.0284	1.0000
Maximum	32	3.5556	0.6389	2.0909	1.8333	1.4167
H						0.9674
*H**						0.6764

7.4.9 Southern Highlands House, Kangaloon, New South Wales, Australia (2001)

This large dwelling is located in the farming community of Kangaloon, which is part of the Southern Highlands district of Sydney. Standing amongst tall trees, the house is sited on agricultural land and is orientated to the north. To shelter it from severe winds, the house has a protective shield in the form of a curved metal plane along the entire length of the southern elevation. Entry points to the house are located at both the east and west ends of the plan, with the west lobby being the formal entry into the zone between the protective shield and the inner volume. Within this curved plane of the south elevation, runs a long gallery (hallway 1) that links a series of rooms. Dividing the sleeping areas of the parents and children between east and west, the communal spaces that face an external northern terrace occupy the centre of the house (Fig. 7.25).

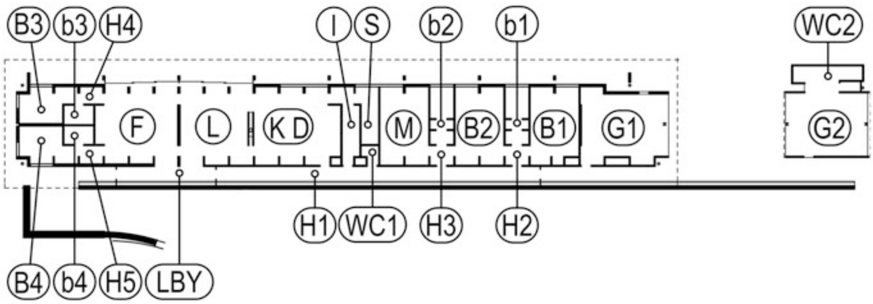


Fig. 7.25 *Southern Highlands House*, annotated plan

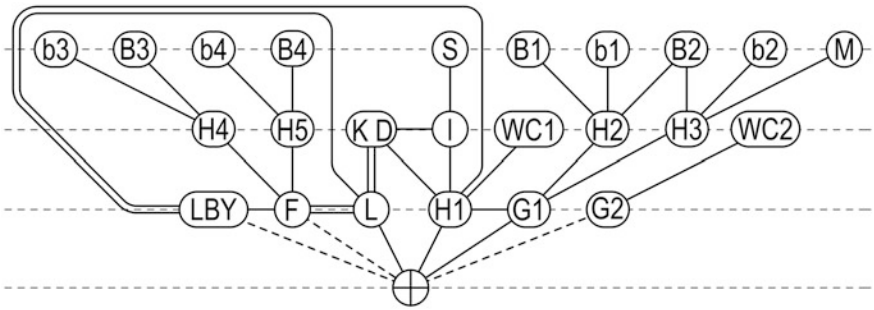


Fig. 7.26 *Southern Highlands House*, plan graph

With twenty-five spaces—and ten exterior doors—this is the most complex of Murcutt's houses examined here (Fig. 7.26). Importantly, despite its linear plan form, much of which is connected by a single-loaded corridor, the house has ten non-trivial loops, six of which involve the exterior. This plan is further complicated by a parallel circulation system, made up of a series of short corridors that are effectively 'airlocks' between spaces. An airlock is an intermediate zone for controlling or isolating the impact of temperature and weather in a plan. The plan also features some partial tree-like sections, mostly involving bedrooms and bathrooms. Overall, if the airlocks and dual roots are ignored, this plan could be considered a much larger variation of the previous three, with a rhizomorphous base (comprising a set of eight loops), and a more arborescent interior (made up of a series of bush-like formations). However, including the airlocks, this large house actually has no instances of bush-like configuration, because the majority of branches are part of loops.

The inequality genotype for the *Southern Highlands House* is: exterior (1.9731) > garage 1 (1.7625) > hallway 1 (1.6249) > foyer (1.5346) lobby > (1.4539) > living (1.4155) > combined kitchen and dining (1.2010) > garage 2, hallways 2 and 3 (1.1275) > laundry (1.0424) > hallways 5 and 4 (1.0045) > toilet 1 (0.9692) > bedroom 2 (0.8370) > toilet 2, music room, bedroom 1 and bathrooms 1 and 2 (0.7673) > storage (0.7269) > bedroom 3 and 4, and bathroom 3 and 4 (0.7083).

Once again, like the *Fletcher-Page House*, the exterior has the highest individual integration result. Of the twenty-five spaces, only ten are above the mean (1.0627), confirming a marginally skewed relationship, where just over one third of the spaces dominate the plan configuration. Multiple spaces in the *Southern Highlands House* also have total depths of over 100, including the storeroom (*TD* = 100), bedrooms 3 and 4 and bathrooms 3 and 4 (all *TD* = 102) (Table 7.11). The *H** result of 0.8310 is within a comparable range to those of the previous houses, confirming a similarly loose or generic planning quality, which is perhaps an accurate reflection of a design with sixteen loops in its spatial configuration. Indeed, many parts of this house resemble an open lattice, with a multitude of possible routes through and around them.

Table 7.11 *Southern Highlands House*, data

Space	TD_n	MD_n	*RA*	*RRA*	i_{RRA}	*CV*
⊕	52	2.1667	0.1014	0.5068	1.9731	1.6167
LBY	62	2.5833	0.2826	0.6878	1.4539	0.7833
F	60	2.5000	0.2826	0.6516	1.5347	1.3333
H4	79	3.2917	0.2826	0.9955	1.0045	2.2000
b3	102	4.2500	0.2826	1.4118	0.7083	0.3333
B3	102	4.2500	0.2754	1.4118	0.7083	0.3333
H5	79	3.2917	0.2609	0.9955	1.0045	2.2000
b4	102	4.2500	0.2609	1.4118	0.7083	0.3333
B4	102	4.2500	0.2609	1.4118	0.7083	0.3333
L	63	2.6250	0.2609	0.7059	1.4166	0.9500
K,D	70	2.9167	0.2609	0.8326	1.2010	0.7500
H1	58	2.4167	0.2391	0.6154	1.6249	2.3333
l	77	3.2083	0.2065	0.9593	1.0424	1.5000
S	100	4.1667	0.1993	1.3756	0.7269	0.3333
G1	56	2.3333	0.1993	0.5792	1.7265	0.8333
WC1	81	3.3750	0.1920	1.0317	0.9693	0.1667
H2	73	3.0417	0.1775	0.8869	1.1275	2.7500
B1	96	4.0000	0.1775	1.3032	0.7673	0.2500
b1	96	4.0000	0.1775	1.3032	0.7673	0.2500
B2	90	3.7500	0.1667	1.1946	0.8371	0.5000
H3	73	3.0417	0.1413	0.8869	1.1275	2.7500
b2	96	4.0000	0.1377	1.3032	0.7673	0.2500
M	96	4.0000	0.1304	1.3032	0.7673	0.2500
G2	73	3.0417	0.1232	0.8869	1.1275	1.1667
WC2	96	4.0000	0.1159	1.3032	0.7673	0.5000
Minimum	52	2.3334	0.1014	0.5068	0.7083	0.1667
Mean	81.3600	3.3900	0.2078	1.0382	1.0097	1.0000
Maximum	102	4.2500	0.2826	1.4118	1.9731	2.7500
H						1.0228
*H**						0.8130

7.4.10 Walsh House, Kangaroo Valley, New South Wales, Australia (2005)

The principle frontage of the *Walsh House* addresses a series of striking views across the Kangaroo Valley to the north, while the east face is directed towards a large rock formation. The roofline of the house is tilted up to the north, and extends past the high northern windows in order to protect them from the summer sun (Fig. 7.27). There is a single large window on the southern wall that adjoins the combined kitchen and dining room (Fig. 7.28). The *Walsh House* is constructed from recycled materials and the south and west elevations have a character reminiscent of a working farmhouse.

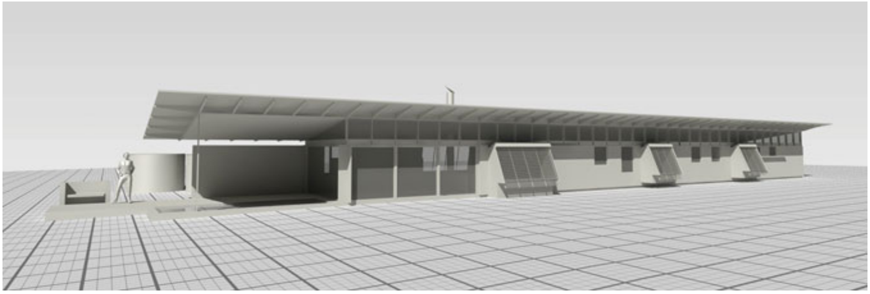


Fig. 7.27 *Walsh House*, perspective view

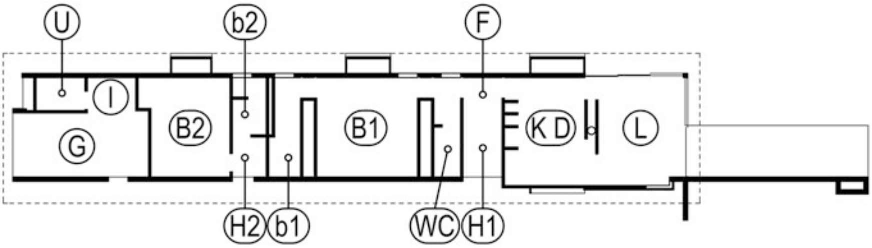


Fig. 7.28 *Walsh House* annotated plan

The plan graph of this house reveals a hierarchical structure with most access branches stemming from the exterior (Fig. 7.29). With only a single, non-trivial loop, this plan is less permeable than all but one of the previous designs by Murcutt, the *Carruthers House*. The loop goes from the exterior, to hallway 1, then the foyer, the kitchen and dining areas, and the living area, before returning to the outside. The garage, utility area and laundry can only be accessed from the exterior.

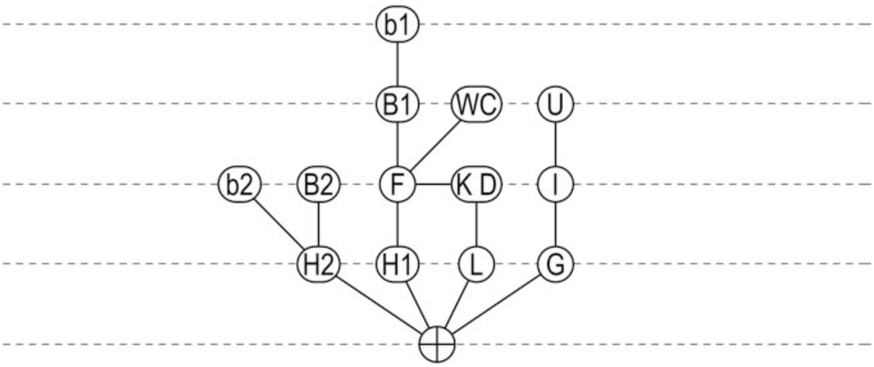


Fig. 7.29 *Walsh House*, plan graph

Table 7.12 *Walsh House*, data

Space	TD_n	MD_n	*RA*	*RRA*	i_{RRA}	*CV*
⊕	27	2.0769	0.1795	0.6727	1.4865	1.8333
G	35	2.6923	0.2821	1.0572	0.9459	0.7500
l	45	3.4615	0.4103	1.5377	0.6503	1.5000
U	57	4.3846	0.5641	2.1143	0.4730	0.5000
H2	35	2.6923	0.2821	1.0572	0.9459	2.2500
B2	47	3.6154	0.4359	1.6338	0.6121	0.3333
b2	47	3.6154	0.4359	1.6338	0.6121	0.3333
H1	30	2.3077	0.2179	0.8169	1.2241	0.5000
F	33	2.5385	0.2564	0.9611	1.0405	2.5000
B1	43	3.3077	0.3846	1.4416	0.6937	1.2500
b1	55	4.2308	0.5385	2.0182	0.4955	0.5000
WC	45	3.4615	0.4103	1.5377	0.6503	0.2500
L	33	2.5385	0.2564	0.9611	1.0405	0.7500
K,D	36	2.7692	0.2949	1.1052	0.9048	0.7500
Minimum	27	2.0769	0.1795	0.6727	0.4730	0.2500
Mean	40.57	3.1209	0.3535	1.3249	0.8411	1.0000
Maximum	57	4.3846	0.5641	2.1143	1.4865	2.5000
H						1.0031
*H**						0.7646

Similarly, hallway 2, bedroom 2 and bathroom 2, are also isolated from the planning of the remainder of the house, even though they too, like the garage, are under the same roof. Indeed, despite a formal expression that suggests this house is made up of a single domestic unit, the design actually functions as three isolated pavilions, connected only by the exterior.

The inequality genotype for the Walsh House is: exterior (1.4865) > hallway 1 (1.2241) > family room (1.0405) > living room (1.0405) > garage and hallway 2 (both, 0.9459) > combined kitchen, living and dining (0.9048) > bedroom 1 (0.6937) > laundry and toilet (both 0.6503) > bedroom 2 and bathroom 2 (both 0.6121) > bathroom 1 (0.4955) > utility room (0.4730). The *H** result of 0.7646 is in the same range as the previous four houses, none of which, the mathematics suggest, are strongly determined (Table 7.12).

7.5 Comparative Analysis

For the first part of the comparative analysis, the plan graphs are examined to identify any patterns in the way they are structured. This requires classifying the components of each graph into three substructural types: non-trivial loops, bushes and enfilade branches.

- A non-trivial loop is one that includes three or more spaces.
- A bush is a structure with three or more branches arising from a single root and where none of the branches are part of any loop.
- An enfilade is an isolated branch, or series of linearly connected branches, that are not part of a loop or bush.

Collectively these three substructural types account for all of the configurational properties in the ten graphs.

Each plan graph is divided into the three substructural types and the frequency and proportional representation of these types are determined (Table 7.13). For example, the *Marie Short House* plan graph has six substructures: three loops, one bush and two enfilade branches. Thus proportionally, 50% of the substructures in the *Marie Short* plan graph are looped, and approximately 16% are bushes and 33% are enfilades. The mean number of substructures across the entire set of houses is 6.5, with a range between 3 (*Ball-Eastaway House*) and 18 (*Southern Highlands House*).

The standard deviation of the substructural data for each house provides an indication of how tightly clustered the results are. The more tightly clustered, the more likely there is a pattern or level of consistency in the data. For example, in a normally distributed set of results, 68% will be within one standard deviation above or below the mean, and 95% within two standard deviations, above or below the mean. This provides a benchmark against which the Murcutt data can be compared. If there is a high level of consistency in the data, it will be much more clustered (that is, have a smaller standard deviation) than that of the normally distributed set of results.

For loop substructures, 48% (that is SD of 24.1113 $\times$ 2) of the data is within one standard deviation, above or below the mean; for bushes and enfilades the

Table 7.13 Structural types, number of types and as a proportion of the structures in a plan

	Structures	***Loops***		***Bushes***		***Enfilades***	
Houses	#	#	%	#	%	#	%
Marie Short	6	3	50.0000	1	16.6666	2	33.3333
Nicholas	6	5	83.3333	1	16.6666	0	0.0000
Carruthers	3	0	0.0000	2	66.6666	1	33.3333
Fredericks	6	2	33.3333	3	50.0000	1	16.6666
Ball-Eastaway	3	1	33.3333	1	33.3333	1	33.3333
Magney	5	3	60.0000	1	20.0000	1	20.0000
Simpson-Lee	6	2	33.3333	0	0.0000	4	66.6666
Fletcher-Page	5	3	60.0000	0	0.0000	2	40.0000
Southern Highlands	18	10	55.5555	0	0.0000	8	44.4444
Walsh	6	1	16.6666	0	0.0000	5	83.3333
Mean	6.4000	3.0000	42.5555	0.9000	20.3333	2.5000	37.1110
SD	4.2478	2.8284	24.1113	0.9944	23.2776	2.4608	24.0438

results are, respectively, 46% and 48%. Thus, all three are more clustered than the data in a normally distributed set. For results within two standard deviations, above or below the mean 96% of loops, 93% of bushes and 96% of enfilades are within this range. In combination, this suggests that the core data for structural subtypes has a high degree of consistency.

The second method for comparing the structural properties of the plan graphs requires examining the number and proportion of spaces that are part of each substructural type. For example, in the *Marie Short House*, there are twelve spaces in total, seven of which are part of loops, three, part of bushes and two, part of enfilades. Thus, 58% of the spaces in the design are part of loops, 25% bushes, and 15% enfilade branches (Table 7.14).

The mean value for the proportion of spaces on loops is 45% with a standard deviation of 22.1728. For a normal distribution of data 68% of the results would fall within a range of one standard deviation above or below the mean, in this case giving a range between 22% (45.0601 − 22.1728 = 22.8873) and 67% (45.0601 + 22.1728 = 67.2329). As seven of the ten (70%) designs exhibit values within this range, Murcutt's architecture is slightly more clustered than a normal distribution. However, the range of two standard deviations above or below the mean contains only nine of the ten (90%) houses, whereas a normal distribution would contain 95% of the data. Thus in terms of the proportion of spaces on loops the *Carruthers House* is an outlying result in Murcutt's architecture. For spaces in bush structures, 80% are within two standard deviations of the mean, and for enfilade spaces, only 60% are within two standard deviations of the mean.

Table 7.14 Spaces in structural types, number of spaces and as a proportion of the spaces in a plan

	Spaces	***Loops***		***Bushes***		***Enfilades***	
Houses	#	#	%	#	%	#	%
Marie Short	12	7	58.3333	3	25.0000	2	16.6666
Nicholas	10	7	70.0000	3	30.0000	0	0.0000
Carruthers	9	0	0.0000	7	77.7777	2	22.2222
Fredericks	15	4	26.6666	9	60.0000	2	13.3333
Ball-Eastaway	11	4	36.3636	3	27.2727	4	36.3636
Magney	12	8	66.6666	3	25.0000	1	8.3333
Simpson-Lee	14	6	42.8571	0	0.0000	8	57.1428
Fletcher-Page	10	7	70.0000	0	0.0000	3	30.0000
Southern Highlands	25	11	44.0000	0	0.0000	14	56.0000
Walsh	14	5	35.7142	0	0.0000	9	64.2857
Mean	13.2000	5.9000	45.0601	2.8000	24.5050	4.5000	30.4347
SD	4.5898	2.9230	22.1728	3.1198	26.9530	4.4284	22.3913

The next stage of the comparative analysis is focussed on the integration values of functional spaces. In order to construct a comparison between the inequality genotypes of the ten houses some rationalisation of the data is required. First, the integration results for the same functional room types are averaged for each house. Thus, if there are three bedrooms, a single mean integration measure is produced from the three. Next, six spatial types are merged into three combined categories and their results averaged. The combined categories are: living and family rooms; studio and music rooms; bathrooms and toilets. Furthermore, several room types for which there are less than two instances are removed from the comparison. These spaces are the lobby, court, alcove, utility and storeroom spaces. After these changes, we are left with the data for constructing a simplified inequality genotype that provides a better basis for comparison (Tables 7.15 and 7.16).

The first observation arising from the simplified data is that the maximum, mean and minimum integration levels differ markedly across the houses (Fig. 7.30). In particular, in the *Marie Short*, *Ball-Eastaway* and *Nicholas* houses, a small number of spaces connect the majority of the plan (respectively two hallways and the dining room). For the remainder of the houses, secondary halls, living spaces and the exterior also provide connections, reducing the reliance on single spaces.

The role of the exterior in the social configuration of space is the least consistent across the designs, playing an important role in the five more recent houses, and a much reduced, almost insignificant role in the early works. A designated garage is only present in six of the houses, and it is typically either close to or slightly above the mean (Fig. 7.31). When a hallway is present in a house, it is always above the mean and the living room also tends to be above the mean in the majority of cases (Fig. 7.32). As might be anticipated, the dining room and kitchen are close to the mean in the majority of cases (Fig. 7.33). The one exception to this is the Nicholas House, where the edges of the dining room operate as a surrogate hallway, providing the major circulation area for the entire house. The bedrooms and bathrooms are below the mean in all cases (Fig. 7.34).

In summary, the more private rooms (bedrooms and bathrooms) in the houses generally have integration values less than their means and the more public spaces (garage, living and hallways) typically have integration values higher than their means. Only the role of the exterior does not fit into this general pattern, being peripheral to the social structure of the early plans, and central to the later ones. From this result it might be concluded that Murcutt's planning displays a consistent social structure but, disappointingly, the data isn't so compelling. It just confirms a loose pattern that might be anticipated in any relatively contemporary design for either a nuclear family or a couple with guests.

The final approach to comparing the plan graphs is on the basis of Relative Difference Factor. Only one of the H^* measures is below the 0.5 benchmark (*Ball-Eastaway House*, $H^* = 0.4459$), all of the remainder are above, with the majority being well above (Table 7.17). The mean, $H^* = 0.7003$, confirms that the set of plan graphs do not display evidence of a deliberate strategy to produce a particular configuration.

Table 7.15 Early Murcutt designs, simplified data for integration values for functional spaces

Zoning	Key	Function	*Marie Short*	*Nicholas*	*Carruthers*	*Fredericks*	*Ball-Eastaway*
Public	⊕	Exterior	0.8705	1.1000	0.8870	1.3076	1.1059
Semi-Public	V	Veranda	1.4363	1.1000			0.8546
	H	Hall	3.9172		2.9567	1.1904	4.4234
	G	Garage				1.1242	
Semi-Private	L	Living Area	1.5669	2.2000	0.8064	1.2273	1.0208
	D	Dining	1.5669	5.5000	2.2176	1.0699	1.6588
	ST/M	Studio/Music			0.8064		
	K	Kitchen	1.5669	2.2000	0.8064	1.0699	1.6588
Service	l	Laundry				0.6923	1.1059
Private	B	Bedroom	1.3651	1.1000	0.8870	0.7335	1.1059
	WIR	Walk-in-wardrobe	0.7292			0.5604	
	b/WC	Bathroom/WC	1.1192	1.8333	0.8870	0.5604	1.1059
Minimum			0.7292	1.1000	0.8064	0.5604	0.8546
Mean			1.5709	2.1476	1.2818	0.9536	1.5600
Maximum			3.9172	5.5000	2.9567	1.3076	4.4234

Table 7.16 Late Murcutt designs, simplified data for integration values for functional spaces

Zoning	**Key**	**Function**	***Magney***	***Simpson-Lee***	***Fletcher-Page***	***Southern Highlands***	***Walsh***
Public	⊕	Exterior	1.5154	1.0953	1.8333	1.9731	1.4865
Semi-Public	V	Veranda					
	H	Hall	1.2123	1.1323	1.3750	1.1904	1.0850
	G	Garage	1.0697	0.7176	1.0000	1.4270	0.9459
Semi-Private	L	Living Area	0.6528	1.1561	1.3750	1.4166	1.0405
	D	Dining	0.6994	1.1561	1.3750	1.2010	0.9048
	ST/M	Studio/Music		0.7176	0.7333	0.7637	
	K	Kitchen	0.6994	0.8324	1.3750	1.2010	0.9048
Service	l	Laundry	1.5154			1.0424	0.6503
Private	B	Bedroom	0.7853	0.6814	1.0342	0.7709	0.6529
	WIR	Walk-in-wardrobe		0.7052	0.7333		
	b/WC	Bathroom/WC	0.6683	0.5012	0.5829	0.7813	0.6020
Minimum			0.6528	0.5012	0.5829	0.7637	0.6020
Mean			0.9798	0.8659	1.1417	1.1764	0.9129
Maximum			1.5154	1.0953	1.8333	1.9731	1.4865

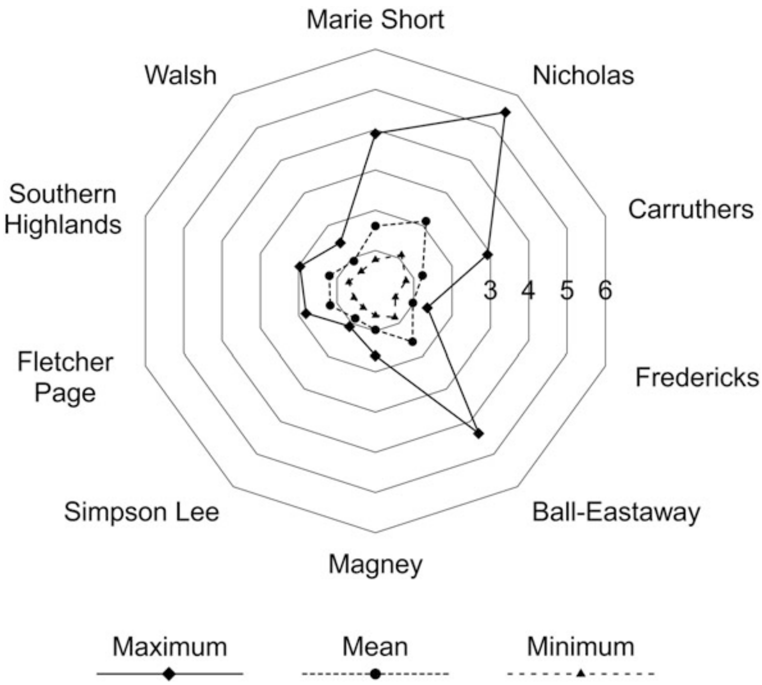


Fig. 7.30 Maximum, mean and minimum, integration results

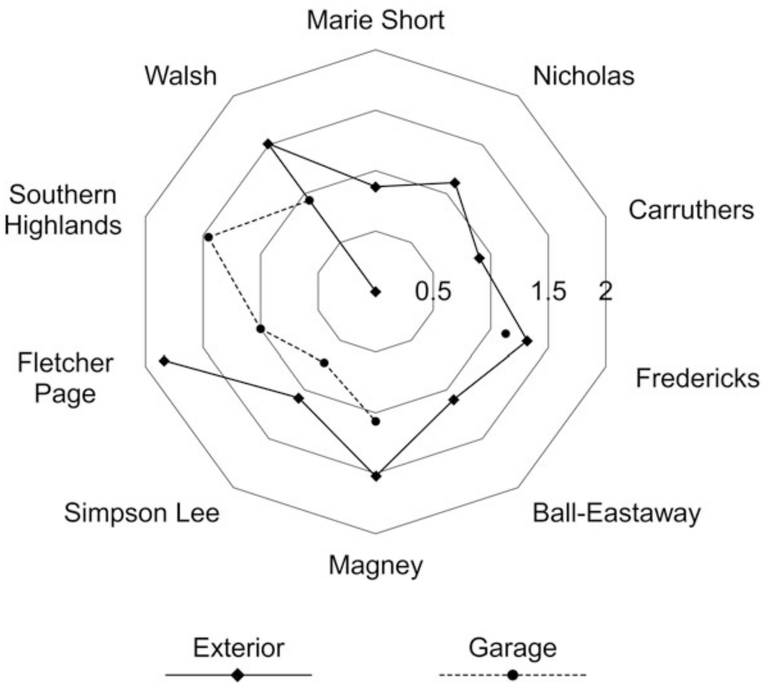


Fig. 7.31 Exterior and garage, integration results

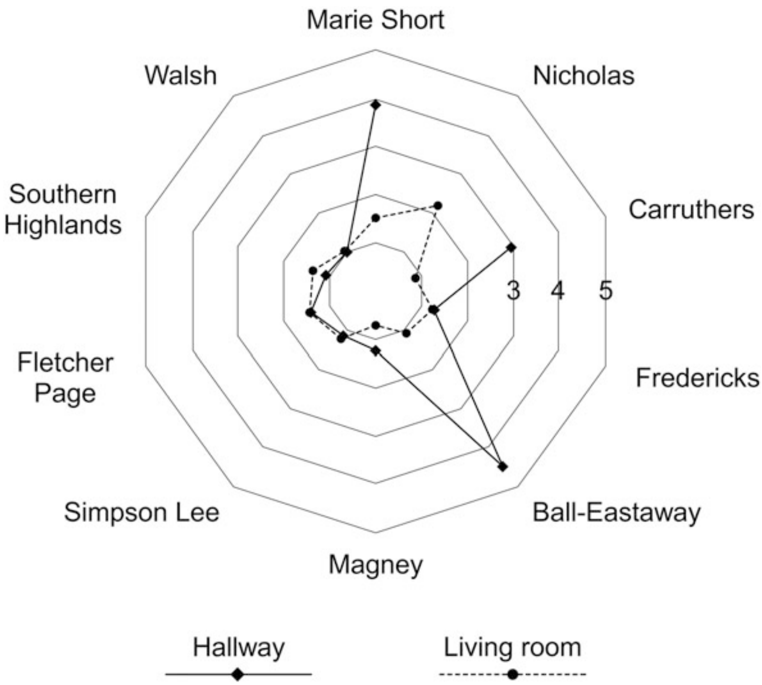


Fig. 7.32 Hallway and living room, integration results

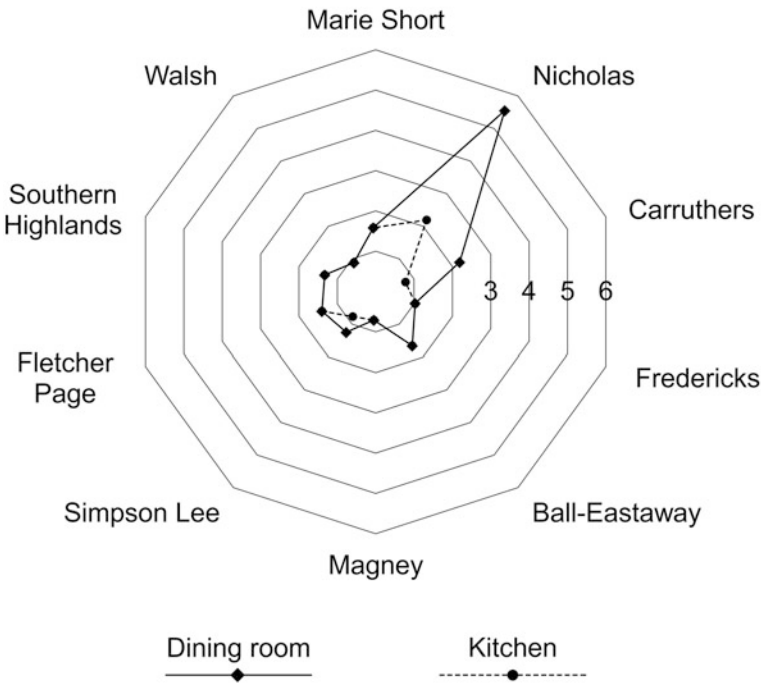


Fig. 7.33 Dining room and kitchen, integration results

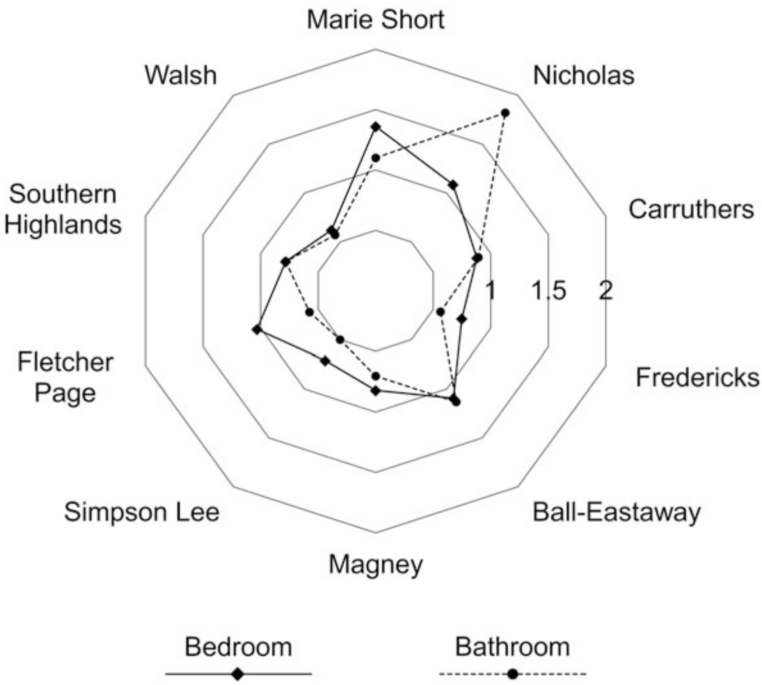


Fig. 7.34 Bedroom and bathroom, integration results

Table 7.17 Comparison of relative Difference Factors (*H**)

Houses	*H**	Indication
Marie Short	0.5738	>0.5
Nicholas	0.6180	>0.5
Carruthers	0.7216	>0.5
Fredericks	0.8087	>0.5
Ball-Eastaway	0.4459	<0.5
Magney	0.8389	>0.5
Simpson-Lee	0.7746	>0.5
Fletcher-Page	0.6764	>0.5
Southern Highlands	0.7800	>0.5
Walsh	0.7646	>0.5
Mean	0.7003	>0.5

7.6 Conclusion

The first hypothesis in this chapter maintains that the spatial configuration of Murcutt's rural domestic architecture has a consistent underlying social pattern. The visual analysis of the plan graphs identify some minor recurring patterns, and the mathematical analysis of the substructural types and the proportion of spaces within these types, also suggests a level of clustering in the data that implies the presence of a moderate or low-level pattern. The inequality genotype data coupled with the analysis of rooms by functional types also indicates the presence of a pattern, albeit an obvious or weak one. In general, Murcutt's architecture displays a tendency to create shallow inequality genotypes wherein hallway > living room, dining room, kitchen > bedroom, bathroom. The exterior is the only space that does not fit into this pattern, ranging from the highest in several cases, to amongst the lowest in others. When weighing up all of these indicators, it is difficult to declare the hypothesis either emphatically true or false. There is definitely a simple, low-level or weak pattern in Murcutt's social planning, but it is not enough to support the first hypothesis.

The second hypothesis holds that the spatial configuration of Murcutt's rural domestic architecture has a deliberate underlying social pattern. The evidence gathered from the comparison of relative Difference Factor results is generally negative. Murcutt's plan graphs tend to be generic or homogenous, displaying few of the features that would be regarded as evidence of a high level of determination or deliberation.

Murcutt himself notes that a simple formal expression does not necessarily imply the presence of a simple interior (Murcutt 2007: 26). This is certainly the case with the interiors of the ten houses investigated in this chapter. With the possible exception of the 'train carriage' planning in the *Ball-Eastaway House*, the remainder of the spatial configurations are more generic than the literature suggests. Certainly Pallasmaa's (2006) claim, outlined earlier in this chapter, that the form and spatiality of Murcutt's architecture are perfect reflections of each other, is impossible to maintain in light of the these findings. Murcutt's spatial planning, while generally neatly zoned into served and servant spaces, is clearly not the primary or even the secondary driver of his design approach.

If then, as these results suggest, something other than topology is shaping Murcutt's houses, what might it be? If Murcutt's description of his design approach is accepted *prima facie*, then his primary considerations are for climate and tectonics. From his earliest design sketches his focus is on structural systems, local materials and ecology. In practice though—and despite being on different sites and using different materials and structural systems—these priorities lead to the production of a consistent set of formal solutions. This is not to suggest that Murcutt is, contrary to his own stated intent, letting form dominate his concerns for climate or tectonics. Rather, it means that he has developed a limited formal language that can readily accommodate his other goals. But where then, does spatial configuration fit into Murcutt's stated design strategy? If environmental responsiveness, and formal expression are his priorities, this may explain why there is no clear spatial pattern in his interiors. The room layouts broadly conform to the type of social patterns that might be anticipated in a range of rural retreats for families and professional couples, but beyond that they appear to be secondary to his decision-making.

Part III
Frank Lloyd Wright

Chapter 8
Wright and Spatial Preference Theory

Part II of this book examined a series of twenty Modernist villas using a range of mathematical techniques for testing well-known claims about form, function and intelligibility. The focus of Part III is on the analysis of various elements or features in the domestic architecture of Frank Lloyd Wright which have previously been linked to particular types of spatial and visual experiences.

Wright famously called for buildings to be designed in such a way as to promote a harmonious relationship between their occupants and both the built and natural environments. Writers and critics have repeatedly noted that Wright employed several strategies to achieve this relationship, but one of the best known concerns the way in which he was able to create living spaces that feature a strong sense of enclosure, coupled with access to carefully framed views into other interior and exterior spaces. Furthermore, these experiential qualities are, putatively, enhanced by the way Wright choreographs the experience of passing through these houses from the entry to the living room. This experience combines a sense of spatial complexity and mystery, along with a shifting relationship between outlook and enclosure, to entice a visitor to move along the path to its conclusion in a place of relative sanctuary. These five experiential properties of Wright's architecture—comprising a sense of outlook, enclosure, mystery, complexity and enticement—have all been linked to accounts of involuntary or subconscious positive emotional responses. Both those inhabiting his living spaces as well as those merely passing through are left with a sense of wellbeing.

This is a seductive argument, seemingly uncovering a powerful if elusive connection between human emotions and architectural elements or features. Such is its appeal that it has since been repeated in many publications (Kellert 2005; Augustin 2009; Lippman 2010) and it has also been linked to the work of renowned Modernist and Regionalist architects including Alvar Aalto (Roberts 2003), Jorn Utzon (Weston 2002), Sverre Fehn (Unwin 2010) and Glenn Murcutt (Drew 1985). However, despite its apparent acceptance, there is a marked lack of evidence supporting this proposition. Moreover, even the argument that Wright's architecture is an exemplar of this approach is not especially compelling because it has never

M. J. Ostwald and M. J. Dawes, *The Mathematics of the Modernist Villa*,
Mathematics and the Built Environment 3,
https://doi.org/10.1007/978-3-319-71647-3_8

been convincingly demonstrated that there actually is a recurring pattern of form, space and vision in Wright's domestic architecture.

This situation is the catalyst for Part III of this book, which measures and compares the spatial, formal and visual attributes of Wright's architecture. These three characteristics—typically encapsulated in the portmanteau term 'spatio-visual'—are all measurable using isovists (introduced in Chap. 2 and described in detail in Chap. 4), provided it is possible to map or correlate certain isovist attributes to the environmental properties of outlook, enclosure, mystery, complexity and enticement.

To address this problem, in the present chapter several distinct emotional, phenomenal or psychological qualities which have been theorized as being behind the success of Wright's architecture are mapped to spatio-visual characteristics that can be measured and interpreted using isovists. These possible connections are then tested in an analysis of three locations in the living room of one of Wright's most respected works, the *Heurtley House*. This house has been chosen because it is regarded as the first to feature the ideal combination of the spatio-visual properties that are responsible for the emotional power of Wright's architecture. As such, the fundamental purpose of this chapter is not to test the properties of the *Heurtley House*, but rather to examine which isovist techniques and measures are capable of usefully quantifying the type of spatio-visual characteristics that are most commonly linked to the emotional experience of architectural spaces.

8.1 Introduction

Frank Lloyd Wright is one of the twentieth century's most successful architects, leaving behind a complex legacy of evocative designs, many of which allegedly elicit positive emotional responses from their inhabitants (Lind 1994; Heinz 2006). Multiple explanations for these phenomenological qualities exist, although few are as enduring as Grant Hildebrand's (1991) application of spatial preference theory to the analysis of Wright's domestic architecture.

Hildebrand's research uses qualitative techniques to identify thirteen architectural elements or features which, in varying combinations, explain the emotional power and appeal of Wright's architecture. Hildebrand accepts that these features are not unique to Wright's work, but argues that only Wright consistently incorporates a minimum of ten of these in each design, creating a clear pattern of architectural elements. Hildebrand explains the connection between the tangible characteristics of Wright's architecture (its space and form) and the emotional response it evokes (happiness, a sense of safety and security) using prospect-refuge theory and information theory. Prospect-refuge theory seeks to explain humanity's innate preference for certain environmental conditions in natural settings, but it also appears to offer a feasible explanation linking architectural space and form to perception and experience.

Hildebrand's application of prospect-refuge theory to Wright's architecture is responsible for propagating this concept as both an analytical and a design strategy in architecture (Weston 2002; Roberts 2003; Unwin 2010). However, despite the evocative qualities of Hildebrand's argument, there is little empirical or quantitative evidence confirming its validity (Dosen and Ostwald 2016a). Indeed, one of the basic tenets of Hildebrand's argument—that Wright's houses exhibit similar spatio-visual properties—is yet to be demonstrated. Certainly, past research successfully uses mathematical and computational means to examine the formal similarities of Wright's domestic architecture (Koning and Eizenberg 1981; Laseau and Tice 1992; Ostwald and Vaughan 2010; Vaughan and Ostwald 2011; Amini Behbahani et al. 2016; Lee et al. 2017), but none of these previous studies consider the relationship between space and outlook, the connection that is pivotal to all of the arguments that rely on prospect-refuge theory and information theory. Therefore, the present chapter is the first of a series that are concerned with quantitative methods for testing the spatio-visual geometry of Wright's architecture. These chapters do not test prospect-refuge theory or information theory, but rather they use isovist analysis to quantify various architectural characteristics that allegedly contribute to feelings of emotional wellbeing.

This chapter commences with an overview of prospect-refuge theory, information theory and Hildebrand's reading of these two ideas in Wright's architecture. These sections also provide a detailed explanation of the environmental characteristics of outlook, enclosure, mystery, complexity and enticement. Thereafter, drawing on past research (Conroy 2001; Conroy-Dalton and Bafna 2003; Wiener and Franz 2005; Markhede and Koch 2007; Dosen and Ostwald 2013a, 2016b), the chapter tabulates a set of isovist measures that have either been convincingly correlated to perceptual properties or for which reasonable evidence or logic suggest such a correlation is likely. The latter category includes several isovist measures analysed by Arthur Stamps which 'would seem to be a measure of both prospect and refuge' (2005: 740). Once this preliminary mapping is complete the chapter undertakes an isovist analysis of the living room of the *Heurtley House*. This analysis uses a computer model of the house developed from Wright's final working drawings to generate three isovists, and then measure and calculate their mathematical characteristics. These characteristics are then compared with the environmental preference properties associated with outlook, enclosure, mystery, complexity and enticement. Finally the relative validity or usefulness of each of these measures is determined.

8.2 Environmental Preference Theory

It is difficult, if not impossible, to identify the precise moment when questions regarding humanity's apparent innate preference for certain environmental conditions began to be asked. Through the work of Charles Darwin (1859), John Dewey (1934), Adrian Stokes (1947) and Konrad Lorenz (1964), amongst many others, a persistent thread may be seen that ties environmental preference to human survival instincts. Yet, even the seminal work of first century Roman architect Marcus Vitruvius Pollio contains an account of a primitive tribe being driven by survival instincts to seek out a specific type of environment where they could be both safe and prosper (Rykwert 1981; Vitruvius 2009). Despite such examples, researchers in architectural and spatial psychology commonly describe environmental preference theory as beginning to be formalised in the 1970s. It was at this time that people began to explicitly ask why it is that we prefer to inhabit certain types of spaces, or environments that feature similar characteristics or features. For example, Jay Appleton's book, *The Experience of Landscape*, asks '[what do] we like about landscapes and why do we like it'? (1975: vii) These two questions, posed in various forms by different authors, are often described as the catalyst for the field that is now known as environmental preference research.

Multiple theories exist which seek to explain why innate environmental preferences exist. Such theories draw on a range of biological and socio-cultural factors to explain people's attitudes to, and behaviours in, space. For example, Appleton argues that our preference for particular environments is due to biological drives inherited from previous generations, and proposes two interconnected theories to explain this phenomenon: habitat theory and prospect-refuge theory. An alternative explanation with a similar biological basis is Stephen and Rachel Kaplan's (1982) information theory. In architecture, aspects of both of these theories are frequently merged, as they are, for example, in accounts of the emotional power of Wright's architecture.

Habitat theory 'seeks to relate pleasurable sensations in the experience of landscape to environmental conditions favourable to biological survival' (Appleton 1975: vii). In order to make this connection, it is suggested that humans—and indeed all animals—possess an innate ability to assess the capacity of their surroundings to meet their basic biological needs for survival, including provision for food and shelter. A perception that the environment is conducive to survival evokes a positive emotional state such as relaxation. Conversely, a perception that the environment is unfavourable to survival evokes negative emotional responses, including anxiety and restlessness. Habitat theory states that these emotional responses drive creatures to intuitively seek out environments that enhance their probability of survival, a process which allows those sensitive to such factors to live long enough to procreate, and thereby pass these environmental preferences on to future generations. Conversely, individuals occupying environments incapable of meeting basic biological needs are eventually eliminated from the population through natural selection. It is important to note that in habitat theory, it is the *perception* that an environment meets our needs, rather than its *actual* capacity to meet our needs, that evokes the emotional response. Thus, an environment that is intuitively assessed as safe and secure may not actually be so, for a wide variety of reasons, but it will still produce a favourable emotional response, even if logic suggests this is erroneous. This tension between the actual characteristics of an environment and its symbolic properties is a recurring and often problematic theme in environmental preference research.

The concept of an innate and immediate assessment of the environment is not unique to Appleton's theories. A direct and unmediated understanding with no processing required underpins James Gibson's (1966, 1979) conception of visual perception, which, as Chap. 4 noted, is also the starting point for isovist analysis. Stephen Kaplan observes that people's 'preference judgements are often made so rapidly that they precede rather then follow conscious thought' (Kaplan 1988b: 57). Furthermore, despite (or perhaps because of) the ease with which these judgements are made, the participants are generally unable to explain them afterwards (Kaplan 1987). Thus, Appleton's habitat theory explains why we prefer particular environments over others, but it does not identify which features of the environment evoke these responses. Appleton (1975) offers a second proposition—prospect-refuge theory—to identify these environmental features. Stephen and Rachel Kaplan's explanation of environmental preference-related behaviour also builds on a similar foundation to habitat theory, but it outlines a slightly different proposition—information theory—to explain desirable environmental features.

Prospect-refuge theory defines the elements of the environment that allow us to meet our basic biological needs (Dosen and Ostwald 2013b). Prospect, understood as outlook, represents opportunity; it is the property of the environment that offers an unimpeded capacity to see, and therefore the ability to locate distant resources, the route to these resources and identify any potential hazards that may be encountered. Prospect also bestows the ability to identify distant (or 'secondary') prospect and refuge locations (such as mountain peaks and caves). Refuge, understood as enclosure or the capacity to evade, represents safety; it is the property of an environment that provides an opportunity to hide, take shelter, or escape from hazards. A hazard is 'an incident or condition prejudicial to the attainment of comfort, safety or survival' (Appleton 1975: 269); it may be animate (other creatures) or environmental (storms, drought, cliffs etc.).

Appleton conceives prospect-refuge theory in terms of the primitive behaviour of predator and prey. Viewed in this way, prospect allows predators to locate prey, and prey to identify approaching predators. Refuge allows predators and prey to hide or flee, and protects them from the elements. Environments that feature the right combination of prospect and refuge represent an ideal situation wherein predators can stalk unsuspecting prey, and prey can observe predators whilst remaining safely hidden or close enough to a safe location to ensure a successful escape. Prospect and refuge are, therefore, both physical and perceptual states. They suggest, respectively, the presence of actual outlook opportunities, along with the provision of a sense of visual permeability or depth. Similarly, refuge is a combination of physical enclosure, meaning the degree to which a space is surrounded by surfaces, and a sense that these provide a measure of safety. The right combination of prospect and refuge conditions serves to increase survival odds, thus the ability to 'see without being seen' (Appleton 1975: 73) allows animals to thrive. This situation in turn evokes positive emotional responses and, in humans, environmentally-derived pleasure.

Complicating this otherwise straightforward behavioural explanation of environmental preference is, as previously intimated, Appleton's claim that the pleasure evoked by an environment is not just limited to our experience of an *actual* environment. Artificial representations of environments including, for example, a landscape painting or poem featuring evocative prospect-refuge depictions, will also allegedly elicit a positive emotional response similar to that of actually experiencing the environment. These so called ‘symbols’ of prospect-refuge conditions can include everything from representations (paintings, photographs, literature), to simulations (fountains, fire places) and artefacts (materials, textures and objects). Such symbols are also potentially important, as the following section reveals, for architectural extrapolations of prospect-refuge theory. For example, some materials used in architecture are regularly described in phenomenological accounts as enhancing other more physical prospect-refuge conditions and thereby as having an impact on emotional wellbeing (Norberg-Schulz 1980; Harries 1997). The inclusion of these symbols in an argument about behavioural and attitudinal factors is a complicating factor which the other major explanation for innate environmental preference, the Kaplans’ information theory, largely avoids.

Information theory, like prospect-refuge theory, argues that environmental preferences are biologically determined. This explanation assumes that our hunter-gatherer forbears utilised wit to ensure their survival to parenthood, despite having few of the physical advantages that many other creatures on the African savannah possessed. In order for them to be successful, the hunter-gathers learnt to collect and exploit environmental information. Developing this proposition, Stephen and Rachel Kaplan argue that individuals who are better able to gather and exploit information are more likely to survive and pass this ability on to successive generations. This, in turn, ensures an evolutionary preference for environments that are rich in information which can be both gathered and exploited.

Information theory interprets the environment in terms of four key measures: complexity, mystery, legibility and coherence. Complexity relates to the amount of information available in the environment, and mystery is the ability to infer new information from what is already known. Legibility is associated with the capacity to ‘oversee and to form a cognitive map’ of an environment and thus, it is ‘greater when there is considerable apparent depth and a well defined space’ (Kaplan 1988a: 51). Coherence allows for information to be broken into manageable volumes. This, in turn, provides ‘the capacity to predict within the space’ (Kaplan 1987: 11).

Early researchers in the field originally assumed that there was an inverted U-shaped relationship between volume of information (x-axis) and preference (y-axis), such that very high or very low levels of information would be the least favoured, with the highest preference levels occurring where there are moderate levels of stimulus or complexity (Scott 1993). However Stephen Kaplan (1987) found that complexity is actually a relatively poor indicator of environmental preference in comparison with mystery and legibility, both of which are individually effective and are especially powerful when combined.

There are several counterarguments to the logical basis for both prospect-refuge and information theory, and the evidence collected by experimental psychologists is also heavily disputed. Probably the most controversial aspect of both theories is their shared evolutionary basis, which assumes that environmental preference is biologically determined. The most vocal opposition to this position is found among researchers who believe that environmental preference is purely culturally determined and maintain that cultural forces wholly subsume biological drives and therefore negate the role of biology in preference decisions (Daniels and Cosgrove 1989). Appleton (1975) actually says very little about non-biological drivers of behaviour, seeing them as merely alternative methods of satisfying one's biological needs. The Kaplans' information theory is more circumspect in this regard, suggesting that personal factors—such as a traumatic experience or learnt or acculturated attitudes—serve to moderate inherited or biological influences.

A significant volume of research exists to support both sides of the biological and cultural determinism dispute. This is the fundamental question at the heart of the 'nature versus nurture' divide and it is unclear where to draw the line between each philosophy, or how to interpret their differences in spatio-visual terms. For example, Stephen Bourassa (1991) champions the developmental model of Russian psychologist Lev Vygotsky, which contains three simultaneous states of existence. In Vygotsky's model, environmental preference is the result of a combination of biological laws, cultural rules and personal strategies. Following a detailed review of the field, John Falk and John Balling arrive at a similar conclusion, stating that the results suggest that environmental 'preference is a complex amalgam of factors, with innate preferences forming a foundation which is then overlain by both sociocultural and personal experience factors' (2010: 489).

A more focused criticism of prospect-refuge theory is concerned with its reliance on the imagined practices of a primitive African hunter-gatherer. This conceit has since been disputed by many anthropologists on the basis of scientific evidence, but has also been criticised as being an artificial cultural construct. For example, Denis Cosgrove (1980) argues that such a concept of a primitive environment is a contemporary ideological construct which is simply representative of the way groups of people identify themselves today through their imagined relationship with nature. The environment is an especially 'fertile concept' for people to interpret as they will (Daniels and Cosgrove 1989). Appleton's (1975) romanticised notion of the African savannah is fundamentally an artificial contrivance and so, Cosgrove (1980) warns, we must be wary of accepting it *a priori*.

Brian Hudson (1995) is also critical of Appleton's reliance on an imagined primitive society but for different reasons. Hudson notes that modern humans still require refuge in the form of shelter from the elements, and that a large portion of the information our brains process is still gained through vision, which requires prospect. Thus, there is no reason to suggest that these tastes and needs are inherited. Hudson's second oblique criticism is that an environment which offers protection from the elements could well evoke a positive reaction and thereafter imbue refuge features in that environment with symbolic significance. Consequently, Hudson agrees with Appleton's conclusion, but questions the structure and basis of his argument. For instance, Hudson and Appleton both accept that the presence of symbols may explain human emotional responses, an idea which is inherently appealing but which has proven difficult to validate. The problem with accepting the thesis that environmental preference is as much dependent on symbolic properties as actual attributes is that it introduces a large degree of subjectivity.

8.3 Environmental Preference Theory and Frank Lloyd Wright

Hildebrand's *The Wright Space: Pattern and Meaning in Frank Lloyd Wright's Houses* (1991) and his *Origins of Architectural Pleasure* (1999), collectively lay the foundations for a general theory of environmental preference in architecture. At its core, Hildebrand's proposition is that humans will intuitively feel pleasure inhabiting interior spaces that replicate the characteristics of those environments which primitive peoples found conducive to survival. This argument is drawn from a combination of prospect-refuge theory and information theory, although instead of using natural environments and elements as examples, Hildebrand uses architecture.

In *The Wright Space* Hildebrand analyses the spatio-visual characteristics of thirty-three of Frank Lloyd Wright's domestic designs. Through this process Hildebrand identifies thirteen architectural elements or features that collectively make up a distinct pattern (the titular 'Wright Space') that is responsible for the positive emotional experiences felt by people either moving through these houses or inhabiting them. Focussing on the living rooms, Hildebrand proposes that the emotional appeal of Wright's architecture is a result of their carefully controlled mix of prospect and refuge characteristics. The centre of the room provides a balance of prospect and refuge while the location near the hearth offers a more refuge-dominant experience. By providing such a graduated mix of perceptual qualities Wright enables the visitor to first enter the room and from there, identify and occupy a location appropriate to their psychological needs. However, prospect and refuge are not the sole factors shaping the pattern in Wright's architecture.

Hildebrand argues that mystery and complexity also play an important role in Wright's architecture. Mystery—the sensation wherein new information is not seen but inferred from what is already visible—relates to the areas of the building that are just out of sight. It is regarded as a strong, positive predictor of environmental preference (Kaplan et al. 1989). Complexity refers to the amount of visual information available in an environment, and Hildebrand suggests that complex and ambiguous spatial definitions and relationships are a key characteristic of Wright's houses. However, as previously noted, the Kaplans' research had already found that complexity is a relatively poor indicator of preference when compared with mystery (Kaplan et al. 1989). There is a further property, order, which Hildebrand regards as essential to the creation of the Wright Space. Having some similar features to the Kaplans' concepts of 'legibility' and 'coherence', order is associated with the ability to sense the underlying geometric systems or modular grids that define Wright's architecture and which are especially prominent in his Textile-block houses.

The final phenomenological property that is evoked in the theory of the Wright Space is associated with the experience of moving through Wright's domestic works, following a path from the entrance through to the living room. While Hildebrand offers a detailed diagrammatic and textual account of this experience in terms of the shifting balance between prospect and refuge, mystery and complexity, he also describes the way this experience of passage somehow compels the visitor to move towards the living room on a pathway of discovery. It was only in Hildebrand's second book, the *Origins of Architectural Pleasure* (1999), that he was able to define this quality as 'enticement', that is the natural desire to explore a particular path through space. Enticement could be defined as a spatio-visual condition arising from a combination of four factors—a shift from refuge-dominant to prospect-dominant positions, from small to large spaces, from dark to light spaces, and towards places of higher mystery—which triggers a tendency to move and explore.

Together, these five perceived properties of architectural space—prospect, refuge, mystery, complexity and enticement—constitute a complete theory of environmental preference in architecture (Table 8.1). However, preference is not associated with any one of these, but rather with various balanced combinations. For example, an increase in prospect does not require a decrease in refuge; the two are not mutually exclusive. The concept of refuge may evoke the sense of a 'small and dark' space, and prospect could suggest a space which is 'expansive and bright' (Hildebrand 1999: 22), but the two only elicit feelings of safety and security when they are present in the right combination. Furthermore, prospect can be of both an exterior space or an interior one, the former potentially being associated more with feelings of safety, while the latter may shape feelings of mystery or complexity. Mystery is also a major determinant of enticement, although passage from refuge-dominant to prospect-dominant positions, just as from darker to lighter spaces, allows a person to 'see without being seen, and so will ensure … relative safety during exploration' (Hildebrand 1999: 54). With these five types of spatial perception in mind, which architectural elements or features are intended to evoke them?

Hildebrand argues that Wright's architecture demonstrates a near ideal balance between the five perceptual conditions, because of the presence of thirteen distinct elements that Wright first began to incorporate in his Prairie house designs. Hildebrand describes these thirteen elements, which he argues are all present in Wright's 1902 *Heurtley House*, as follows. 'The major spaces are elevated well above the terrain they overlook. The fireplace is withdrawn to the heart of the house … emphasised by a low ceiling edge and flanking built-in seating and cabinetwork. The ceiling forward of the fireplace zone sweeps upward into the roof' (1991: 25). Within the interior there are also 'views to contiguous spaces' and 'glass and glazed doors are located on walls distant from the fire,' beyond which there is a 'generous elevated terrace' (1991: 25). '[D]eep overhanging eaves' reach out to embrace the site, behind which the outline of a 'central chimney' is evident, along with 'broad horizontal groupings of window bands, and conspicuous balconies or terraces'(1991: 25). Finally, the 'connection from exterior to interior is by means of a long and circuitous path' (1991: 25).

Table 8.1 Preliminary mapping of five properties of environments to their evoked, perceptual and physical characteristics

Factor	Evoked quality	Perceptual property	Physical characteristic
Prospect	A sense of control or power	The spatio-visual characteristic of an environment that supports the act of viewing long distances	A raised position providing an outlook, vista or view into another space, either internal or external to that currently inhabited
Refuge	A sense of isolation or protection	The spatio-visual characteristic of an environment that envelopes or surrounds and thereby protects	An enclosed (meaning visually bounded by surfaces) and constrained (meaning having close proximity to surfaces) space
Complexity	A sense of visual stimulation or information	The spatio-visual characteristic of an environment that communicates environmental information	The number, distribution and nature or type (surface or occluded) of edges that define an environment
Mystery	A sense of what is unseen or hidden	The spatio-visual characteristic of an environment that suggests the potential for new knowledge or allows for the prediction of possibilities based on what is known	The proportion of a space which is visually bounded by occluded edges and the number of these edges
Enticement	A sense that exploration is desirable	The spatio-visual characteristic of an environment that encourages a person to move in a particular direction	A measure of the difference between the location of the viewer and the distance and direction to the visual mass or centre of a space

Superficially, the identification of these elements would appear to not only offer a tangible connection between human perceptions and architecture, but a recipe that might be used to create spaces which evoke positive emotions. However, a close review of these architectural elements immediately raises some questions about whether they actually achieve the stated condition, or just symbolise it. For instance, a central fireplace or hearth is part of three of the thirteen elements, yet it doesn't serve any of the perceptual properties in a literal sense. Its primary impact is symbolic, as it represents a deep space in a house where people can gather and find warmth. Yet, the hearth is often not deep in the plans, alternative places of gathering are available and warmth is only a positive in certain seasons and locations. Similarly, low ceilings and horizontal window bands are present in a large number of structures that would not otherwise be considered conducive to safety and psychological comfort. For example, the majority of factories produced in the aftermath of the Industrial Revolution contain both of these elements, as do many other institutional building types, including clinics and prisons. Wide eaves are often praised for their capacity to evoke a sense of refuge but their physical benefit, providing shelter from the elements, is only slightly superior to more shallow eaves, or many other forms of weather protection. All of these examples suggest that the secret of the Wright Space is not necessarily contained in all of these individual features. Certainly some of the thirteen, like elevated living spaces and terraces do actually support outlook or prospect, but others, like overhanging eaves, function primarily as symbols of refuge.

If these thirteen architectural elements are examined to determine whether their cumulative emotional impact is based on actual measurable features, as opposed to symbolic or representational ones, it becomes apparent that there are substantial differences across the set (Table 8.2). For example, focussing only on elements which actually support two or more of the perceptual properties, only three of the thirteen are significant: views into contiguous interiors; a circuitous path from exterior to interior; and glazed elements and connections. Conversely, three of the thirteen elements only function in any consistent way as symbolic elements: enclosed hearth; overhanging eaves; and a central chimney. The final element, ‘balconies or terraces’, is actually very similar to the earlier ‘elevated terraces’. The latter refers to Wright’s ‘prospect platforms’, that is major viewing locations, whereas the former seems to refer to his ‘Juliet’ balconies and connecting terraces, which function as transition zones, suggesting the presence of an outlook, but not necessarily providing one.

The difference between the physical attributes and the symbolic properties of these elements is also tellingly revealed when the thirteen are subdivided into those which are solely part of the interior, those that are only externally apparent and those which promote or support connections between the two. Of those elements that actually shape perceptual properties, seven are associated with interior spaces only and an equal number with the transition between exterior and interior spaces. Only one of the exterior elements has a physical impact on a perceptual property.

A further way of looking at these thirteen elements is to ask which are most closely associated with each of the perceptual qualities. Ignoring the difference between actual and symbolic impact for the moment, the majority of the elements are associated with refuge, prospect and enticement, having respectively ten, nine and seven connections. Mystery and complexity are associated with a much lower number of elements, respectively five and three. If only physical relationships are considered, then prospect (five connections), refuge (three connections) and enticement (three connections) are the highest, with complexity and mystery being equal (two connections). While such a breakdown is open to debate, it does demonstrate that some of Hildebrand’s architectural elements are much more conducive to measurement than others, and that most of the features of his architectural answer to environmental preference theory are about interior inhabitation (living rooms) and interior movement (from the entry to the living room).

One final tangible architectural element noted by Hildebrand, and which is amongst the most important even though it is not part of his initial list, is ‘reduplication’. Reduplication occurs when specific spatial qualities are simultaneously reinforced by the presence of multiple strategies. This occurs when, for example, a narrow corridor has a low ceiling (spatial ‘compression’), or a large room has a high ceiling (spatial ‘expansion’), with the combination of formal elements serving to

Table 8.2 The thirteen characteristics of the Wright Space, divided by architectural zones and mapped to perceptual factors

Perceptual properties							
Zone	**Elements**	**Prospect**	**Refuge**	**Mystery**	**Complexity**	**Enticement**	**Total**
Interior	Elevated living spaces	⊕, ∅	∅				1⊕, 2∅
	Central, enclosed fireplace		∅				1∅
	Low ceilings		⊕, ∅				1⊕, 1∅
	Furniture integrated into walls		⊕, ∅		∅		1⊕, 2∅
	Views into contiguous interior spaces	⊕, ∅		⊕, ∅	⊕	⊕	4⊕, 2∅
Transition	A circuitous path from exterior to interior			⊕, ∅	⊕	⊕, ∅	3⊕, 2∅
	Glazed elements and connections	⊕		∅		⊕, ∅	2⊕, 2∅
	Horizontal window bands	⊕				∅	1⊕, 1∅
	Balconies or terraces	∅					1∅
	Close ceiling and roof relationship		⊕, ∅				1⊕, 1∅
Exterior	Elevated terraces	⊕, ∅					1⊕, 1∅
	Overhanging eaves		∅				1∅
	Central chimney		∅			∅	2∅
Total		5⊕, 4∅	3⊕, 7∅	2⊕, 3∅	2⊕, 1∅	3⊕, 4∅	

Key: ⊕ physical or actual relationship, ∅ symbolic or representational relationship emphasise the desired condition. Thus, the Wright Space is characterised by the changing and reduplicated relationship between these five factors, and not the presence of a single static condition. Moreover, Hildebrand argues that Wright's use of constricted and twisting paths through space serves to heighten the experience of emerging from a small, labyrinthine passage, into a large, open room with high ceilings and elevated views over surrounding areas. Such a pattern, if it does exist, would be one that benefits from, or relies on, reduplication.

8.4 Isovists and Environmental Preference

Since first being proposed, prospect-refuge theory and information theory have both been repeatedly tested using interviews, surveys and observation studies (Dosen and Ostwald 2013a; 2016a). The results have ranged significantly, with a large number of the more recent studies noting that the evidence is inconclusive (Stamps 2006; 2008a, b). One of the problems with many of the early studies is that the environments being tested lacked the specific measurable conditions required to correlate human perceptions to physical characteristics. Stephen Kaplan originally suggested that the solution to this problem is to construct a 'rough conceptual model of the three-dimensional space' (1987: 22) being tested so that its actual properties may be better understood and then potentially modelled in more detail as a precursor to measuring them. Geometric measures derived from such a detailed model may then be analysed mathematically to derive universal attributes of particular prospect-refuge or enticement patterns. This is the procedure followed in the final part of the present chapter in order to extract mathematically coherent information from a set of spatial conditions. However, whereas Kaplan called for the study of such measurable properties for the purpose of comparing them with human perceptions, the purpose of this chapter, and the ones that follow, is solely to investigate patterns within the spatio-visual properties of sets of buildings.

It will be remembered from Chap. 4 that an isovist is the set of all points in space visible from a particular vantage position. A two-dimensional isovist is represented as a polygon on a plan, which signifies the volume of space that can be seen from a position, and is bounded by various view limits most commonly defined by surfaces and lines of visual occlusion. Once an isovist is constructed, the primary mathematical measures that can then be derived from it include, amongst others, area, perimeter, concavity, circularity and elongation. From the radial lines used for generating the isovist, it is possible to develop several additional measures, including variance (M_2), skewness (M_3), kurtosis and entropy. Two of these measures, relative area and skewness, have been previously identified as potential indicators of environmental preferences associated with prospect-refuge characteristics. For example, Jan Wiener and Gerald Franz (2005) asked participants to find the best hiding and vantage locations in a virtual interior. These spaces feature, respectively, the smallest and largest viewshed areas, and the results of their research show that participants displayed a high level of competency in identifying these two types of spaces, each with distinct isovist area properties. Whereas the research of Wiener and Franz (2005) demonstrates that people have a natural ability to assess space in terms of planar geometry, Arthur Stamps (2006; 2008a, b) takes this suggestion further by directly comparing environmental geometry with environmental preference. In particular, he suggests that the isovist measure skewness might be a 'measure both of prospect and of refuge' (Stamps 2005: 740) and that this effectively captures the variation in distance between observer and isovist boundary (Stamps 2008a).

According to the past research and simple spatial logic, a total of twenty-eight different isovist measures may be mapped to the perceptual qualities of prospect, refuge, complexity, mystery and enticement (Dawes and Ostwald 2013a; Ostwald and Dawes 2013c). Table 8.3 contains a complete list of isovist measures, grouped in accordance with these perceptual properties. Significantly, some of these measurements are absolute while others are relative. The former are called 'scaled' (*Sc*), meaning that they possess an absolute value (for example, length in metres, or area in square metres). The latter are called 'scale-free' (*SF*), because they are relativised or normalised in some way (for example, the proportion of an isovist perimeter that is occluding is a scale-free measure). Scale-free measures allow for comparisons to be made between isovists with different geometric properties. For example, two isovists may possess vastly different areas and perimeter lengths, yet the proportion of their perimeter that is occluding, the ratio between area and perimeter, and number of straight perimeter edges, may be identical. Effectively, these isovists possess different absolute measures, yet identical scale-free properties, because one is a scaled-up or scaled-down copy of the other. Both scaled and scale-free measures are useful for comparing spatio-visual properties, the former being especially critical for comparing spaces in the same building, and the latter across multiple buildings.

A further issue associated with mapping isovist measures to perceptual properties is that some measures may be an indicator of prospect *or* refuge, while others could reflect the combination of prospect *and* refuge. Thus, a very small isovist area (A) might suggest a place of refuge, whereas a very large one might imply a place of prospect. A is, for that reason, potentially an indicator of either prospect or refuge. Alternatively, the standard deviation ($RL_{(SD)}$) and variance (M_2) of an isovist's radials provides a measure of the degree to which that isovist has both long and short views. Consequently, when interpreted with the assistance of other measures, $RL_{(SD)}$ or M_2 may suggest the degree to which prospect and refuge are jointly present in a space.

8.5 Initial Application of Isovists to Perceptual Properties

This section describes the method for measuring the spatio-visual characteristics of the living room of Wright's *Heurtley House*. As with the methods used previously in this book, a new three-dimensional CAD model provides the basis for this

Table 8.3 Isovist measures classified against their potential perceptual application

Isovist measure	Abbreviation	Scaled (Sc) Scale-free (SF)	Perceptual indicators
Area (m^2)	A	Sc	Prospect *or* Refuge
Perimeter (m)	P	Sc	
Shortest radial length (m)	$RL_{(S)}$	Sc	
Average radial length (m)	$RL_{(A)}$	Sc	
Longest radial length (m)	$RL_{(L)}$	Sc	
Convex deficiency	Con	SF	
Circularity	$Circ$	SF	
Area:Perimeter Ratio	$A{:}P$	SF	
Elongation—Γ	$El_{(\Gamma)}$	SF	
Elongation—Ψ	$El_{(\Psi)}$	SF	
Std dev of radial lengths	$RL_{(SD)}$	SF	Prospect *and* Refuge
M_2—Variance	M_2	SF	
M_3—Skewness	M_3	SF	
M_4	M_4	SF	
Kurtosis	K	SF	
Occlusivity (m)	O	Sc	Mystery
Number of occluded radials	$RO_{(\#)}$	SF	
Average occluded length (m)	$RO_{(A)}$	Sc	
Occluded:Perimeter Ratio	$O{:}P$	SF	
Average Occ length:Area	$RO_{(A)}{:}A$	SF	
Entropy (bits) 1 mm	$Ent_{(1\ mm)}$	SF	Complexity
Entropy (bits) 100 mm	$Ent_{(100\ mm)}$	SF	
Number of polygon edges	$Pol_{\#}$	SF	
Compactness	Com	SF	
Jaggedness	J	SF	
Drift (m)	Dr	Sc	Enticement
Area in directed view cone	$T_{(A)}$	Sc	
% of total area in view cone	$VC\%$	SF	

approach, being constructed from measured drawings and documentary photographs of the house (Storrer 1974; Futagawa and Pfeiffer 1987a).

The 1902 Prairie Style *Heurtley House* is located in the Chicago suburb of Oak Park (Fig. 8.1). It has two levels above ground and, unlike typical American homes of the period, the living and dining areas are on the upper level, allowing Wright to raise their ceilings and capture elevated views of the neighbourhood (Hildebrand 1991; Lind 1994). The house features a hearth located at the core of the building, on the internal edge of the living room and opposite a horizontal band of windows (Fig. 8.2). These elements, coupled with an open-plan design, elevated terraces, deep overhanging eaves and a complex approach path, complete Wright's architectural pattern of the era.

Fig. 8.1 *Heurtley House*, perspective view

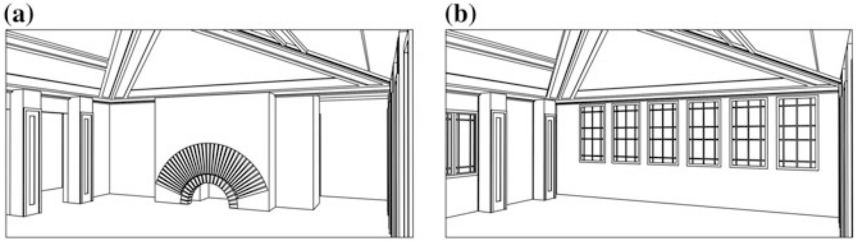


Fig. 8.2 *Heurtley House*, hearth and major widows in living room

Hildebrand (1991) identifies the *Heurtley House* as the first of Wright's works that demonstrates the complete pattern of thirteen prospect-refuge elements. Furthermore, while there is some debate about whether this is Wright's first fully realised Prairie house (Heinz 2006), or even if it is part of the same shape grammar family (Koning and Eizenberg 1981; Lee et al. 2017), it is identified in a previous computational study as being representative of the stylistic feature set of Wright's houses (Ding and Gero 2001); a determination which is close to Hildebrand's classification of the work.

Hildebrand's claims about specific spaces in the *Heurtley House* centre on the spatio-visual characteristics of three positions in the living room. The first is located at the threshold of the main entrance to the room, the second is 1 metre in front of the hearth and the third is at the geometric centre of the room. The living room's geometric centre is located at the intersection point of diagonal lines drawn between the corners of the room, a position which also corresponds to the ridge of the raised ceiling above. The isovist adjacent to the hearth is aligned to the centre of its supporting arch. These three positions approximate zones that are allegedly significant in terms of the perceptual properties of the space. These zones are, respectively, the first view of the room, the ideal position adjacent to the hearth from which to feel warmth and protection, and the experience of observing the room and adjacent spaces from its geometric centre. Hildebrand's analysis suggests that the perceptual properties of these positions should vary slightly with greater refuge experienced at the hearth, greater prospect at the room centre and greater mystery at the doorway.

Three isovists are used to test these properties. Each is manually constructed in a CAD program following the radial line procedure (see Chap. 4). The isovist plane for this analysis is located 1.65 metres above the floor to approximate the eye level of a standing observer of Wright's stature. The resolution of radial lines is set at 5° and the view distance is limited to 20 metres. The 5° radial increments do create minor anomalies in the isovists (which would be reduced, but not entirely eliminated, by using a higher resolution such as 1° radial increments) but the manual processing time to produce a more accurate result is prohibitive and the difference in the result negligible for the purposes of the present chapter (Chap. 9 uses a computational version). The 20 metres view limit is sufficient for the isovists to extend beyond the furthest visible windows, which are treated as transparent surfaces, while eliminating the need for accurate models of the building's surrounds. Mullions, posts, columns and similar elements of less than 100 mm width are small enough to be 'seen around' by an observer tilting their head and are therefore excluded from the isovist construction.

8.6 Results

Three isovists form the basis for the analysis of the spatio-visual qualities of the living room. Isovist 1 is at the entry (Figs. 8.3 and 8.4), isovist 2 is in front of the hearth (Figs. 8.5 and 8.6), and isovist 3 is in the centre of the room (Figs. 8.7 and 8.8). Twenty-seven measures derived from the isovist polygons and their generating lines provide a total of eighty-one results (Table 8.4). The results are categorised in accordance with the part of prospect-refuge or information theory which either past research or logic suggests they might reflect.

8.6.1 Measures Which Isolate Prospect or Refuge

Prospect is, in isolation, a relatively straightforward concept. Prospect-dominant views are those allowing larger volumes of space to be surveyed. High values for isovist area, and average and longest radial lengths are all indicators of a larger view area or distance. These measures identify isovist 3 as possessing the greatest prospect characteristics ($A = 323.770$, $RL_{(A)} = 9.162$, $RL_{(L)} = 20.000$). This is in accordance with Hildebrand's theorised condition.

Refuge consists of either being hidden from view (meaning the least volume of space being surveilled) or of being enclosed (relating to boundary or surface

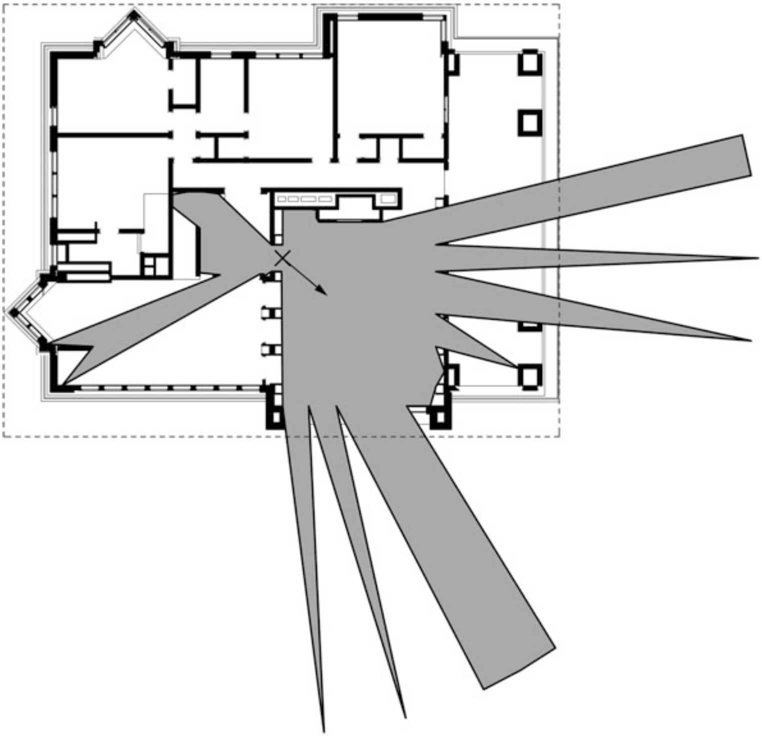


Fig. 8.3 Isovist 1, Living room entrance. View distance is set at 20 metres. Arrow indicates direction of drift

Fig. 8.4 Perspective view from the living room entrance and looking in the direction of drift

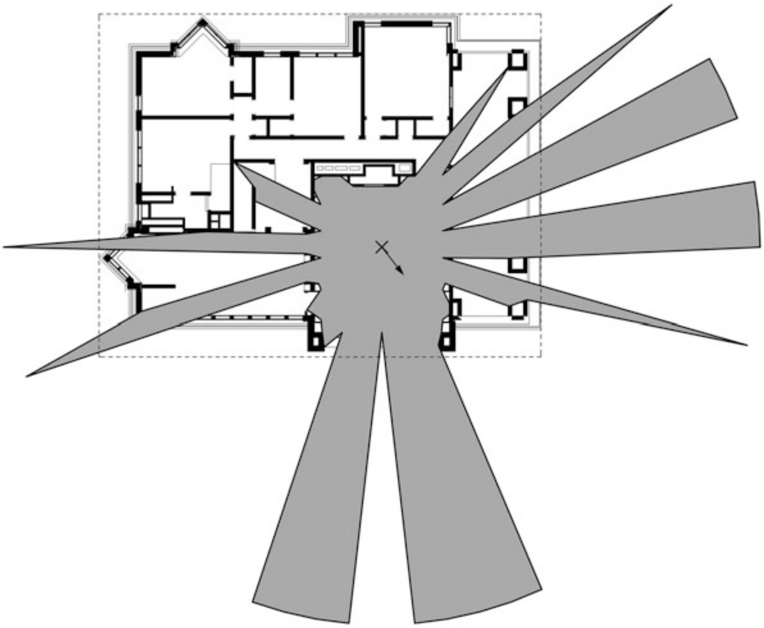


Fig. 8.5 Isovist 2, 1000 mm forward of hearth. View distance is set at 20 metres. Arrow indicates direction of drift

Fig. 8.6 Perspective view from the living room hearth and looking in the direction of drift

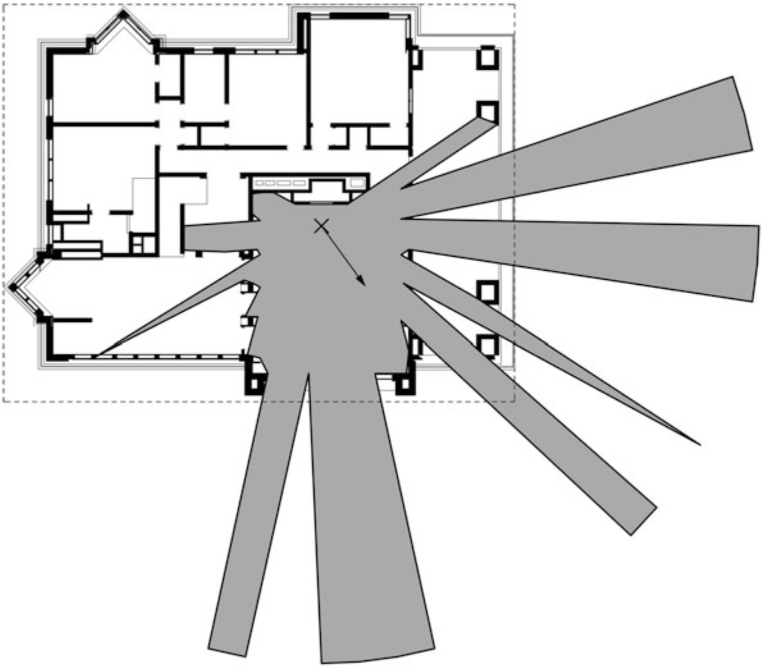


Fig. 8.7 Isovist 3, centre of the room. View distance is set at 20 metres. Arrow indicates direction of drift

Fig. 8.8 Perspective view from the living room centre and looking in the direction of drift

Table 8.4 Results for Wright's *Heurtley House*

Isovist measure	Isovist 1 (entry)	Isovist 2 (hearth)	Isovist 3 (room centre)
Area (m^2)	167.500	254.710	323.770
Perimeter (m)	221.760	248.497	295.464
Shortest radial length (m)	0.56	1.00	3.27
Average radial length (m)	5.851	7.224	9.162
Longest radial length (m)	20.00	20.00	20.00
Convex deficiency	0.66	0.52	0.62
Circularity	23.363707	19.29241	21.456688
Area:Perimeter Ratio	0.755	1.025	1.096
Elongation—Γ	0.29	0.36	0.46
Elongation—Ψ	0.21	0.23	0.22
Std dev of radial lengths	6.052	6.969	6.735
M_2—Variance	36.621	48.572	45.362
M_3—Skewness	316.683	358.701	267.833
M_4	5259.037	5997.043	3993.715
Kurtosis	3.921	2.542	1.941
Occlusivity (m)	202.202	219.496	262.857
Number of occluded radials	27	28	33
Average occluded length (m)	7.49	7.84	7.79
Occluded:Perimeter Ratio (%)	91.181	88.329	88.964
Average Occ length:Area	0.04	0.03	0.02
Entropy (bits) 1 mm	5.52	5.35	5.42
Entropy (bits) 100 mm	3.77	4.43	3.69
Number of polygon edges	42	43	53
Jaggedness	293.60	242.44	269.63
Drift (m)	2.451	3.429	1.895
Area in directed view cone	146.76	249.27	235.93
% of total area in view cone (%)	87.62	97.86	72.87

conditions). In the former situation, this is simply the inverse of the prospect measure, with isovist 1 being the smallest of the three (A = 167.500, $RL_{(A)}$ = 5.851, $RL_{(L)}$ = 20.000). In terms of enclosure, Stamps (2005) relates elongation to the concept of refuge. High $El_{(\Gamma)}$ values and low $El_{(\Psi)}$ values identify that a space is long and narrow. These measures suggest that isovist 1 ($El_{(\Gamma)}$ = 0.29) and isovist 2 ($El_{(\Psi)}$ = 0.23) are the least elongated and therefore most refuge dominant views. Stephen Kaplan (1988b) also relates refuge to enclosure, defining a refuge-dominant space as possessing a 'well-defined' boundary. If a well-defined boundary is an efficient means of defining space, the boundary will enclose the largest area with the minimum perimeter and approximate a circle. Isovist 3 possesses the highest area: perimeter ratio (A:P = 1.096) suggesting that it is the most enclosed view, but does this make it refuge-dominant? Probably not, because using the same logic about enclosure, a high value for Benedikt's (1979) circularity measure indicates that isovist 1 possesses the strongest refuge characteristics (*Circ* = 23.36).

It might be assumed that the shortest radial measure, meaning how close a person is to a wall, could be a strong indicator of refuge, but Stamps (2005) has shown that there is a negative correlation between the minimum nearest distance and the sense of enclosure. Paradoxically, this finding suggests that being too close to a wall, or being too enclosed, undermines feelings of refuge, whereas being in a larger space and able to see all of that space can heighten refuge feelings. On this basis, isovist 3 has the highest refuge characteristics ($RL_{(S)}$ = 3.27) and isovist 1 the lowest ($RL_{(S)}$ = 0.56). While this interpretation may be reasonable, it is possible that Stamps (2005) is identifying claustrophobic qualities in peoples' reactions, rather than refuge tendencies, and as the *Heurtley House* living room is a large spacious area, this may be much less relevant.

In summary, the isovist measures for prospect appear to broadly match Hildebrand's expectations, although the artificial view limit of 20 metre means that the longest radial is consistent in all three cases, so that its relevance cannot be immediately evaluated. The measurements for refuge are more problematic. First, calculations of the proportion of spatial enclosure might provide an indication of refuge potential (circularity and area-perimeter ratio), but a very large, prospect-dominant space can be completely enclosed by surfaces, so this isn't, in isolation, useful. Measures for shortest radial are seemingly more consistent, but Stamps's warning about their actual perceptual impact means that this measure too is not to be relied upon in isolation. Overall, it is only by viewing all of these measures in combination that a sense of the refuge potential of a space is provided. However, Hildebrand's suggestion that the hearth, isovist 2, will be the most refuge-dominant, is only supported by one of the six methods used. The majority suggest that isovist 1, in the doorway, is the most refuge-dominant position.

8.6.2 Measures Which Combine Prospect and Refuge

Stamps (2005) proposes that some statistical measures, including skewness, appear to quantify the combined prospect-refuge characteristics of isovists. Stamps also demonstrates that high skewness indicates that the observation point is close to an edge or corner of the isovist and low skewness indicates the observation point is more central to the isovist. This does imply that statistics-based measures might be able to capture the combined prospect-refuge properties of isovists. For example, the skewness result for isovist 2 is the highest (M_3 = 358.701) and that observation point is close to the edge of the polygon, whereas isovist 3, which is in the centre of the room, does indeed have the lowest result (M_3 = 267.883). However, while this result is apparently useful, statistical measures of the radial lines do not directly relate to the shape of the isovist. For example, it is possible to construct three completely different isovists, each from sixteen radial lines that all have four lines

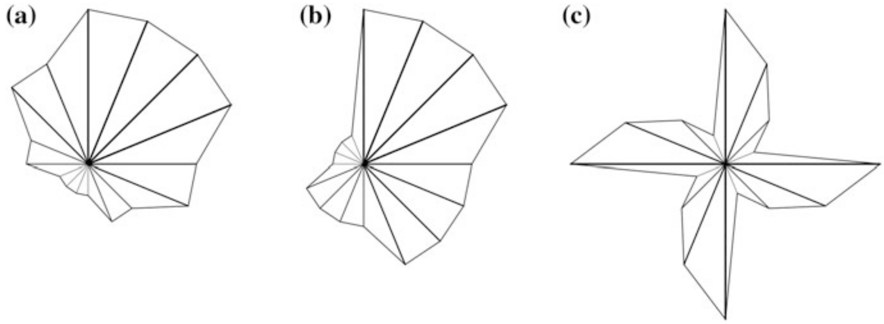


Fig. 8.9 **a** Symmetric, **b** shell and **c** pinwheel isovists with identical M_2, M_3 and $RL_{(SD)}$ values. However area, perimeter and, intuitively, prospect-refuge characteristics are different

1000, 700, 400 and 200 mm long (Fig. 8.9). While the measures of M_2, M_3 and $RL_{(SD)}$ are identical for each of these three polygons, the isovists possess different shapes and have different areas and perimeters. Thus, statistical measures may be useful for providing an indication of 'the dispersion of the perimeter relative to the observer location' (Stamps 2005: 739) but they do not quantify the prospect-refuge characteristics of particular spaces.

8.6.3 Measures for Mystery

Mystery, in spatial terms, relates to the volume of space that is just out of sight from a given location, or the space that we sense but do not see. If a person is within a rectangular, fully enclosed room, then the isovist will occupy the entire room and consequently, there is no mystery. The component of the isovist polygon that most effectively represents this definition of mystery is the occluding radial. Benedikt's (1979) occlusivity measure calculates the total length of occluding edges of an isovist perimeter. For the three isovists in the *Heurtley House*, occlusivity increases as the occupant moves from the doorway toward the centre of the living room, suggesting that isovist 3 is the one with the highest level of mystery (O = 262.857). However, this may be misleading because Benedikt's occlusivity is a scaled or absolute measure which relies on the assumption that the total occluded length indicates mystery. It may be more useful to measure occlusivity as a proportion of the total perimeter; a process which demonstrates that each of the three isovists is almost identical, and the smallest, isovist 1, is the most mysterious (O:P = 91.181%).

An alternative to these approaches might be to count the number of occluding radials to gauge the level of mystery. However a large number of extremely short occluding radials, such as those generated by passage along a tight colonnade, may hold very little potential for mystery. Perhaps then, the average length of occluded radials is a better measure than total length or highest number? Following this logic, isovist 2 has the highest average occluded line length ($RO_{(A)}$ = 7.84). However, average radial length is a scaled measure, biased toward larger isovists. Dividing average occluding radial length by isovist area allows a scale-free comparison and indicates that, like the measure for proportional occlusivity, isovist 1 is the most mysterious view ($RO_{(A)}$:A = 0.04).

Both occlusivity as a proportion of the total perimeter and the ratio of average occluding radial to isovist area identifies the entry to the living room as the space which is highest in mystery, a result which broadly aligns with Hildebrand's expectations.

8.6.4 Measures for Complexity

Stamps (2003) demonstrates a strong correlation between the mathematical measure of entropy and the concept of visual complexity, and suggests that the length difference between adjacent radial lines is a good indicator of isovist complexity. The maximum possible entropy of radial line length difference, resulting in the least homogenous perimeter, for a 72 radial (5°) isovist is 6.17. Using this measure, isovist 2 possesses the lowest entropy value when measuring the difference in radial line lengths at 1 mm accuracy ($Ent_{(1\ mm)}$ = 5.35), a result which indicates that isovist 2 is the least complex view. However it is possible that a 1 mm difference between the lengths of two adjacent radial lines is simply too fine a measure to represent human vision. The average person would find it challenging to identify a 1 mm difference between two lines at a distance of 1 m let alone across the entire width of a room, or at the end of a long hallway. When measuring the line length differences at 100 mm accuracy, isovist 2 possesses the highest entropy value ($Ent_{(100\ mm)}$ = 4.42) suggesting, contrary to the previous result, that this is the most complex view. This means that, if entropy is to be used as a measure of complexity, then defining an ideal accuracy of measurement is a critical precursor to interpreting the outcome. In addition, due to the artificial visibility boundary which is set at 20 metres, a large portion of the radial lines in all three isovists have the same length. If these lines were allowed to continue until intersecting a solid object the portion of lines sharing no length difference would decrease and, therefore, the entropy measures of the three *Heurtley House* isovists are likely to be artificially low.

An alternative measure of spatio-visual complexity involves counting the number of straight edges of each isovist polygon, because a more complex polygon requires a greater number of edges, however this concept is invalid for a circular room where the number of polygon edges will equal the number of radial lines. On this basis, which also makes sense from a phenomenological perspective, isovist 3 is the most complex view ($Pol_{\#}$ = 53). In contrast, jaggedness calculations indicate that isovist 1 is the most complex view (J = 293.59) and isovist 2 is the least complex view (J = 249.44).

Overall, the results for complexity are inconsistent in their mapping to isovist characteristics with both entropy and edge calculations providing only a partial measure of this property while jaggedness appears to provide a better reflection of it.

8.6.5 Measures for Enticement

While past research has not directly associated Ruth Conroy's (2001) measure of *Drift* (*Dr*) with prospect-refuge theory, it does capture several perceptual properties that are missed by other measures. Drift is the distance between the observation point and the centre of gravity of the isovist polygon. This distance represents both the direction and magnitude of the 'visual pull' of the isovist. A larger magnitude of drift indicates that a larger proportion of the isovist area, thus prospect and 'visual interest', is located in one direction relative to the observation point. In a room with three, mostly solid walls, and a fourth wall that is largely open, drift would provide a reasonable measure of the dominance and strength of the prospect, relative to the refuge, and of the level of enticement to move. However, in the living room of the *Heurtley House*, there are fragments of views in four directions; something which is especially evident in isovist 3 ($Dr = 1.895$), which might be expected to have the strongest level of enticement, but which actually has the weakest (Fig. 8.10). But then, an isovist is the view in any direction from a point in space, whereas it could be argued that prospect is dependent on the human cone of vision. To achieve the maximum prospect in a single view at any given time, one must face the direction which will allow the greatest area to be visible. Thus, by aligning a 180° view cone to the drift direction it is possible to measure how much of the isovist is visible when looking towards the dominant visual orientation. Using this measure, 97.86% of the complete isovist is visible from position 2 compared to only 72.87% for isovist 3. This is an interesting result because another definition of mystery might include the space that is sensed behind the viewer but is not directly surveilled by them while watching the dominant outlook. In this sense isovist 2 has the least mystery and isovist 3 the most. Taking into account all of the factors which are responsible for enticement—including the tendency to move towards larger spaces, longer view distances and higher levels of mystery—drift remains a valuable isovist measure for modelling a perceptual property associated with discovery.

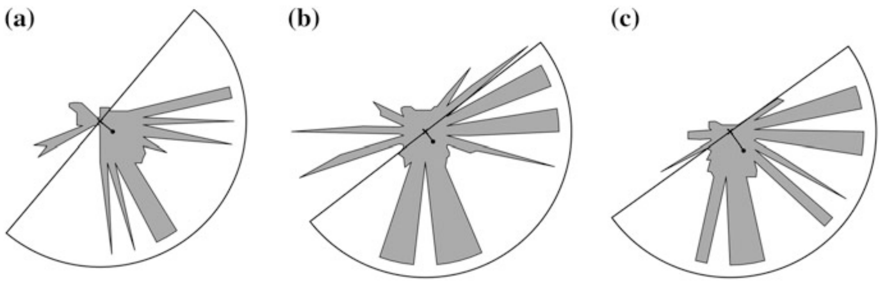


Fig. 8.10 **a** Isovist 1, **b** isovist 2, **c** and isovist 3 with view cones aligned to the direction of visual pull

8.7 Conclusion

Through this analysis of the *Heurtley House* it is clear that several of the isovist measures do provide useful descriptions of the spatio-visual characteristics that are most commonly associated with prospect or outlook, mystery and enticement. Prospect is measurable using a combination of the size of the visible area, the longest view distances and the strength and direction of the outlook. The proportion of the visible perimeter that is made up of occluding radials is also a clear measure of mystery, and drift closely approximates several of the properties of enticement. The three measures for complexity are less consistent, with jaggedness offering the best potential to be useful for rooms with either an excess or paucity of geometric information. In contrast, none of the twenty-seven isovist measures, in isolation, provides a clear result for refuge or enclosure, with viewshed area, shortest view distance and degree or efficiency of enclosure all providing partial indicators.

The combination of these perceptual properties is more complex, with measures like skewness and elongation appearing to capture some of the essence of both prospect and refuge characteristics in a simple room, but being less successful for more complex spaces. It is further likely that there are limits or ranges for the proportion of each of these measures that an isovist must fall within for a room to exhibit desirable perceptual qualities. For example, if the enticement is insufficient, then the room either does not have a clear outlook or it has too many conflicting outlooks that confuse the visual direction. Thus, a minimum drift value may be a useful test. Second, if the room is either too enclosed or too open—claustrophobic or agoraphobic—then there is no sense of refuge. Setting a range for either the perimeter length of the isovist that is 'surface' or the combined angle of radials which meets a 'surface' could also provide a useful minimum and maximum value.

In interpreting these results, remember that this mapping of spatio-visual characteristics to perceptual properties can provide important indicators about a space, but they cannot necessarily be extrapolated to predict people's emotional reactions to a space. Prospect-refuge theory and information theory are about psychological reactions to environments, objects, forms and spaces. These reactions, as past studies have shown, can be influenced by a wide range of personal factors including age, cultural background and education as well as particular tectonic and spatial conditions, like the colour or texture of building materials and the quality of the light. Furthermore, Wright's houses are often richly textured, with carefully designed ornament, prominent fireplaces which provide physical warmth, and dramatic outlooks to natural landscapes. None of these factors can be studied using isovists or related computational means. This is also why the tension between the actual and symbolic properties of architectural features has been highlighted on several occasions in this chapter and previously in Chap. 4. We are only interested in the actual features; the symbolic ones might help us interpret a mathematical result in a more nuanced way, but they are not measurable using the same methods.

Finally, at no stage in this chapter have we considered the phenomenological criticisms of Hildebrand's argument that have been published in the past (Seamon

1992). While there are many counterarguments to his position, our interest is not in the actual emotional reactions people allegedly feel, but in two questions. First, are the spatio-visual characteristics of Wright's buildings consistent? Second, do these broadly accord with the predicted perceptual properties these spaces are meant to possess? To answer these questions we have to carefully examine the two examples Hildebrand uses to make his case: Wright's living rooms and the experience of passage through Wright's architecture, from the entry to the living room. Building on the background provided in the present chapter, and its mapping of isovist measures to phenomenal qualities, Chap. 9 starts to answer these two questions with an analysis of Wright's living room spaces. Chap. 10 then considers the experience of passage. In this way, the set of cases studied (and the pool of data generated from them) is greatly increased, and the opportunities to answer these two questions, and to learn more about Wright's architecture, are improved.

Chapter 9
Experiencing Wright's Living Spaces

Chapter 8 describes a dominant theory about the spatio-visual characteristics of Frank Lloyd Wright's domestic architecture and the way in which these features allegedly shape emotional responses. This theory argues that a distinct spatio-visual pattern is responsible for shaping two types of experience in Wright's architecture: that associated with Wright's living room spaces and that with passage through his houses. The focus of the present chapter is on the visual experience of the geometry of Wright's living rooms.

Wright's living rooms are thought to feature a distinct pattern of spatial and formal features that provide a balance of outlook and enclosure, along with lesser, but still significant properties associated with mystery and complexity. Past research has theorised that these properties are collectively responsible for eliciting a sense of wellbeing from visitors. This distinct spatio-visual pattern is typically regarded as being present in every one of Wright's domestic designs, beginning with the living room of the *Heurtley House* in 1902. However, although this explanation for the phenomenal appeal of Wright's living rooms is widely accepted, little quantitative evidence exists to confirm that these rooms actually exhibit any pattern of spatio-visual characteristics, let alone the particular pattern required to induce such a homogeneous set of emotional responses. To further complicate this issue, Wright did not design in a single consistent way throughout his entire seventy-year career, completing domestic works in at least three distinct styles. This implies that the pattern, should one exist at all, potentially transcends stylistic differences.

This chapter uses isovists to examine the spatio-visual characteristics of the living rooms of seventeen of Wright's most famous houses. The specific isovist characteristics that are measured and compared correlate to various aspects of the experience of prospect, refuge and mystery (see Chap. 8). However, the focus in Chap. 9 is not on quantifying these properties, but on a two-part question: is there a pattern of spatio-visual characteristics in these designs, and is it more clearly present in any particular stylistic group? The test used to determine if such a pattern exists compares statistical indicators derived from the isovist data for the set of

M. J. Ostwald and M. J. Dawes, *The Mathematics of the Modernist Villa*,
Mathematics and the Built Environment 3,
https://doi.org/10.1007/978-3-319-71647-3_9

houses with those that would be present in a 'normal' sample. If the isovist data is more clustered than the normal sample, then a pattern potentially exists.

9.1 Introduction

Frank Lloyd Wright produced over 300 residential designs during his career, including works associated with three distinct stylistic periods: the Prairie Style, Textile-block and Usonian houses. Furthermore, two of his most famous works—the *Aline Barnsdall House*, also known as the 'Hollyhock House', and the *Edgar J. Kaufmann House*, also known as 'Fallingwater'—do not fit neatly within any of these stylistic categories, although the former could be viewed as a precursor to the Textile-block designs and the latter to the Usonians. Despite such clear stylistic differences across Wright's body of work, and the manifest difficulty of situating two of his most celebrated designs into this oeuvre, many scholars argue that Wright employed a consistent pattern of space and form in his living rooms (Hildebrand 1991; Laseau and Tice 1992). Furthermore, some suggest that Wright's undeviating application of this pattern led to the creation of environments that are conducive to people's emotional health and wellbeing (Twombly 1979; Lind 1994; Hale 2000; Heinz 2006). Drawing on prospect-refuge theory and information theory, and supported by personal accounts and a diagrammatic and historical analysis, Hildebrand (1991) offers one of the more convincing explanations of how Wright's architectural pattern is responsible for this phenomena. Hildebrand names this particular spatio-visual pattern the 'Wright Space'.

Hildebrand (1991) argues that a unique formal and spatial pattern exists in Wright's domestic architecture that is responsible for triggering positive emotional reactions. Enumerating thirteen design features that, in combination, have this effect, Hildebrand suggests that individually they are not unique to Wright, however Wright is the only architect to use a minimum of ten of these in every house he produced after 1902. Past research has sought to test the type of relationship between emotional response and spatial and environmental features which Hildebrand proposes is so critical to Wright's architecture, using both surveys and isovist analysis (Wiener and Franz 2005; Dosen and Ostwald 2013a, 2016b). A small number of studies have also used computational means to consider related claims about architecture, cognition and emotion (Conroy 2001; Stamps 2009). The majority of this past research focuses on the more general claim that specific types of spatial features support emotional or psychological welfare. What is largely absent in this research is any detailed consideration of the existence of the 'Wright Space'. In particular, are the prospect-refuge related properties of Wright's living spaces similar enough to even constitute a pattern?

This chapter uses isovists to analyse the spatio-visual characteristics of three locations in each of the living rooms of seventeen of Wright's houses. Moreover, for each of these locations and for each house, two versions of the analysis are undertaken, the first treating windows as opaque and the second as transparent. This variation of the method is significant in itself, as most architectural applications of isovist analysis do not consider exterior views or take into account the methodological complexity that this entails. However, Hildebrand's definition of outlook encompasses both vistas to adjacent habitable areas ('interior prospect') and the capacity to see the outside world ('exterior prospect') and so both versions are tested here. This whole process leads to the production of 102 isovists from which 714 measures are derived. Then, using simple statistical methods, these measures are investigated to determine if they present a pattern, if such a pattern is stronger in any particular style, and finally if it is broadly in accordance with Hildebrand's theory.

The following section briefly revisits key aspects of both spatial psychology and isovist analysis to emphasise the particular issues that are pertinent here. Because this chapter is entirely focussed on the experience of Wright's living room spaces, not all aspects of the methods and theories described previously are directly relevant. Thereafter, two hypotheses are formulated for testing, each identifying mathematical trends that would be expected in the data if there were a pattern and it were to conform to Hildebrand's original proposition. Next, the method used to undertake this research is described along with its limitations and scope. Finally the results are presented and discussed both holistically and in terms of each of Wright's three styles of domestic architecture. The chapter concludes by revisiting the hypotheses in the light of the final results.

9.2 Psychology, Geometry and Domesticity

Hildebrand argues that the strong emotional appeal of Wright's living rooms is a result of the way Wright uses space and form to carefully control the degree to which each of these rooms features a choreographed balance of outlook and enclosure. Environments that feature both outlook (or prospect) and enclosure (or refuge) opportunities are thought to be innately preferred by humans as habitats, because they offer the simultaneous ability to observe while remaining sheltered (Appleton 1975). However, in practice the ideal relationship between prospect and refuge characteristics has never been convincingly determined, although in Wright's architecture it is evidently neither equal nor fixed and the way it accommodates contiguous and external spaces also complicates the task of testing this proposition. These three factors are each worthy of more detailed consideration, both in terms of their role in the Wright Space and in relation to more general considerations of spatio-visual geometry.

Starting with the first of these issues, proportional equity, imagine a room that is square in plan and has two adjacent walls (that is, they share a corner edge) that are solid or opaque and with the other two walls (which also share an edge) being glass or transparent. From the centre of the room, the perimeter would be 50% open and 50% enclosed, ostensibly providing an equal balance between prospect and refuge. But if each of the four walls of this room were vertically divided in two and had a glass half and a solid half, this new room would have the same proportion of open (50%) and enclosed (50%) boundaries as the previous room, but its character would be very different. Instead of being able to survey a single, almost 180° arc of vision in one direction, while being protected from behind in an identical arc, the second version of the room would allow four distinct 45° arcs of vision, each separated by an equivalent blind spot or refuge angle. In a sense, both rooms feature the same quantum of prospect and refuge conditions, but with very different opportunities and challenges.

Historians and critics have never identified the relative proportions of prospect and refuge present in Wright's living rooms. Instead, they talk of dominant view directions, coupled with glimpsed or peripheral vistas. The implications of their descriptions are that, regardless of the proportion of prospect or refuge in a room, prospect at least is unlikely to be grouped into a singular zone and is more likely to include fragments of views that are at least partially spread around an arc of more than 180°. But if we return to the example of the two rooms with square plans, each with 50% of their perimeters solid and the other 50% transparent, the practical difference between the two rooms is actually expressed in terms of levels of fragmentation or discontinuity of prospect. This is significant for Wright scholars because these properties, which are often associated with complexity or mystery, are thought to be crucial to achieving the ideal balance between outlook and enclosure.

Hildebrand argues that mystery and complexity play an important role in Wright's living rooms, as they mediate between prospect and refuge conditions. However, the degree to which one of Wright's living rooms is mysterious or complex is neither elucidated nor explained. Nevertheless, there is a suggestion that levels of prospect and refuge are heightened by the sense that new information may be inferred from what is already visible (a sense of mystery) and that a large volume of visual information is also available (a sense of complexity) (Kaplan 1987; Kaplan et al. 1989). Thus, the presence of a partially fragmented or discontinuous prospect alongside a refuge with a greater number of edges is potentially more important than achieving a single ideal balance or ratio between prospect and refuge.

The second issue pertaining to the relationship between prospect and refuge in one of Wright's living rooms is that it is evidently not a fixed one. Hildebrand's argument is that the centres of each of Wright's living rooms provide a more balanced composition of prospect and refuge, while the location near the hearth offers a more refuge-dominant experience. The entry to the room has a heightened sense of mystery and complexity and a stronger level of enticement. By providing such a graduated mix of spatio-visual qualities, Wright enables the visitor to first enter the room and, from there, identify and occupy a location that is suitable for his or her psychological needs. This ability to subtly alter the balance of prospect and refuge properties by selecting one's location is critical for eliciting positive emotional responses. This would, for example, allow a person to move from a prospect-dominant position when searching for resources or information, to a more refuge-dominant one if danger appears.

A final factor which is central to the spatio-visual pattern in Wright's living rooms is that not only is the type of prospect important—that is, its level of geometric discontinuity and occlusivity—but so too is whether it is of an interior or exterior space. This last issue is significant because it reminds us that outlook is not necessarily defined by a view of the landscape. Indeed, for half of the diurnal cycle the world is dark, and for much of the year, the exterior is obscured by environmental conditions. Furthermore, glass is not necessarily transparent under all lighting conditions and the impacts of glare, distortion and diffraction cannot be underestimated. For all of these reasons, the importance of exterior prospect is at least partially symbolic, as it is the opportunity to see, rather than the act of taking in the view in a methodical way that is significant. Interior prospect through contiguous spaces is rarely obscured, and yet it too allows for the gathering and inferring of information that is arguably more important from a psychological perspective, because it is more immediate. The two types of prospect are thus complimentary, serving different purposes.

These three properties of Wright's living rooms—the relationship between prospect, refuge and space, the role of mystery and complexity, and the different impact of interior and exterior prospect—are all measurable using isovists. However, isovist analysis is frequently limited to indoor environments because such a focus removes the need for setting artificial view limit s or mapping the often changeable and diffuse exterior conditions which undermine the effectiveness of isovist boundaries (Davies et al. 2006). Thus, indoor analyses typically exclude external views by treating glass as an opaque material. While some authors have undertaken both 'indoor' and 'outdoor' analyses in a single project (Stamps 2011), little data exists which directly compares the isovist properties of environments generated for windows that are both opaque and transparent (Fig. 9.1).

9.3 Method

9.3.1 Hypotheses

Hildebrand (1991) claims the presence of a pattern in the spatio-visual characteristics of Wright's living rooms and in the experience of prospect, refuge, mystery and complexity that this pattern stimulates. If such a pattern exists, then similarities should be observable in measures derived from isovists produced for specific locations in Wright's living rooms. To test this, a representative sample of living rooms is required along with a means of determining the presence of a pattern.

The set of living rooms used for the analysis in this chapter includes five works from each of Wright's three main stylistic periods—Prairie Style, Textile-block and Usonian houses—along with his two stand-alone masterworks, 'Hollyhock' and 'Fallingwater'. Listed chronologically, these seventeen houses are the *Henderson*, *Heurtley*, *Cheney*, *Evans* and *Robie* houses from the Prairie Style; the *Barnsdall*

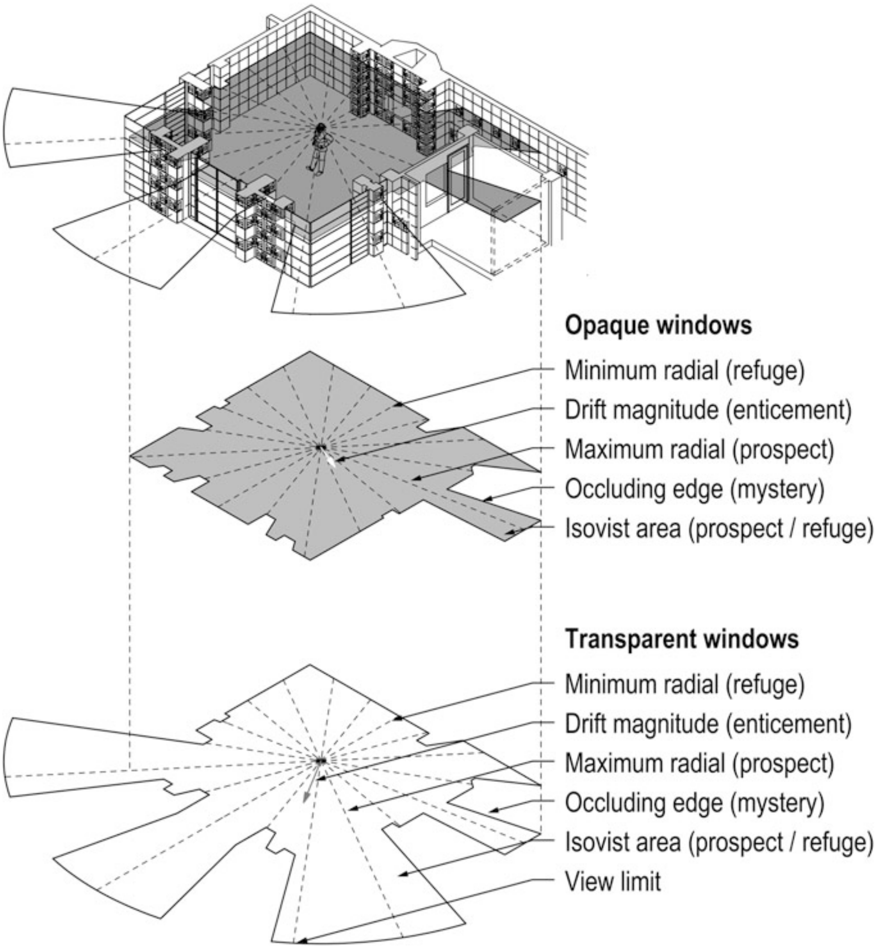


Fig. 9.1 Isovist measures under opaque and transparent window conditions. Note that some radial lines have been omitted for clarity

House (Hollyhock); the *Millard*, *Storer*, *Freeman*, *Ennis* and *Lloyd Jones* houses from the Textile-block series; the *Kaufman House* (Fallingwater); and the *Jacobs*, *Schwartz*, *Lloyd Lewis*, *Affleck* and *Palmer* houses from Wright's Usonian period. Importantly, these houses are not a random selection, because fifteen of the designs (the exceptions being the *Henderson* and *Lloyd Jones* houses) are featured prominently in Hildebrand's argument for the existence of the Wright Space. This is, therefore, a set of houses that are most likely to provide evidence of the pattern. Should evidence not be present in these works, or if it is relatively poor, then the existence of the Wright Space, insofar as it is expressed in Wright's living rooms, must be called into question.

The next issue is the determination of what constitutes a pattern. In a random data sample with a normal distribution of results, 68% will occur within a range of one standard deviation of the mean (above or below). Thus, in a sample where more than 68% of data falls within this range, the majority of the data is more similar than that of a random sample. In a set of seventeen houses, if twelve (11.5 being 68%) or more houses are within one standard deviation of the mean value for that measure, then some level of clustering is present in the data. However, these seventeen houses already have much in common, so a second figure can also be used to test how consistent the pattern is. Once again, in a random data sample with a normal distribution of results, 38.2% of the data will be within 0.5 standard deviations of the mean. Thus, if seven or more (6.46 being 38.2%) houses are within this range then it might be assumed that the existence of the pattern is more consistent, or that particular houses or styles participate more strongly in the pattern. Neither of these measures is necessarily a perfect indicator of the strength of the pattern, but both can be used to provide some insight into the data.

Therefore, using a set of seventeen cases as a source of isovist data, and a normally distributed set as a benchmark, two hypotheses are tested in this chapter (Table 9.1). The first maintains that *Wright's living rooms possess a high degree of spatio-visual similarity*. If Wright's houses are similar in terms of their spatio-visual characteristics, then more than twelve of the set of seventeen houses will provide results for each measure within one standard deviation of the mean. Given that the majority of the test cases have been chosen because they are allegedly similar, and because the two indicators used to identify the presence of a pattern are both

Table 9.1 Spatial properties mapped to specific hypotheses, analytical methods and result indicators

	Property	Hypothesis	Method	Indicator of a positive result
1	Wright space pattern	*Wright's living rooms possess a high degree of spatio-visual similarity*	Isovist analysis	(i) ≥ 12 of the set of 17 houses provide results within one standard deviation of the mean (ii) ≥ 7 of the results are within 0.5 standard deviation of the mean
2	Internal and external prospect	*Inclusion of external views increases prospect, mystery and enticement but reduces compactness and evidence of a pattern*	Isovist analysis	(i) The values for area, max radial, occlusivity, proportional occlusivity and enticement will increase under transparent window conditions, while compactness values will decrease (ii) Transparent window conditions will feature fewer results within 1 standard deviation of the mean, and 0.5 standard deviations of the mean, than opaque window results

relative to data that does not possess any strong structure, it might be assumed that this test is not an especially onerous one. It is true that the conditions are, within the limits of the method, potentially loaded towards a positive outcome for the first hypothesis. But alternatives, such as including a sample of non-representative houses (those which scholars regard as atypical) or using a more demanding test, will present a different type of bias.

The second hypothesis holds that *the inclusion of external views increases prospect, mystery and enticement, but reduces compactness and evidence of a pattern*. Again, if this is true then seven or more of the set of seventeen will be within one half of a standard deviation of the mean (Table 9.1). The basis for this hypothesis is found in the theorised relationship between interior and exterior prospect described in the previous section, and in the practicalities of constructing different types of isovists. Applications of isovist analysis often consider windows to be opaque in order to limit their scope to fully enclosed spaces and thereby negate the subjectivity that arises from handling variations in external surfaces and artificial view limits. This can be problematic when using isovist analysis to compare open designs, with large expanses of glazing, to enclosed designs, with limited or no glazing. However, if windows are treated as transparent, isovists will necessarily incorporate larger volumes of space that have the potential to capture higher levels of prospect (isovist area and longest radial), mystery (occlusivity and proportional occlusivity) and complexity (lower compactness). Furthermore, depending on the observation location, transparent windows might create reduced refuge indicators (shortest radial lines) and enticement (drift magnitude and direction) will be highly variable. For these reasons, it is logical that houses analysed under transparent window conditions will exhibit less similarity. This is because such cases have a higher number of confounding factors than those whose analysis involves isovists that document interior conditions only. This issue, while partially an artefact of the methodology, is also an indicator of the potential presence of a pattern, leading to formulation of a further hypothesis.

9.3.2 Approach

Digital models for each of the houses were produced using Wright's final working drawings as a basis (Futagawa and Pfeiffer 1987a, b, c, d). *The Lloyd Jones House* is the sole exception to this, being based on the measured survey of the completed building (Pfeiffer and Goessel 2010). Additional details for each house were gleaned from historic photographs, surveys and site visits. The three-dimensional CAD models of each house form the basis for two versions of the two-dimensional floor plans analysed using isovists. The floor plans capture a horizontal slice through the building 1.65 m above the main living room floor level that is intended to approximate the eye height of the architect, who was notorious for calibrating designs to his own body, regardless of his client's stature (Hildebrand 1991). In all plans, the doors to dedicated service and storage areas that form no part of the circulation system are drawn as being closed, while all other internal doors are open.

The analysis of the 102 isovists (those derived from the seventeen houses, with three positions in each living room and transparent and opaque versions of each position) was undertaken using UCL Depthmap. A 100 mm grid is used to locate each isovist position in the plan for analysis. Two versions of the floor plans were created, the first presenting all glazing as opaque and the second as transparent. The opaque version consists of a single floor plan for each house and includes an additional solid line that is drawn wherever glazing is located. The transparently glazed floor plans do not contain these additional solid lines and therefore the isovists incorporate exterior spaces. However, the inclusion of exterior spaces presents a significant challenge for isovist analysis because without a solid surface to intersect with, an isovist will have infinite length. Incorporating an artificial view limit circumvents this problem by providing a means of defining the perimeter of the isovist.

The view limit takes the form of a circle centred on each observation point. The radius of the circle is equal to 110% of the length of the longest radial line attainable under opaque window conditions, from any of the three observation points in that house. This value ensures that each observation location is able to see out of any visible window, while preventing the external area from becoming excessively large. However, this requires creating a unique floor plan for each isovist generated under transparent window conditions to ensure the view limit for any observation location does not have an impact on the remaining observation points. In contrast, all three of the observation points for opaque window conditions are taken from a single floor plan. This process also means that each view limit for each house is different, which might seem counterintuitive, but the use of a fixed view limit of identical length for every house (however large or small) actually produces a larger and more artificial variation in the data which is difficult to reconcile. Furthermore, it is preferable to develop a method that allows for comparisons to be made between houses, regardless of their size. Thus, the decision to relate the view limit to the longest internal view length ensures that the impact of exterior sections of the isovist is always relative to the scale of the house.

For each living room three observation locations are identified. The first is the threshold to the living room, defined as the location halfway between the surfaces that constitute the primary entrance to the room, on a path leading from the front door. The second observation point is the centre of the living room and is the position where diagonal lines drawn between opposite corners of the room intersect. The third location is set one metre back from the hearth into the living room and aligns with the centre of the hearth. The only exception is the *Barnsdall House*, which features a shallow pool in the living room, preventing the visitor from being positioned close to the hearth. In that house, the closest practical position, 1.77 m from the centre of the hearth, is used as an alternative.

9.4 Results

The 102 isovists generated for this chapter are all graphically depicted, with their position in each living room floor annotated, and each isovist polygon presented as an overlay of the opaque isovist (shaded) over the transparent (unshaded) variation (Tables 9.2, 9.3, 9.4, 9.5 and 9.6). The graphical representation of the isovists provides a means of intuitively interpreting the seventeen living rooms, and the changing experience of each precise location in these spaces. For example, even before any mathematical measures are considered, it is apparent that it is rare for prospect to be in a single direction and in an uninterrupted arc of more than 30°, or less than 180° when taking into account its full extent. Prospect is almost always fragmented but extensive and exterior-prospect is typically more pronounced when viewed from the centre of each room than from other locatins.

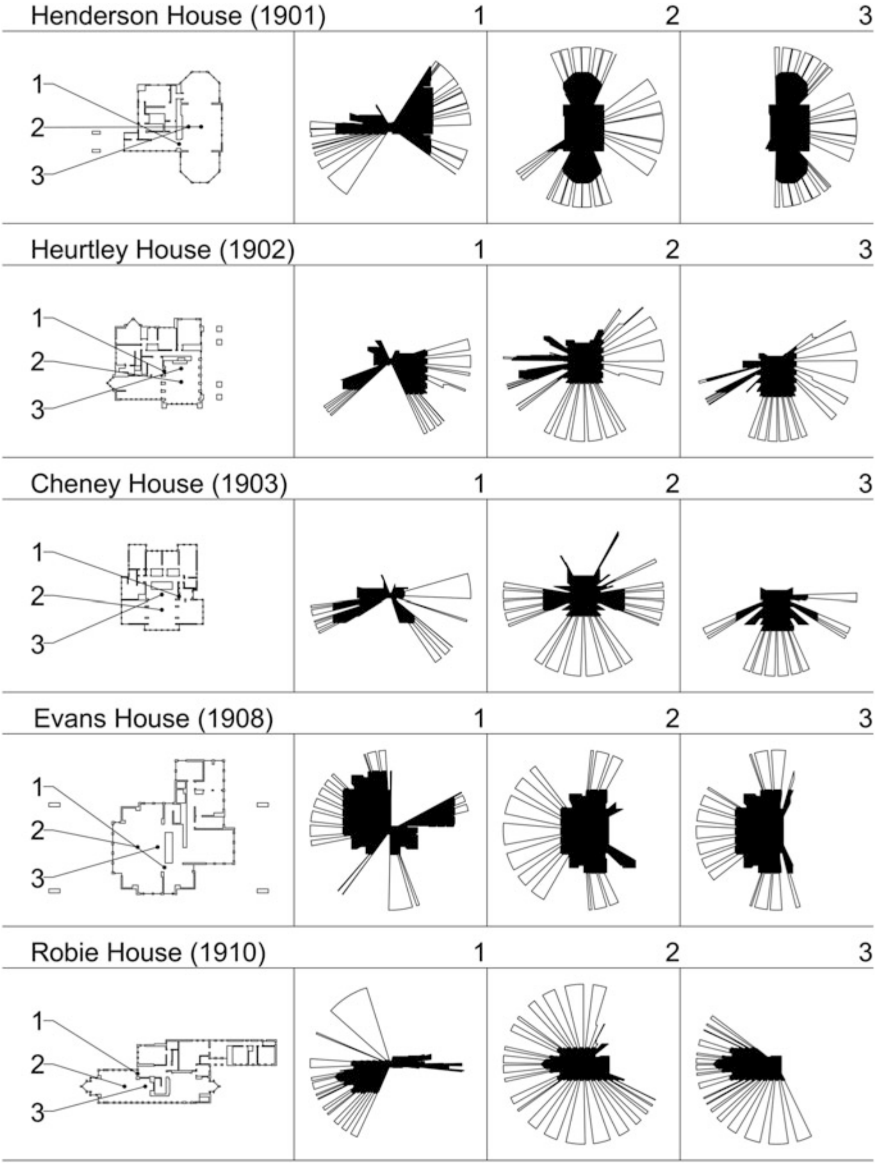
The isovist analysis of Wright's architecture produces a total of 714 results. If we consider the seventeen houses to be a single data set, we arrive at 42 outcomes for analysis (seven measures, three isovist locations, two window conditions). These can be tested to determine the number of houses with results located within one standard deviation of the mean for each measure (Table 9.7). According to the first hypothesis, any result of twelve or greater indicates a higher than anticipated degree of similarity between the houses, and a result of less than or equal to eleven indicates greater difference than anticipated.

Measures for isovist area (a potential indicator of prospect or refuge) for all three observation positions indicate that all isovist polygons generated under opaque window conditions exhibit a degree of clustering, or a pattern in the results; 1σ is $\geq$ 12 and $\frac{1}{2}\sigma \geq 7$. When exterior views are included in the isovist area, a similar result is identified for isovist polygons located at the living room thresholds and the hearth, with only the central location being less clustered at the finer scale ($\frac{1}{2}\sigma = 6$). External views, such as those available during daylight conditions, increase the volume of visible space at observation points and yield data consistent with relatively prospect-dominant experience compared to the more refuge-oriented night views where external areas are shrouded in darkness (Fig. 9.2).

Measures for maximum radial line lengths regardless of whether windows are opaque or transparent, exhibit a general pattern (in all six cases, 1σ is $\geq$ 12), although it is less emphatic at a finer scale (in only two of the six cases, $\frac{1}{2}\sigma \geq 7$). In particular, when exterior views are included, the strength of the pattern is reduced (Fig. 9.3). The data for minimum radial line length is identical regardless of window condition. This is because each observation point is located closer to a solid surface than a window. If the observation points were closer to windows than built surfaces, a difference between results for the opaque and transparent window conditions would be recorded.

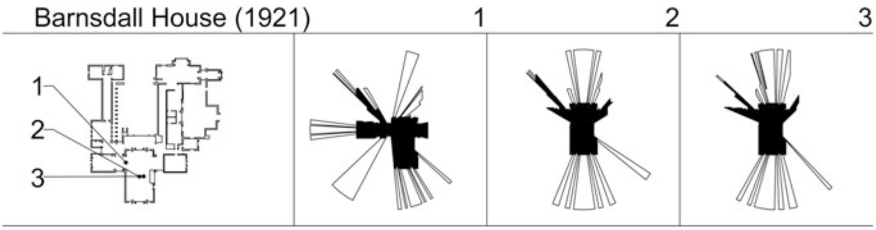
Occlusivity is the absolute length of the portions of the isovist boundary that relate to the space which lies just out of sight due to being obscured by built surfaces, and is regarded as a measure for the perceptual quality of mystery. Occlusivity values for all isovist polygons limited to interior spaces indicate general

Table 9.2 Isovists derived from three locations in each of five Prairie Style houses



Key: Shaded isovists represent opaque window conditions whereas unshaded areas show the extent of isovist polygons that extend beyond the glazed surfaces

Table 9.3 Isovists derived from three locations in the *Barnsdall House*



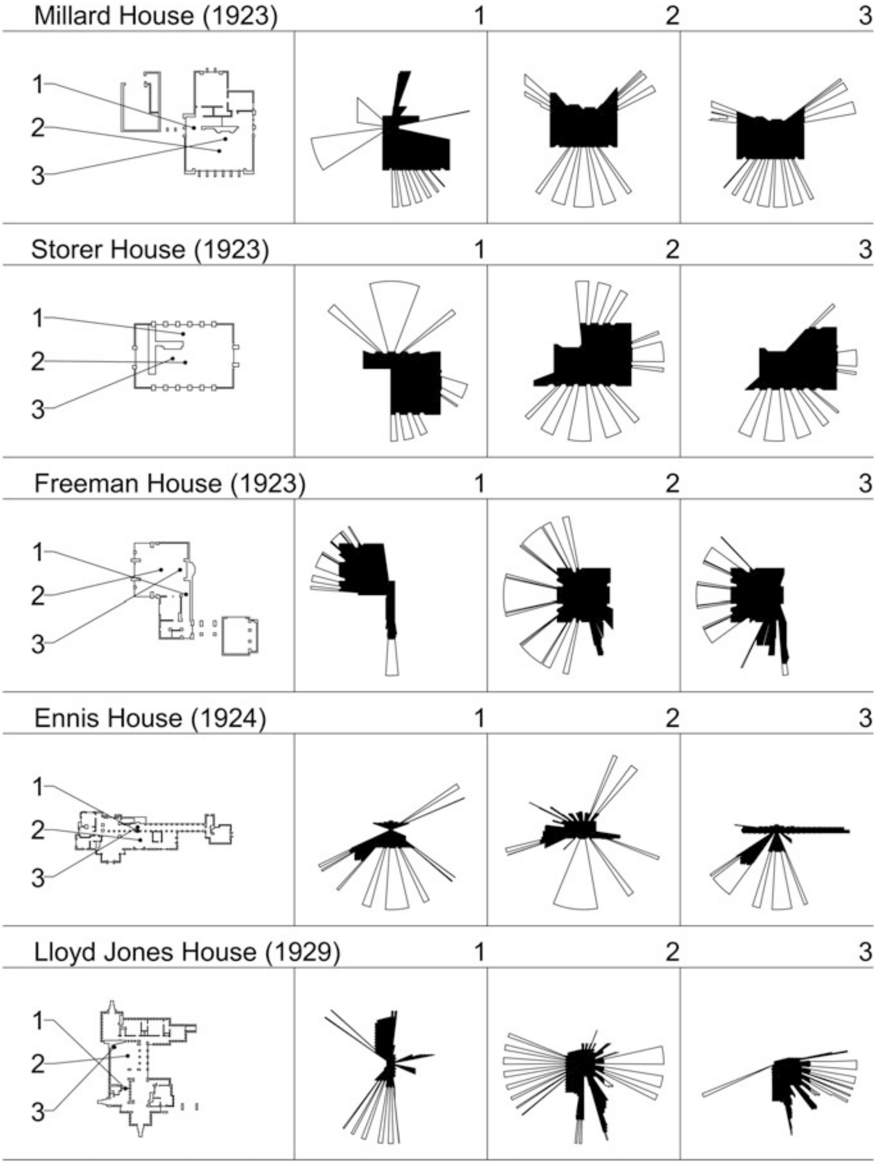
Key: Shaded isovists represent opaque window conditions whereas unshaded areas show the extent of isovist polygons that extend beyond the glazed surfaces

levels of clustering (in three cases, 1σ is ≥ 12, whereas in only one case ½σ ≥ 7), while for transparent conditions the threshold and hearth locations are less similar, and the result for the centre of the room does not express a clear pattern at all (½σ = 4). However, proportional occlusivity, being the percentage of the perimeter that consists of occluding edges, potentially provides a better value for mystery because it allows comparisons between spaces of different scale. For the opaque window conditions only one location, the centre of the room, qualifies as demonstrating a general pattern (σ = 14), while for the transparent variation the reverse situation occurs with the hearth location possessing no pattern of results (1σ = 10, ½σ = 4). Values for both measures of occlusivity are significantly higher when external views are available (Fig. 9.4).

Drift magnitude measures the distance between the observation point and the centre of the isovist polygon that entices the visitor to orient themselves in this direction in order to gain the largest possible view. Under both opaque and transparent window conditions, the isovist data for room centre and hearth views exhibit various degrees of a pattern, while the threshold location does not have a clear pattern in the data (for opaque, 1σ = 11 and ½σ = 4; for transparent, 1σ = 10 and ½σ = 7). The availability of external views serves to increase the strength of visual enticement and direct the gaze of the visitor toward the external areas (Fig. 9.5). Compactness, a measure of isovist complexity, shows higher levels of similarity for views from the room threshold, centre and hearth under transparent glazing conditions (only the hearth location is ½σ < 7). In contrast, only the centre location for opaque windows shows any level of pattern (1σ = 12). Higher compactness values indicate that the visible area is closer to that of a circle than a view with lower compactness, and the fragmentary nature of external views in Wright's architecture results in much lower compactness values (Fig. 9.5).

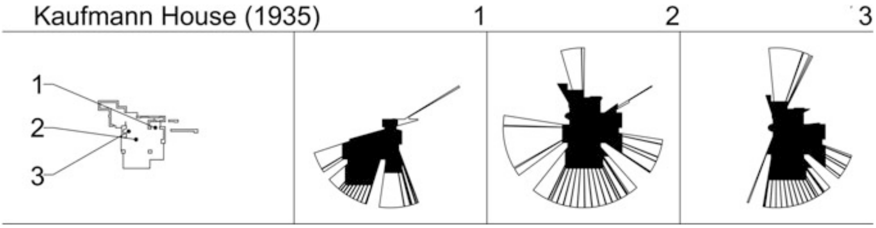
In summary, thirty-two of the forty-two measures developed for the six conditions demonstrate the presence of a pattern of results which is stronger or more consistent than might be found in a normal, random set of data (Table 9.7). Sixteen of the forty-two results are within 0.5 standard deviations of the mean.

Table 9.4 Isovists derived from three locations in each of five Textile-block Style houses



Key: Shaded isovists represent opaque window conditions whereas unshaded areas show the extent of isovist polygons that extend beyond the glazed surfaces

Table 9.5 Isovists derived from three locations in the *Kaufmann House*



Key: Shaded isovists represent opaque window conditions whereas unshaded areas show the extent of isovist polygons that extend beyond the glazed surfaces

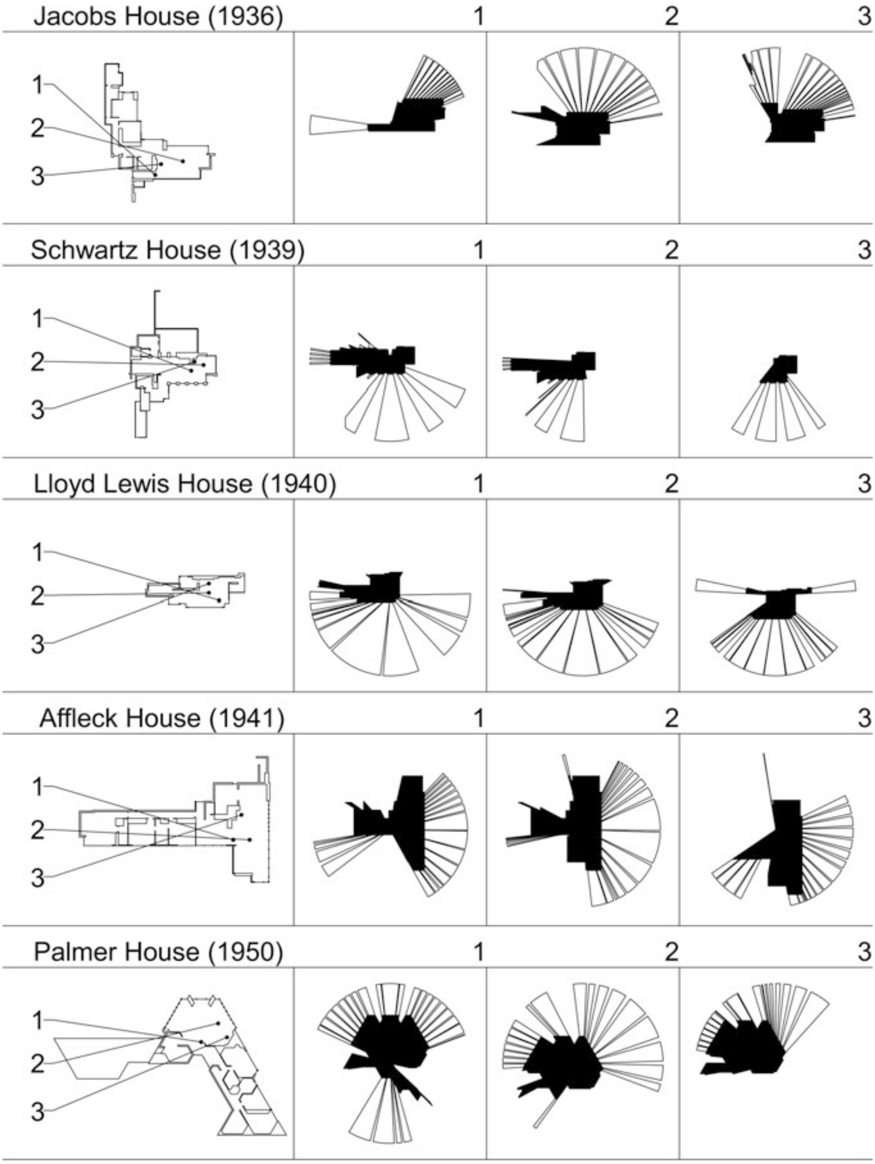
9.5 Analysis

In this section, the results of the isovist analysis are examined relative to Wright's different stylistic periods and to different individual houses. For three locations in each house, for both solid and transparent window variations, the results are tabulated for each of the seven isovist measures. These results are all examined relative to two factors: the presence of a result within one standard deviation of the mean, and within one half of the standard deviation of the mean. A summary of the complete set of results provides an indicator of both the significance and consistency of each style in the overall pattern and of individual houses within this pattern.

For the results for isovist area, all thirty of the Prairie house measures are within one standard deviation of the mean and twenty-six are within half of this. The Prairie houses are, in terms of this measure, very much at the core of the data set. Conversely, fewer than half of each of the other two styles, the Textile-block and Usonian houses, are within the central part of the data (Table 9.8). The pattern in the results for maximum radial length is similarly dominated by the Prairie works, with the majority of the Textile-block houses (27 out of 30) falling outside the core of this data set completely (Table 9.9). The data for minimal radial line length at the hearth location is virtually irrelevant as each observation point, with the exception of the *Barnsdall* data, is located 1 m from the hearth (give or take a small variation that results from using a 100 mm grid to locate the observation point) (Table 9.10). The Textile-block houses form the outliers for minimum radial line lengths observed from the room centre, yet occupy a central position in the data when viewed from the room threshold.

The results for occlusivity and proportional occlusivity show both the Prairie Style and Usonian houses to be generally within one standard deviation of the mean, although this pattern is less consistent when considering results within half that range. For the Textile-block houses, allegedly amongst the highest in mystery and complexity, only six of the thirty indicators are within one half of the standard deviation, the majority being outliers in the pattern (Tables 9.11 and 9.12). Drift magnitude is marginally more consistent in the Prairie Style houses than both the

Table 9.6 Isovists derived from three locations in each of five Usonian Style houses



Key: Shaded isovists represent opaque window conditions whereas unshaded areas show the extent of isovist polygons that extend beyond the glazed surfaces

Table 9.7 Summary data, number of houses that occur within one standard deviation of the mean value

	Opaque windows						Transparent windows						Pattern	
	T		C		H		T		C		H			
	1σ	½σ	1σ	½σ	1σ	½σ	1σ	½σ	1σ	½σ	1σ	½σ	1σ	½σ
Area	14	7	16	10	14	9	15	8	12	6	12	8	6/6	5/6
Max Rad	12	5	14	5	14	7	13	6	13	7	13	5	6/6	2/6
Min Rad	13	5	11	4	15	13	13	5	13	4	11	13	4/6	2/6
Occlusivity	15	6	14	5	15	7	12	9	12	6	11	4	5/6	2/6
Prop Occ	11	6	14	5	11	4	12	4	12	5	10	4	3/6	0/6
Drift Mag	11	4	13	7	15	7	10	7	10	6	12	6	4/6	3/6
Compact	11	4	12	6	11	4	12	8	12	7	13	6	4/6	2/3
Pattern	4/7	1/7	6/7	2/7	5/7	5/7	6/7	4/7	6/7	2/7	4/7	2/7	32/42	16/42

Key: *T* threshold, *C* centre, *H* hearth

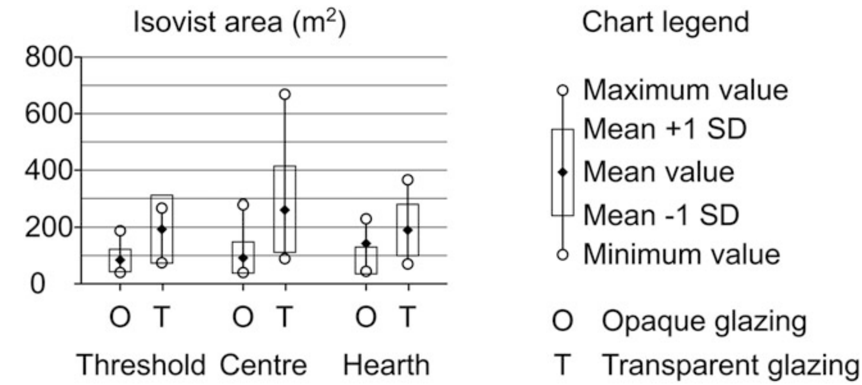


Fig. 9.2 Data summary for the area measure and chart legend

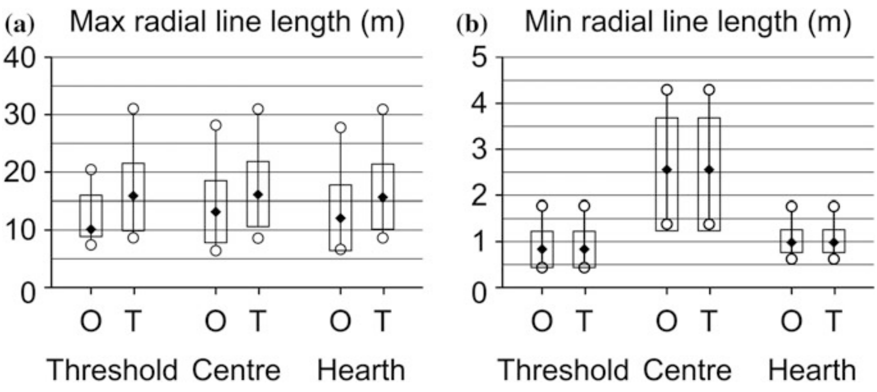


Fig. 9.3 Data summary for **a** maximum and **b** minimum radial line length measures

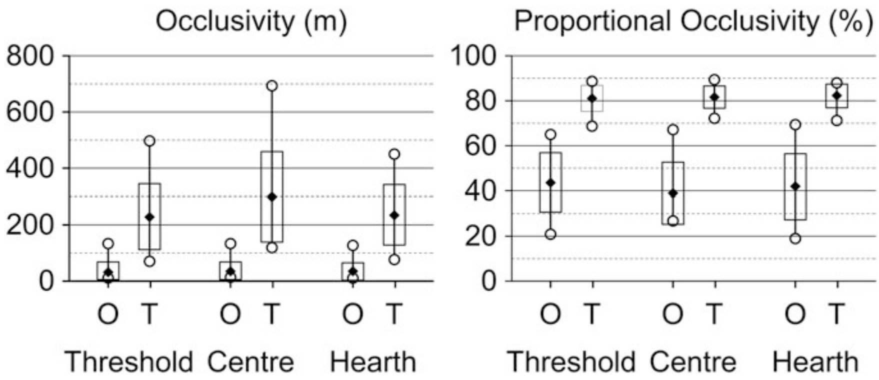


Fig. 9.4 Data summary for occlusivity and proportional occlusivity measures

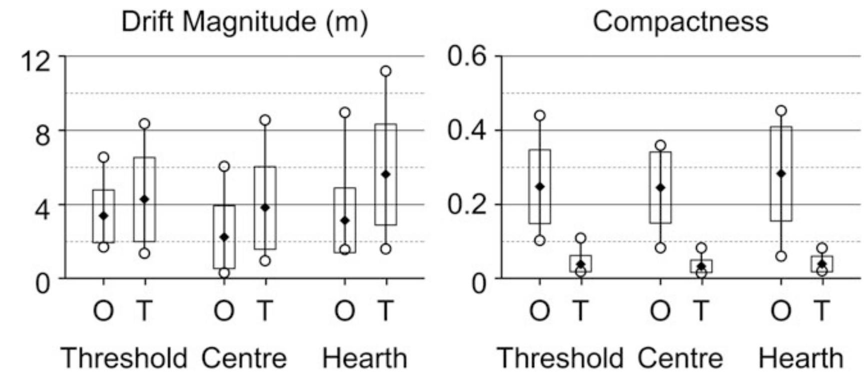


Fig. 9.5 Data summary for drift magnitude and compactness measures

Table 9.8 Results for isovist area for each house relative to the complete set

Isovist area	Opaque windows						Transparent windows						Totals		Sum	
	T		C		H		T		C		H		⊕	∅	⊕	∅
Henderson	⊕	∅	⊕	∅	⊕	∅	⊕	∅	⊕	∅	⊕	∅	6	6		
Heurtley	⊕	∅	⊕	∅	⊕	∅	⊕	∅	⊕	∅	⊕	∅	6	6		
Cheney	⊕		⊕	∅	⊕	∅	⊕		⊕	∅	⊕	∅	6	4		
Evans	⊕	∅	⊕	∅	⊕	∅	⊕	∅	⊕		⊕		6	4		
Robie	⊕	∅	⊕	∅	⊕	∅	⊕	∅	⊕	∅	⊕	∅	6	6	30	26
Barnsdall			⊕						⊕				2	0	2	0
Millard	⊕		⊕		⊕		⊕						4	0		
Storer			⊕		⊕		⊕						3	0		
Freeman	⊕	∅	⊕	∅	⊕	∅	⊕		⊕		⊕		6	3		

(continued)

Table 9.8 (continued)

Isovist area	Opaque windows						Transparent windows						Totals		Sum	
	T		C		H		T		C		H		⊕	∅	⊕	∅
Ennis	⊕		⊕	∅	⊕	∅	⊕	∅	⊕	∅	⊕	∅	6	5		
Lloyd Jones							⊕						1	0	20	8
Kaufmann	⊕		⊕				⊕	∅					3	1	3	1
Jacobs	⊕		⊕		⊕		⊕		⊕	∅	⊕	∅	6	2		
Schwartz	⊕		⊕	∅	⊕		⊕		⊕		⊕	∅	6	2		
Lloyd Lewis	⊕	∅	⊕	∅	⊕	∅							3	3		
Affleck	⊕	∅	⊕	∅	⊕	∅	⊕	∅	⊕		⊕	∅	6	5		
Palmer	⊕		⊕		⊕		⊕	∅	⊕		⊕		6	1	27	13
Sum	14	7	16	10	14	9	15	8	12	6	11	8	82	48		

Key: *T* threshold to the living room, *C* centre of the living room, *H* close proximity to the hearth, ⊕ result which is situated within one standard deviation of the mean, ∅ result which is situated within 0.5 standard deviation of the mean

Table 9.9 Results for maximum radial length for each house relative to the complete set

Maximum radial	Opaque windows						Transparent windows						Totals		Sum	
	T		C		H		T		C		H		⊕	∅	⊕	∅
Henderson	⊕	∅	⊕		⊕	∅	⊕	∅	⊕	∅	⊕		6	4		
Heurtley	⊕	∅	⊕	∅	⊕	∅	⊕	∅	⊕	∅	⊕	∅	6	6		
Cheney	⊕	∅	⊕	∅	⊕	∅	⊕	∅	⊕	∅	⊕	∅	6	6		
Evans	⊕		⊕		⊕		⊕		⊕		⊕		6	0		
Robie	⊕		⊕		⊕	∅	⊕	∅	⊕	∅	⊕	∅	6	4	30	20
Barnsdall	⊕												1	0	1	0
Millard	⊕		⊕		⊕		⊕		⊕		⊕		6	0		
Storer					⊕								1	0		
Freeman	⊕	∅	⊕		⊕	∅	⊕		⊕		⊕		6	2		
Ennis	⊕	∅	⊕										2	1		
Lloyd Jones													0	0	15	3
Kaufmann	⊕		⊕	∅	⊕	∅	⊕	∅	⊕	∅	⊕	∅	6	5	6	5
Jacobs	⊕		⊕	∅	⊕		⊕	∅	⊕	∅	⊕	∅	6	4		
Schwartz	⊕		⊕		⊕	∅	⊕		⊕		⊕		6	1		
Lloyd Lewis			⊕	∅	⊕		⊕		⊕	∅	⊕		5	2		
Affleck			⊕		⊕		⊕		⊕		⊕		5	0		
Palmer			⊕		⊕		⊕		⊕		⊕		5	0	27	7
Sum	12	5	14	5	14	7	13	6	13	7	13	5	79	35		

Key: *T* threshold to the living room, *C* centre of the living room, *H* close proximity to the hearth, ⊕ result which is situated within one standard deviation of the mean, ∅ result which is situated within 0.5 standard deviation of the mean

Table 9.10 Results for minimum radial length for each house relative to the complete set

Minimum radial	Opaque windows						Transparent windows						Totals		Sum	
	T		C		H		T		C		H		⊕	∅	⊕	∅
Henderson	⊕	∅	⊕		⊕	∅	⊕	∅	⊕		⊕	∅	6	4		
Heurtley	⊕		⊕		⊕	∅	⊕		⊕		⊕	∅	6	2		
Cheney			⊕	∅	⊕	∅			⊕	∅	⊕	∅	4	4		
Evans	⊕		⊕		⊕	∅	⊕		⊕		⊕	∅	6	2		
Robie	⊕				⊕	∅	⊕				⊕	∅	4	2	26	14
Barnsdall			⊕						⊕				2	0	2	0
Millard	⊕	∅	⊕	∅	⊕	∅	⊕	∅	⊕	∅	⊕	∅	6	6		
Storer	⊕	∅			⊕	∅	⊕	∅			⊕	∅	4	4		
Freeman	⊕				⊕	∅	⊕				⊕	∅	4	2		
Ennis	⊕				⊕	∅	⊕				⊕	∅	4	2		
Lloyd Jones	⊕	∅			⊕	∅	⊕	∅			⊕	∅	4	4	23	18
Kaufmann	⊕		⊕		⊕		⊕		⊕		⊕		6	0	6	0
Jacobs	⊕		⊕	∅	⊕	∅	⊕		⊕	∅	⊕	∅	6	4		
Schwartz			⊕						⊕				2	0		
Lloyd Lewis			⊕	∅	⊕	∅			⊕	∅	⊕	∅	4	4		
Affleck	⊕	∅	⊕		⊕		⊕	∅	⊕		⊕		6	2		
Palmer	⊕				⊕	∅	⊕				⊕	∅	4	2	22	12
Sum	13	5	11	4	15	13	13	5	11	4	15	13	78	44		

Key: *T* threshold to the living room, *C* centre of the living room, *H* close proximity to the hearth, ⊕ result which is situated within one standard deviation of the mean, ∅ result which is situated within 0.5 standard deviation of the mean

Table 9.11 Results for occlusivity for each house relative to the complete set

Occlusivity	Opaque windows						Transparent windows						Totals		Sum	
	T		C		H		T		C		H		⊕	∅	⊕	∅
Henderson	⊕	∅	⊕	∅	⊕	∅	⊕	∅	⊕	∅			5	5		
Heurtley	⊕	∅	⊕		⊕	∅	⊕	∅	⊕	∅	⊕	∅	6	5		
Cheney	⊕				⊕		⊕		⊕		⊕	∅	5	1		
Evans	⊕	∅	⊕		⊕	∅	⊕		⊕		⊕		6	2		
Robie	⊕		⊕		⊕		⊕	∅			⊕		5	1	27	14
Barnsdall	⊕		⊕	∅	⊕				⊕	∅			4	2	4	2
Millard	⊕	∅	⊕		⊕						⊕		4	1		
Storer	⊕		⊕		⊕								3	0		
Freeman	⊕		⊕	∅	⊕	∅			⊕		⊕		5	2		
Ennis	⊕	∅					⊕	∅	⊕	∅	⊕		4	3		
Lloyd Jones													0	0	16	6
Kaufmann	⊕		⊕	∅	⊕	∅	⊕	∅					4	3	4	3
Jacobs			⊕		⊕		⊕	∅	⊕	∅	⊕		5	2		

(continued)

Table 9.11 (continued)

Occlusivity	Opaque windows						Transparent windows						Totals		Sum	
	T		C		H		T		C		H		⊕	∅	⊕	∅
Schwartz	⊕		⊕	∅	⊕	∅	⊕	∅			⊕		5	3		
Lloyd Lewis	⊕		⊕		⊕	∅	⊕		⊕		⊕		6	1		
Affleck	⊕		⊕		⊕		⊕	∅	⊕	∅	⊕	∅	6	3		
Palmer	⊕	∅	⊕		⊕		⊕	∅	⊕		⊕	∅	6	3	28	12
Sum	15	6	14	5	15	7	12	9	11	6	12	4	79	37		

Key: *T* threshold to the living room, *C* centre of the living room, *H* close proximity to the hearth, ⊕ result which is situated within one standard deviation of the mean, ∅ result which is situated within 0.5 standard deviation of the mean

Table 9.12 Results for proportional occlusivity for each house relative to the complete set

Proportional occlusivity	Opaque windows						Transparent windows						Totals		Sum	
	T		C		H		T		C		H		⊕	∅	⊕	∅
Henderson	⊕		⊕	∅	⊕		⊕		⊕	∅			5	2		
Heurtley	⊕		⊕		⊕		⊕	∅	⊕		⊕	∅	6	2		
Cheney							⊕	∅	⊕		⊕		3	1		
Evans	⊕	∅	⊕		⊕						⊕		4	1		
Robie			⊕		⊕		⊕						3	0	21	6
Barnsdall	⊕	∅	⊕		⊕		⊕		⊕	∅	⊕		6	2	6	2
Millard	⊕	∅	⊕		⊕						⊕	∅	4	2		
Storer	⊕		⊕		⊕		⊕						4	0		
Freeman	⊕	∅	⊕	∅	⊕	∅							3	3		
Ennis							⊕		⊕		⊕		3	0		
Lloyd Jones											⊕	∅	1	1	15	6
Kaufmann	⊕	∅	⊕		⊕		⊕		⊕		⊕		6	1	6	1
Jacobs			⊕	∅			⊕	∅	⊕	∅			3	3		
Schwartz			⊕	∅	⊕	∅					⊕		3	2		
Lloyd Lewis	⊕		⊕		⊕	∅	⊕	∅	⊕		⊕		6	2		
Affleck	⊕		⊕		⊕		⊕		⊕	∅	⊕	∅	6	2		
Palmer	⊕	∅	⊕	∅	⊕	∅	⊕		⊕	∅	⊕		6	4	24	13
Sum	11	6	14	5	13	4	12	4	10	5	12	4	72	28		

Key: *T* threshold to the living room, *C* centre of the living room, *H* close proximity to the hearth, ⊕ result which is situated within one standard deviation of the mean, ∅ result which is situated within 0.5 standard deviation of the mean

Table 9.13 Results for drift magnitude for each house relative to the complete set

Drift Magnitude	Opaque windows						Transparent windows						Totals		Sum	
	T		C		H		T		C		H		⊕	∅	⊕	∅
Henderson	⊕		⊕		⊕				⊕		⊕		5	0		
Heurtley			⊕	∅	⊕	∅	⊕	∅	⊕	∅	⊕	∅	5	5		
Cheney	⊕	∅			⊕	∅	⊕	∅	⊕	∅	⊕	∅	5	5		
Evans	⊕		⊕		⊕		⊕		⊕		⊕		6	0		
Robie	⊕		⊕	∅			⊕	∅	⊕	∅	⊕	∅	5	4	26	14
Barnsdall			⊕	∅	⊕	∅	⊕	∅					3	3	3	3
Millard	⊕	∅	⊕	∅	⊕		⊕		⊕				5	2		
Storer	⊕	∅	⊕		⊕	∅					⊕		4	2		
Freeman	⊕		⊕		⊕	∅	⊕	∅	⊕	∅	⊕	∅	6	4		
Ennis	⊕				⊕						⊕		3	0		
Lloyd Jones							⊕	∅	⊕	∅			2	2	20	10
Kaufmann			⊕		⊕				⊕		⊕		4	0	4	0
Jacobs	⊕		⊕	∅	⊕	∅	⊕	∅	⊕		⊕	∅	6	4		
Schwartz	⊕	∅			⊕								2	1		
Lloyd Lewis	⊕		⊕	∅	⊕								3	1		
Affleck			⊕		⊕		⊕		⊕	∅	⊕		5	1		
Palmer			⊕	∅	⊕	∅			⊕		⊕	∅	4	3	20	10
Sum	11	4	13	7	15	7	10	7	12	6	12	6				

Key: *T* threshold to the living room, *C* centre of the living room, *H* close proximity to the hearth, ⊕ result which is situated within one standard deviation of the mean, ∅ result which is situated within 0.5 standard deviation of the mean

Table 9.14 Results for compactness for each house relative to the complete set

Compactness	Opaque windows						Transparent windows						Totals		Sum	
	T		C		H		T		C		H		⊕	∅	⊕	∅
Henderson	⊕		⊕		⊕		⊕		⊕	∅			5	1		
Heurtley	⊕						⊕	∅	⊕		⊕		4	1		
Cheney							⊕	∅	⊕		⊕	∅	3	2		
Evans	⊕		⊕		⊕	∅	⊕	∅	⊕		⊕	∅	6	3		
Robie			⊕	∅	⊕		⊕				⊕		4	1	22	8
Barnsdall	⊕	∅	⊕		⊕				⊕	∅	⊕		5	2	5	2
Millard	⊕	∅	⊕	∅					⊕		⊕	∅	4	3		
Storer					⊕		⊕		⊕				3	0		
Freeman	⊕		⊕	∅	⊕						⊕		4	1		
Ennis	⊕						⊕	∅	⊕	∅	⊕	∅	4	3		
Lloyd Jones											⊕		1	0	16	7
Kaufmann			⊕		⊕	∅	⊕	∅	⊕		⊕		5	2	5	2
Jacobs			⊕	∅			⊕	∅	⊕	∅	⊕		4	3		
Schwartz	⊕		⊕		⊕	∅							3	1		

(continued)

Table 9.14 (continued)

Compactness	Opaque windows						Transparent windows						Totals		Sum	
	T		C		H		T		C		H		⊕	∅	⊕	∅
Lloyd Lewis	⊕	∅	⊕	∅	⊕	∅	⊕	∅	⊕	∅	⊕	∅	6	6		
Affleck	⊕		⊕	∅	⊕		⊕	∅	⊕	∅	⊕	∅	6	4		
Palmer	⊕	∅	⊕		⊕		⊕		⊕	∅	⊕		6	2	25	16
Sum	11	4	12	6	11	4	12	8	13	7	14	6	73	35		

Key: *T* threshold to the living room, *C* centre of the living room, *H* close proximity to the hearth, ⊕ result which is situated within one standard deviation of the mean, ∅ result which is situated within 0.5 standard deviation of the mean

Textile-block and Usonian designs, but overall, all three of these styles shape the pattern (Table 9.13). Compactness, like occlusivity, is a measure wherein the Usonian houses feature more consistently and centrally in the pattern than the Prairie houses (Table 9.14).

In summary, with forty-two results for each house there are 210 results for each style (Table 9.15). Of the 210 results for the Prairie Style houses, 182 (86.7%) are within one standard deviation of the mean and 102 (48.6%) are within half of this range. For the Textile-block houses, 124 (59.0%) are within one standard deviation of the mean and fifty-eight (27.6%) are within half of this range. Finally, for the Usonian designs, 173 (82.4%) are within one standard deviation of the mean and eighty-one (38.6%) are within half of this range. Thus, the Prairie Style works are

Table 9.15 Summary of results for all measures for each house relative to the complete set

House	Totals		Totals as %	
	1σ	½σ	1σ	½σ
Henderson	38	22	90	52
Heurtley	39	27	93	64
Cheney	32	23	76	55
Evans	40	12	95	29
Robie	33	18	79	43
Barnsdall	23	9	55	21
Millard	33	15	79	36
Storer	22	6	52	14
Freeman	34	17	81	40
Ennis	26	14	62	33
Lloyd Jones	9	7	21	17
Kaufmann	34	12	81	29
Jacobs	36	22	86	52
Schwartz	27	10	64	24
Lloyd Lewis	33	19	79	45
Affleck	40	17	95	40
Palmer	37	15	88	36
Mean	31.53	15.41	75.07	37.11

most consistently part of the pattern, followed by the Usonian designs. Conversely, the Textile-block houses are the most divergent in terms of the overall set of results, and barely conform to the pattern (Table 9.15).

The *Barnsdall* and *Kaufmann* houses do not belong to any of the three architectural styles Wright employed. The former was constructed for Aline Barnsdall, an oil heiress, as part of a larger and unrealised theatre and arts complex in East Hollywood (Fig. 9.6). It features limited glazing, imbuing the house with refuge-dominant qualities that are enhanced by views into a large internal courtyard and walls that lean in toward the roof. However, the *Barnsdall House* does incorporate prospect features, such as the corner glazing that appears in later works including the *Freeman House* and Fallingwater. Of the forty-two results for the *Barnsdall House* only twenty-three (54.8%) are within one standard deviation of the mean and only nine (21.4%) are within half this range. Compared to each style, this data indicates the experience of the living room of the *Barnsdall House* is most similar to the Textile-block designs. This outcome might be anticipated, as the *Barnsdall House* was designed immediately prior to the first of the Textile-block houses and it displays the Mayan motifs that come to characterise them.

The *Kaufmann House* is located in a wooded Pittsburgh valley and it utilises a series of reinforced concrete cantilevered floors to give the impression that it floats above a small waterfall (Fig. 9.7). The house features long, horizontal window bands reminiscent of the Prairie Style and incorporates prospect corner glazing to enhance the outlook of the design, while relatively low ceilings and deep floor plans create a refuge for visitors to withdraw toward the centre of the house. Mathematically, the *Kaufmann House* is most like the Usonian designs, with thirty-four (81.0%) of its results located within one standard deviation of the mean, however the *Kaufmann House* is less central to the data than the Usonian designs, with only twelve (28.6%) of its results within the half standard deviation range. Like the *Barnsdall House*, the *Kaufmann House* appears to be a prototype for the spatial experiences found in the style that would immediately follow.

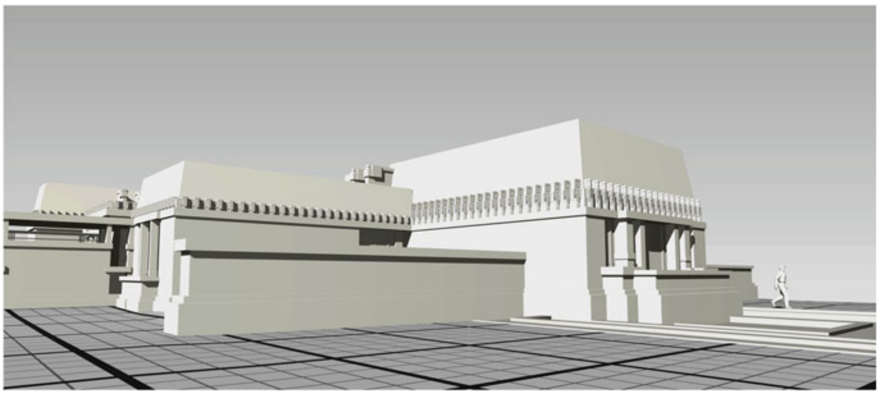


Fig. 9.6 *Aline Barnsdall House* ('Hollyhock')

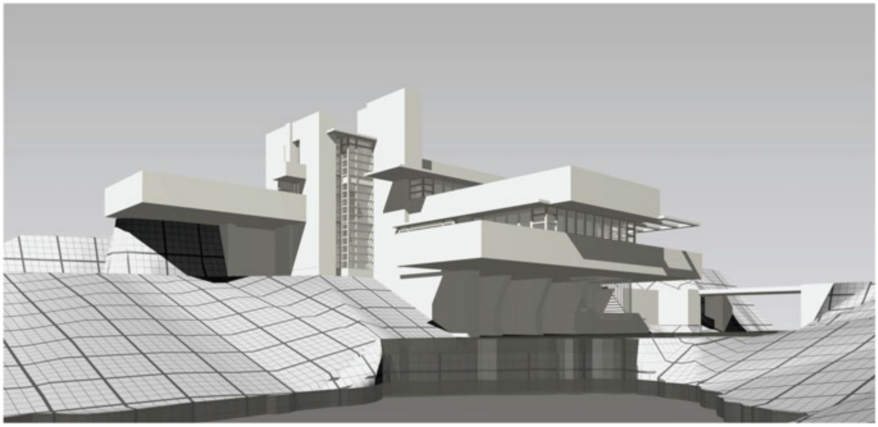


Fig. 9.7 *Edgar Kaufmann House* ('Fallingwater')

Within the three major stylistic groups there are also some designs with notable results. For example, 93% of the measures derived from the *Heurtley House* are within one standard deviation of the mean and 64% are within half of this. This means that the *Heurtley House* is the most typical of the data in the entire sample. The *Henderson House* from the same stylistic set, and the *Affleck* and *Jacobs* houses, from the Usonian Set, are also central to the larger pattern. Of the Textile-block designs, only the *Freeman House* has a similar set of characteristics.

9.6 Conclusion

This chapter examines the claim that the living spaces Frank Lloyd Wright produced throughout his career feature similar spatio-visual characteristics. If we revisit the first, two-part hypothesis presented earlier in the chapter and the data tested for individual houses and stylistic groups, then 75% (which is greater than the benchmark 68%) are within one standard deviation of the mean, and 37% (which is less than 38.2% benchmark) are within 0.5 standard deviation. Thus, there is a general, but not consistent, pattern across the complete set of data. Therefore, the first hypothesis, that Wright's *living rooms possess a high degree of spatio-visual similarity*, despite stylistic differences, is broadly confirmed.

The availability of external views has a somewhat predictable impact on the results of the isovist analysis. As expected, the values for isovist area, maximum radial line length, occlusivity, proportional occlusivity and drift magnitude all increase when not limited to internal spaces. The values for compactness decrease under transparent window conditions and, combined, these results confirm that the first part of the second hypothesis is true. The result for the second part of this hypothesis is less clear. External views do consistently and negatively impact on the presence of a pattern, when the pattern is defined as the number of houses within one standard deviation of the mean. However, this is not the case when the pattern is defined as the number of results within half of this range. Within this smaller range only isovist area and proportional occlusivity indicate the degradation of a pattern. Results for maximum radial line length, occlusivity, drift magnitude and compactness indicate a larger number of results within the half standard deviation range, though for the first measures the difference is limited to a single additional result under transparent window conditions. Therefore it might be argued that the inclusion of external views has a significant impact on the values developed through isovist analysis but a minimal impact of the ability of basic statistical analysis to determine the presence of a pattern. Alternatively this result might be an artefact of limiting the extent of external views to 110% of the longest internal view. Changing the length of this view limit or applying a single absolute view limit to all houses may provide a different result.

Chapter 10
Enticement in, and Through, Wright's Architecture

As the previous chapters reveal, a recurring argument offered by historians and critics is that Frank Lloyd Wright's domestic designs employ a distinct combination of spatial and formal features to evoke a sense of emotional wellbeing in visitors. There are two parts to this argument, which uses spatial psychology and environmental preference theory to explain the power or appeal of architecture. The first part, its psychological basis (see Chap. 8), maintains that certain environmental characteristics evoke particular feelings. The second part of the argument, that Wright's domestic spaces somehow encapsulate or exhibit these ideal environmental characteristics, is reliant on two different propositions. The first of these is that a particular arrangement of spatio-visual features is present in all of Wright's major living room spaces. That part of the theory, at least insofar as it argues for the existence of a consistent pattern in Wright's living rooms, is critically examined in Chap. 9. The second proposition, that movement through Wright's architecture is responsible for evoking the psychological response, is the focus of the present chapter. The particular type of movement that is thought to evoke the ideal emotional state involves the controlled passage through Wright's architecture, along a 'pathway of discovery' from the main entry door to the centre of the living room and then to the hearth. The method used in this chapter to mathematically examine the spatio-visual experience of movement along this path is isovist field analysis (see Chap. 4). Fifteen houses, five each from Wright's Prairie Style, Textile-block and Usonian periods, are used for this analysis. Because the present chapter builds on the previous two, after a short background, only new or relevant aspects of the method, its behavioural explanation and architectural focus, are described.

M. J. Ostwald and M. J. Dawes, *The Mathematics of the Modernist Villa*, Mathematics and the Built Environment 3,
https://doi.org/10.1007/978-3-319-71647-3_10

10.1 Introduction

Born in Wisconsin in 1867, Frank Lloyd Wright commenced work as a draughtsman at the age of 19 and over the next few years completed a range of projects for Louis Sullivan's office in Chicago. After setting up his own practice in 1893, Wright developed the first of his three great domestic styles, the Prairie houses, and slowly gained national prominence as a result of their success. In the following years, inspired by new technology, he experimented with a mono-material construction system producing a number of so-called 'Textile-block' designs. While relatively few of these were built, they are regarded as Wright's second great domestic style and some of them have since become amongst the most iconic houses of their era. The origins of the final stage of Wright's work can be traced to the 1930s when, in the midst of the Great Depression, he was forced to develop a new approach to domestic architecture in response to the growing need for low cost accommodation. Wright called this third set of works, which he produced until the final years of his life, Usonian architecture.

During his almost 70 year career and across these three stylistic movements, Wright was ultimately responsible for the design of over 300 residential dwellings. When historians review this body of work a recurring theme is the way in which these houses seem to evoke or stimulate positive emotional responses from their occupants (Twombly 1979; Laseau and Tice 1992; Lind 1994; Hale 2000; Heinz 2006). While multiple attempts have been made to account for this allegedly intuitive, immediate and universal reaction to Wright's architecture (Lin 1991; Harries 1997; Assefa 2003; Norberg-Schulz 1979; Hale 2000), the most widely accepted explanation is derived from a combination of prospect-refuge theory and information theory.

Prospect-refuge theory (Appleton 1975) and information theory (Kaplan and Kaplan 1982) were separately developed to explain human preference for particular environments. These theories collectively suggest that environments which offer a balance of outlook, enclosure, complexity and mystery satisfy basic human psychological needs through their capacity to evoke the type of spatial qualities that shaped human evolution in primitive societies. While the initial focus of these two theories was on natural environments and the properties of relatively static and localised conditions, proponents of both theories acknowledge that their ideas are equally relevant to understanding architectural space and to explaining the experience of movement though an environment.

Combining these two theories and adding his own insights, Hildebrand's (1991) explanation for the emotional impact of Wright's domestic architecture is that certain paths through these houses feature a particular pattern of spatio-visual properties which balance shifting prospect and refuge qualities alongside mystery, complexity and enticement. Hildebrand dubbed this pattern the 'Wright Space', arguing that it incorporates a singular combination of spatio-visual properties that resonate with primitive survival instincts and thereby evoke positive emotional reactions.

Taking Hildebrand's argument as its starting point, the purpose of the present chapter is twofold: first, to examine whether there is a pattern of spatio-visual properties in passage through Wright's domestic architecture; second, to see if there is any correlation between the measurements derived from these properties and the experiential qualities that they are allegedly associated with. In order to answer these two questions, fifteen of Wright's houses are examined, including five each from his Prairie, Textile-block and Usonian styles.

For this chapter, isovist fields are used to construct a comparison of the visual experience of a person moving along a path through each house, from the front door to the living room and hearth. Every step along this path generates a different isovist, from which the changing spatio-visual experience of the architecture can be described and mathematically compared. Through this process it is possible to determine whether a pattern exists in the experience of passage through these houses and if it conforms to any of the theorised qualities of the Wright Space. Thus, the purpose of this chapter is not to test prospect-refuge theory or information theory, but rather to examine a group of the designs that have been repeatedly presented as architectural exemplars of this theory in action. If there is no strong pattern in the data, then the existence of the Wright Space is questionable, and its basis as the origin of prospect-refuge related design values must also be carefully reviewed. If a pattern does exist, then it is possible to examine whether or not it conforms to the characteristics that are thought to evoke the psychological reaction.

This particular application of isovist analysis to investigating paths through Wright's architecture has both theoretical and technical limitations. With regard to the former, the method is only capable of providing quantitative data about the geometric properties of sight lines in the context of the built forms that shape or restrict them. The method, as it is applied here, is incapable of accommodating or modelling an individual's actual perception of the environment. This is because personal factors such as physical stature, age, cultural background, education and previous experience all influence environmental perception (Nasar 1984; Kaplan and Herbert 1988). Furthermore, the role of prospect-refuge 'symbols' (including the representational content of artwork on walls, dramatic views through windows, or decorative artefacts within an environment) cannot be assessed using this method. Technical limitations of the method include a lack of capacity to capture the experiential qualities of colours or surface textures, both of which may have a psychological impact on the experience of a space. Finally, isovist analysis is conventionally a two-dimensional method, focussed on plan geometry. To partially ameliorate this issue, data pertaining to floor-to-ceiling heights at each isovist generation position along the paths through the fifteen houses is also recorded for analysis. Thus, while not a comprehensive three-dimensional review of each house, both two and three-dimensional geometric features are included in the results and analysis.

The structure of the remainder of this chapter commences with a brief background to relevant aspects of environmental preference theory and to Hildebrand's application of these ideas in architecture. Next, specific aspects of isovist field analysis that are necessary for this chapter are noted before four hypotheses are developed for testing. These hypotheses articulate patterns in the isovist data that correspond to the phenomenological qualities which Hildebrand argues are unique to the Wright Space. Specific methodological details of this analysis are described in the section that follows, before the data for each house is presented textually and graphically. This chapter concludes by reviewing the hypothesised outcomes in light of the final results.

10.2 Environmental Experience

A common proposition in architectural theory is that the experience of moving through any environment, whether natural or artificial, is potentially able to shape a person's emotional state. Without resorting to specific psychological or behavioural explanations, it would seem reasonable to accept that the experience of following a long, winding path through a building to a small, dark room is very different to that of following a short, direct route, to a large, light-filled space. The first of these experiences is possibly one of growing mystery or of discovery, with its final destination being initially a place of unknown properties and later, potentially, an ideal hiding place. The emotional impact of the second path is likely more immediate and straightforward. The experience is one of clear directionality; there is no confusion about where to go, the final destination is fully exposed. The spatial and formal cues present in the second path suggest movement towards an important place, potentially for meeting others or to allow for improved surveillance.

Such interpretations of the emotional impact of these two imagined paths are necessarily speculative, because there are many different features shaping both types of passage. For example, if the first, winding path features a ceiling height and corridor width that gradually decrease, claustrophobic feelings might be heightened along its route. Similarly, if the second path increases in height and width along its length, then the sense of importance, of ceremonial or ritual purpose, will be similarly enhanced. Simplistically, the first of these paths is one of increasing refuge, while the second emphasises prospect.

The presence of views to alternative paths and spaces can also change the experience of the act of passing through a building. For example, the existence of a wide variety of lateral or secondary paths which lack any visual signs of leading to a distinct space, may result in a sense of confusion or disorientation. However, such a diversity of routes might also evoke a feeling of freedom, reinforcing the notion that the visitor has a choice of paths and destinations. Conversely, the absence of any side paths, or views to any other spaces, might increase the sense that the destination is more important or inevitable, triggering either a heightened perception of foreboding or of arrival. Once again, these types of paths could be thought of as moderating the degree to which a person gradually experiences the innate complexity or mystery, clarity or legibility, of a space.

These examples—of different types of paths, room sizes and ceiling heights, along with alternative routes and views into other spaces—are all typical of architects' descriptions of the imagined or intended emotional impact of movement through a building. Indeed, a common conceit in architectural design is that emotional responses can be choreographed through the careful use of space and form (see Chap. 6). Such descriptions and intentions are often found in phenomenologically-inspired design theories, where architects provide accounts of the apparently universal experience of space and form, regardless of the myriad of physical, cultural and social differences which shape every person's actual experience of a building. Whether convincing or not, such spatio-visual truisms are inherently seductive and, in a few important cases, there is even evidence that people do offer surprisingly similar accounts of their experience of movement through a building. This is allegedly the case with Frank Lloyd Wright's domestic architecture.

As previously stated, there are two parts to this argument about the experience of Wright's architecture. The first is that there is a distinct pattern of spatio-visual properties present in the routes through Wright's architecture, from a primary exterior entry, through to the living room and hearth. The second is that this pattern is capable of evoking a positive emotional response. This second part has been examined previously and five environmental qualities—prospect, refuge, complexity, mystery and enticement—have been identified as being potentially able to evoke feelings of safety, security and wellbeing. The focus of the remainder of this section is therefore on the first part of Hildebrand's argument, about the spatio-visual pattern that is present in Wright's architecture.

The act of following a path through a building involves both a constantly shifting location and the concomitant passage of time. Thus, the pattern of spatio-visual experience is revealed simultaneously in both a sequential (from point x to point y) and a temporal (from time x to time y) manner. Hildebrand argues that the spatio-visual properties of the Wright Space are revealed when following a distinct programmatically-defined path, from the public realm (represented as a major exterior door) to a more private family space (the living room) and then to its innermost location (the hearth). The path itself is defined as the most direct route between these three locations, regardless of the particular house plan, its number of levels or size. This means that the pattern is concerned with shifting spatial and formal properties as sequentially and temporally revealed, and Hildebrand's argument is that these changes are repeated in a similar way in each house.

Hildebrand identifies four specific, measurable spatio-visual characteristics of passage through Wright's architecture. First, the paths are narrow and constrained before opening out into large living areas, where the location of highest refuge is adjacent to the hearth and the centre of this room offers a slightly more elevated prospect, providing a balanced relationship between outlook and enclosure. Second, Wright uses particular combinations of architectural features to emphasise the shift from a refuge-dominant entry to a prospect-oriented living space. This reinforcing strategy, called 'reduplication', occurs when, for example, Wright combines low ceiling heights with narrow corridor widths, or high ceiling heights with large room widths. Such a combination serves to dramatize the shift from one state to another. The third part of the pattern is that the approach path draws the visitor through the house to the centre of the living room. This quality, known as 'enticement', is meant to be strongest at the start of the path and decrease as the centre of the living room is reached. Ideally, enticement should not work against the dominant direction of the path, meaning that a person should not be strongly drawn to leave the route and enter more private areas or service zones. The fourth part of the pattern is that the approach path to the living room is imbued with a high level of mystery and complexity, while the hearth offers a much lower level of mystery.

In summary, passage through Wright's architecture along this predetermined path involves passing through and emerging from a constricted, labyrinthine passage into a more spacious room with elevated views over surrounding areas. Thus, the Wright Space is characterised by the changing and reduplicated relationship between prospect, refuge, mystery, complexity and enticement, and not the presence of a single static condition.

10.3 Method

10.3.1 Hypotheses

Four hypotheses are framed for testing in this chapter, all of which are derived from Hildebrand's arguments about the spatial and psychological characteristics of Wright's architecture (Table 10.1). The four hypotheses are tested using a combination of isovist and metric measures which have empirical, mathematical or logical evidence connecting them to prospect, refuge, mystery, complexity and enticement (Stamps 2005, 2011; Wiener and Franz 2005; Meilinger et al. 2009; Wong et al. 2012; Ostwald and Dawes 2013c; Dawes and Ostwald 2013a). While some of these measures have been questioned in the past, or shown to be ineffective in certain circumstances, as Chaps. 4 and 8 indicate, they remain useful for the present purpose, which is primarily concerned with spatial properties and only indirectly, or by inference, with psychological ones (Table 10.2).

The first hypothesis maintains that in Wright's domestic architecture a shift occurs from refuge-dominant to prospect-dominant conditions as one moves along a path from the entry to the living room. This hypothesis is tested using linear trendlines generated from measures for isovist area (A), maximum radial line ($RL_{(L)}$) and minimum radial line ($RL_{(S)}$) along with the actual height (H) of the space. The second hypothesis is associated with the argument that the emotional impact of Wright's architecture is enhanced through reduplication of spatio-visual properties associated with prospect and refuge geometry. This hypothesis is tested using correlations between four different prospect and refuge measures, to see if any are consistently aligned in Wright's architecture. The third hypothesis suggests that, as one moves along a path from the entry to the living room, enticement is in the forward direction and gradually reduces in magnitude. In practical terms, the space of the path should entice a visitor forward along the path toward the living space where enticement should then be at its lowest level, encouraging a person to remain

Table 10.1 Spatial properties mapped to specific hypotheses, analytical methods and result indicators

	Property	Hypothesis	Method	Indicator of a positive result
1	Prospect and refuge	In Wright's domestic architecture, a shift occurs from refuge-dominant to prospect-dominant conditions while moving along a path from the entry to the living room	Isovist analysis using A, H, $RL_{(S)}$ and $RL_{(L)}$ measures	From the start to the finish of the path: (i) linear trendlines generated for A, H and $RL_{(S)}$ will increase (ii) a linear trendline for $RL_{(L)}$ will increase or remain stable
2	Reduplication	In Wright's domestic architecture, multiple different spatial properties reinforce the same prospect-refuge conditions while moving along a path from the entry to the living room	Isovist analysis using A, H, $RL_{(S)}$ and $RL_{(L)}$ measures	Strong correlations ($R^2 > 0.7$) between A, H, $RL_{(S)}$ and $RL_{(L)}$ measures are evidence of reduplication Weak correlations ($R^2 < 0.3$) between A, H, $RL_{(S)}$ and $RL_{(L)}$ measures confirm that reduplication is not occurring
3	Enticement	In Wright's domestic architecture, while moving along a path from the entry to the living room: (i) enticement is in the forward direction (ii) enticement gradually reduces in intensity	Isovist analysis using D_A and D_M measures	(i) D_A will be within the range ±75° for >50% of the path length (ii) From the start to the finish of the path, a linear trendline generated for D_M will decrease
4	Mystery and complexity	In Wright's domestic architecture, levels of mystery and complexity will decrease while moving along a path from the entry to the living room	Isovist analysis using O, $O{:}P$ and J measures	From the start to the finish of the path, linear trendlines generated for O, $O{:}P$ and J data will decrease

there. This hypothesis is tested using Drift Angle (D_A) and Drift Magnitude (D_M), the former of which is expected to be within the range ±75° (that is, 75° to left or right of the centreline of the viewer's vision) for more than 50% of the path. While a cone of vision in the range of ±90° is technically forward of the observer, angles beyond ±75° suggest a perpendicular rather than forward trajectory. As strength of enticement is meant to fall along the path, a linear trendline is developed for Drift Magnitude to test this property. The final hypothesis holds that levels of mystery and complexity will decrease while moving along a path from the entry to the living room. To test this, linear trendlines are developed from the isovist measures for Occlusivity (O), Proportional Occlusivity ($O{:}P$) and Jaggedness (J).

Table 10.2 Isovist and metric measures mapped to perceptual indicators

Measure	Definition	Spatial experience
Isovist area (*A*)	Area of isovist polygon	Prospect or refuge
Maximum radial line ($RL_{(L)}$)	Length of the longest single radial line used to generate the isovist	Prospect or refuge
Minimum radial line ($RL_{(S)}$)	Length of the shortest single radial line used to generate the isovist	Prospect or refuge
Height (*H*)	Floor to ceiling height at isovist observation point	Prospect or refuge
Occlusivity (*O*)	Total length of all occluded edges. Occluded edges are ones that are not defined by building surfaces, thus they are the unknown or ill-defined part of the visual experience of a space	Mystery
Proportional occlusivity (*O*:*P*)	The percentage of the isovist perimeter (*P*) consisting of occluded (*O*) edges	Mystery
Jaggedness (*J*)	Jaggedness is the ratio of perimeter^2 to area. A high *J* value indicates a more visually complex isovist	Complexity
Drift magnitude (D_M)	Distance from observation point to centre of mass of isovist polygon	Enticement
Drift angle (D_A)	Angle between visitor facing direction and centre of mass of isovist polygon	Enticement

10.3.2 Approach

The fifteen cases which are the subject of the present analysis are the *Henderson*, *Heurtley*, *Cheney*, *Evans* and *Robie* houses from the Prairie Style; the *Millard*, *Storer*, *Freeman*, *Ennis* and *Lloyd Jones* houses from the Textile-block series; and the *Jacobs*, *Schwartz*, *Lloyd Lewis, Affleck* and *Palmer* houses from Wright's Usonian period. Of these fifteen houses, thirteen feature in Hildebrand's argument for the existence of a pattern in the spatio-visual experience of movement through Wright's architecture. The two exceptions are the *Henderson* and *Lloyd Jones* houses. Importantly, because the majority of these houses are central to Hildebrand's arguments for the Wright Space, this means that these fifteen cases are ones which are most likely to reveal the pattern and to show evidence that supports Hildebrand's argument if it, respectively, exists and is correct. Conversely, if the pattern is not clear, or it does not support the theorised conditions, then the entire argument must be called into doubt.

The CAD models of the fifteen houses used for this analysis are derived from Wright's final construction drawings for all houses (Futagawa and Pfeiffer 1987a, b, c, d) with the exception of the *Lloyd Jones House*, which is based on a measured survey of the completed design (Pfeiffer and Goessel 2010). Wright was notorious for calibrating the vertical dimensions of his designs to his own height, regardless of the stature of his clients (Hildebrand 1991). For this reason, each floor plan in the analysis represents a horizontal slice through the building 1.65 m above the floor level to approximate Wright's experience of his architecture.

A lack of reliable and consistent information regarding the grounds of each building limits the analysis to interior spaces, thus external doors were treated as closed and windows as opaque. This decision, while consistent with the theory being tested and replicating the actual experience at certain hours of the day and times during the year, does limit the effectiveness of some measures and ignores the impact of external landscape symbols and hazards. However, as Chap. 9 reveals, measures for interior prospect were more clustered and consistent than those which included exterior prospect. This limit to the available data means that it is not possible to analyse the external paths leading to the house even though they are included in Hildebrand's characterisation of Wright's architecture and are recorded in the general discussion and diagramming of the results for each house in this chapter. In addition, doors to dedicated storage and mechanical plant areas are considered to be closed while all other internal doors are treated as open.

Each plan is analysed using UCL Depthmap and an isovist field generated from a 100 mm grid. The subset of this data selected for analysis corresponds to every fifth grid point located on a path from the front door to the living room and hearth of each house. Selecting every fifth observation point of the 100 mm grid approximates the stride length of a person of Wright's stature and allows an accurate tracing of the path. Where possible, the paths identified in each house replicate those identified in Hildebrand's (1991) analysis of Wright's architecture. If Hildebrand did not explicitly document or describe the path, then they are generated using rules extrapolated from his diagrams and text. Thus, these paths all follow straight lines, use only 90° turns and minimise the distance travelled and the number of turns required to reach their destination. Paths avoid dedicated service areas (such as kitchens or servant's entrances), pass one metre in front of the living room hearth, and terminate in the centre of the living room, unless the design requires the visitor to pass through the room centre before reaching the hearth, where the path will end. The centre of the living room is defined as the position identified by the intersection of lines drawn from diagonally opposite corners of the room.

There are two exceptions to these rules. First, Wright utilises an equilateral triangular grid in the *Palmer House* and its form, circulation areas and movement path also make use of 60° turns. Thus, both 60° and 90° turns occur in the path through that design. The second exception to the rules relates to the *Schwartz House*, which does not have a defined living room but does feature both a lounge and recreation room. The lounge is chosen as the surrogate living space in this instance as it features a larger number of elements from Hildebrand's pattern than the recreation room.

In instances where the front door and living room are located on different storeys, a hybrid floor plan is created to allow for the seamless analysis of the spatial experience of vertical circulation (Ostwald and Dawes 2013b). As an example of this method of constructing isovists across levels, consider the path through the *Robie House* (Fig. 10.1). Isovist polygons are created for all portions of the ground floor (Plan A). The isovists which correspond to 500 mm steps along the

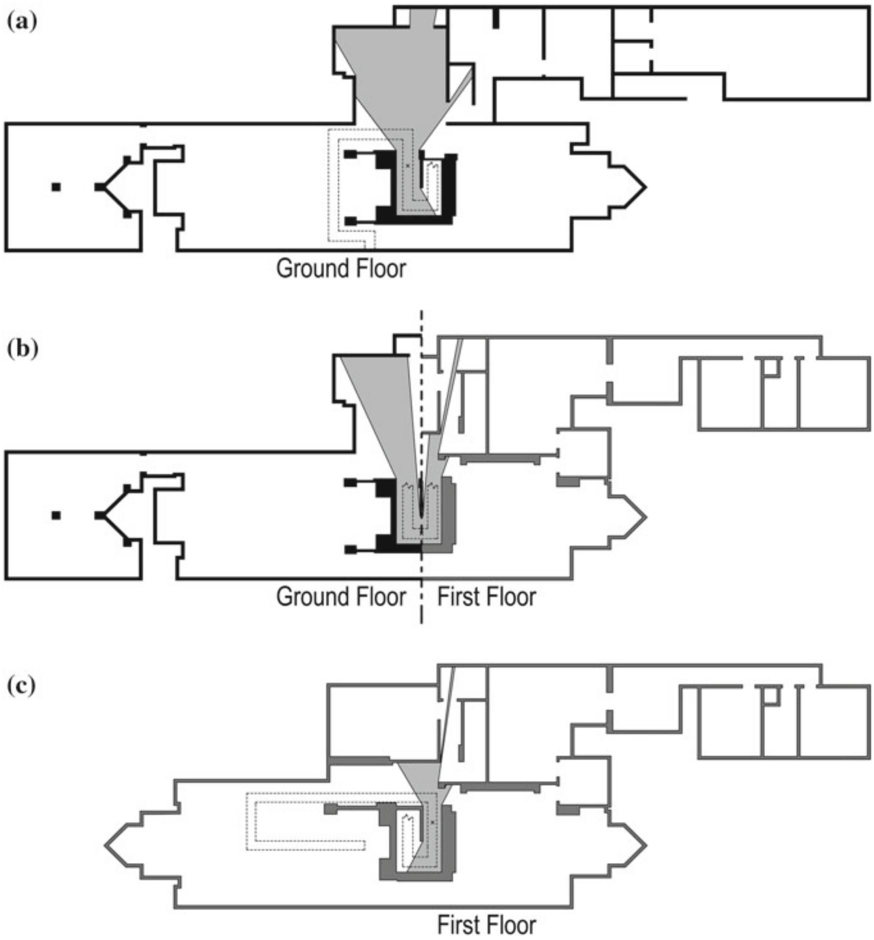


Fig. 10.1 Three hybrid floor plans required for isovist analysis of vertical circulation in the *Robie House*

path leading up to the staircase are identified and their data recorded. At the base of the stairs the isovist (shown on Plan A) yields identical mathematical data regardless of whether it is generated using either Plan A or a hybrid Plan B, which includes the base of the stairs and portions of the upper level that are not yet visible. The central landing of the stairs is a transition point where portions of both storeys are visible and the isovist must incorporate information from both storeys. Isovist polygons are generated for all portions of the hybrid floor plan (Plan B) and the isovist which corresponds to the transition point is selected and its data recorded. Isovist polygons are then generated for the upper storey (Plan C) and the isovists which correspond to 500 mm steps along the path leading to the living room are identified and their data recorded.

For each house an axonometric diagram of the path is provided and annotated, along with four graphs to present the data associated with this path. Each graph represents the path through the house from the front door (to the left side) to the living room, end point (to the right). The first graph in each set plots isovist Area (A) and Jaggedness (J), the second depicts the longest ($RL_{(L)}$) and shortest ($RL_{(S)}$) length radial lines and ceiling Heights (H), the third plots data for absolute (O) and proportional ($O{:}P$) occlusivity and the final plots Drift Angle (D_A) and Drift Magnitude (D_M). Each graph incorporates a number of reference points that correspond to the accompanying isometric diagram of the house, to allow for an intuitive visual appraisal of the results that also preserves the mathematical values. The reference points are signified in the text using square-bracketed numbers [1] for exterior points and capital letters [A] for interior positions. A short textual description of each path, including specific mathematical values corresponding to reference points, accompanies the graphic presentation of results.

10.4 Prairie House Results

Chicago in 1900 was a critical time and place in architectural history, because it was there that Wright first began to consistently combine the design features that would become the Wright Space. 'Within two years he developed this configuration to a canonical state that informed the vast majority of his residential work for the rest of his career' (Hildebrand 1991: 19). Externally, the Prairie houses feature heavy refuge-oriented, masonry walls and deep overhanging eaves. These refuge features are balanced with prospect-oriented ones, including raised viewing terraces and wide bands of glazing. Together the wide windows, gentle roof pitch, raked brickwork and thin bands of plaster detailing serve to establish strong horizontal lines that evoke the low and flat prairie landscape. Internally the prospect-refuge pattern continues with a dominant hearth flanked with cabinetry and seating at the centre of the plan, opposite which is a wall of glazing with a viewing terrace beyond, both of which are protected by deep eaves that rise to a peak in the centre of the living room. The journey from the front door to the living room consists of a long circuitous path that features careful use of screening devices. The Prairie houses are generally larger designs for wealthy clients and feature rich decoration and facilities for household staff (Koning and Eizenburg 1981).

10.4.1 Henderson House Elmhurst, Illinois, USA (1901)

The *Henderson House* represents an early prototype of the Prairie Style (Fig. 10.2). It exhibits a number of Hildebrand's list of characteristic Wrightian phenomenological characteristics, though fewer than are found in his later works. In this instance the living, dining and reception areas share a raised ceiling and the hearth

Fig. 10.2 *Henderson House*, external perspective

is located opposite a glazed wall, beyond which a terrace completes the truncated cruciform plan. The external approach path to the house follows a straight line from the street, passing under the wide eaves of the hipped roof and rising to the terrace and front door. This terrace functions as a traditional porch, unlike those in the other Prairie houses, which Wright often isolated from the approach path. The route into and through the house is complicated by a pair of dog-leg manoeuvres that are required to pass from the porch, through the front door and entry hall to the main corridor. Beyond this, the route to the centre of the living room requires only two direction changes (Fig. 10.3).

The data derived from the *Henderson House* shows that upon emerging from the entry space [A] the visitor experiences a minor but rapid increase in prospect ($A = 5.56 \rightarrow 29.60$ m^2) and intense enticement ($D_M = 6.31$ m, $D_A = 86.36°$) directing attention left and toward the living room (Fig. 10.4). Proceeding along the path toward the living room threshold [B], prospect and absolute mystery indicators gradually rise as more of the house is both revealed and suggested ($A = 29.62 \rightarrow 69.57$ m^2, $O = 20.00 \rightarrow 37.55$ m, O:P remains stable ≈ 46%). The most mysterious location [B] coincides with a low enticement ($D_M = 2.10$ m) and the intersection of paths leading to the living room, kitchen and entry. Prospect is highest ($A = 111.17$ m^2) only after crossing the threshold to enter the living room [C], where, ceiling height becomes slightly higher ($H = 2.32 \rightarrow 2.83$ m). Prospect, mystery and enticement decrease as the hearth is passed [D], and the visitor moves toward the centre of the room (Figs. 10.4, 10.5 and 10.6).

Along almost the entire length of this path, the drift angle is less than 90°, indicating that visual enticement is drawing the visitor toward the living room (Fig. 10.7). The only exception occurs where the visitor finally reaches the centre of the living room and the strength of enticement is negligible ($D_M = 0.34$ m) and attention is directed back toward the hearth. Along the length of the path a high positive correlation occurs between area and ceiling height, while moderate positive correlations between longest view distance and area, and moderate positive correlations between minimum view distance and area and height indicate

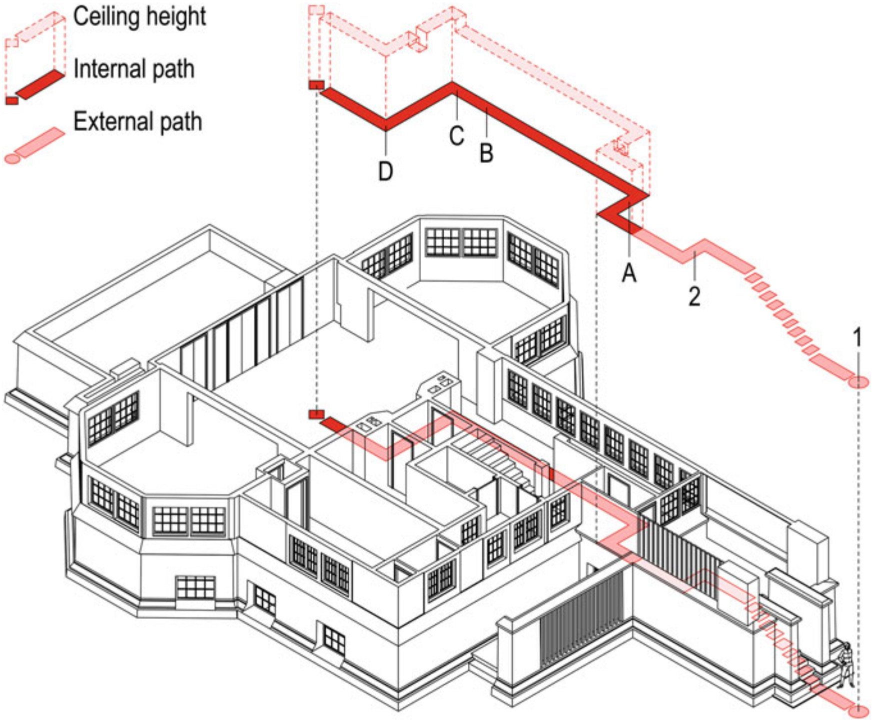


Fig. 10.3 *Henderson House*, axonometric showing movement path

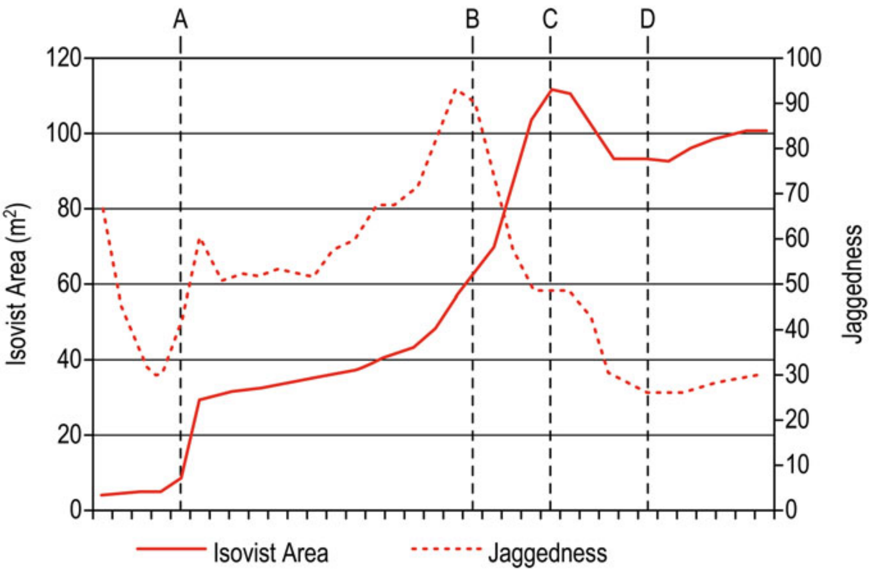


Fig. 10.4 *Henderson House*, area and jaggedness data

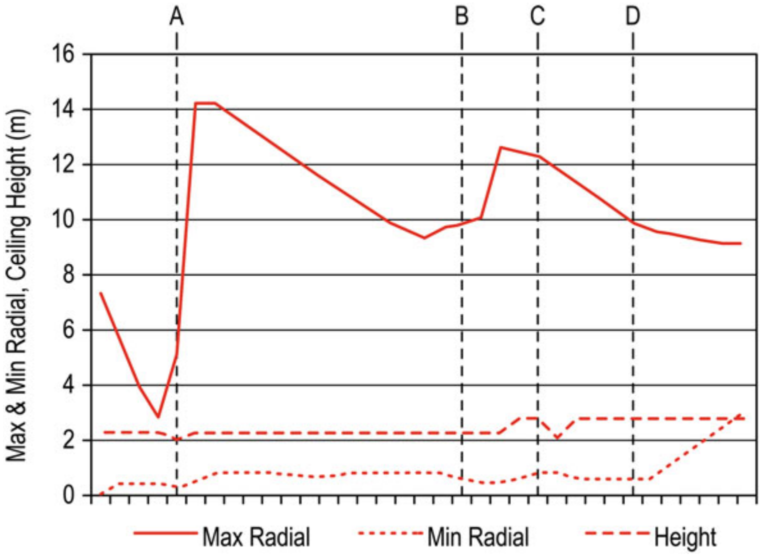


Fig. 10.5 *Henderson House*, minimum radial length, maximum radial length and height data

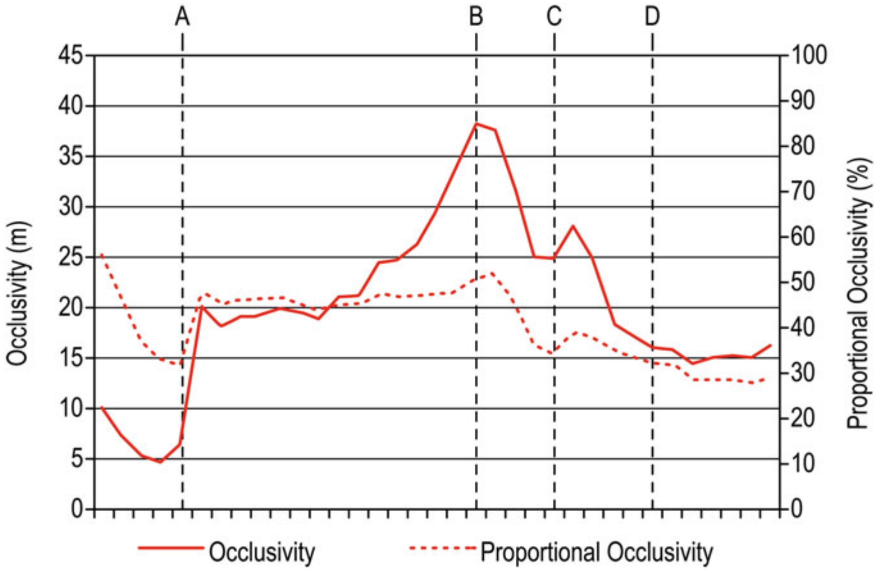


Fig. 10.6 *Henderson House*, occlusivity and proportional occlusivity data

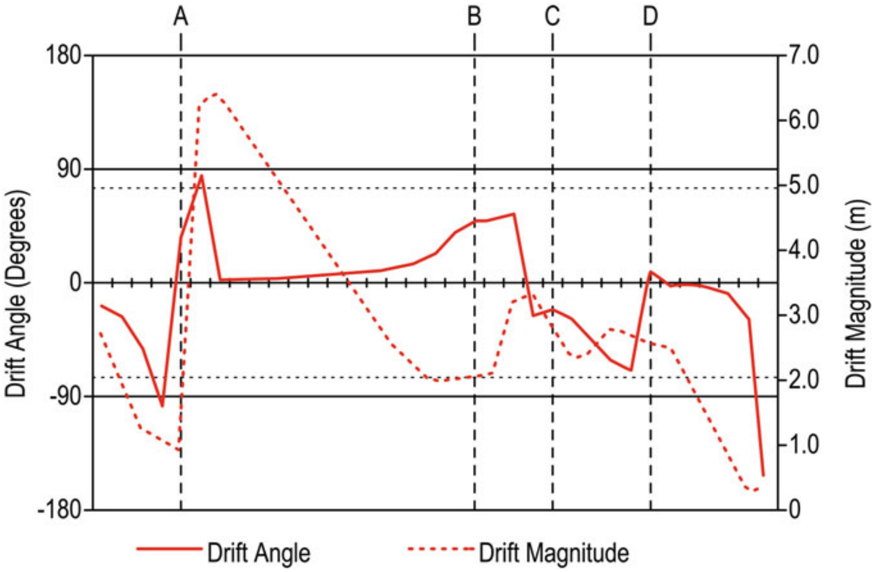


Fig. 10.7 *Henderson House*, drift angle and drift magnitude data

Table 10.3 *Henderson House*, reduplication of isovist data

Henderson House	Area	Height	Max radial	Min radial
Area	1	0.7738	0.3150	0.4775
Height		1	0.0624	0.4910
Max radial			1	0.0335
Min radial				1

reduplication in a variety of prospect and refuge experiences (Table 10.3). High visual pull at the start of the path coupled with increasing levels of information and mystery confirm that the experience of the *Henderson House* is that of a journey of discovery, albeit a relatively minor one. Upon reaching the living room centre, further movement yields little additional information and the low levels of visual pull and mystery discourage such movement.

10.4.2 Heurtley House, Oak Park, Illinois, USA (1902)

The *Heurtley House* is the first of the Prairie houses to display all thirteen of Hildebrand's prospect-refuge features and is therefore, he argues, the 'first fully mature prairie house' (Hildebrand 1991: 35). This design departs from contemporary planning conventions by locating the living and dining rooms on the first

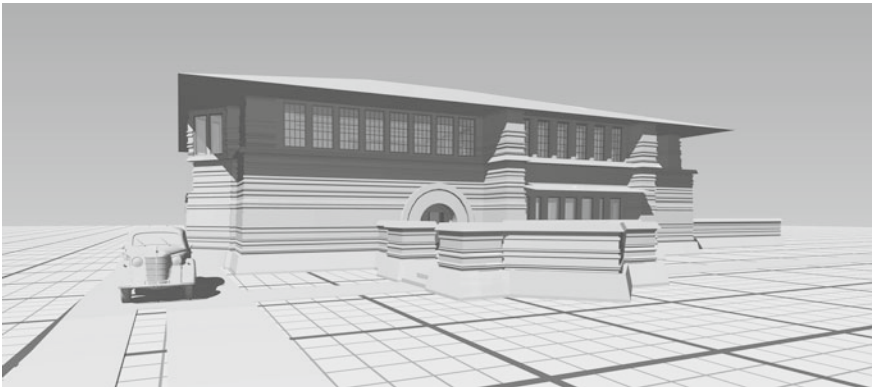


Fig. 10.8 *Heurtley House*, external perspective

floor in order to capture elevated views of the neighbourhood (Fig. 10.8). The external path to the house demonstrates the early signs of the deliberate complexity Wright became famous for, through the inclusion of two redundant 90° turns. Internally the route is even more complex; three 90° turns separate the front door and the base of the stairs, two further 90° turns are encountered while ascending the stairs, and two more before reaching the hearth. A final turn is required to reach the centre of the living room (Fig. 10.9).

Like the *Henderson House*, entry to the *Heurtley House* is by way of an enclosed hall [A] that obscures the rest of the building (A = 11.01 m^2). The isovist field data demonstrates that, as the visitor moves beyond this point both prospect and mystery rise while beginning to ascend the stairs (A = 48.09 m^2, O = 45.30 m, $O{:}P$ = 64.12%) [B] (Figs. 10.10, 10.11 and 10.12). Walking toward the stairs also requires the visitor to move away from the playroom, by resisting the strongest, and most distracting, enticement of the path (D_M = 6.24 m, D_A = −157.94°). The direction of enticement remains behind the visitor (D_A = 169.86°) while ascending the stairs, which restricts vision, allowing only limited prospect, mystery, and complexity. Thus, a person walking up the stairs is strongly resisting the innate spatio-visual cues of the house at this point. The extreme constriction coupled with the abundant ceiling height (H = 4.88 m) in the staircase causes a negative effect on the correlation of height and other prospect-refuge measures as indicated by low data correlations between height and other measures (Table 10.4). Reduplication, as indicated by moderate positive correlations, occurs between visible area, longest view distance and shortest view distance. Reaching the landing [C] and gaining a view of the first floor offers a complex (J = 103.86) and mysterious ($O{:}P$ = 64.12%) experience. This corresponds to a sharp increase in enticement (D_M = 0.92 → 4.20 m), drawing the visitor toward the living and dining rooms [D] (Fig. 10.13). Prospect continues to increase while approaching the living room centre and mystery peaks (O = 54.73 m) immediately before reaching the hearth [E]. Along the latter part of this route, enticement directs attention toward the dining room, then the living room and finally back to the dining room once more.

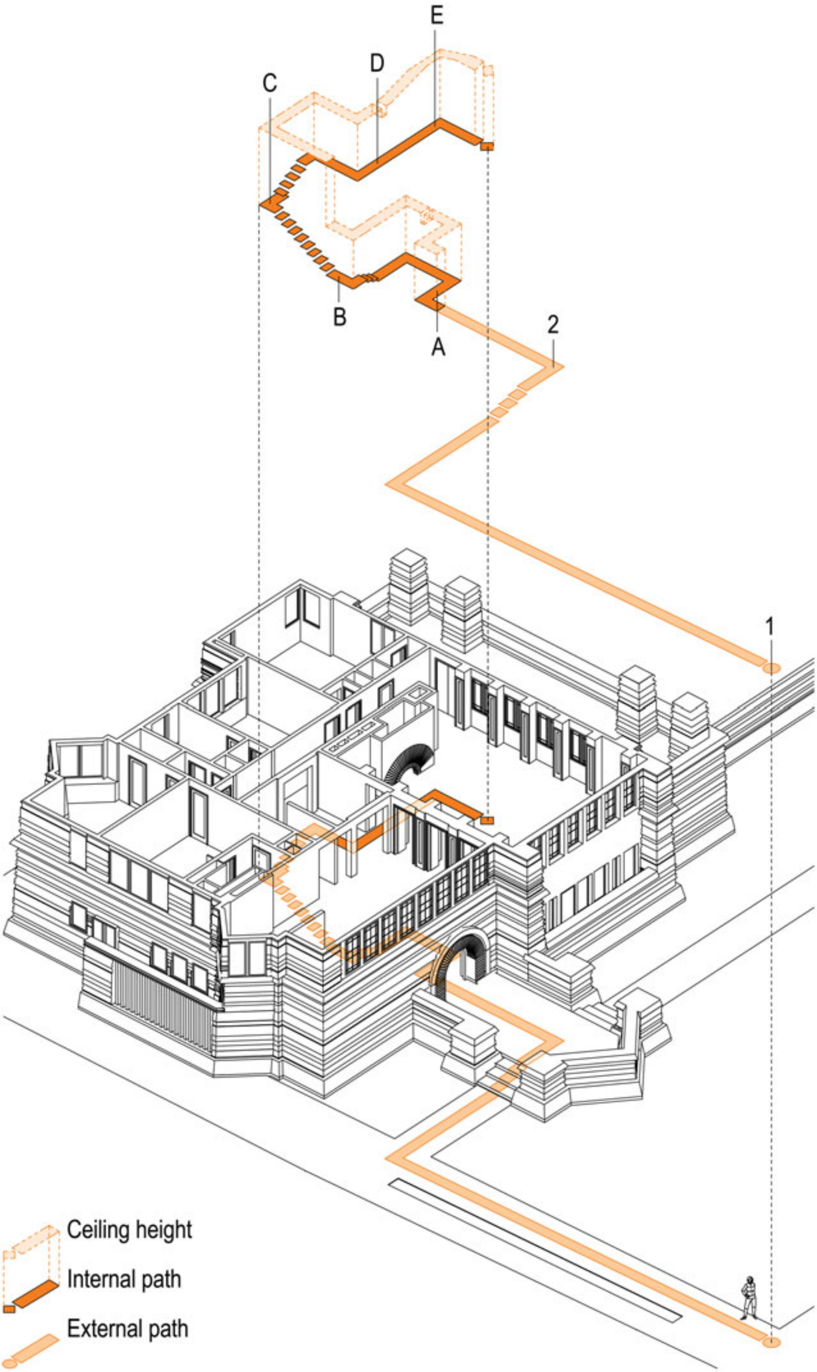


Fig. 10.9 *Heurtley House*, axonometric showing movement path

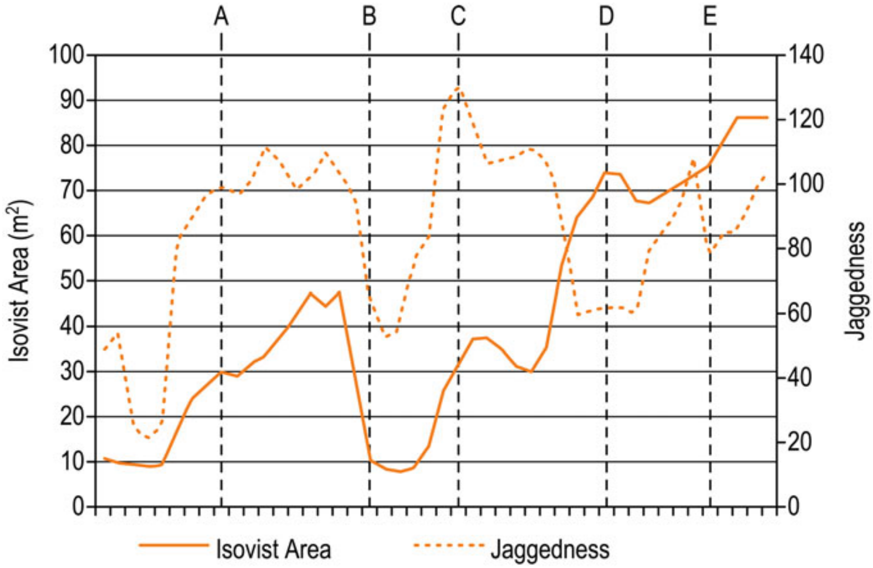


Fig. 10.10 *Heurtley House*, area and jaggedness data

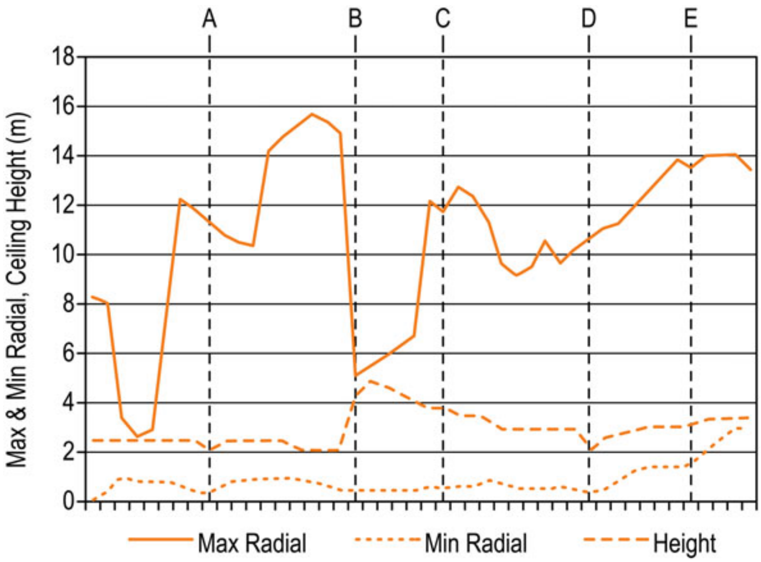


Fig. 10.11 *Heurtley House*, minimum radial length, maximum radial length and Height data

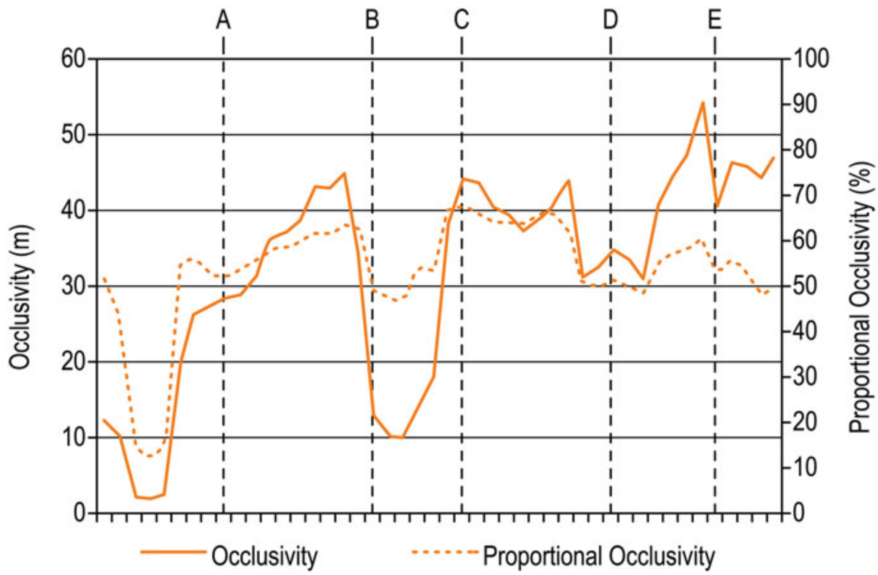


Fig. 10.12 *Heurtley House*, occlusivity and proportional occlusivity data

Table 10.4 *Heurtley House*, reduplication of isovist data

Heurtley House	Area	Height	Max radial	Min radial
Area	1	−0.1194	0.6657	0.6603
Height		1	−0.2824	0.1188
Max radial			1	0.3812
Min radial				1

In summary, the living room centre is the location of highest prospect, having both the largest isovist area and high ceilings (A = 86.15 m^2, H = 3.46 m). However, this is coupled with a significant degree of mystery (O = 47.54 m, O:P = 50.14%) and mild enticement (D_M = 2.19 m; D_A = −89.91°) toward the dining room, confirming that this is a more dynamic space than the living room of its predecessor, the *Henderson House*.

10.4.3 Cheney House Oak Park, Illinois, USA (1903)

In the *Cheney House* 'the glass and overhangs' in the façade 'may suggest penetrability, but the house protects its actual access through ambiguity (the dual walkways), masking (the screening of view from the street), and convolution' (Hildebrand 1991: 38). Traversing the correct exterior entry path requires a visitor to ascend several stairs, and navigate two redundant 90° turns [2, 3]. This elaborate exterior route leads

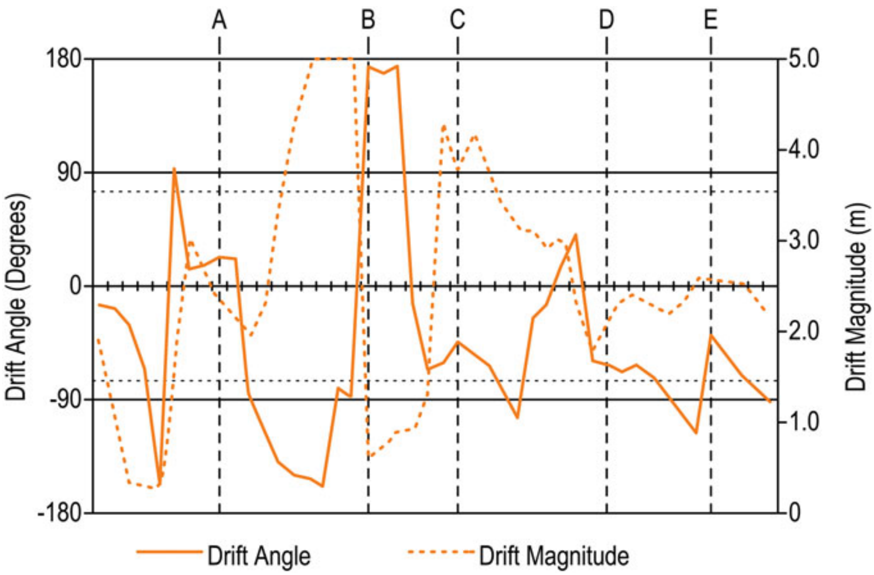


Fig. 10.13 *Heurtley House*, drift angle and drift magnitude data

the visitor to the entry of the house and, once inside, another dog-leg [A] is all that separates the entrance from the living room threshold [B], the hearth [C] and the centre of the room. The absence of a second story allows Wright to raise the ceilings of the library, living and dining rooms and the hearth is again opposite a glazed wall. The bookcases defining the living room and adjacent to the hearth, approximately 1.5 m tall, are not high enough to obscure the view of a visitor of Wright's stature (Fig. 10.14). The *Cheney House* also possesses the shortest internal path and most elaborate external path of all the Prairie Style houses (Fig. 10.15).

The isovist data for the *Cheney House* shows that a visitor moving toward the living room experiences increasing levels of prospect (A = 37.38 → 88.70 m^2) (Fig. 10.16). In contrast, mystery tends to decrease from the beginning of the dog-leg [A] until reaching a position halfway between the living room threshold [B] and the hearth (C) (O = 74.23 → 35.44 m, O:P = 76.64 → 50.88%). This location offers a glimpse of the fifth bedroom, over the bookcase adjacent to the fire. Mystery then declines until the visitor approaches the living room centre (Figs. 10.17 and 10.18). Enticement is high and forward (D_M = 5.70 m, D_A = 20.70°) close to the front door, drawing the visitor past the library and toward the living room (Fig. 10.19). The direction of enticement remains fixed on the centre of the living room except when crossing the threshold to this room [B], where it aligns with the direction of travel (D_M = 2.43 m, D_A = 3.11°). The end of the path offers high prospect and mystery (A = 88.79 m^2, O:P = 59.37%), with little enticement, offering an experience that is more static than that of the *Heurtley House* and with more mystery than the *Henderson House*. Moderate correlations between height and both area and longest view distance demonstrate reduplication

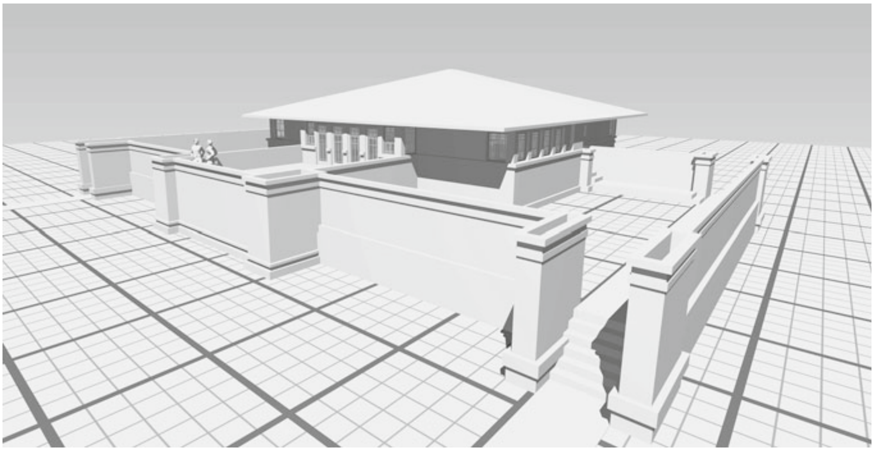


Fig. 10.14 *Cheney House*, external perspective

in the third dimension, which is reinforced by a strong positive correlation between height and shortest view distance (Table 10.5). A moderate negative correlation between area and longest view distance indicates that Wright substituted long views for large, rounder spaces in this design.

10.4.4 Evans House, Chicago, Illinois, USA (1908)

Wright's *Evans House* was designed as an example of a 'fireproof house' which could be built for $5000 (MacCormac 2005: 143). The house sits atop a low hill and its approach is by way of a simple journey up a long driveway [1] to the carport (Fig. 10.20). Here, under the protection of the canopy [2], a single 90° turn and a flight of stairs brings the visitor to the front door (Fig. 10.21). Inside, after passing through the entry [A] with its low ceiling, the living room and dining room form a semi-continuous space with the hearth located at the centre of the house and opposite a wall of glazing. A single turn [B] takes the visitor to the hearth and thereafter one additional turn [C] is needed to reach the centre of the room.

Entry to the *Evans House* is through a semi-enclosed foyer where enticement directs attention to the living room (D_M = 4.79 m, D_A = 2.34°), then towards a hall that leads to the kitchen, as this direction gradually enters into view (D_M = 2.61 m, D_A = −66.15°). The first appearance of this corridor [A] causes a spike in mystery and complexity (O = 46.94 m, O:P = 62.29%, J = 133.90) and contributes to the rapid increase in prospect that peaks (A = 90.84 m^2) at the living room threshold [B]. Upon entering the living room, enticement focuses attention on the centre of the living room while prospect decreases near the hearth (A ≈ 75 m^2) [C] as this central mass obscures vision of the remainder of the house. Like the *Henderson House*, enticement decreases (D_M = 2.04 m, D_A = −4.62° → 0.55 m, 155.39°)

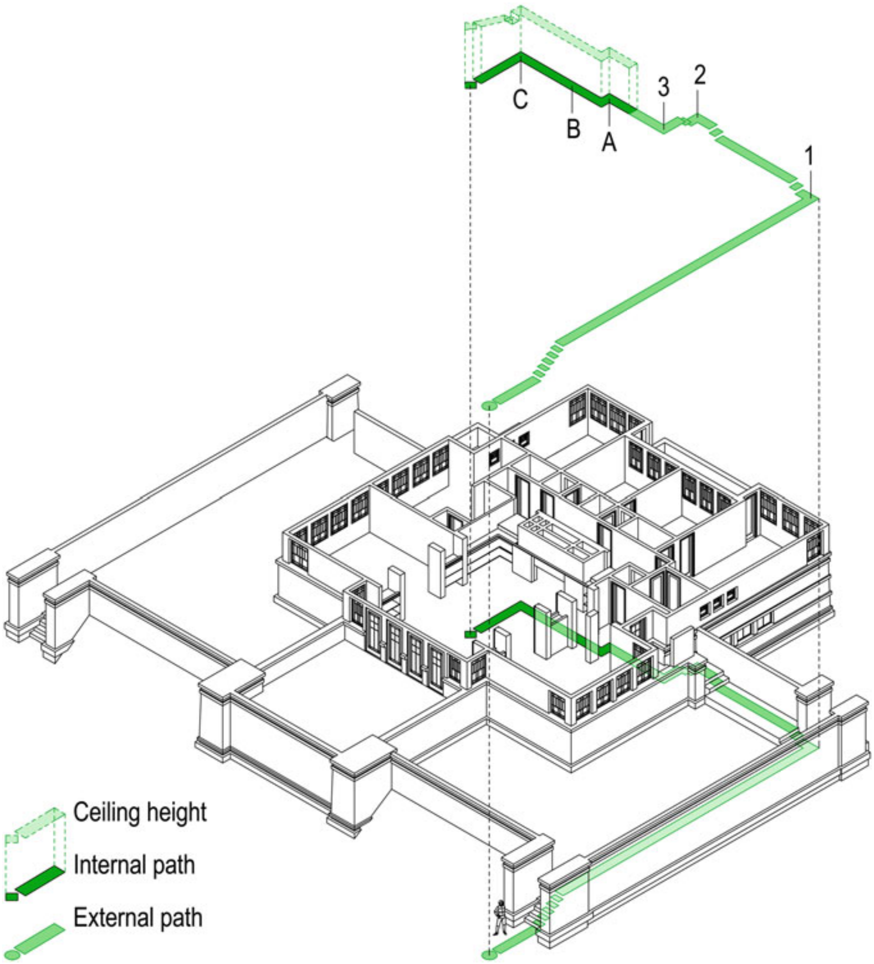


Fig. 10.15 *Cheney House*, axonometric showing movement path

until the visitor steps past the centre of the living room where enticement directs attention toward the hearth but with negligible strength. Unusually, Wright placed the living room below the bedrooms and maintained a single ceiling height throughout (H = 2.45 m). Effectively, in this example there can be no correlation between height and any other prospect-refuge measure that shows variation (Table 10.6). Moderate negative correlations exist between longest radial line and other measures suggesting that Wright may have substituted longest view distance for other prospect features. The living room centre is very much like that of the *Henderson House*, offering high prospect and little mystery, complexity, or visual pull to encourage further movement (Figs. 10.22, 10.23, 10.24 and 10.25).

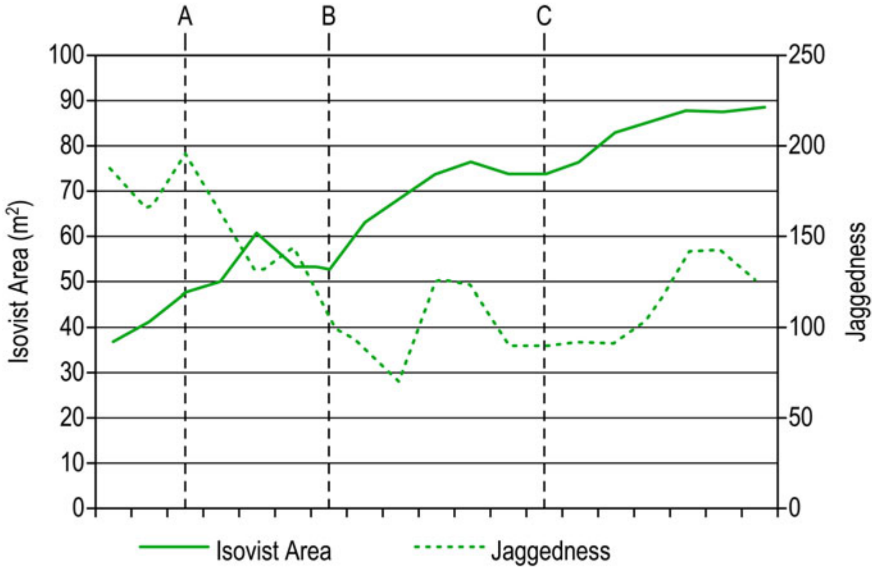


Fig. 10.16 *Cheney House*, area and jaggedness data

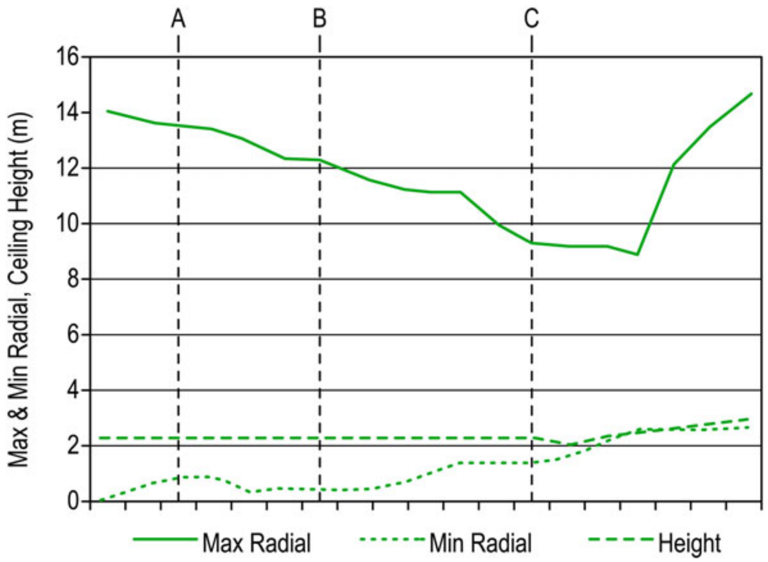


Fig. 10.17 *Cheney House*, minimum radial length, maximum radial length and Height data

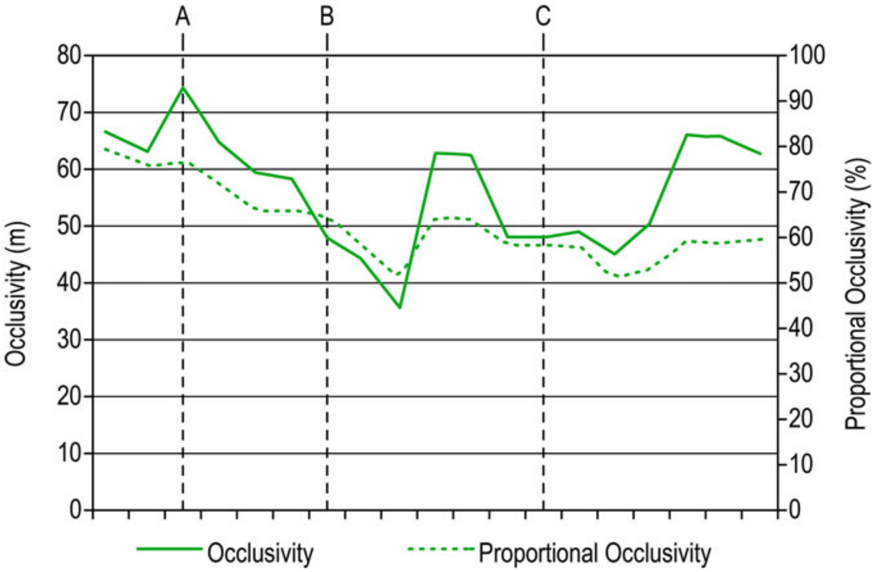


Fig. 10.18 *Cheney House*, occlusivity and proportional occlusivity data

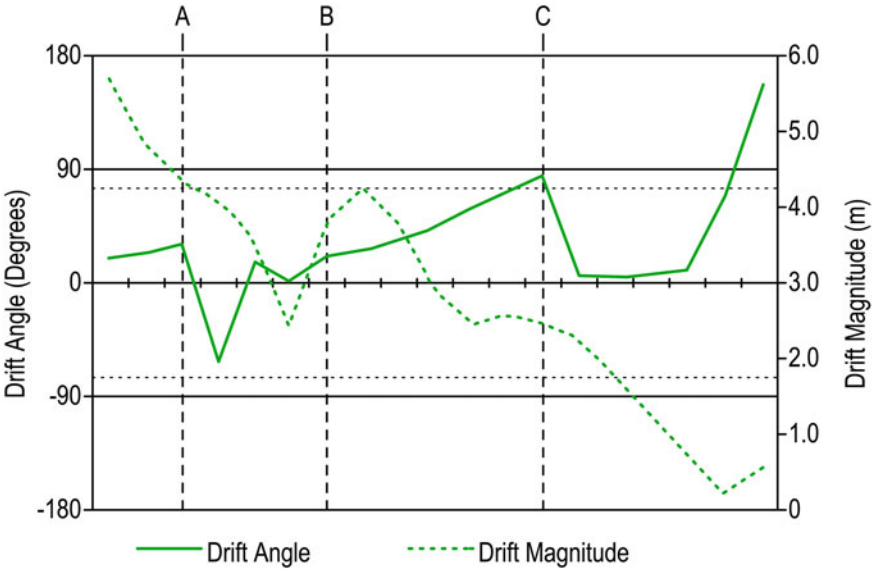


Fig. 10.19 *Cheney House*, drift angle and drift magnitude data

Table 10.5 *Cheney House*, reduplication of isovist data

Cheney House	Area	Height	Max radial	Min radial
Area	1	0.5494	−0.4806	0.8702
Height		1	0.3779	0.7083
Max radial			1	−0.2742
Min radial				1

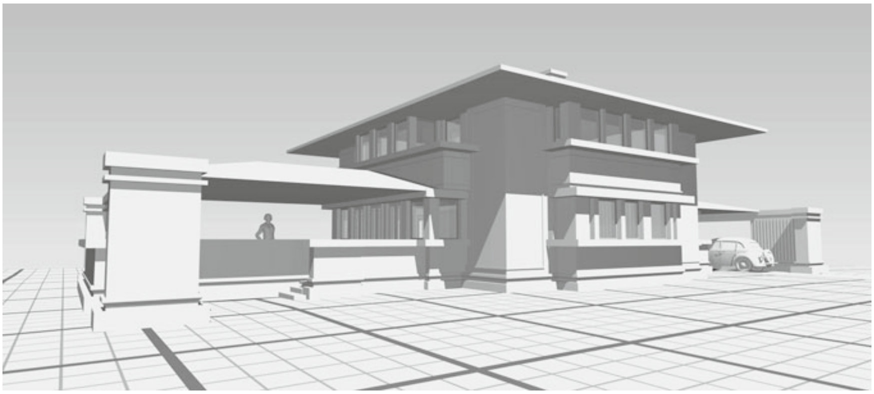


Fig. 10.20 *Evans House*, external perspective

10.4.5 Robie House, Chicago, Illinois, USA (1910)

The *Robie House* has several possible approach paths, including those from three different entries for visitors and inhabitants, official functions and servants (Fig. 10.26). To further complicate matters, there are also multiple possible routes though the house from some of these entrances (Ostwald and Dawes 2013b; Vaughan and Ostwald 2014). The path chosen for the present analysis commences with an elaborate formal promenade around part of the exterior. However, its interior path from location [A] onwards also encompasses the route followed by all of the other possible paths to the living room, making it the most useful one for analysis. Thus, even if there is some debate about which exterior door should be chosen as the starting point for this analysis, all of the options are accommodated in the route chosen.

The *Robie House* exterior promenade features six 90° turns from the street to reach an entry door (Figs. 10.27). The internal path is similarly complex as, upon entering, the visitor must immediately turn left or right as the hearth mass blocks further progress. The path then takes two further turns to arrive at the base of the stairs [B] on the opposite side of the central mass. The visitor must then navigate the stairs before emerging onto the first floor. A left turn [D] brings the visitor to the living room, and two further direction changes are required to reach the hearth.

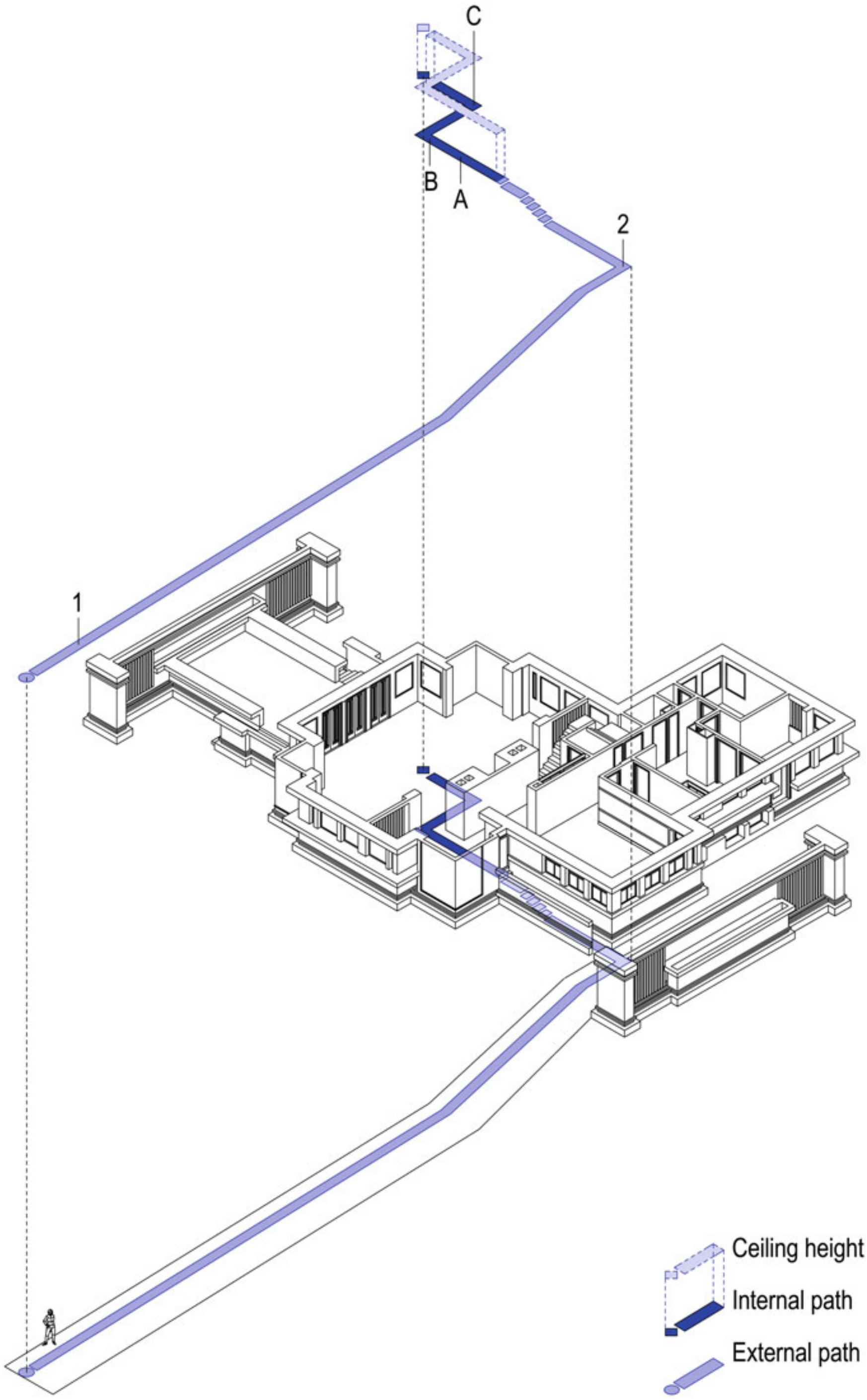


Fig. 10.21 *Evans House*, axonometric showing movement path

Table 10.6 *Evans House*, reduplication of isovist data

Evans House	Area	Height	Max radial	Min radial
Area	1	[a]	−0.372257623	0.329204201
Height		1	[a]	[a]
Max radial			1	−0.452904176
Min radial				1

[a]*Note* As the height of this path never varies, there is no correlation possible

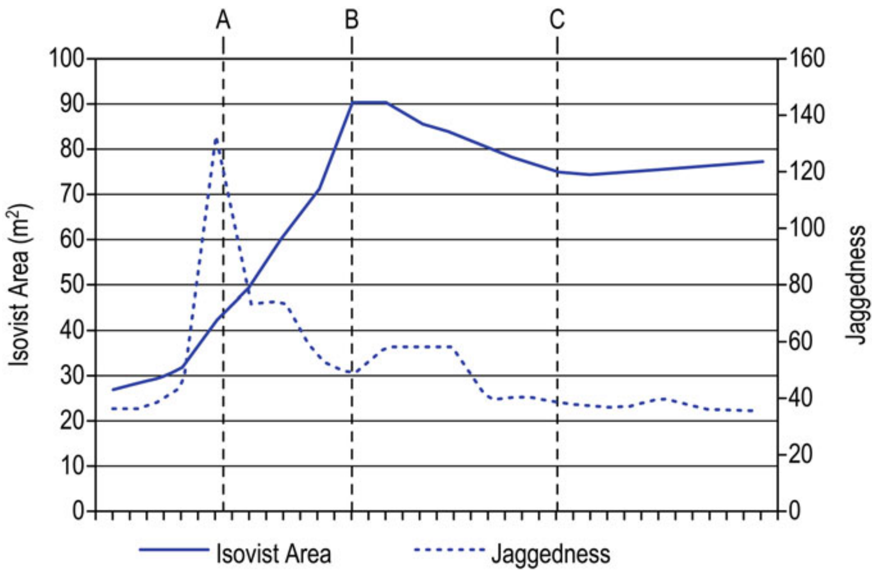


Fig. 10.22 *Evans House*, area and jaggedness data

Upon entering the house mild enticement levels direct attention away from the path and toward the playroom (D_M = 2.29 m, D_A = 11.26°). After resisting this initial impulse, enticement then directs attention away from the direction of travel and toward the centre of the billiards room. The path continues past the billiard room threshold [A], which is the location of maximum prospect (A = 94.50 m^2) and to the base of the stairs [B], which offers the longest view on this path ($RL_{(L)}$ = 20.13 m). Stepping onto the stairs dramatically changes the spatial experience: prospect, mystery and complexity fall suddenly while ceiling height peaks (A = 71.70 → 34.46 m^2, $RL_{(L)}$ = 20.13 → 7.37 m, O = 40.09 → 13.43 m, O:P = 43.35 → 36.45%, H = 1.97 → 4.93 m). Enticement directs attention away from the path that ascends the stairs (D_M = 2.27 m, D_A = −121.36° → 4.40 m, 178.63°) and increases in strength until the final glimpse of the lower level disappears while traversing the landing [C]. The constrained experience of the stairs causes prospect, mystery and complexity to fall sharply, before emerging onto the

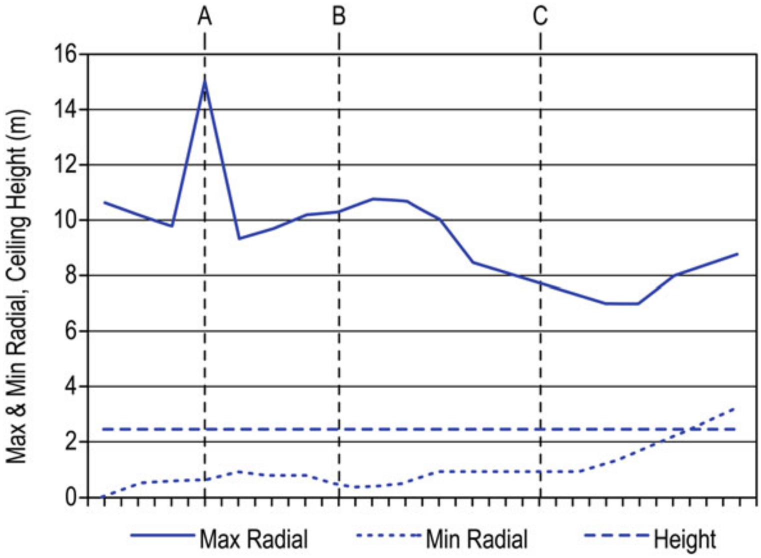


Fig. 10.23 *Evans House*, minimum radial length, maximum radial length and Height data

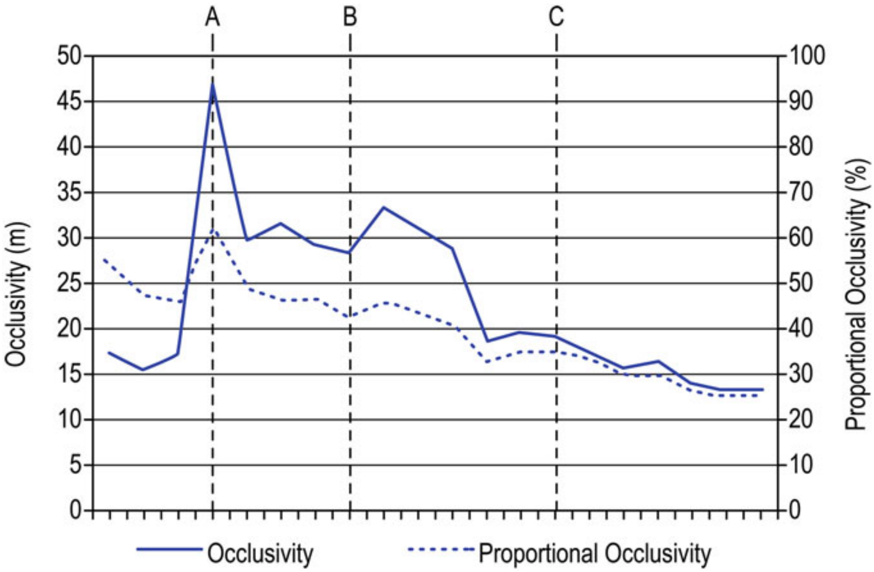


Fig. 10.24 *Evans House*, occlusivity and proportional occlusivity data

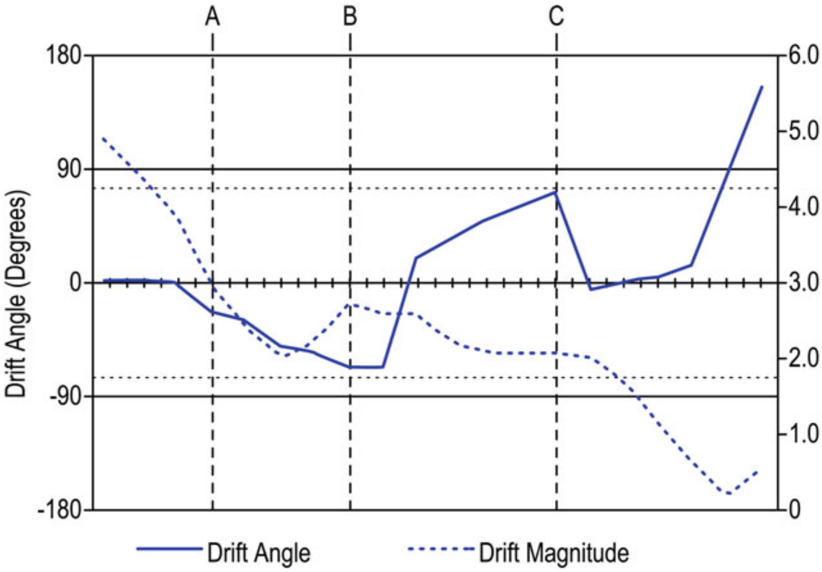


Fig. 10.25 *Evans House*, drift angle and drift magnitude data

Fig. 10.26 *Robie House*, external perspective

first floor [D]. At the top of the stairs in the *Robie House*, the strength of enticement is negligible (D_M = 0.53 m, D_A = 57.50°) and slightly left-biased, indicating a relatively neutral location with a high degree of prospect (A = 48.94 m^2). This prospect increases across the living room threshold [E] as the room becomes visible and before views back down the hall are obscured after turning [F] to face the centre of the living room. Here enticement reaches its lowest level (D_M = 0.37 m) and discourages movement toward the hearth and away from the centre of the room (D_M = 5.05 m). Again, the centre of the living room provides high prospect and

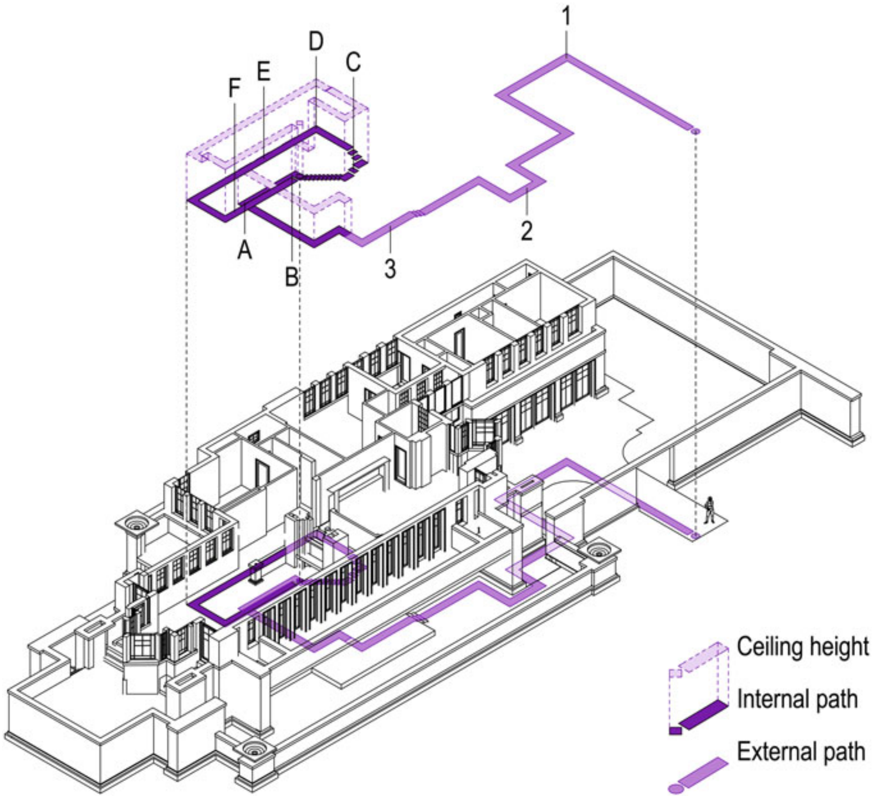


Fig. 10.27 *Robie House*, axonometric showing movement path

little mystery or enticement to encourage further movement (Figs. 10.28, 10.29, 10.30 and 10.31).

The *Robie House* has a similar vertical transition to that found in the *Heurtley House*, but unlike the latter design, the *Robie* utilises visual pull and prospect to deliver the visitor directly to the stairs. The stairs remain a significant transition point after which visual pull remains centred on the staircase, providing no guidance and confusing the journey. It is only upon entering the living room, a threshold of several steps, that visual pull again begins to direct the visitor forward to the centre of the room. In summary, the journey through the *Robie House* is one of strong guidance through the lower level and weak guidance through the upper floor.

The only strong positive reduplication of prospect and refuge features occurs between isovist area and longest view distance (Table 10.7). There is a moderate negative correlation between height and both area and longest view distance. The large isovist areas and long views in the vertically constrained lower level and the smaller visible areas with higher ceilings in the staircase zone, directly contribute to this result.

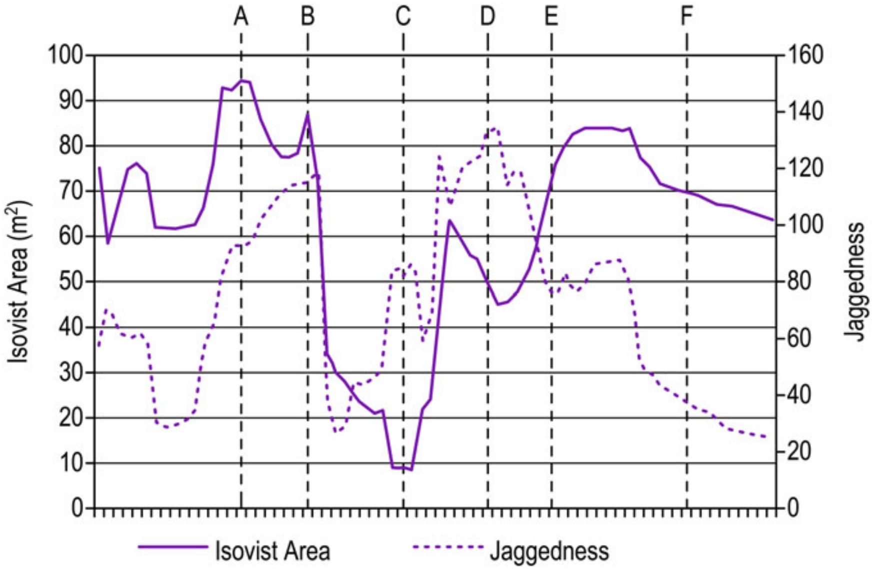


Fig. 10.28 *Robie House*, area and jaggedness data

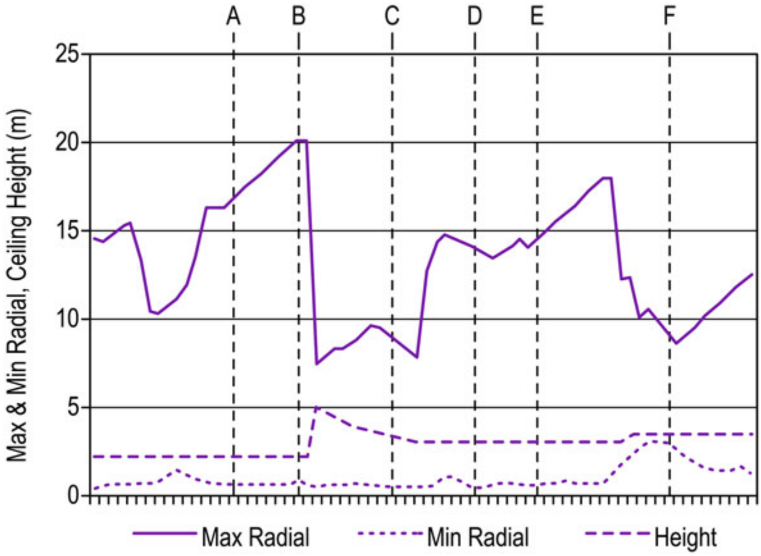


Fig. 10.29 *Robie House*, minimum radial length, maximum radial length and height data

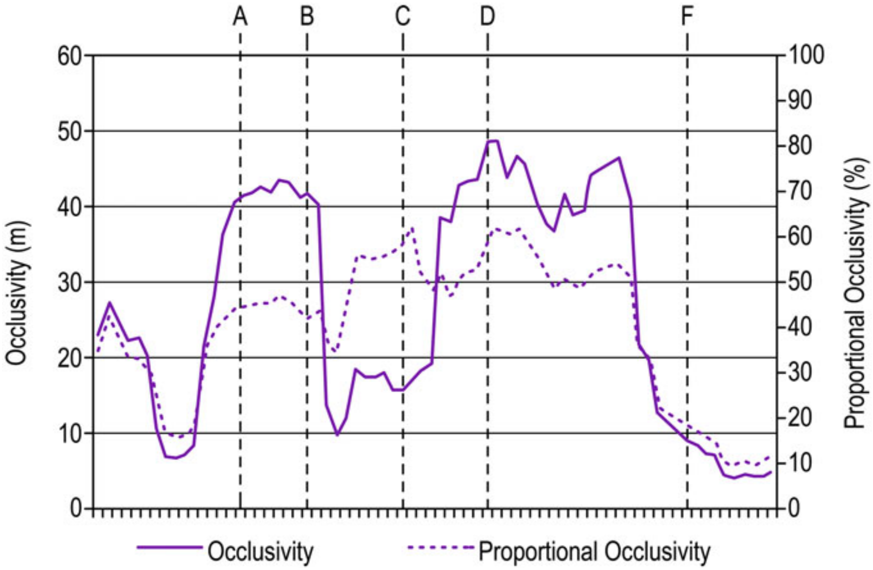


Fig. 10.30 *Robie House*, occlusivity and proportional occlusivity data

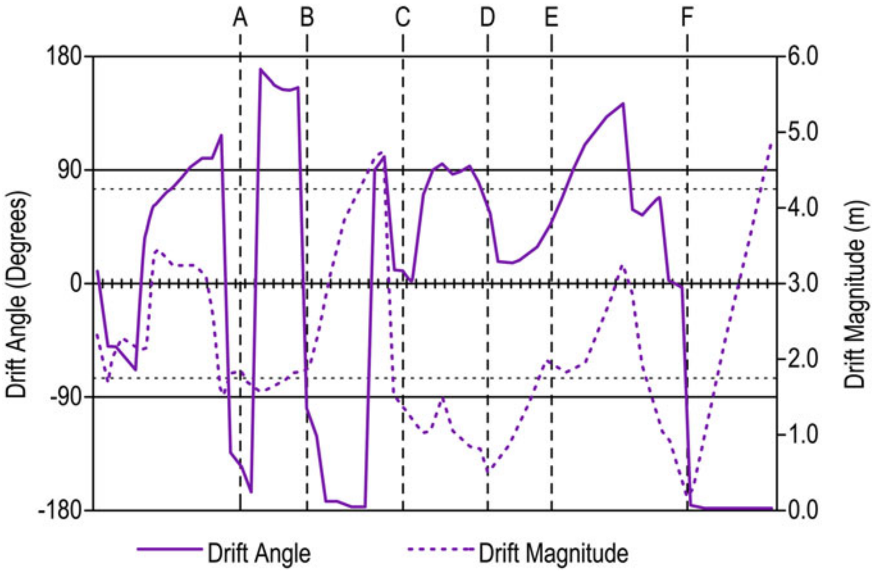


Fig. 10.31 *Robie House*, drift angle and drift magnitude data

Table 10.7 *Robie House*, reduplication of isovist data

Robie House	Area	Height	Max radial	Min radial
Area	1	−0.5697	0.7035	0.2214
Height		1	−0.6721	0.2439
Max radial			1	−0.3416
Min radial				1

10.5 Textile-block House Results

The Textile-block houses constitute something of an anomaly in Wright's career. Despite producing relatively large numbers of Prairie Style and Usonian designs, Wright only completed five houses in the Textile-block series and one precursor project, the *Barnsdall House*, which has some of the same characteristics but is sufficiently different for most historians to exclude it from the series (see Chap. 9). The impetus for this design approach originated in Wright's experience with the Mayan-Revival-styled Imperial Hotel in Japan and his desire to enhance the aesthetic and tectonic qualities of ordinary, mass-produced masonry. After returning from Japan in 1922, Wright established a studio in Los Angeles and began developing a mono-material construction system, based on modular concrete blocks, which he would eventually call textile-blocks. Wright intended the textile-blocks to be the basis of a new machine-produced construction system for use throughout all regions in the United States. The system was to comprise a small number of block variants that could be arranged into an unlimited number of three-dimensional forms.

Whereas low, horizontal forms dominated Wright's earlier Prairie Style architecture, the Textile-block houses emphasise verticality, leading to the view that a shift in Wright's spatial thinking accompanied the change in construction materials and the move to the American west coast. For example, John Sergeant argues that the Californian landscape played a part in the verticality of the Textile-block houses, claiming that 'Wright was confronted by sites that were almost never flat', and as a result of this was forced 'to extend his grid downwards from the floor level of his designs (metaphorically speaking) to encounter the local topography, and by this means contrived to use terraces and retaining walls to tie his concept into the site' (1976: 185). Despite these obvious differences, Hildebrand (1991) claims that, with one exception, the spatial experience is consistent between the Prairie Style and Textile-block works. For Hildebrand, the exception is that in the Textile-block houses refuge conditions are more dominant than they are in Wright's other works. Thus, the shifting balance predicted in the first of the four hypothesised indictors in this chapter may not be as pronounced in this set of designs.

10.5.1 Millard House, Los Angeles, California, USA (1923)

The *Millard House*, known as 'La Miniatura' (Fig. 10.32), presented Wright with his first opportunity to complete a house using the textile-block system. Alice Millard recalled that Wright 'had been so eager to try out his "novel system of

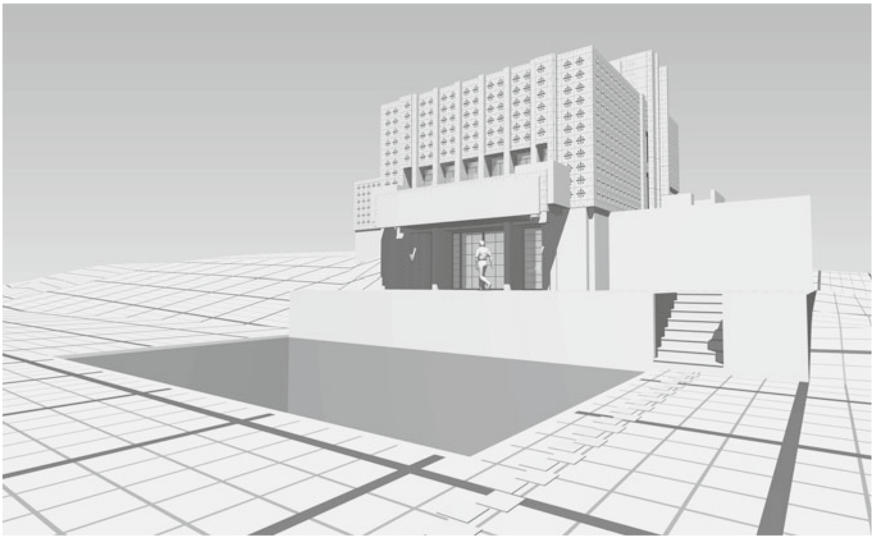


Fig. 10.32 *Millard House*, external perspective

construction" that he had come to her, offering to design a new house without charging the standard architect's fee' (qtd. in Sweeney 1994: 27). Millard agreed to the project, intending to use the house as a showcase for her rare book and antique furniture business. Wright himself selected the location for the house, rejecting a site that Millard already owned as being too exposed and choosing instead a partially hidden site in a nearby ravine (Sweeney 1994). Wright ultimately described the completed house as being 'richly introverted' and a residence of 'exquisite containment' (qtd. in Hildebrand 1991: 80).

The path into and through La Miniatura is relatively short and Millard even complained to Wright about the lack of an entry vestibule (Sweeney 1994). The path commences on the exterior terrace with two changes of direction [1], before entering the foyer and following three further 90° turns to the centre of the living room [C] and the hearth (Fig. 10.33). The isovist areas along the path are relatively consistent (A = 35.50–51.46 m^2), with only limited variations existing in terms of prospect and refuge qualities (Fig. 10.34). A moderate negative correlation between falling-longest and rising-shortest view distances exists across the extent of the path (Fig. 10.34). These results, when coupled with falling levels of jaggedness, indicate that the spaces tend to become more circular and offer limited complexity ($J \approx 27$) and little mystery ($O \approx 25$ m) but do incorporate significant height ($H = 4.22$ m) (Fig. 10.35). Along the path the visitor also moves from an entry space with a low ceiling to a double height room [B], a factor which correlates more with the rise in shortest radial length than an increase in longest ($RL_{(S)} \approx 2$ m). Enticement is strong at the start of the path ($D_M = 4.64$ m, $D_A = -44.61°$), drawing the visitor

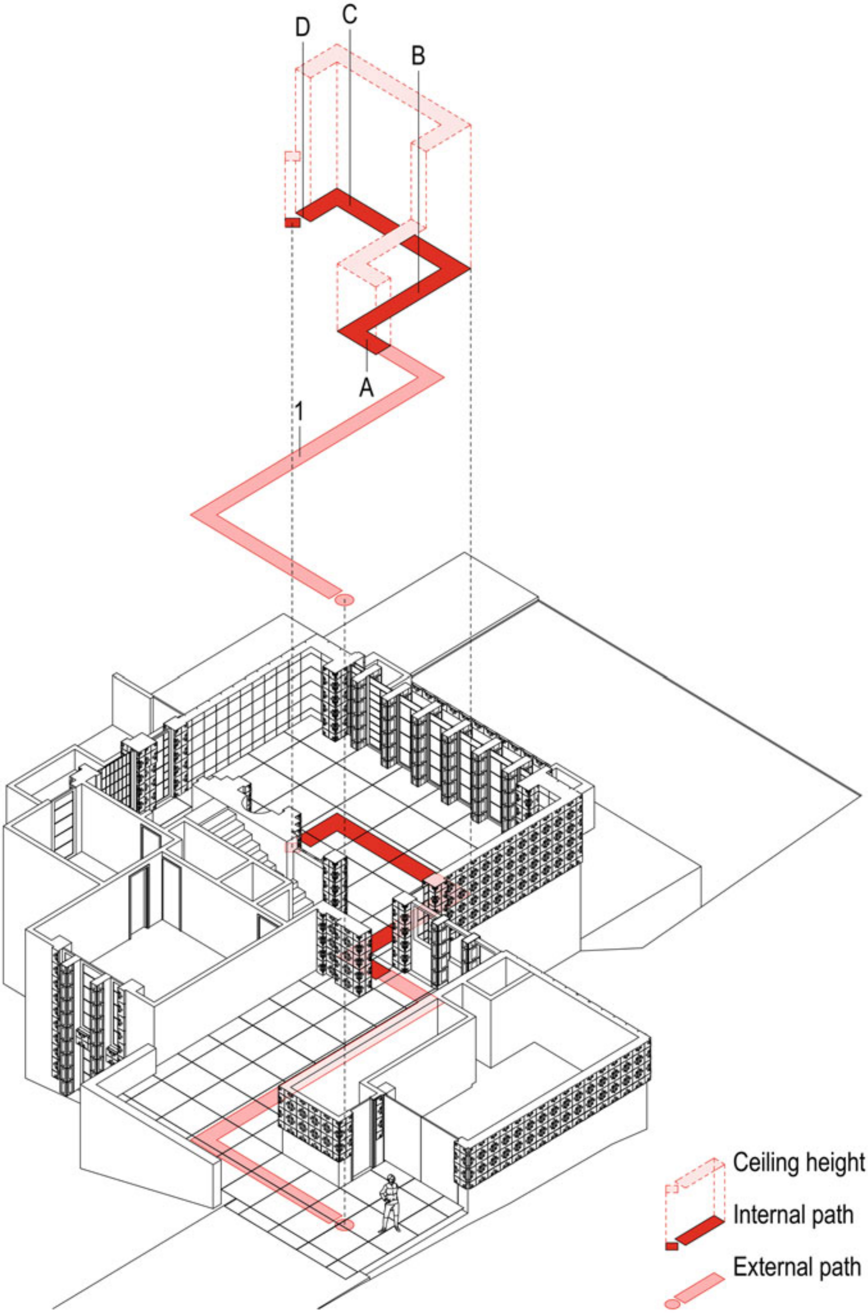


Fig. 10.33 *Millard House*, axonometric showing movement path

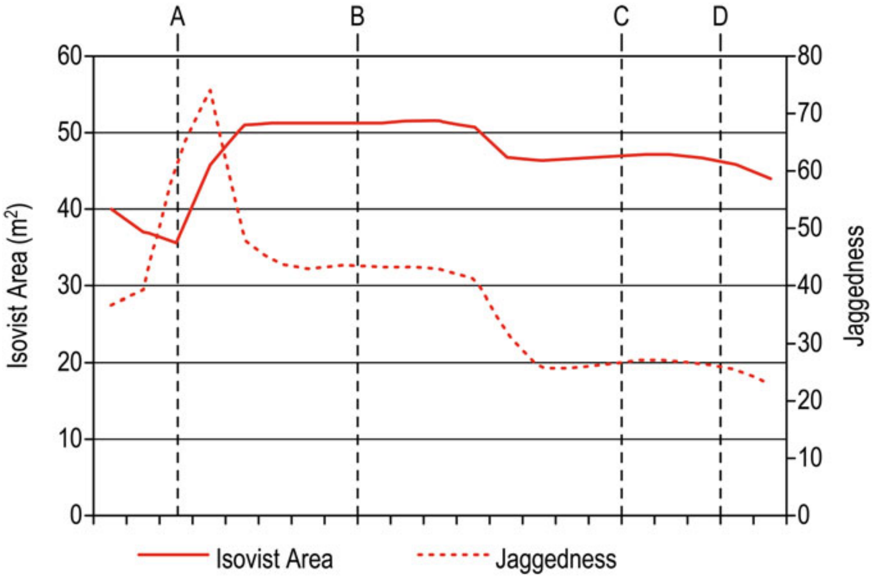


Fig. 10.34 *Millard House*, area and jaggedness data

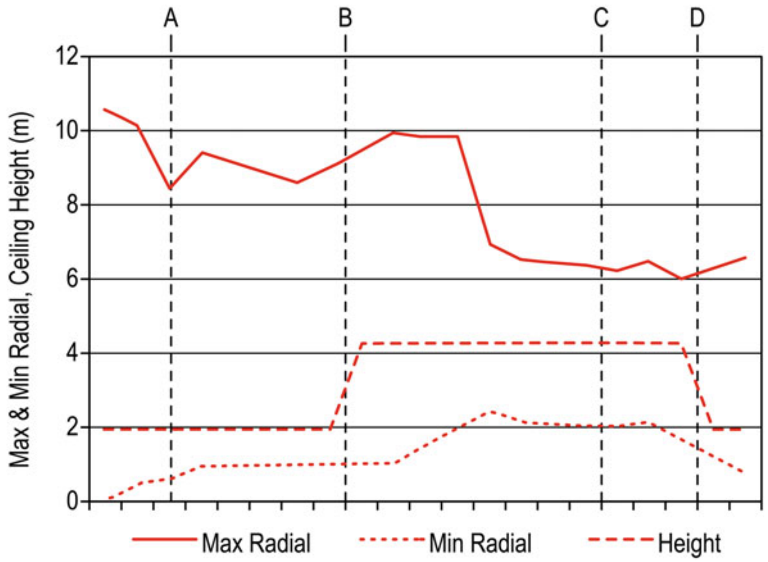


Fig. 10.35 *Millard House*, minimum radial length, maximum radial length and height data

from the front door toward the centre of the living room [C] where it abates (D_M = 0.30 m). The visitor must then resist a minor but increasing enticement (D_M = 0.74 m, D_A = 69.23° → 1.68 m, 152.23°) to move back under the protective ceiling (H = 2.00 m) [D] and toward the hearth (Figs. 10.36 and 10.37). Along

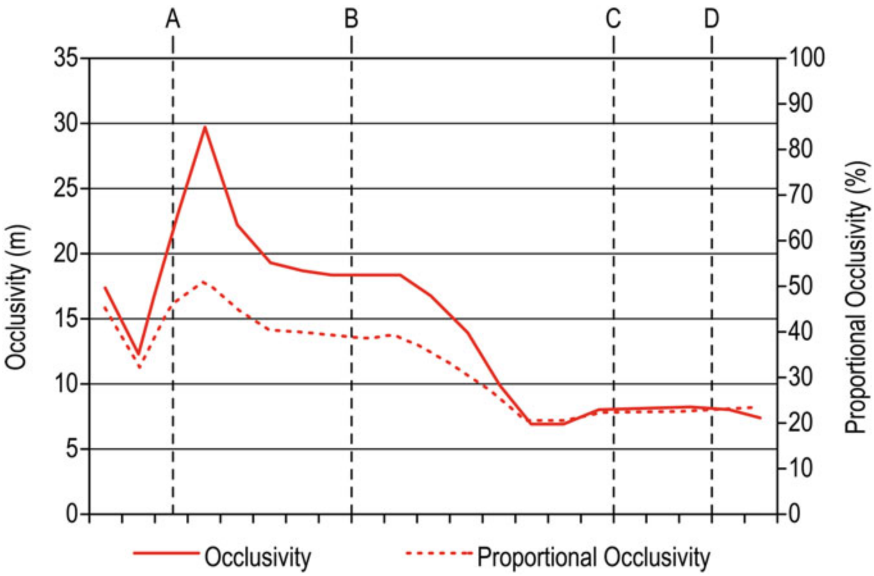


Fig. 10.36 *Millard House*, occlusivity and proportional occlusivity data

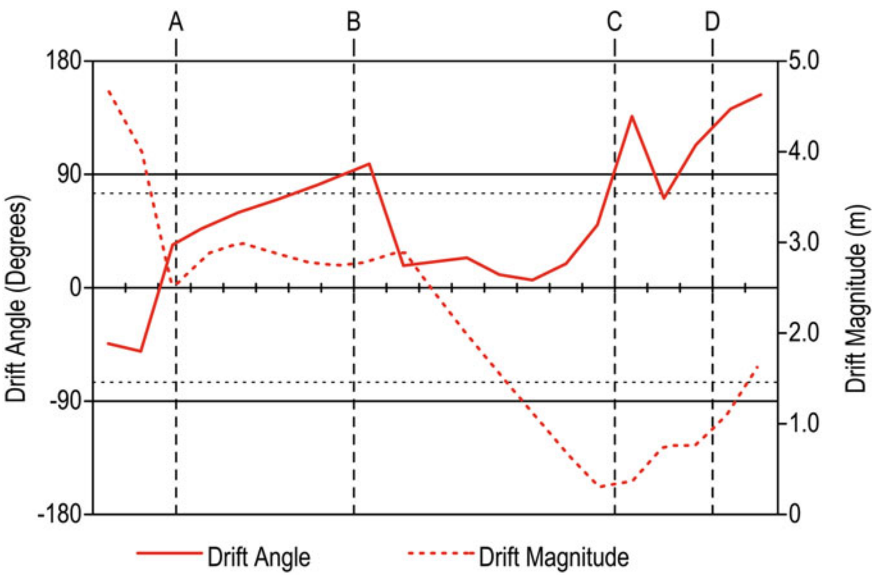


Fig. 10.37 *Millard House*, drift angle and drift magnitude data

most of the length of the path the visitor finds only low levels of mystery ($O \approx 18$ m, $O{:}P \approx 38\%$). Thus, the path might be characterised as being short and lacking significant variation in prospect, mystery and complexity, however it does demonstrate the significance of the third dimension, with room height being used to enhance or dramatize an otherwise stable experience. In particular, a strong positive correlation between height and shortest radial length indicates some reduplication of prospect and refuge experiences in La Miniatura while a moderate negative correlation between height and longest view distance suggests that Wright used the third dimension to substitute high ceilings for longer views (Table 10.8).

10.5.2 Storer House, Los Angeles, California, USA (1923)

Wright's second Textile-block house (Fig. 10.38) was designed for John Storer, a homeopathic physician who had failed California's medical license examinations and turned to real-estate development. Robert Sweeney suggests 'the Storer house may have been built on speculation, and there is slim evidence that Wright was a participant in the venture' (1994: 55). Sweeney also describes the house as being

Table 10.8 *Millard House*, reduplication of isovist data

Millard House	Area	Height	Max radial	Min radial
Area	1	0.3456	0.0524	0.3510
Height		1	−0.3369	0.7906
Max radial			1	−0.6404
Min radial				1

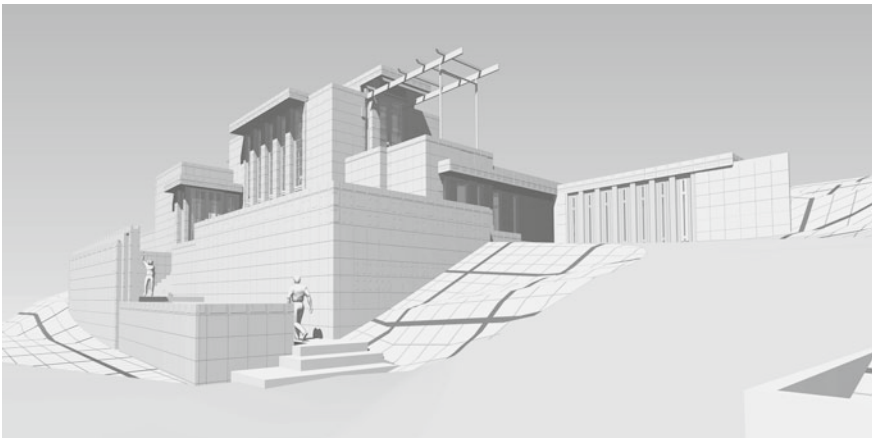


Fig. 10.38 *Storer House*, external perspective

'rather beautifully approached from the street by three terraces, providing changes in level and orientation and an increasing sense of enclosure' (1994: 64).

The entry to the house is understated almost to the point of confusion, by way of the second of five doors opening to the front terraces. Like the *Millard House*, the *Storer House* lacks a separate entrance vestibule, delivering the visitor directly into the lounge room [A] (Fig. 10.39). This position provides a large (for this house) isovist area (A = 35.97 m^2), long interior view distances ($RL_{(L)}$ = 9.42 m) and a strong visual enticement (D_M = 3.22 m, D_A = −46.07°) to move toward the centre of the lounge room (Figs. 10.40, 10.41, 10.42 and 10.43). However, the path to the

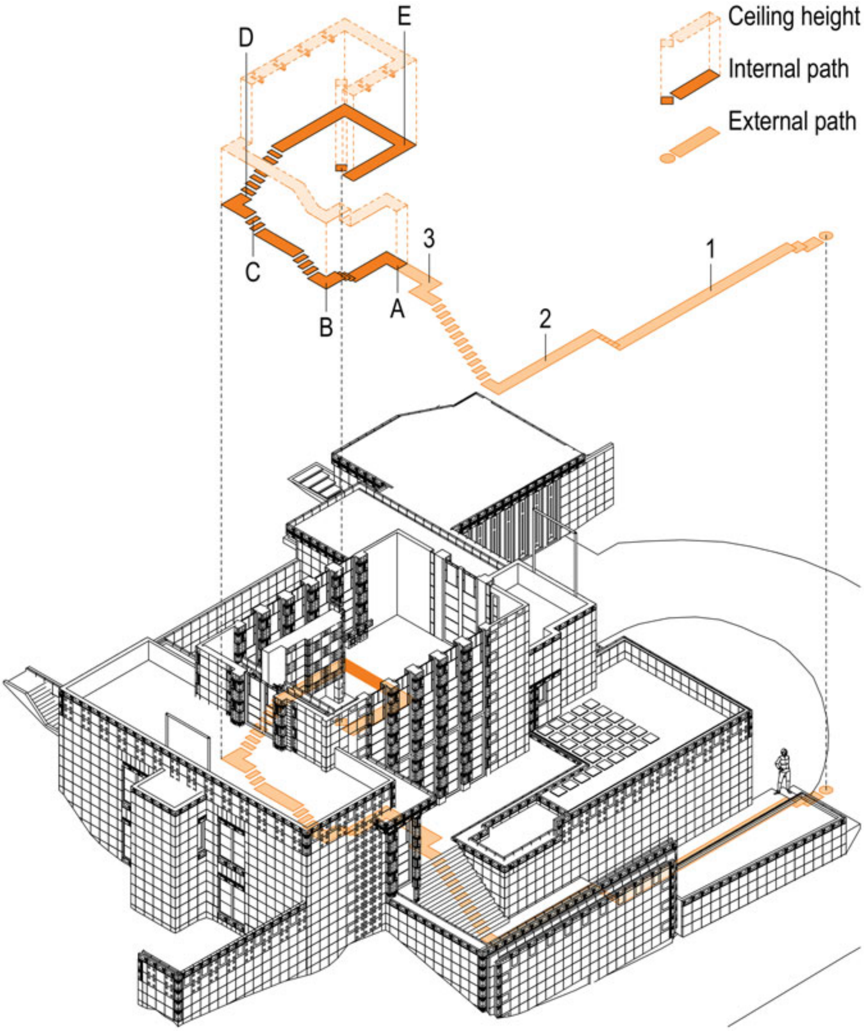


Fig. 10.39 *Storer House*, axonometric showing movement path

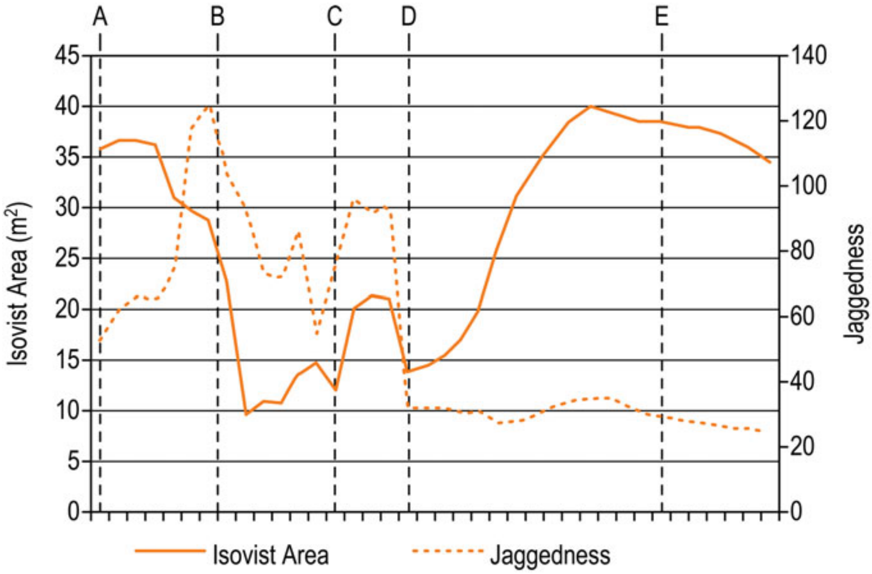


Fig. 10.40 *Storer House*, area and jaggedness data

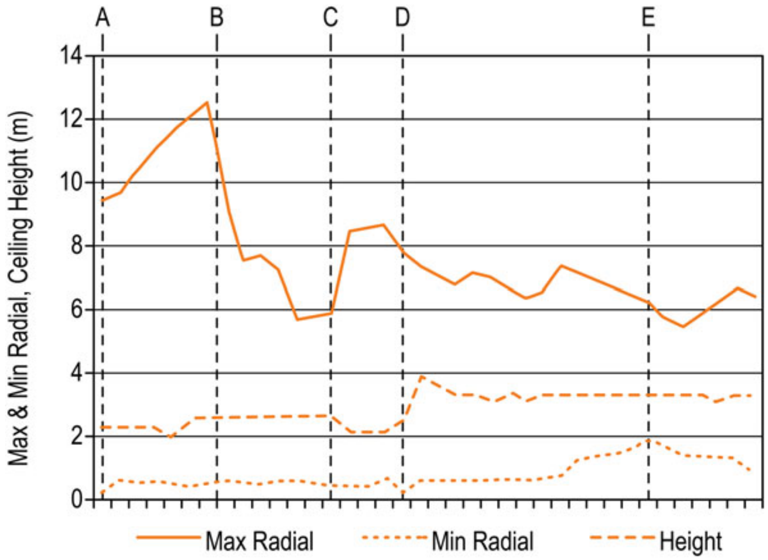


Fig. 10.41 *Storer House*, minimum radial length, maximum radial length and height data

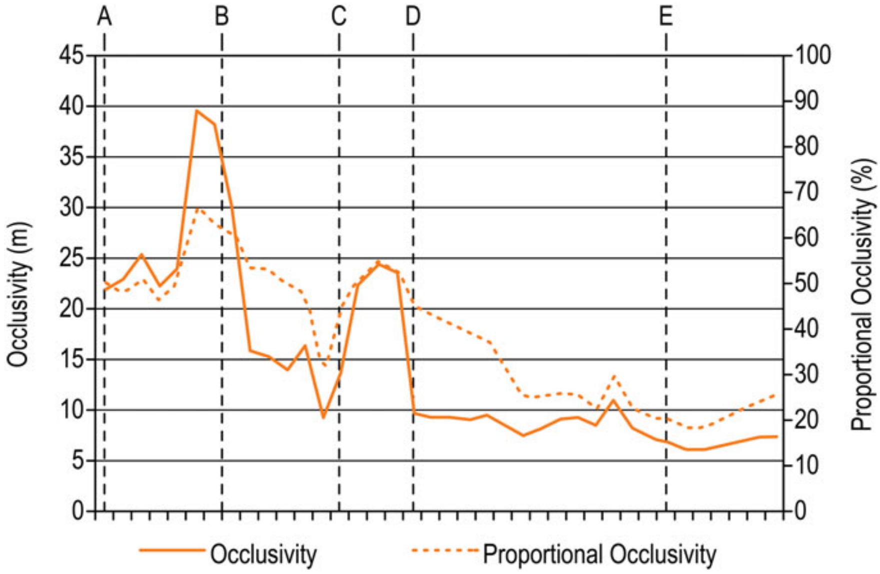


Fig. 10.42 *Storer House*, occlusivity and proportional occlusivity data

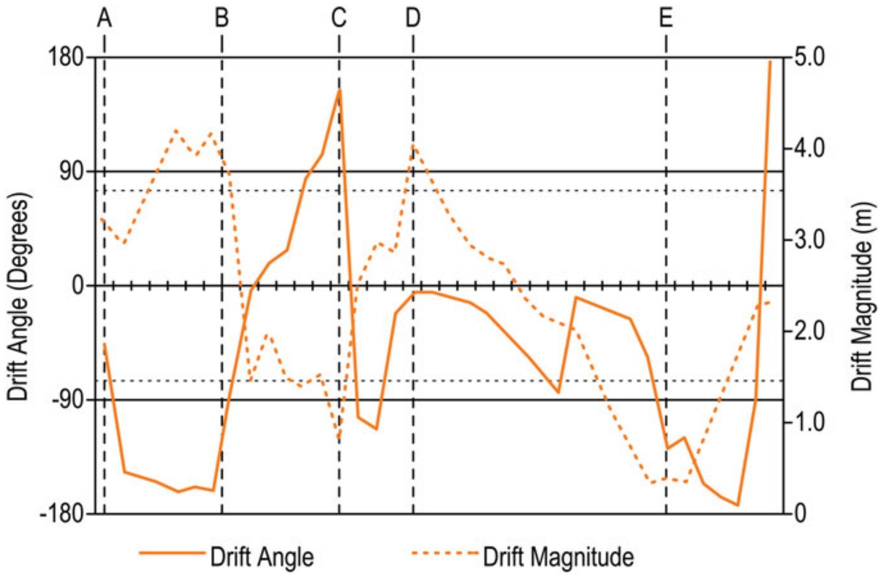


Fig. 10.43 *Storer House*, drift angle and drift magnitude data

living room and hearth is actually largely hidden, requiring six 90° turns and spiralling up around the central chimney mass to the more private living room on the level above. The experience of ascending the stair is variable, and to even approach the base of the stair is counterintuitive, involving the visitor resisting the enticement of the lounge room (D_M = 2.95 m, D_A = −46.06° → 4.22 m, −161.04°). Only after the visitor is partway up the stairs [B] does the adverse effect decrease, and mystery increase (O:P ≈ 50%). The stairs themselves are a refuge-dominant zone (A = 10.82–21.22 m^2) with view distances that are much shorter and more consistent than at the start of the path ($RL_{(L)}$ = 5.70 m). At the top of the first flight of stairs [B] glimpsed views toward the upper level bedrooms create visual complexity (J = 86.54). This is also a distraction from the main path, enticing the visitor to the left (D_M = 1.41 m, D_A = 83.38°) away from the route to the living area. Mystery increases as the visitor approaches the third turn in the path [C] (O:P = 54.98%) revealing the final flight of stairs, before stepping out from under the first floor [D] into a space with high ceilings (H = 2.07 → 3.94 m) and the first views of the living room. After passing the centre of the living room [E], the view from the hearth offers limited complexity (J = 25.14) and mystery (O = 7.48 m, O:P = 25.37%) with no vistas to adjacent interior spaces. Sweeney describes the Storer house as offering 'marked contrasts between its public and private spaces …. The living room, with its fifteen-foot ceiling, is the spatial climax. … The bedrooms, on the other hand, are closed, cavelike spaces' (Sweeney 1994: 64).

The *Storer House* exhibits only moderate and weak correlations between prospect and refuge measures, indicating that the reduplication and substitution of formal features is less pronounced in comparison with some of Wright's other designs. A moderate positive correlation indicates that greater distance to built surfaces occurs in both the horizontal and vertical axes, while moderate negative correlation between height and longest radial line suggests that in some instances height becomes a substitute for a long view (Table 10.9).

10.5.3 Freeman House, Los Angeles, California, USA (1923)

The Freemans were the youngest and least affluent of Wright's Textile-block clients and their chosen site was small and steep but offered extensive views of downtown Los Angeles (Fig. 10.44). The approach path to the house takes several steps down

Table 10.9 *Storer House*, reduplication of isovist data

Storer House	Area	Height	Max radial	Min radial
Area	1	0.2574	0.0390	0.6209
Height		1	−0.6423	0.5550
Max radial			1	−0.4720
Min radial				1

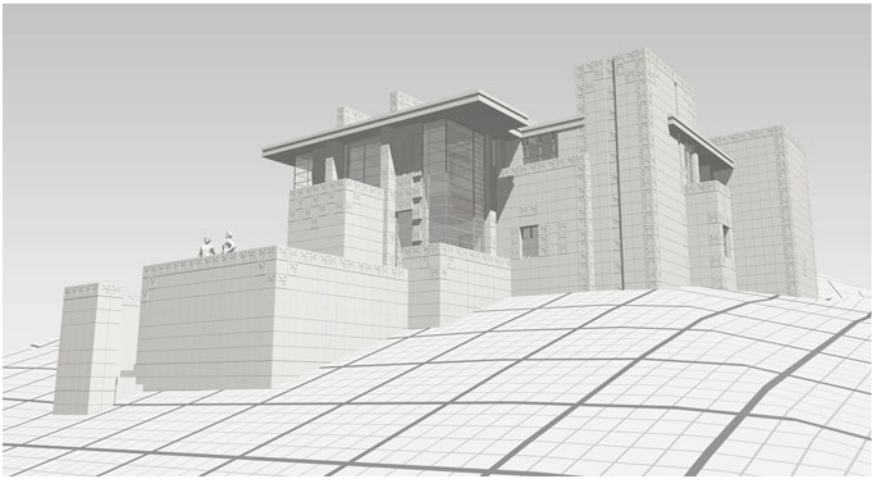


Fig. 10.44 *Freeman House* external perspective

from the driveway [1] and a turn into a loggia that leads to the front door and a poorly illuminated entry hallway beyond (Fig. 10.45). The entry [A] is a small, refuge-dominant space (A = 21.22 m^2) with a distant view of the masonry-mass of the hearth providing a degree of complexity (J = 118.39) and a strong visual enticement leading deeper into the house (D_M = 4.5 m, D_A = −66.81°) (Figs. 10.46 and 10.47). Moving toward the hearth, the narrow corridor temporarily restricts views (A = 16.84 m^2) and reduces mystery (O = 17.05 m, O:P = 49.00%). Approaching and crossing the living room threshold [B] allows the entirety of this space to be seen. This causes a dramatic increase in prospect (A = 23.15 → 62.05 m^2) and while the absolute level of mystery marginally rises (O = 17.17 → 18.43 m), its relative level falls (O:P = 48.60 → 35.17%) as enticement shifts to the left (D_A = 4.5° → 60.5°), to focus attention on the centre of the room.

Wright further enhanced the prospect characteristics of the living room using a raised ceiling to create a tripartite division of the space, centred on the hearth [C]. The visitor experiences this in two stages, the first when crossing the threshold [B] into the living room where the ceiling height increases by one and one-half blocks (H = 2.44 → 3.05 m). Here the visitor must negotiate a dog-leg manoeuvre to pass under a ceiling beam at the same height as the previous corridor, before moving to the front of the hearth [C] with a ceiling three blocks higher than the entry corridor (H = 3.65 m). Wright's usual low ceiling—protecting the hearth and creating a sense of refuge—is absent here, prospect dominates offering the largest (A = 74.98 m^2), if not the longest views ($RL_{(L)}$ = 9.91 m). The centre of the living room [D] offers a similar prospect-dominant experience, but with the entire room and kitchen visible, this location has only limited mystery (O:P = 19.66%) and complexity (J = 37.20) coupled with a slight enticement toward the kitchen (D_M = 1.03, D_A = 101.64) (Figs. 10.48 and 10.49).

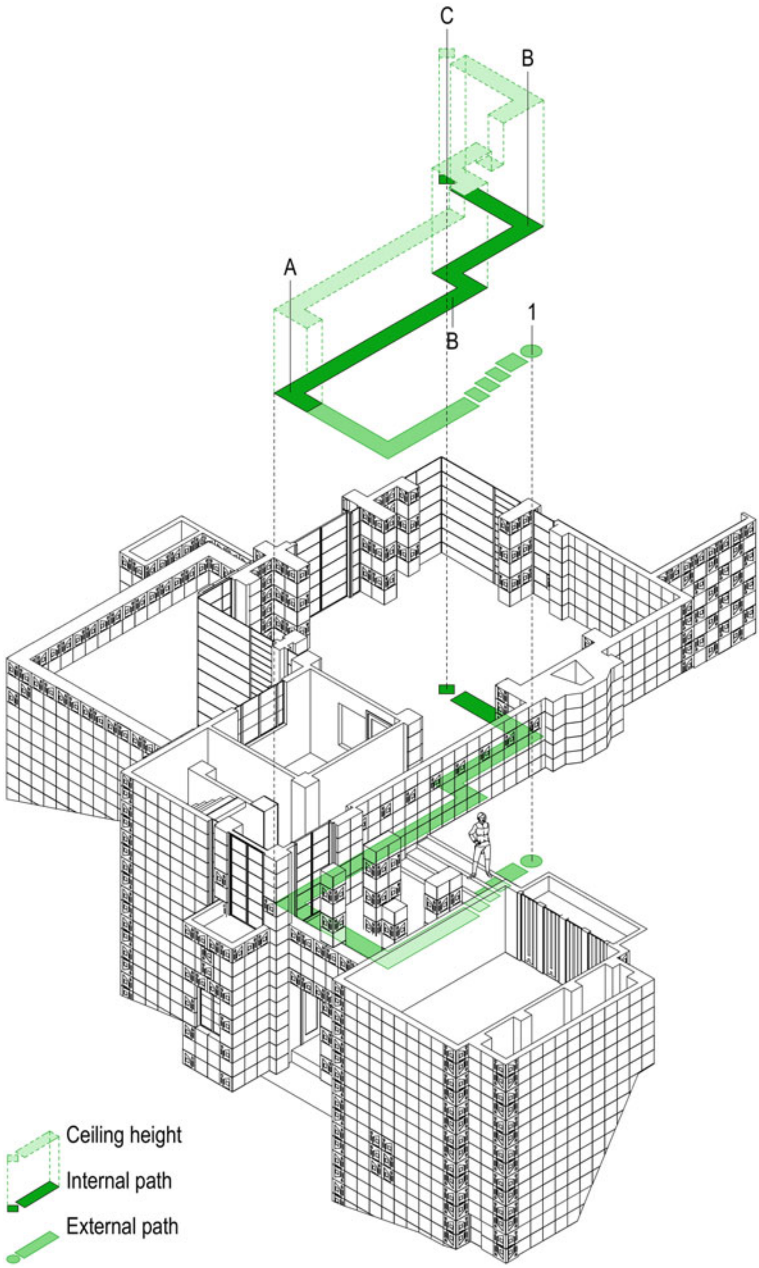


Fig. 10.45 *Freeman House*, axonometric showing movement path

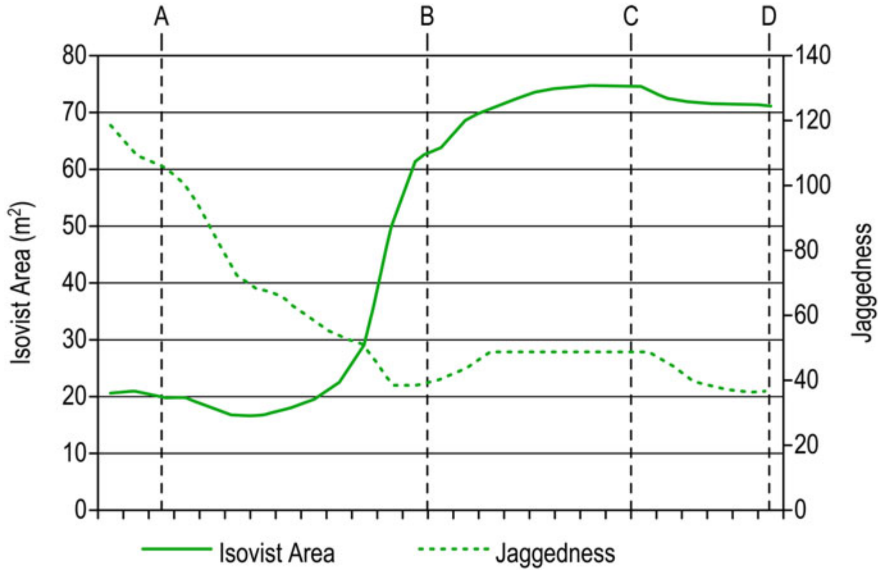


Fig. 10.46 *Freeman House*, area and jaggedness data

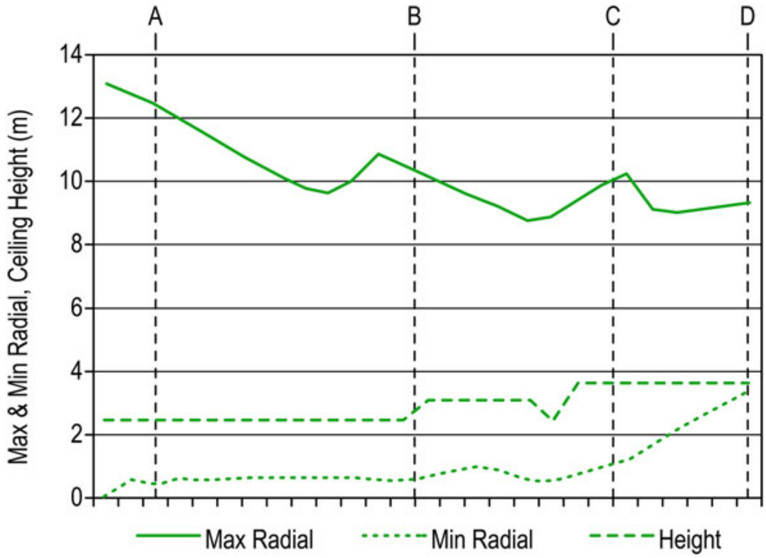


Fig. 10.47 *Freeman House*, minimum radial length, maximum radial length and height data

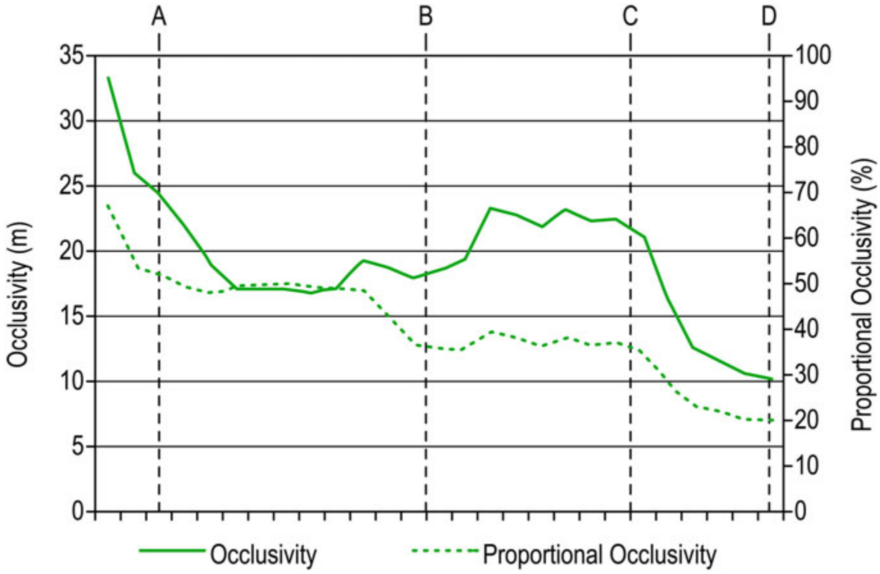


Fig. 10.48 *Freeman House*, occlusivity and proportional occlusivity data

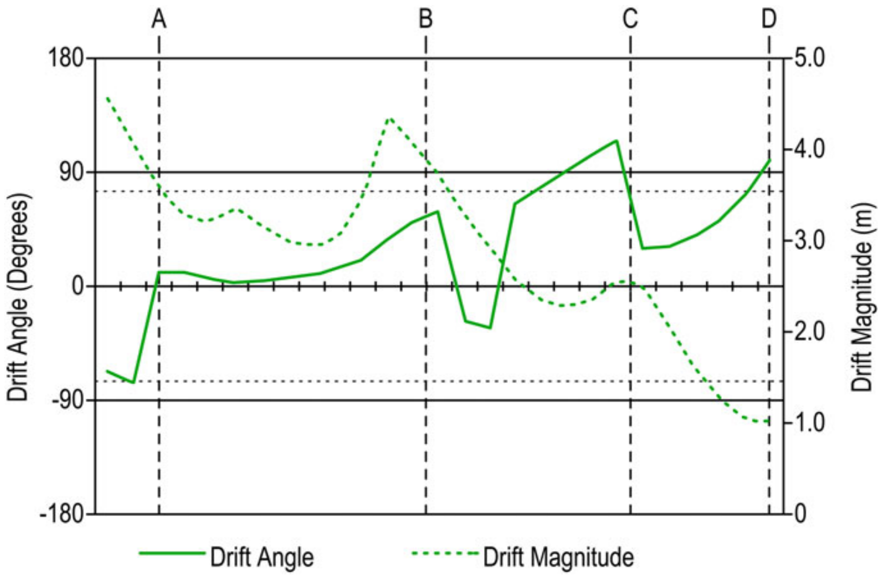


Fig. 10.49 *Freeman House*, drift angle and drift magnitude data

Table 10.10 *Freeman House*, reduplication of isovist data

Freeman House	Area	Height	Max radial	Min radial
Area	1	0.8003	−0.7238	0.5055
Height		1	−0.5965	0.7333
Max radial			1	−0.5107
Min radial				1

Strong positive correlations between area and height, and height and shortest radial indicate reduplication of both prospect and refuge experiences in three dimensions (Table 10.10). A strong negative correlation between area and longest view distances, and moderate negative correlation between height and longest view distance suggests that Wright used area and height as a substitute for view distance in generating an experience of prospect in the living room.

10.5.4 Ennis House, Los Angeles, California, USA (1924)

The *Ennis House* is Wright's final and most ambitious Textile-block design in Southern California (Fig. 10.50). Its site is a dramatic hilltop location, acquired by purchasing and combining adjacent lots. Sweeney describes the house as growing out of a 'podium surrounded by massive retaining walls, which provide a suitably monumental base but also exaggerate the apparent size of the building' (1994: 82). The experience of approaching this house includes the public street access, which wraps around the building, offering multiple different perspectives, before the visitor is finally forced to abandon his or her automobile in the motor court and proceed on foot [1] (Fig. 10.51).

The entry path is by way of a low, dark passage that Hildebrand likens to a Palaeolithic Aurignacian cave. The path analysed here is the one documented and

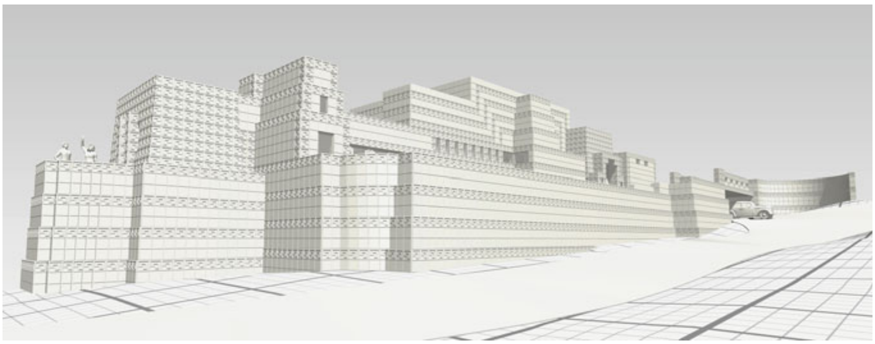


Fig. 10.50 *Ennis House*, external perspective

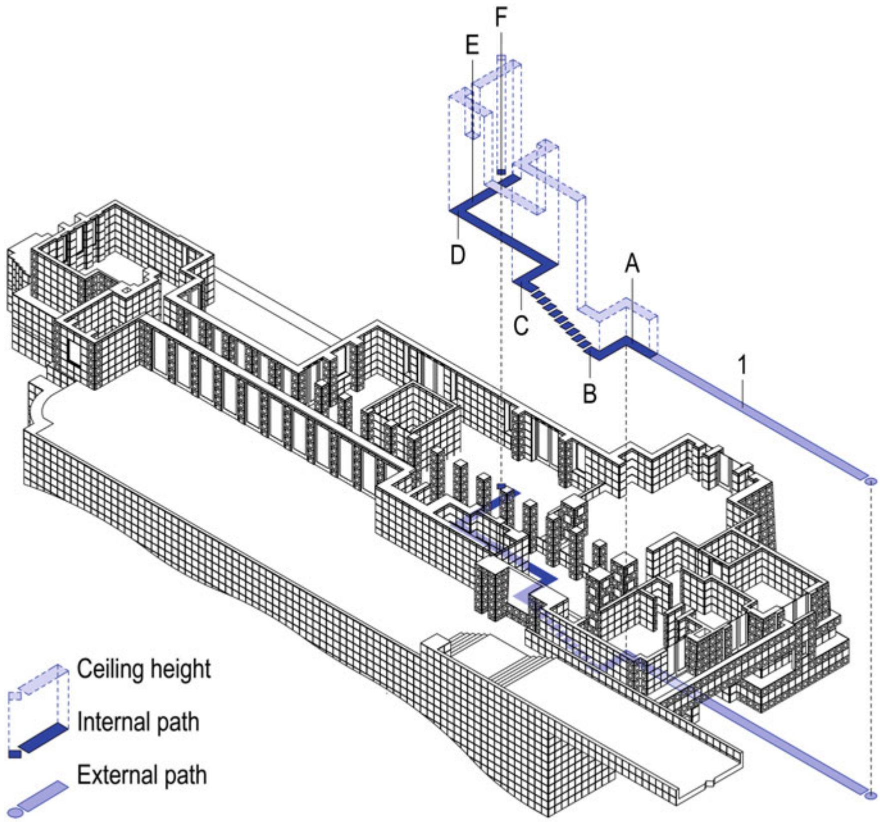


Fig. 10.51 *Ennis House*, axonometric showing movement path

experienced by Hildebrand, not the path originally designed by Wright, which was intended to take the visitor through the garden to the loggia adjacent to the living room. Sweeney describes the entry as evoking the 'strange sense of entering a grand house through the basement' (1994: 95–96) and as space 'suggestive of pagan ritual' (1994: 97). The entry [A] is a small space ($A < 30\ \text{m}^2$) offering short views ($RL_{(L)} < 12$ m, $RL_{(S)} < 1$ m) and low ceilings ($H = 2.00$ m) confirming a strongly refuge-dominant experience. Relatively low jaggedness ($J < 100$) and low levels of mystery ($O < 30$) appear to suggest that the entry space is both simple and straightforward. However, the entry does offer a high degree of mystery with the majority of the edges hiding adjacent spaces ($O{:}P \approx 70\%$). Thus, while only a small space, it implies the presence of a more extensive space that is anticipated but remains unseen, while enticement is initially strong ($D_M = 4.43$ m, $D_A = -25.22°$) directing the visitor first forward and to the right (Figs. 10.52, 10.53, 10.54 and 10.55). Turning to approach the stairs requires the visitor to resist this force until it becomes negligible at the base of the stairs [B] and the entry spaces are no longer visible. Ascending the stairs initially requires resisting an enticement to remain

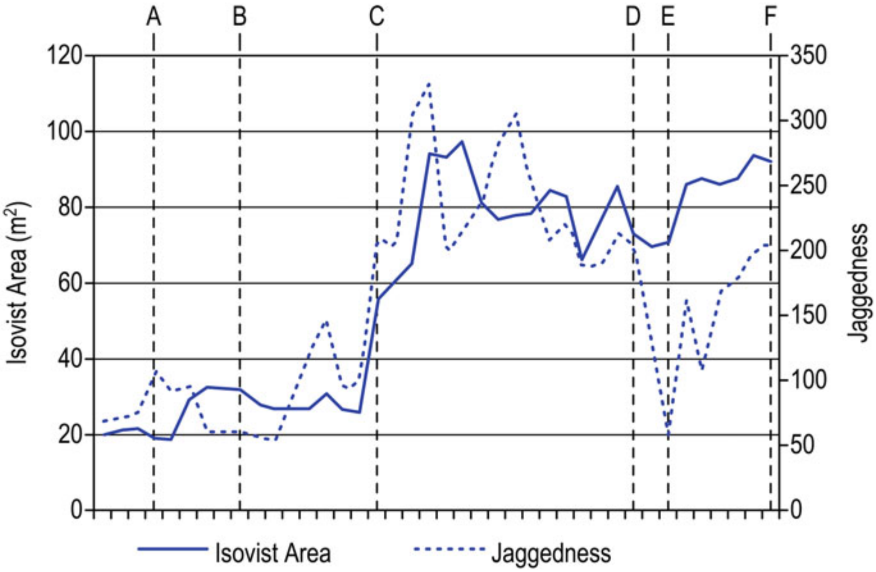


Fig. 10.52 *Ennis House*, area and jaggedness data

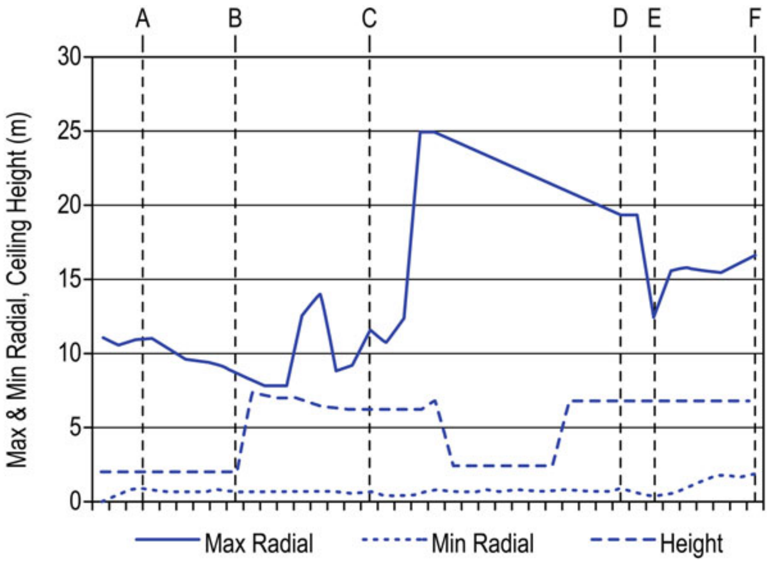


Fig. 10.53 *Ennis House*, minimum radial length, maximum radial length and height data

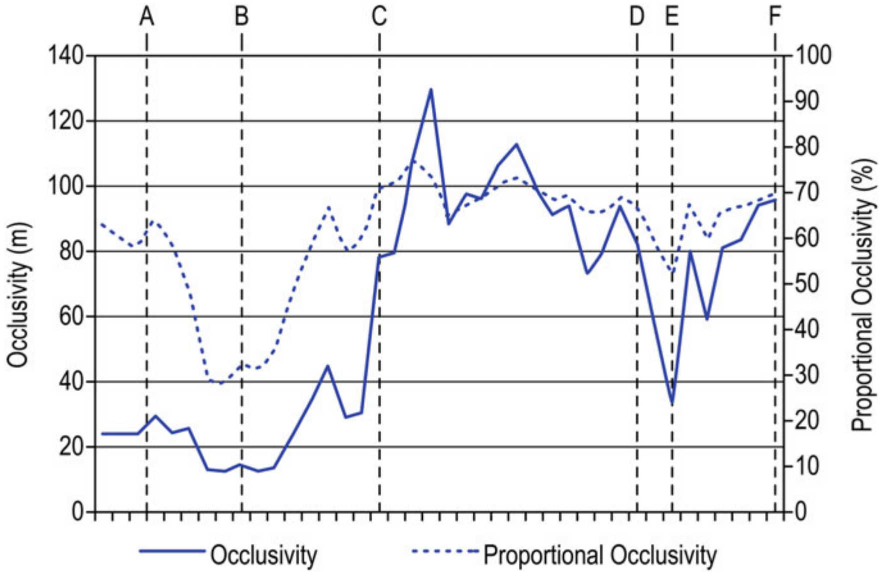


Fig. 10.54 *Ennis House*, occlusivity and proportional occlusivity data

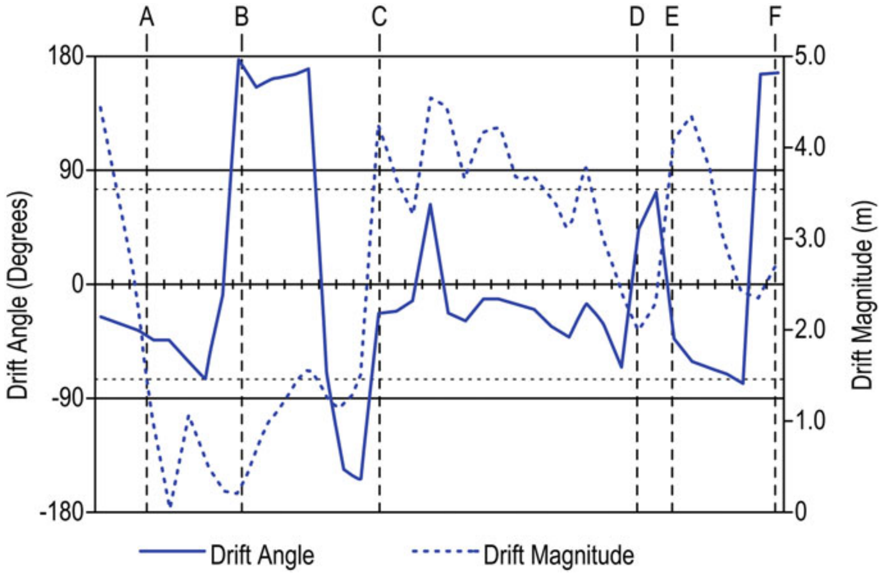


Fig. 10.55 *Ennis House*, drift angle and drift magnitude data

beneath the first floor (H = 1.85 → 7.40 m) before allowing the first glimpses of the services areas, located above the entry, which serve to further discourage forward movement (D_M = 1.40 m, D_A = 166.87° → 4.25 m, −21.45°).

From the top of the stairs [C] the visitor's view remains restricted, with only glimpses provided of the service areas and dining room. Moving forward through a dog-leg turn into the corridor, the entire length of the loggia is brought into view, along with glimpses of the living room. The growing visibility of these spaces causes a rapid increase in prospect (A = 30.86 → 94.78 m^2), view distance ($RL_{(L)}$ = 14.02 → 25.06 m), complexity (J = 148 → 329), mystery (O = 45.31 → 130.41 m, O:P = 67.84 → 73.77%) and enticement (D_M = 1.25 → 4.59 m), all of which draw the visitor toward the hearth [D].

As in the *Freeman House*, the *Ennis House* hearth lacks a low protecting ceiling and is located on the exterior wall of the building—both features that are atypical of Wright's work. Finally entering the living room through a colonnade and beneath a low beam [E], enticement draws attention toward the boundary between living and dining rooms where it will remain focused until the end of the path [F]. High ceilings (H = 6.90 m) enhance the prospect dominant nature of this space (A = 86.23–93.92 m^2) despite the design only offering only a weak correlation between these measures. The columns that divide the dining space from the living room also ensure the continued presence of heightened mystery and complexity.

The reduplication of spatial features is low with only a single strong correlation existing between visible areas and long views (Table 10.11). Low correlations arise from the fact that while multiple formal features of prospect or refuge do occur simultaneously they do not change in a way that suggests deliberate reduplication. In total, Hildebrand argues that this space offers 'some of the most splendid interior prospect in Wright's career, perhaps in all architecture' (1991: 86). While the veracity of the larger part of this claim is beyond the scope of the present chapter, the data for the living room features many of the three-dimensional properties that might be anticipated in a complex, mysterious and prospect-dominant living room.

10.5.5 Lloyd Jones House, Tulsa, Oklahoma, USA (1929)

The *Lloyd Jones House* is the only Textile-block design not constructed in California, being commissioned by Wright's Oklahoma-based cousin and publisher of the Tulsa Tribune. The house also features a more permeable exterior than the

Table 10.11 *Ennis House*, reduplication of isovist data

Ennis House	Area	Height	Max radial	Min radial
Area	1	0.2867	0.8209	0.3833
Height		1	−0.0054	0.2459
Max radial			1	0.1075
Min radial				1

previous houses in this style, with the façade consisting largely of alternating vertical strips of blocks and glazing, supplemented by projecting glass 'prows' (Fig. 10.56). The house is also notable for its scale, offering the largest visible areas of the fifteen houses analysed in the present chapter. However, in comparison with the other Textile-block works, there is relatively little information available about the *Lloyd Jones House* and Hildebrand chose to exclude it from his analysis.

The path through the *Lloyd Jones House* is largely linear in nature, being on one level and with only four turns, three of which are caused by movement within the L-shaped living room to reach its centre [E] and the corner hearth [F] (Fig. 10.57). In the entry [A], the visitor experiences a strong enticement (D_M = 6.88 m, D_A = 9.87°) through the foyer space, which is constrained (A = 60.64–143.64 m^2) and simple (J = 79.61–116.52) relative to the remainder of the house. As the visitor progresses along this path the geometry of the space entices the visitor toward the lounge room (D_M = 8.63 m, D_A = −13.11°) [B], allowing levels of prospect and mystery to increase (A = 159.79 → 234.65 m^2, O = 89.56 → 119.97 m), while the degree of mystery remains high and stable (O:P ≈ 65%), assisted by glimpsed views through the colonnade into the adjacent dining room (Figs. 10.57, 10.58, 10.59, 10.60 and 10.61). The prospect-oriented characteristics of this location are enhanced by a two-textile-block increase in ceiling height [C] throughout the lounge and living rooms (H ~ 2.97 → 3.89 m). A low level of enticement draws the visitor forward and to the right (D_M = 0.85 m, D_A = −9.15°) to step under a low ceiling beam and through a dog-leg [D] in the path to emerge under the living room lantern, where ceiling heights are again raised by two blocks (H = 5.26 m, 4.5 blocks higher than the underside of the beam). Continuing forward, enticement suddenly switches orientation from in front of the visitor to be behind them (D_A = −4.55 → −163.16°) as the majority of the dining room comes into view for the first time and prospect continue to increase (A = 219.96 → 269.91 m^2, $RL_{(L)}$ = 19.00 → 33.04 m). From this location, the visitor is required to resist an increasingly strong pull (D_M = 0.27 → 10.07 m) to proceed forward, before

Fig. 10.56 *Lloyd Jones House*, external perspective

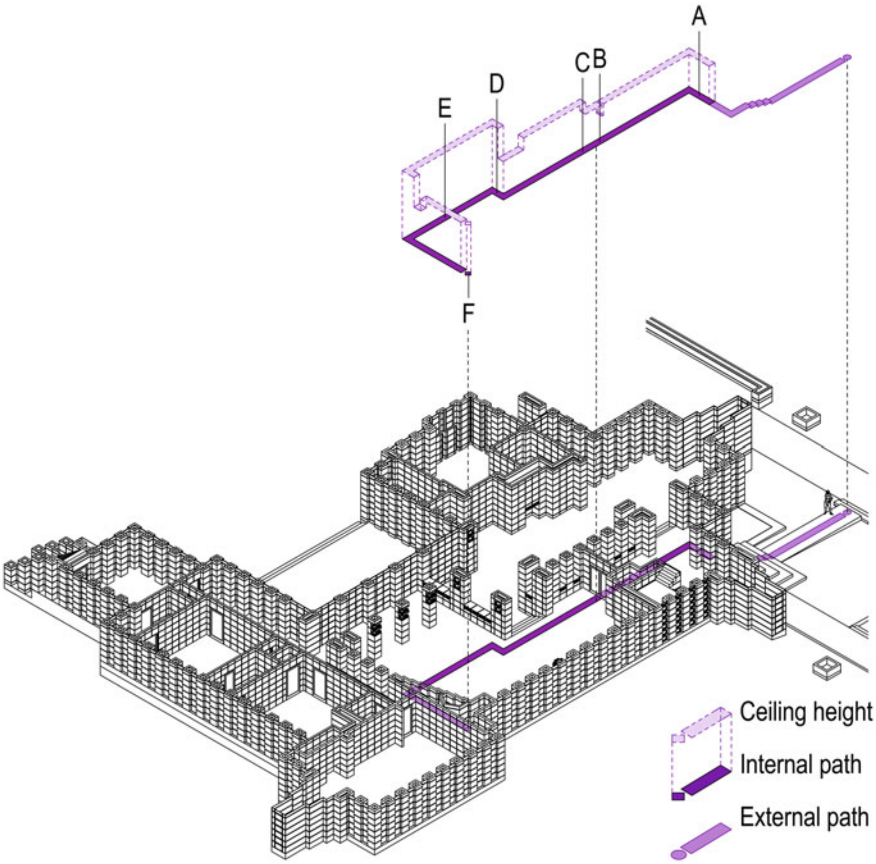


Fig. 10.57 *Lloyd Jones House*, axonometric showing movement path

turning, moving under the same low ceiling beam ($H = 2.97$ m) and toward the hearth [F]. While the hearth does offer slightly reduced prospect, and the ceiling is lower than that of the lantern ($H = 3.88$ m), this location remains prospect-oriented, offering a high degree of mystery (O:$P = 73.02\%$) and complexity ($J \sim 210.73$) relative to the other, much smaller houses. The only indication of an attempt to provide a sense of refuge at this location is the disruption of the façade glazing to feature a solid external wall adjacent to the hearth.

Strong positive correlations between height and area, and height and shortest radial, indicate reduplication of prospect and refuge spatial features in three dimensions. A borderline strong positive correlation (0.6954) between area and shortest radial line, combined with moderate positive correlations between shortest and longest radial lines, and longest radial line and area, indicate minor reduplication occurs between many spatial features (Table 10.12).

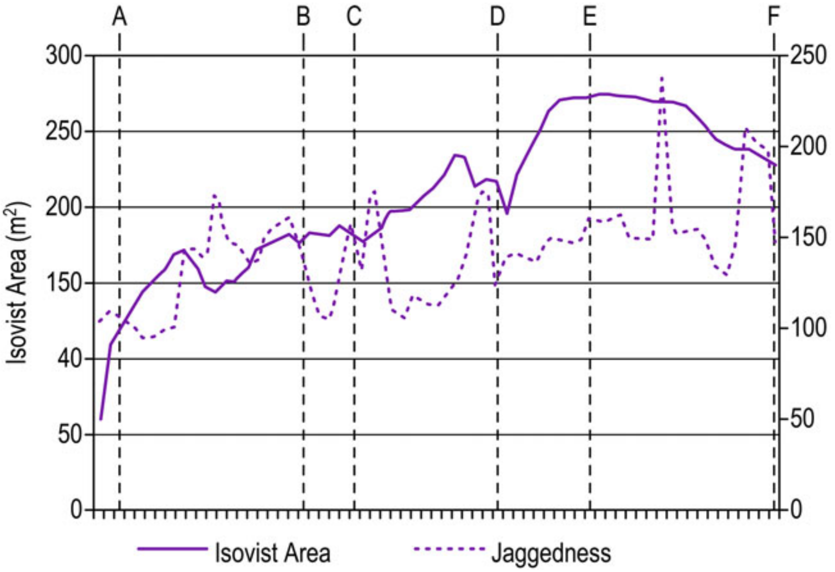


Fig. 10.58 *Lloyd Jones House*, area and jaggedness data

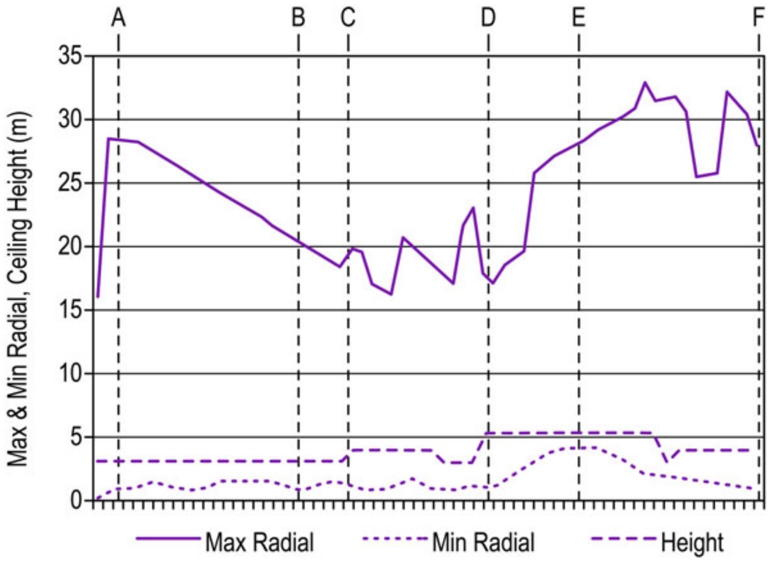


Fig. 10.59 *Lloyd Jones House*, minimum radial length, maximum radial length and height data

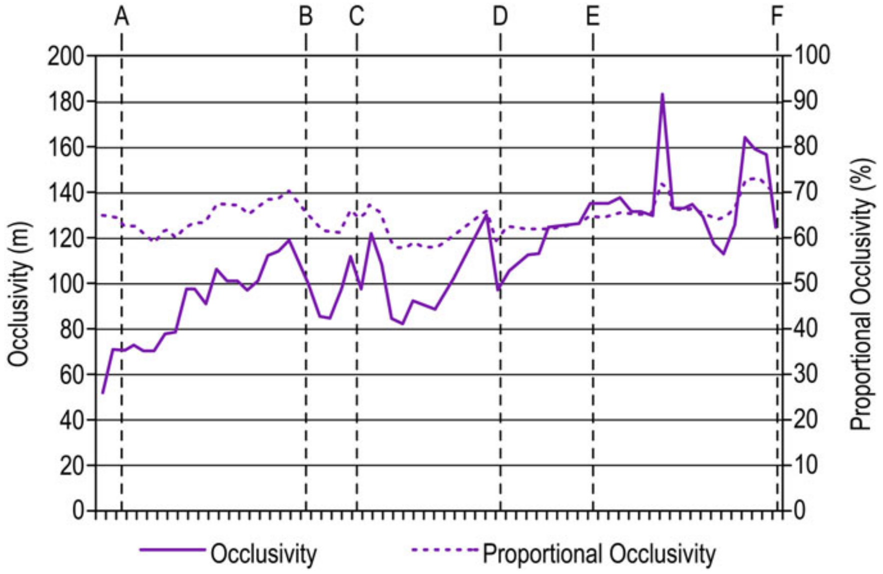


Fig. 10.60 *Lloyd Jones House*, occlusivity and proportional occlusivity data

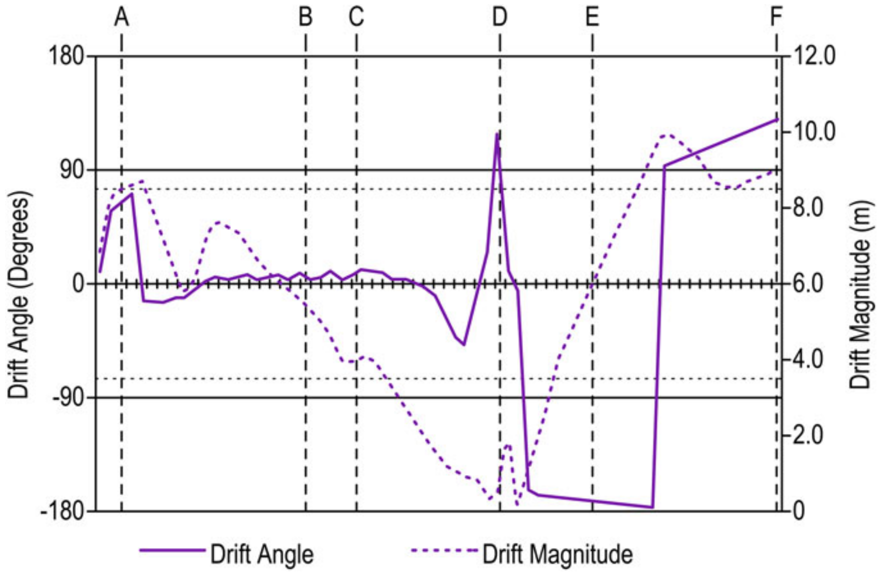


Fig. 10.61 *Lloyd Jones House*, drift angle and drift magnitude data

Table 10.12 *Lloyd Jones House*, reduplication of isovist data

Lloyd Jones House	Area	Height	Max radial	Min radial
Area	1	0.7474	0.3690	0.6954
Height		1	0.2242	0.7165
Max radial			1	0.4138
Min radial				1

10.6 Usonian House Results

In his 1932 autobiography Frank Lloyd Wright stated that the production of a moderately priced house was 'America's major architectural problem' (1998: 489). In response, Wright developed his third architectural style, the Usonian house. This series of designs featured cost-saving strategies including slab-on-ground construction, built-in furniture, a carport instead of a garage and a modular, prefabricated timber construction system to eliminate plastering and painting costs. In addition to reducing the size of his designs to accommodate a more modest income, Wright prepared a series of archetypal planning configurations to suit different sites: L-shape plans for urban lots, and linear, hexagonal or diagonal designs for more open sites.

Regardless of the underlying geometric *parti* of its plan, each Usonian house incorporates a relatively consistent set of relationships between functional spaces, with dining and kitchen areas merged into an alcove off the larger living space with the separation being signalled through the use of materials and built-in furniture. The elaborate formal dining room and servant-operated kitchens of the Prairie houses had no place in the limited budget of a Usonian house. Wright described the Usonian living room as a large space 'with as much vista and garden coming in as we can afford, with a fireplace in it, and open bookshelves, a dining table in the alcove, benches, and living room tables built in' (1998: 492).

Despite (or perhaps because of) their modest budgets, the Usonian houses are considered ideal examples of Wright's interior prospect-refuge pattern. They represent a distillation of the more complex patterns of the Prairie Style and Textile-block houses, including the presence of a carefully controlled path from the front door to a prominently positioned hearth and an expansive living room. According to Hildebrand (1991), the key elements of the pattern—the design of the living room and of the path that connects this room to the home's entry—are all found in the Usonian houses.

10.6.1 Jacobs House, Madison, Wisconsin, USA (1936)

The *Herbert Jacobs House* is regarded as the first completed Usonian design. Wright designed the house for a guaranteed cost of $5500, provided additional financial support in the form of a *lien* (a right to keep a certain asset until a debt is repaid), and allegedly 'appropriated materials from the Racine site of the S. C. Johnson Administration Building, which was under construction at the time' (Rosenbaum 1993: 148) to ensure completion. The *Jacobs House* consists of an L-shaped plan, designed to ensure privacy from the street while maximising the area available for a rear garden (Fig. 10.62). Internally, its walls are richly modelled, stepping into and around the entry, creating alcoves for the kitchen and dining areas and dissolving the boundaries of the space with mitred glass corners. Sergeant stresses that such is the complexity of this small house that there is a need 'to move about to comprehend it' (1976: 28) while noting that the space also has a mysterious quality, associated with the way 'its boundaries always slip beyond view' (1976: 28) and that the spatial experience is both 'complex and ambiguous' (1976: 28).

The approach path leads a visitor to an understated entrance located in the carport (Fig. 10.63). The private entry is within the masonry service core, adjacent to the hearth and opposite an expanse of windows facing the gardens. The path through the Jacobs house has only two turns. It commences in the entry vestibule [A], where limited prospect (A = 16.05 m^2), high complexity (J = 51.46) and a long view ($RL_{(L)}$ = 11.63 m) create a clear enticement (D_M = 5.33 m, D_A = 0.37°), encouraging the visitor to advance (Figs. 10.64, 10.65, 10.66 and 10.67). This gradually reduces as the visitor progresses beyond the living room threshold [B] and to the hearth [C] ($RL_{(L)}$ = 9.41 m). Mystery and complexity are lowest (O:P = 13.71%, J = 27.13) between the entry to the living room [B] and the hearth [C]. When approaching the centre of the living room [C] glimpsed views past the kitchen become available increasing mystery, complexity, and view distance while generating a new enticement in this direction. The living room centre offers the highest levels of prospect (A = 52.73 m^2 and $RL_{(L)}$ = 12.35 m) and mystery (O:P = 31.11%) along with a slight directional force (D_M = 1.67 m) toward the hearth, suggesting the living room centre is a destination space offering a balance of prospect, mystery and complexity.

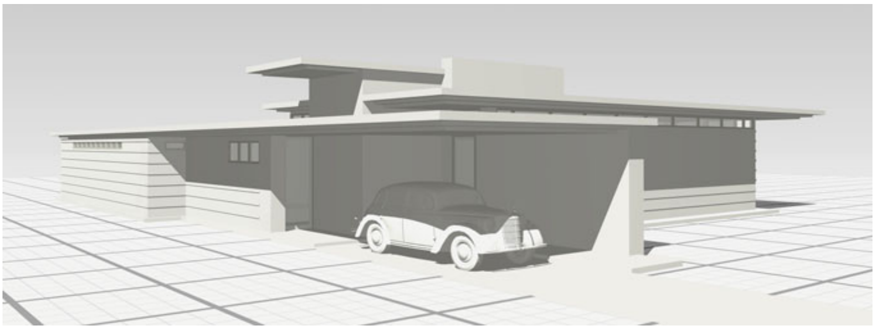


Fig. 10.62 *Jacobs House*, external perspective

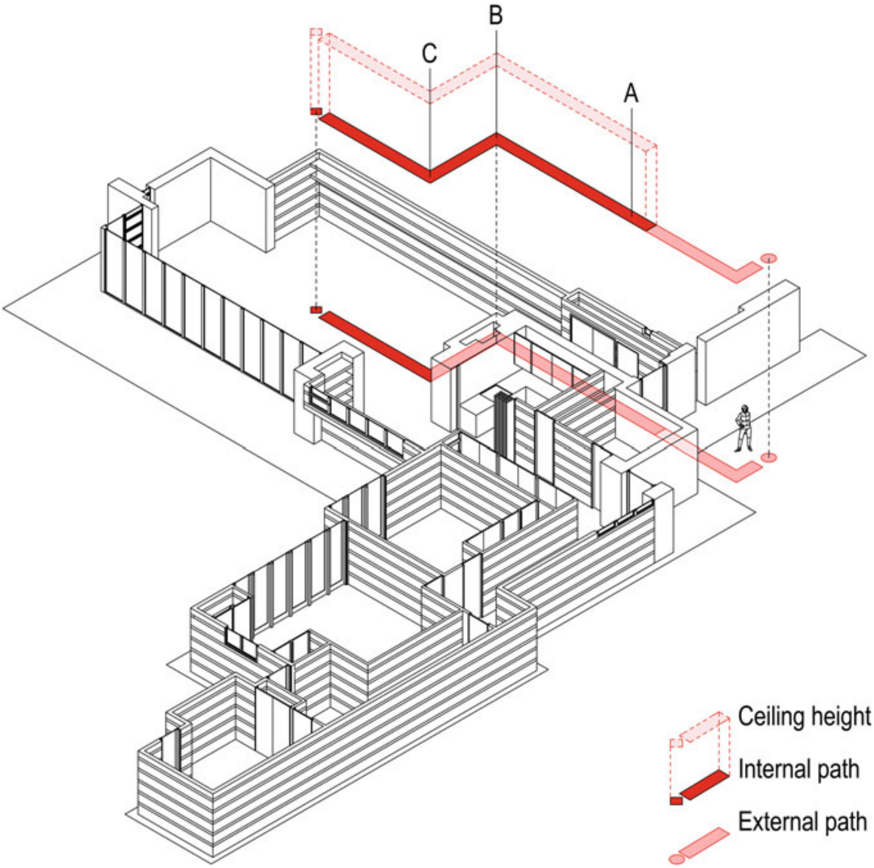


Fig. 10.63 *Jacobs House*, axonometric showing movement path

Reduplication in the *Jacobs House* is similar to that of the *Millard House*: a small entry gives way to a large living room with no intermediary spaces, and produces a strong positive correlation between area and shortest view distance and a moderate negative correlation between area and longest view distance as spaces shift to become larger and rounder (Table 10.13). The key difference from the *Millard House* is that ceiling height (H = 2.86 m) remains constant in the *Jacobs House*. Therefore, no correlation exists between height and other prospect-refuge measures. However, ceiling height is lower over the private wing of the house where rooms are smaller and corridors are narrow, suggesting some reduplication of height might exist, but not between the entry and living room.

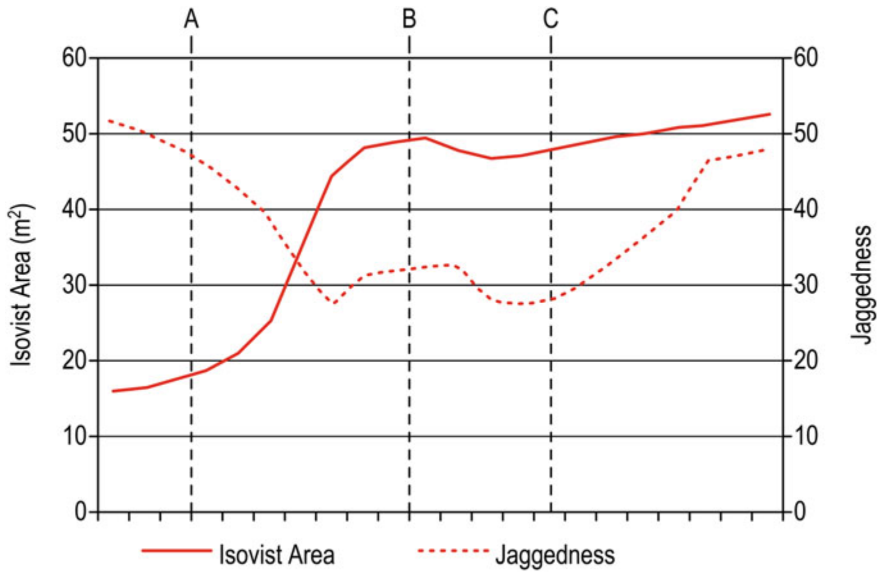


Fig. 10.64 *Jacobs House*, area and jaggedness data

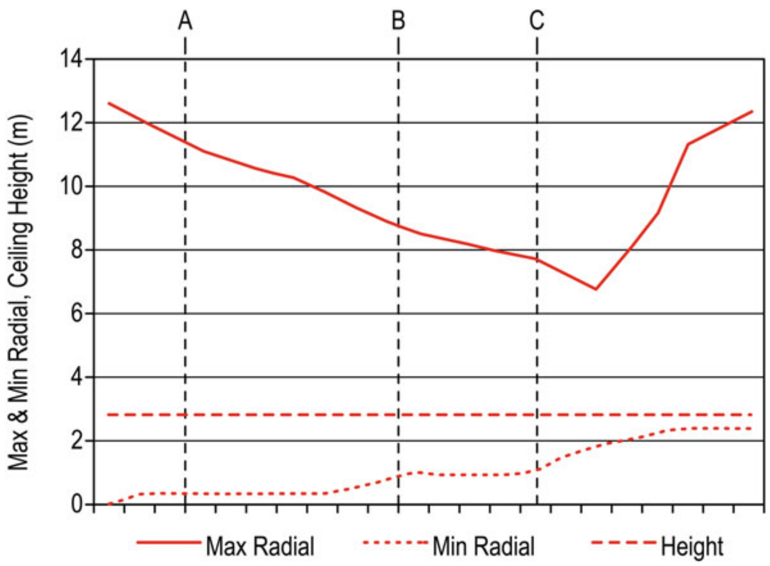


Fig. 10.65 *Jacobs House*, minimum radial length, maximum radial length and height data

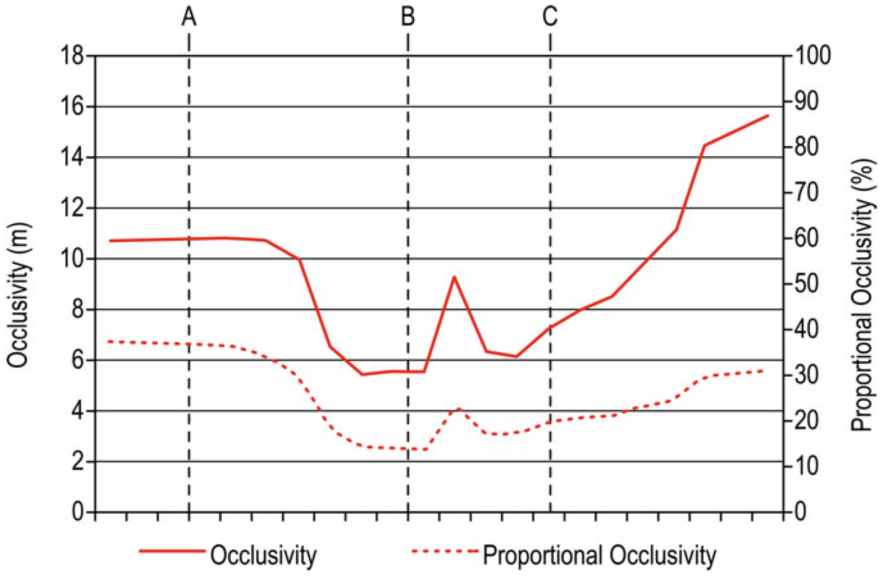


Fig. 10.66 *Jacobs House*, occlusivity and proportional occlusivity data

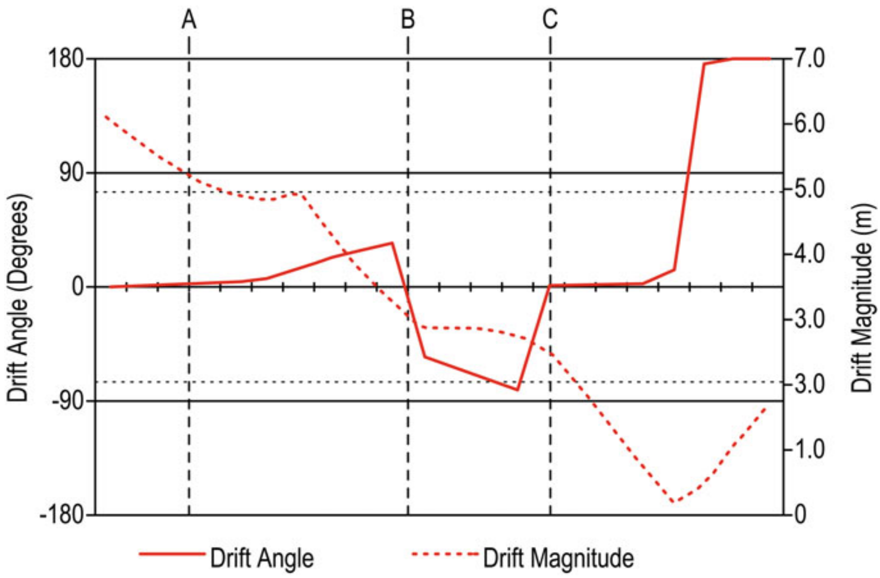


Fig. 10.67 *Jacobs House*, drift angle and drift magnitude data

Table 10.13 *Jacobs House*, reduplication of isovist data

Jacobs House	Area	Height	Max radial	Min radial
Area	1	[a]	−0.5751	0.7281
Height		1	[a]	[a]
Max radial			1	−0.1717
Min radial				1

[a]Note that as the height of this path never varies, there is no correlation possible

10.6.2 Schwartz House, Two Rivers, Wisconsin, USA (1939)

Wright's Usonian architecture was featured in a 1938 issue of *Time* magazine and in an article in *Life* magazine in the same year entitled 'Houses for Different Incomes'. After seeing these issues, businessman Bernard Schwartz 'went to Taliesin to request a version of Wright's contribution, "A House for a Family of $5000–$6000 Income"' (Sergeant 1976: 46), commissioning a house which was very similar to that featured in print (Fig. 10.68).

This *Schwartz House* uses a variation of the L-shaped plan, with the larger wing being dominated by a recreation and lounge space. Sergeant describes this interior as possessing 'great spatial variety, intimacy, and grandeur' (1976: 49). Entry to the house is again through the carport and once inside the visitor makes one 90° turn to pass the kitchen and stairs, then traverses the recreation room before moving through the centre of the lounge room and turning twice to approach the hearth (Fig. 10.69).

At the entry [A] the visitor experiences the longest view distance ($RL_{(L)}$ = 19.62 m) and strongest level of enticement (D_M = 9.36 m) of all the Usonian houses analysed here along with the lowest ceiling level in this house (H = 2.15 m). These features draw the visitor forward, past the point of maximum prospect (A = 103.92 m^2, H = 3.96 m), to the centre of the recreation room [B] where the visitor is furthest from the walls and ceiling ($RL_{(S)}$ = 2.93 m, H = 3.96 m) (Figs. 10.70, 10.71, 10.72 and 10.73). Despite this, the space has only

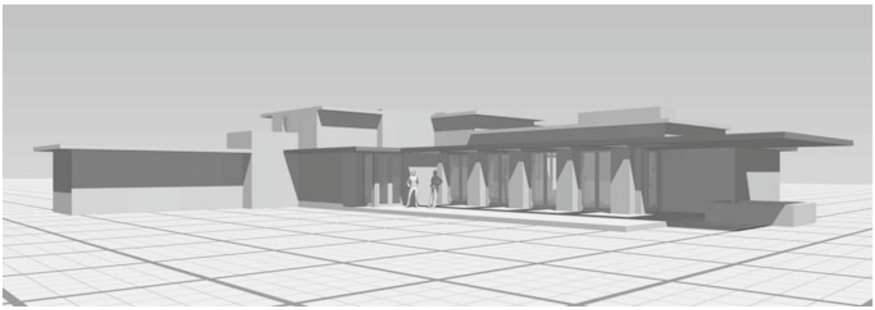


Fig. 10.68 *Schwartz House*, external perspective

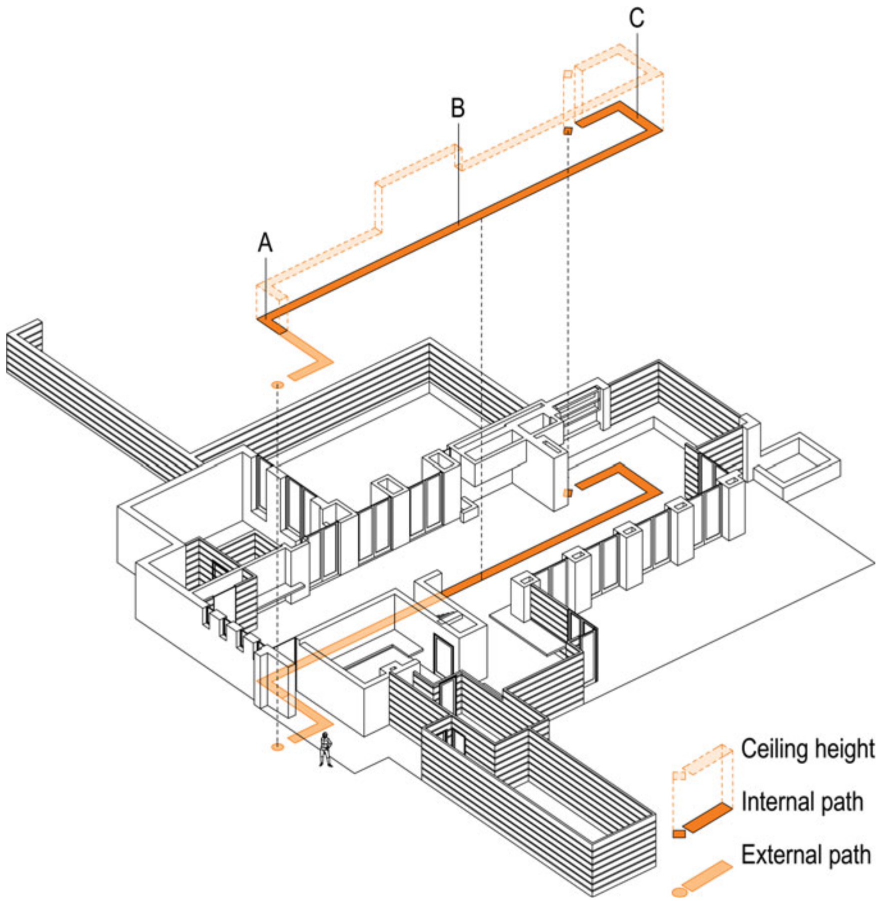


Fig. 10.69 *Schwartz House*, axonometric showing movement path

a moderate positive correlation between ceiling height and both visible area and shortest view distance (Table 10.14). At this location complexity reaches its highest levels (J = 60.69) and, being close to the visual centre of the house, the sense of enticement is weakest here (D_M = 0.36 m). Passing beyond this point to the lounge room requires moving in the opposite direction to the visual pull of the large recreation room and into the protected corner nook of the lounge room [C]. Ultimately, the lounge room and particularly the hearth, are strongly refuge-dominant (A = 50.76 m^2, $RL_{(L)}$ = 11.65 m, $RL_{(S)}$ = 0.88 m, H = 3.07), and relatively static, uncomplicated and contained (D_M = 2.45 m, J = *30.19*, O:P = 39.74%). A borderline strong negative correlation between longest and shortest view distances is triggered by the linear nature of the main wing of the *Schwartz House*, where the longest views are available closest to the short ends of the oblong plan. Moderate negative correlations between longest view distances and both height and area indicate that these measures act as a substitute for the relatively short views available from the centre of the house and its path.

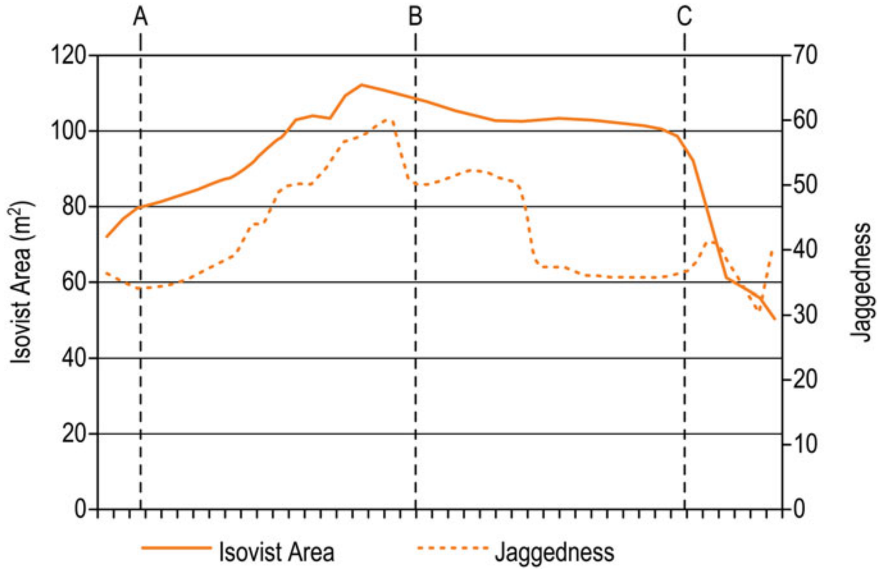


Fig. 10.70 *Schwartz House*, area and jaggedness data

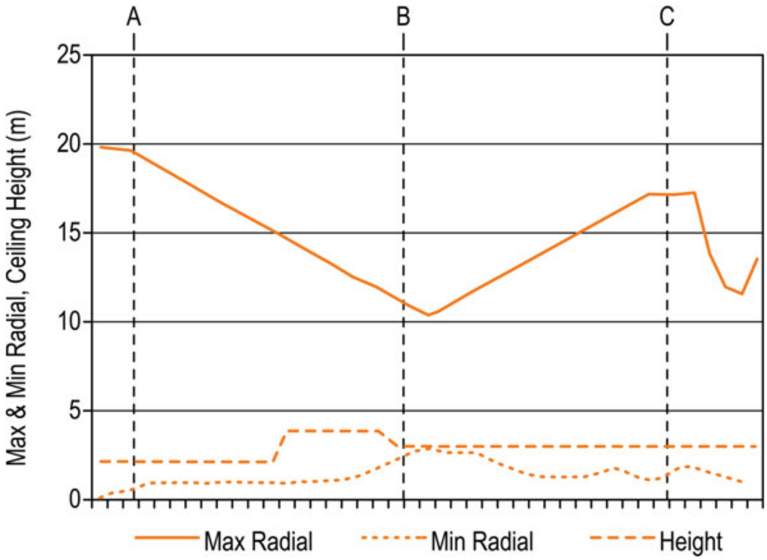


Fig. 10.71 *Schwartz House*, minimum radial length, maximum radial length and height data

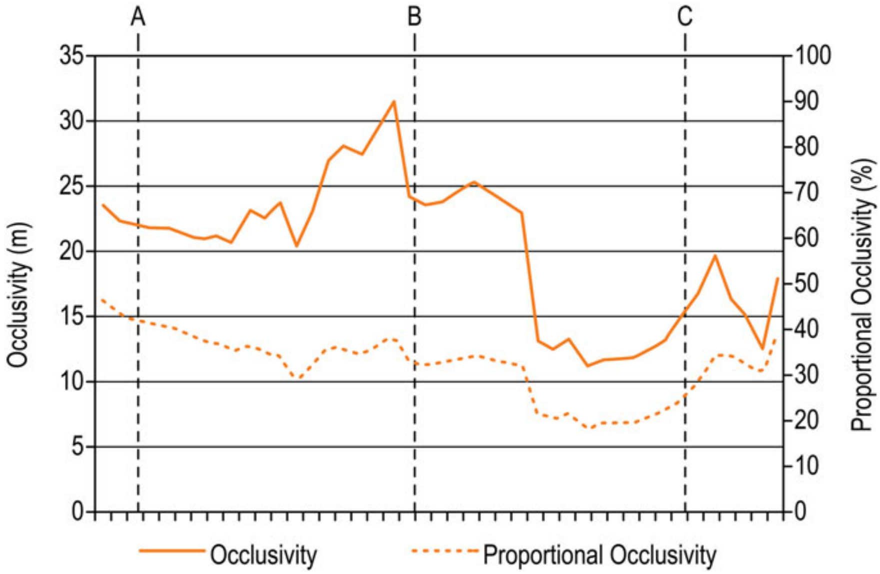


Fig. 10.72 *Schwartz House*, occlusivity and proportional occlusivity data

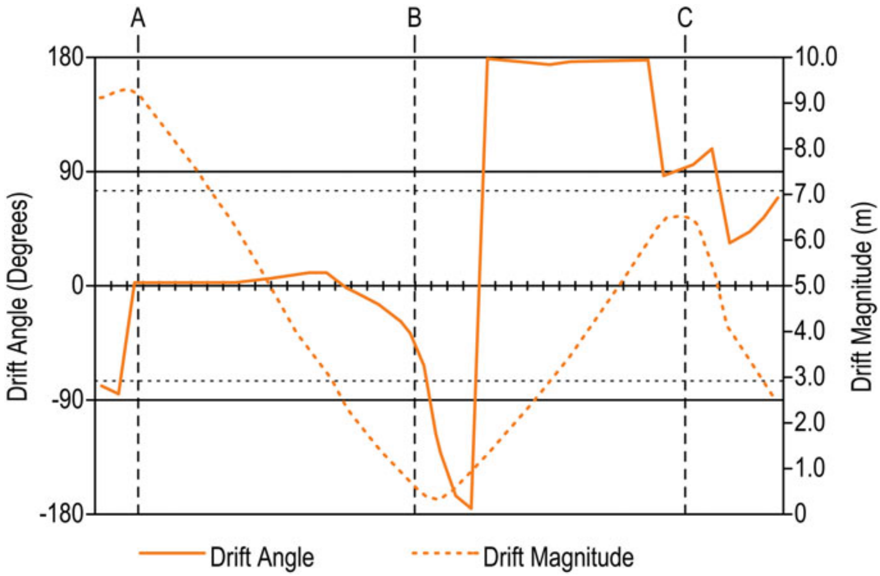


Fig. 10.73 *Schwartz House*, drift angle and drift magnitude data

Table 10.14 *Schwartz House*, reduplication of isovist data

Schwartz House	Area	Height	Max radial	Min radial
Area	1	0.4605	−0.3605	0.4690
Height		1	−0.6224	0.3386
Max radial			1	−0.7009
Min radial				1

10.6.3 Lloyd Lewis House, Libertyville, Illinois, USA (1940)

Designed for the journalists Lloyd and Kathryn Lewis and constructed on the Des Plaines River in Illinois, the threat of flooding and damp ground forced Wright to raise this building from the ground on masonry piers (Fig. 10.74). Sergeant writes that the 'restful proportion of these spaces, subtle changes of level, and assured cypress detailing make this one of Wright's simplest and most successful Usonian interiors' (1976: 66). Wright recalled, with his typical lack of modesty, that the same 'tragedy that befell so many of my clients happened to the Lloyd Lewises. They just liked to stay in their house and didn't care to go out anywhere unless they had to' (qtd. in Sergeant 1976: 66).

The *Lloyd Lewis House* uses a truncated L-shaped plan with an unusual external spatial sequence culminating in an extensive, formal loggia (Fig. 10.75). The first steps of the entry [A] are visually constrained in the horizontal plane ($RL_{(S)}$ = 0.45–0.77 m, $RL_{(L)}$ = 3.94–6.43 m, A = 8.22–10.45 m^2) but not in the vertical one (H = 2.05–3.81 m) and are of variable mystery ($O{:}P$ = 14.64–52.26%). Passing the first stair landing [B] offers a brief, long and constrained ($RL_{(L)}$ = 15.83 m) view down the bedroom corridor while enticement reaching the landing is both strong (D_M = 4.91 m), and typically in a different orientation (up to −180°) to the direction of travel (Figs. 10.76, 10.77, 10.78 and 10.79). Upon reaching top of the second landing [C] the entire living room and portions of the kitchen, dining room

Fig. 10.74 *Lloyd Lewis House* external perspective

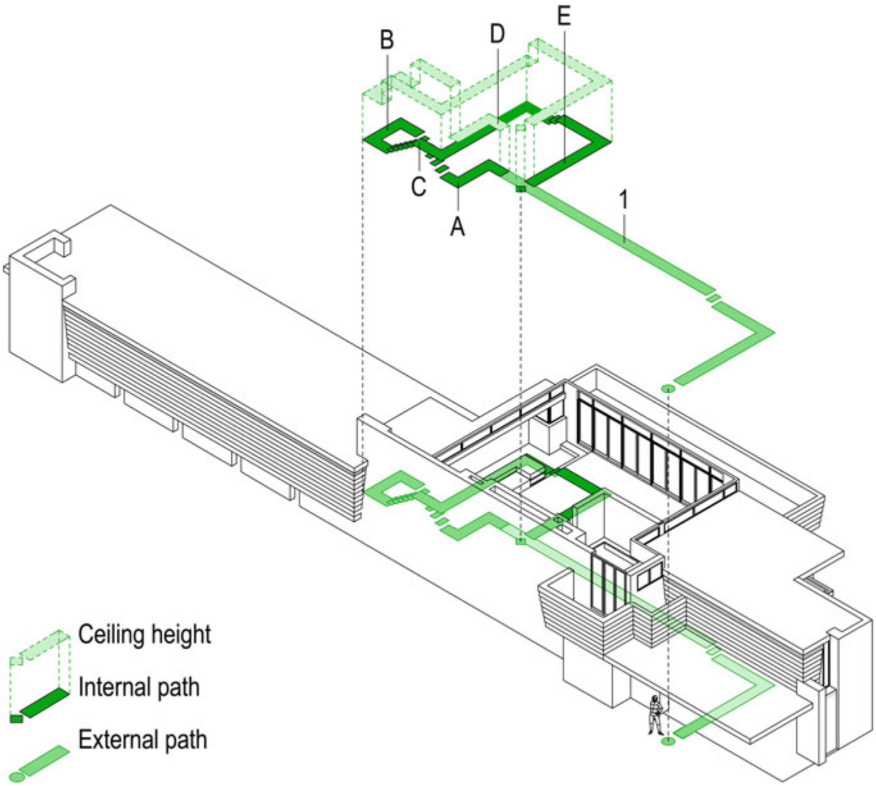


Fig. 10.75 *Lloyd Lewis House*, axonometric showing movement path

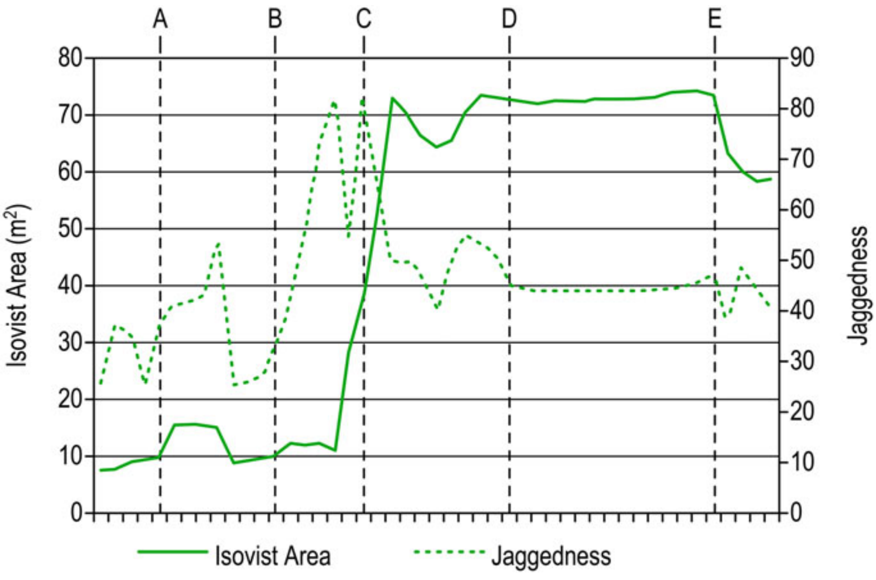


Fig. 10.76 *Lloyd Lewis House*, area and jaggedness data

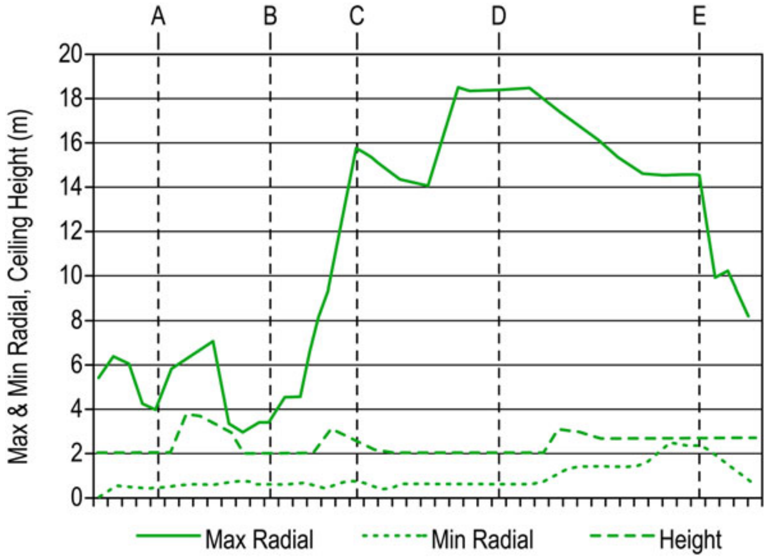


Fig. 10.77 *Lloyd Lewis House*, minimum radial length, maximum radial length and height data

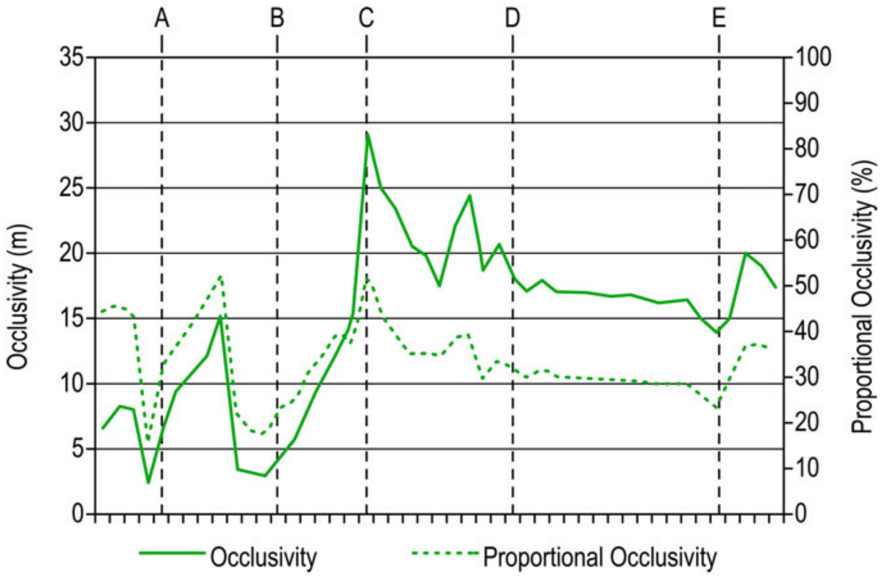


Fig. 10.78 *Lloyd Lewis House*, occlusivity and proportional occlusivity data

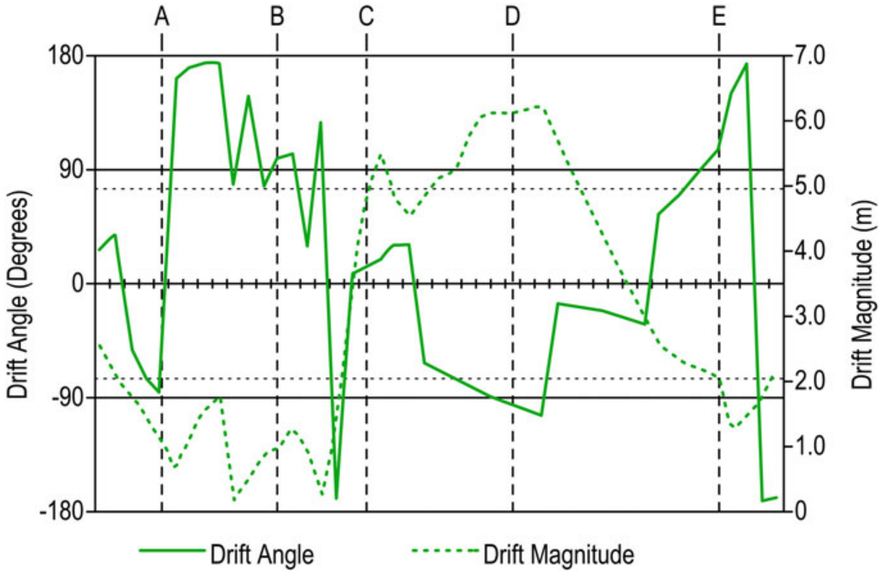


Fig. 10.79 *Lloyd Lewis House*, drift angle and drift magnitude data

and sanctum become visible causing a rapid rise in prospect (A = 28.71 → 73.20 m^2). Mystery peaks at the top of the stairs and enticement increasingly directs attention towards the living room (D_M = 3.54 → 6.29 m), where the waist-high book shelves [D] force the visitor to move perpendicularly to this direction (D_A = 9.81° → −103.45°) before finally entering living room and crossing the room centre [E] to approach the hearth. The living room offers strong prospect and high ceilings (A = 58.79–74.23 m^2, H = 2.75 m) with glimpsed views to adjacent spaces suggesting a static environment at the end of an often-counterintuitive path that offers only brief instances of mystery and complexity, and a pattern of enticement that typically operates contrary to the direction of travel.

A strong positive correlation between area and longest radial line, supported by moderate correlations between shortest view distance and both area and longest views indicate the primary reduplication of prospect and refuge occurs in the horizontal plane (Table 10.15). The only moderate correlation involving height occurs with shortest view distance. While the *Lloyd Lewis House* may have 'one of Wright's simplest and most successful Usonian interiors', a claim that might be supported by the moderate levels of mystery, complexity and reduplication, the path itself is also one of the least directed of Wright's Usonian works and is reminiscent of passage through the labyrinthine Prairie Style designs (Ostwald and Dawes 2013b).

Table 10.15 *Lloyd Lewis House*, reduplication of isovist data

Lloyd Lewis House	Area	Height	Max radial	Min radial
Area	1	0.0295	0.8997	0.5149
Height		1	−0.0233	0.4009
Max radial			1	0.3059
Min radial				1

10.6.4 *Affleck House, Bloomfield Hills, Michigan, USA (1941)*

The *Affleck House*, while initially appearing to be a two-storey design, has the curious property that 'the lower level in fact has little to do with family living spaces; under the guise of utilities and servant's accommodation, it is really a pylon to perch the house over the steep wooded hillside site' (Hildebrand 1991: 132). This design uses an L-shaped plan that is approached through an initially understated path, by way of the rear of the carport. Its materials and forms are strongly horizontal and, with one deviation, the experience of this house is embedded in its planning rather than its section (Figs. 10.80 and 10.81). The exception relates to the constrained entry court, which features a 'top-lit loggia, whose open wall overlooks a pool and streamlet that eventually runs into a pond' (Sergeant 1976: 70).

The path from the front door to the living room consists of only three left-hand turns. The experience of the entry [A] is constrained (A = 8.70 m^2) and contained ($O{:}P$ = 30.33%, H = 2.16 m) with only a gentle enticement to proceed forward into the house (D_M = 2.74 m, D_A = 5.74°) (Figs. 10.82, 10.83, 10.84 and 10.85). As the visitor leaves the vestibule, the bedroom corridor briefly enters view, causing a spike in mystery, complexity and view distance (O = 16.83 m, J = 99.69, $RL_{(L)}$ = 16.03 m), before enticement directs attention toward the centre of the living

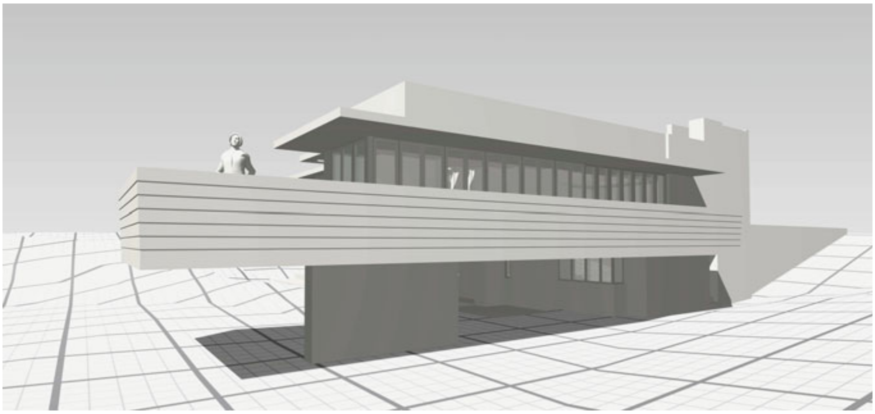


Fig. 10.80 *Affleck House*, external perspective

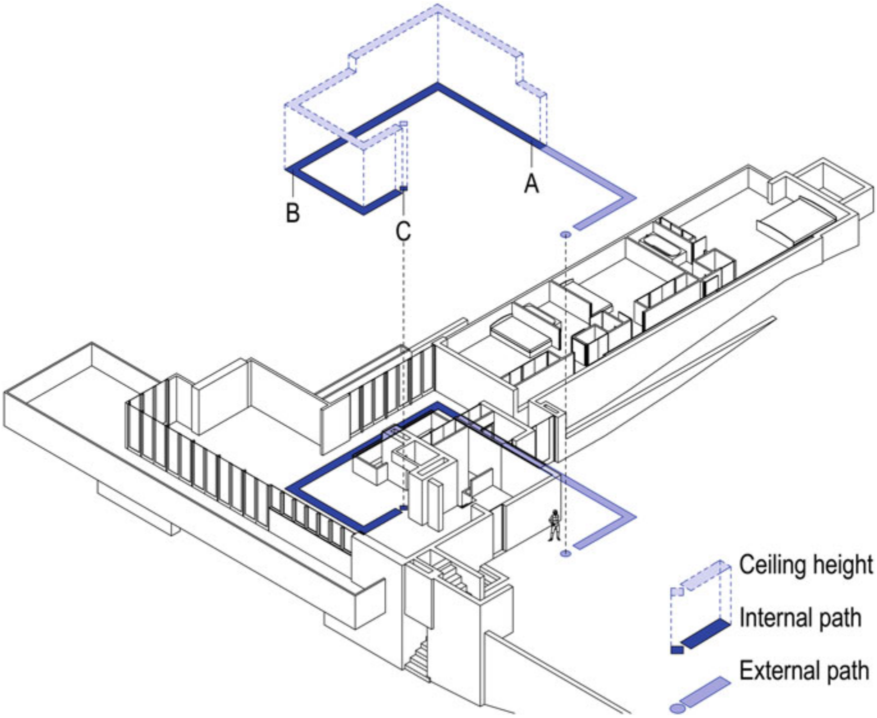


Fig. 10.81 *Affleck House*, axonometric showing movement path

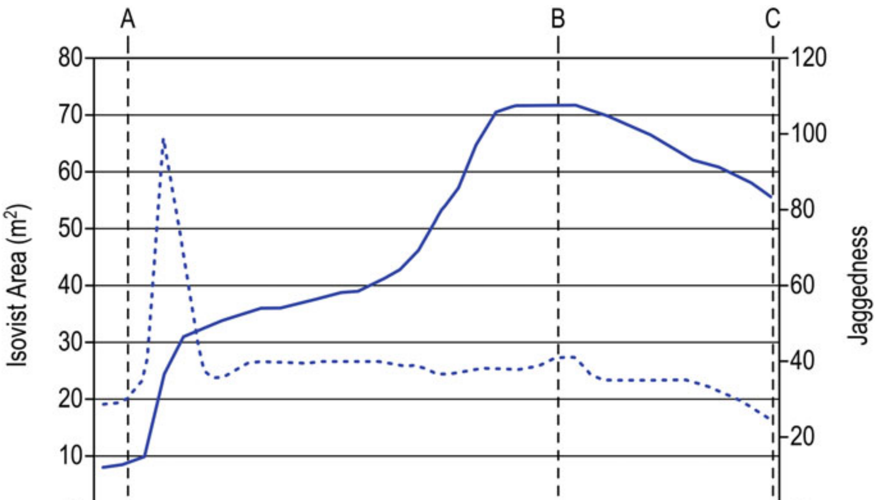


Fig. 10.82 *Affleck House*, area and jaggedness data

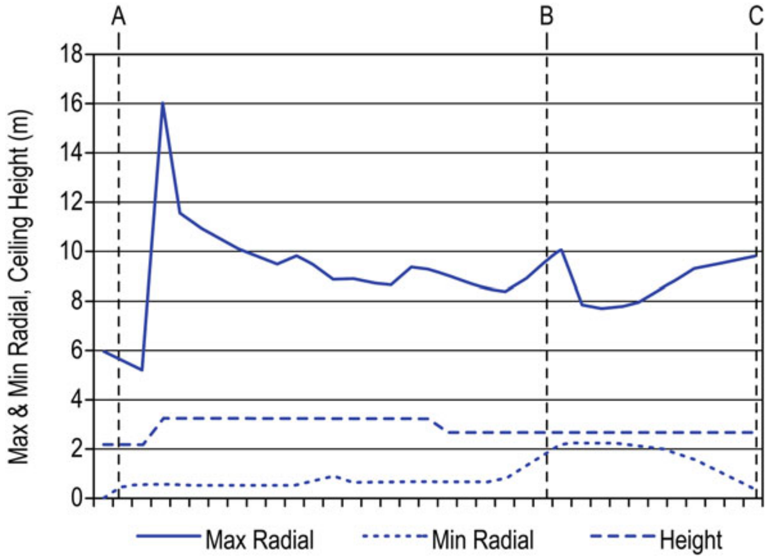


Fig. 10.83 *Affleck House*, minimum radial length, maximum radial length and height data

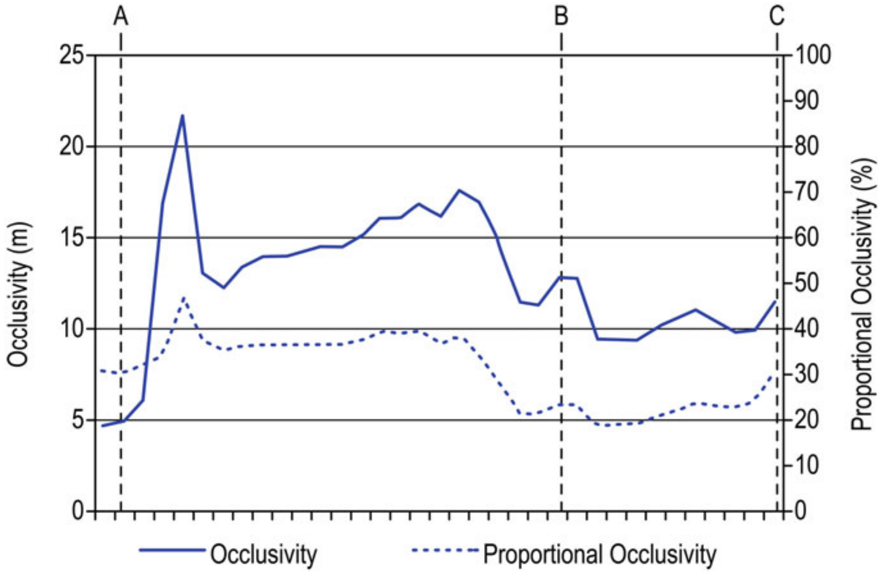


Fig. 10.84 *Affleck House*, occlusivity and proportional occlusivity data

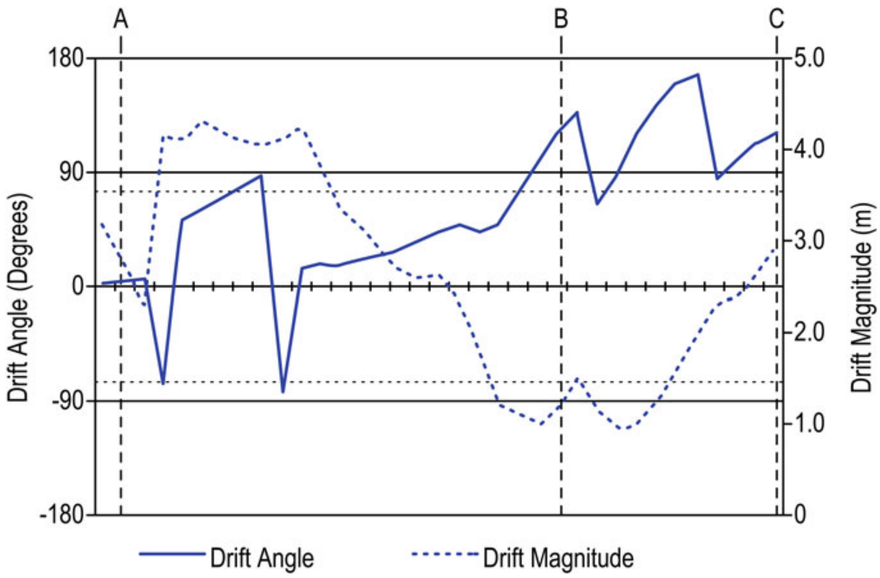


Fig. 10.85 *Affleck House*, drift angle and drift magnitude data

room, drawing the visitor toward this location [B]. The path to the centre of the living room follows a left-hand spiral, until the hearth is reached. Prospect peaks (A = 72.08 m^2) at the centre of the living room [B]. Approaching the hearth [C] requires resisting increasingly enticement (D_M = 0.95 m, D_A = 97° → 2.98 m, 170°). The hearth is prospect-oriented (A = 55.88 m^2, $RL_{(L)}$ = 9.84 m) with a high ceiling (H = 2.71 m), moderate mystery (O:P = 30.78%) and limited complexity (J = 25.04).

Along the complete path through the house the degree of mystery remains relatively stable, suggesting that while the size of the view changes with each step, the proportion of the view that is just beyond sight is similar (O:P ~ 31%). The path through the *Affleck House* is one of limited mystery and increasing prospect, with a visual pull that initially distracts from and then leads the visitor to the living room centre before discouraging further exploration.

A strong correlation exists between area and shortest view distance, indicating that the larger spaces are experienced from positions closer to their centre rather than from the periphery of the design (Table 10.16). Prospect reduplication can be

Table 10.16 *Affleck House*, reduplication of isovist data

Affleck House	Area	Height	Max radial	Min radial
Area	1	−0.112897328	0.021680571	0.719925909
Height		1	0.661692759	−0.26419111
Max radial			1	−0.144092709
Min radial				1

experienced through a moderate positive correlation between ceiling height and maximum view distances. Nevertheless, there is minimal correlation between visible area and either of these measures and the remaining ones display only weak positive and negative correlations indicating negligible reduplication or substitution of spatial features.

10.6.5 Palmer House, Ann Arbor, Michigan, USA (1950)

Alvin Rosenbaum argues that the house designed for Mary and William Palmer in Ann Arbor is the 'culmination of the mature Usonians …[and]… perhaps the highest expression of [Wright's] Usonian art' (1993: 185). Diane Maddex describes this house as 'one of Wright's most welcoming Usonian houses' (1998: 43). The *Palmer House* is famous for its triangular planning, allegedly developed from the geometry of the site (Eaton 2015). Detailed throughout with furniture, fittings and built-in cupboards that replicate its triangular *parti*, it features no 90° angles in plan, and thus movement into and through the house must typically conform to its equiangular constraints (Figs. 10.86 and 10.87).

The exterior approach path from the carport to the *Palmer House* is a largely linear, with only two short stairs and a single 60° direction change [1] to reach the front door. The entry [A] provides a strong sense of both refuge (A = 26.77 m^2) and mystery (O:P = 57.70%) along with a single long view to the dining area ($RL_{(L)}$ = 9.20 m) establishing limited enticement (D_M = 3.93 m, D_A = 75.04°). The path into the living room offers steadily increasing prospect ($A = 33.26 \rightarrow 56.94$ m^2, $H = 2.20 \rightarrow 2.86$ m) that stabilises once within the room [B] (Figs. 10.88, 10.89, 10.90 and 10.91). Mystery and complexity also decrease as the visitor approaches and then enters the living room (O:$P = 61.32 \rightarrow 41.36\%$, $J = 57.80 \rightarrow 46.80$) before stabilising as the entry passes out of sight (O:$P \approx 27\%$, $J \approx 29$). After entering the living room, enticement directs attention to a region located between the living and dining areas and moving toward the hearth requires resisting this increasingly strong sensation (D_M = 2.27 m, D_A = 25.86° $\rightarrow$ 4.36 m, 154.39°). View distances increase near the hearth ($RL_{(L)}$ = 9.14 m) [C] before

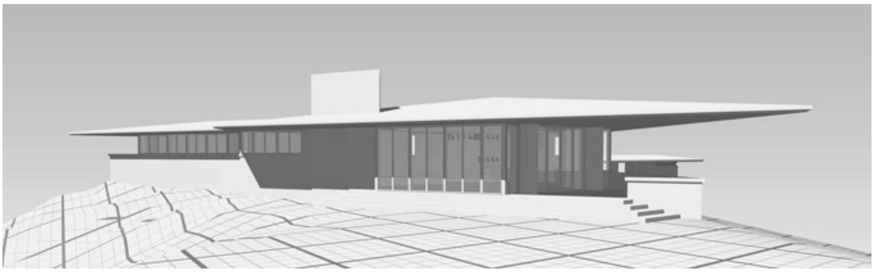


Fig. 10.86 *Palmer House*, external perspective

dropping slightly at the room centre ($RL_{(L)}$ = 9.01 m). The path to the living room threshold is one of discovery while the path within this space is much more passive. The centre of the living room in the *Palmer House* has high prospect properties (A = 49.88 m^2, H = 2.99 m) little mystery (O:P = 26.56%) and moderate enticement (D_M = 2.52 m, D_A = 69.26°).

Strong positive correlations between height and area, and height and shortest view distance, indicate significant reduplication of prospect and refuge features in three dimensions (Table 10.17). A moderate negative correlation indicates that long views are substitutes for visible area, and a moderate positive correlation between area and shortest view distance indicates a spatial pattern similar to that found in the *Jacobs* and *Millard* houses.

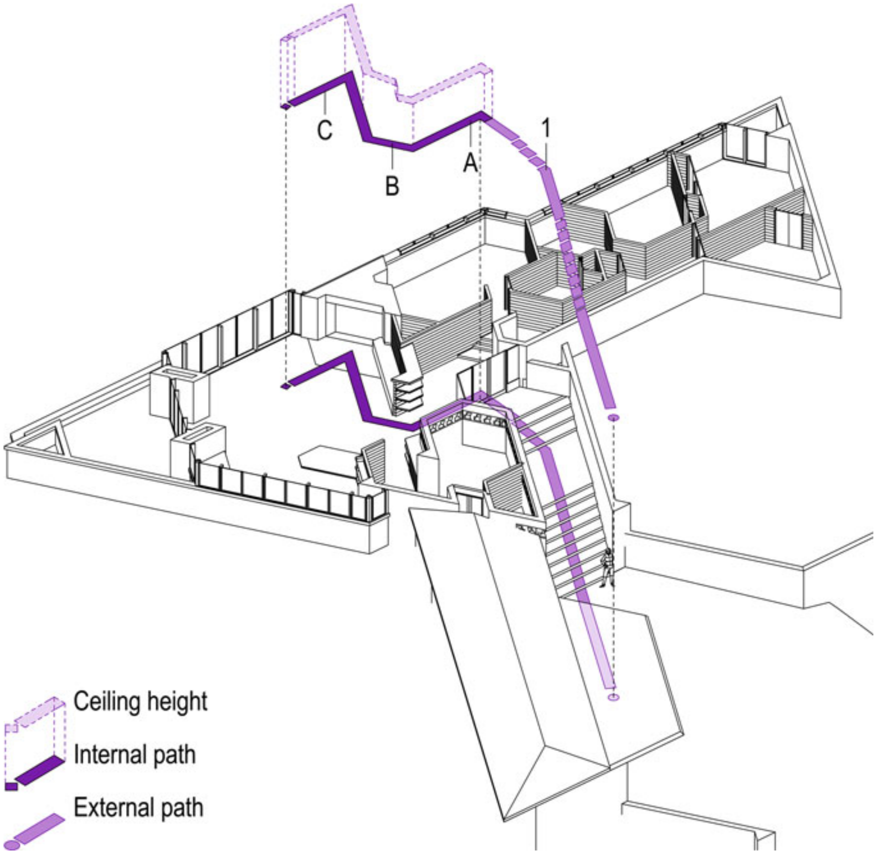


Fig. 10.87 *Palmer House*, axonometric showing movement path

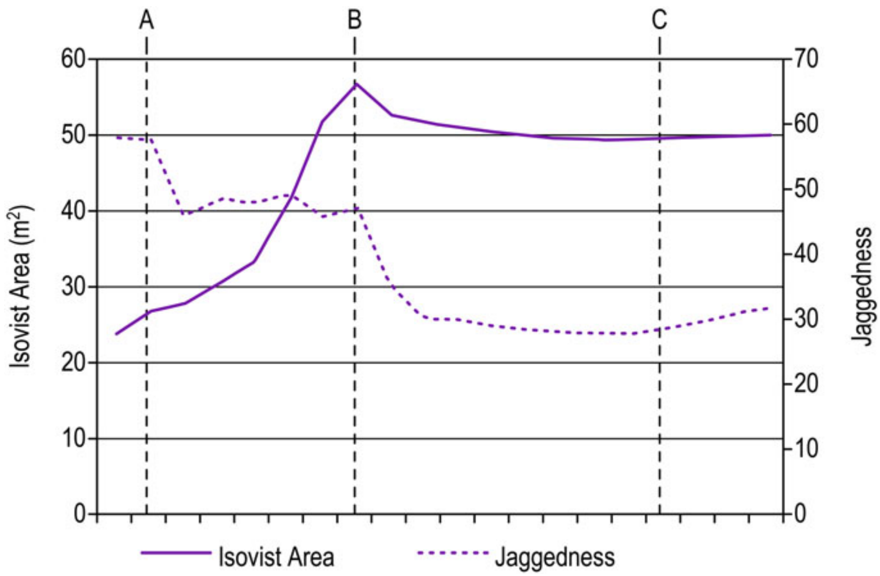


Fig. 10.88 *Palmer House*, area and jaggedness data

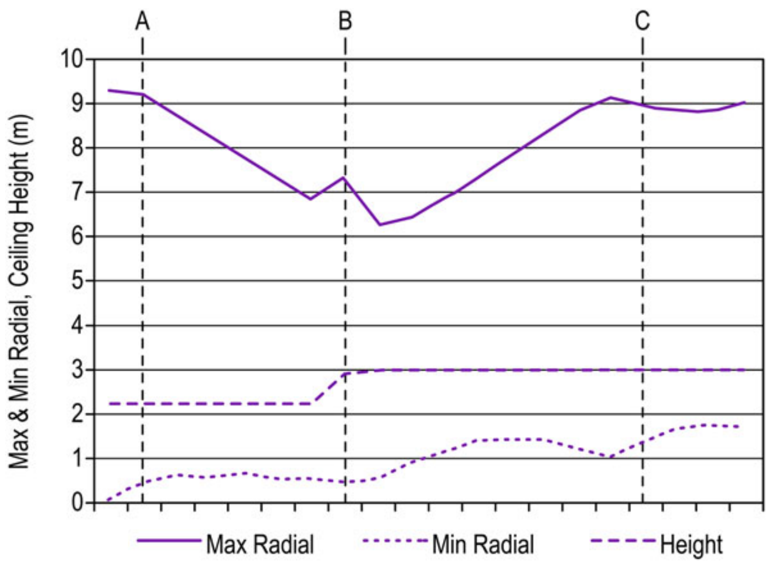


Fig. 10.89 *Palmer House*, minimum radial length, maximum radial length and height data

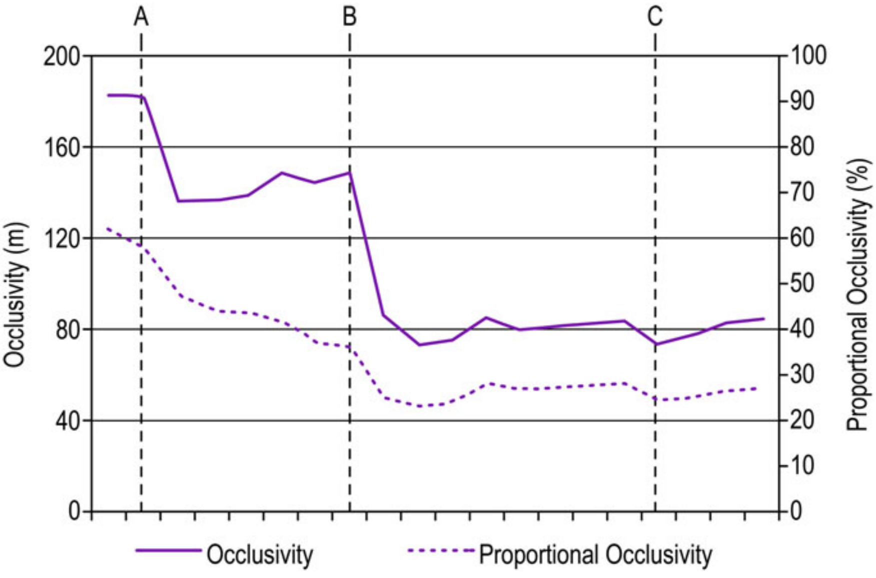


Fig. 10.90 *Palmer House*, occlusivity and proportional occlusivity data

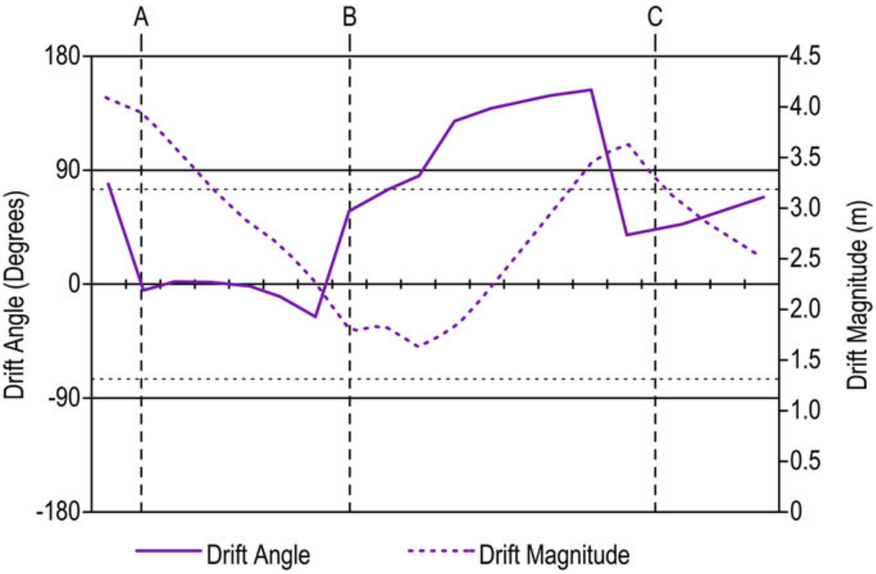


Fig. 10.91 *Palmer House*, drift angle and drift magnitude data

Table 10.17 *Palmer House*, reduplication of isovist data

Palmer House	Area	Height	Max radial	Min radial
Area	1	0.8134	−0.4330	0.5507
Height		1	−0.0805	0.7498
Max radial			1	0.2522
Min radial				1

10.7 Discussion

To support the assessment of the four hypotheses (Table 10.1), the data derived from each path is converted into a linear trendline which is calculated using the least-squares method (thereby minimising the impact of the sum of squared residuals) and then charted against a normalised scale for path-length. Thus, the horizontal axis of the trendline charts in this section depict the values for the entry space at the far left, and results for the living room at far right, regardless of the actual length of each path. A consistent key for all of these charts is also adopted (Fig. 10.92).

The linear trendlines approximate the tendency of a measure to rise or fall over the length of the path by showing a straight line that best represents the data measured at every step. While the linear trendlines represent the overall change of an isovist measure, the trendline of a measure with high variability will be a poor approximation of the spatial experience compared to a measure with less variation. Trendlines that correlate strongly with the data possess high R^2 values, typically exceeding 0.7. Highly variable data sets will generate trendlines that capture the overall change in spatial qualities but will have a weak correlation to the data, giving R^2 values below 0.3. For example a trendline does not articulate the sudden decrease in area associated with ascending a staircase but does document the impact of this small area on the data generated across the entire path. Thus, the rate of change (angle) of the trendline indicates how strongly the experience varies over the length of the path, and the R^2 value indicates how closely the trendline approximates the data.

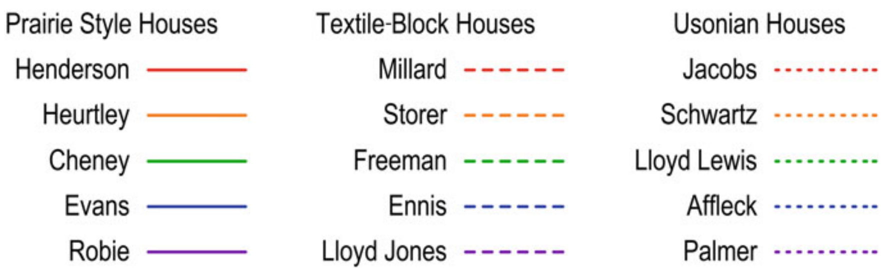


Fig. 10.92 Legend to the data trend charts

10.7.1 Hypothesis 1: Prospect and Refuge

The most important property of the Wright Space is that it allegedly features a shift, across the length of the path, from refuge-dominant to either prospect-dominant or prospect-refuge balanced spaces. The primary indicators that this property is present in a house are that trendline data for *A* and *H* will increase and the secondary indicator is that $RL_{(S)}$ will increase while $RL_{(L)}$ will increase or remain stable.

With one exception the trendline for area increases over the length of the path, conforming to the hypothesised result (Fig. 10.93). The sole exception is the *Schwartz House* which displays a near horizontal line, indicating no change in visible area, and the strength of this trend (R^2 = 0.0105) indicates that this line is a very poor representation of the actual spatial experience. The *Schwartz House* is also the only design without a designated 'living room', the path traverses a large, open recreation room before turning to terminate in the small lounge room. The only house with a weaker trend consistency is the *Robie House* (R^2 = 0.0014), which also possesses an almost level trendline. Of the eleven houses with trend lines showing substantial increases in area, eight possess strong trends, the strongest of which is the *Cheney House* (R^2 = 0.9442), and three possess moderate strength trends, the weakest being the *Evans House* (R^2 = 0.4907).

Trendlines for height increase in twelve of the fifteen cases (Fig. 10.94). The houses that do not conform to the hypothesised result include the *Evans* and *Jacobs* houses, which contain a single ceiling height throughout the areas traversed by the path, and therefore possess level trendlines, and the *Affleck House*, which displays a

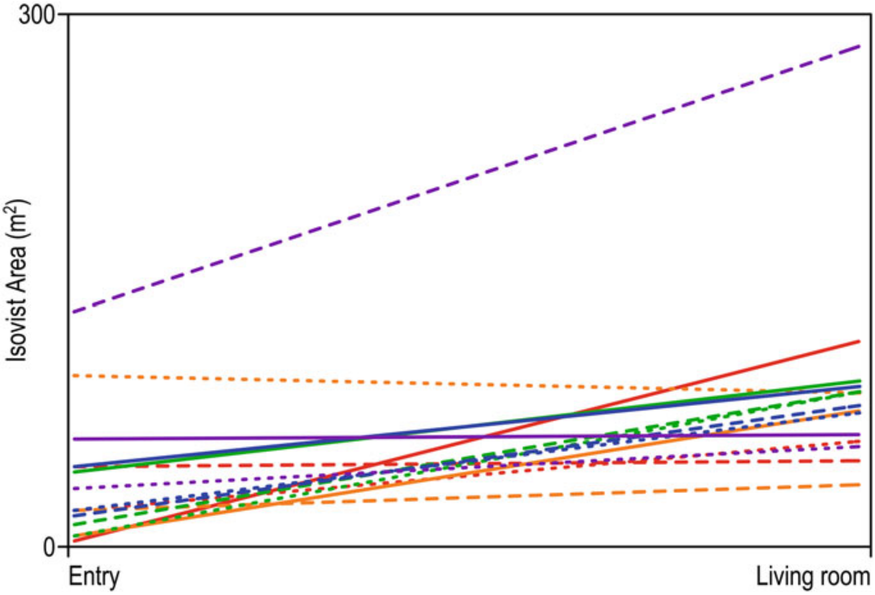


Fig. 10.93 Data trends of isovist areas (*A*)

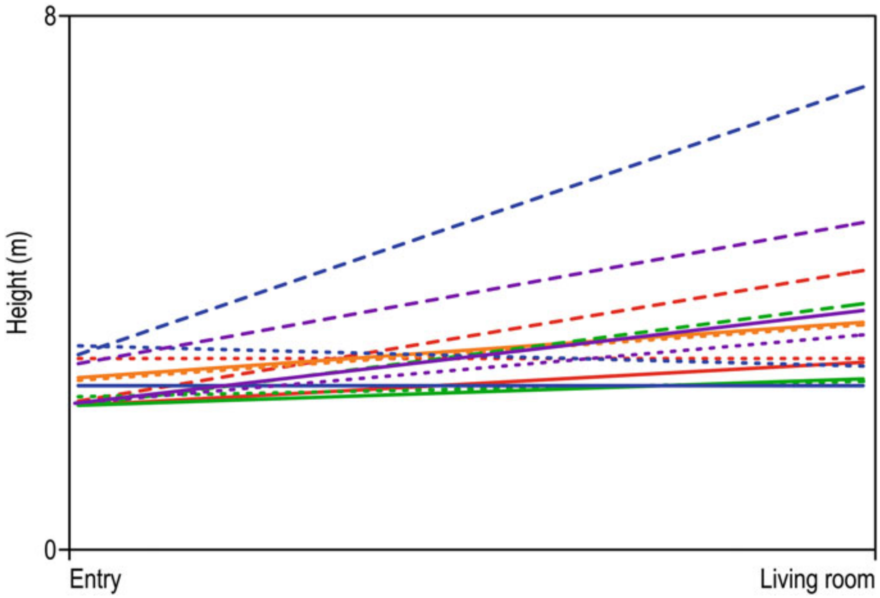


Fig. 10.94 Data trends of height (*H*)

weak (R^2 = 0.0655) and marginally decreasing trend. Data for the shortest radial line also conforms to the hypothesised result with every house showing an increasing trend over the length of the path and a range of strengths (R^2 = 0.1474–0.9056) (Fig. 10.95).

Only data for the longest radial line shows significant variation from the hypothesised result: eight houses possess decreasing trends of varying strength (R^2 = 0.0055–0.7005) (Fig. 10.96). This result highlights the challenge of using $RL_{(L)}$ as a measure of prospect. Due to the practical need to treat windows as opaque, $RL_{(L)}$ data is only a reflection of interior-prospect, which is still a critical part of the Wright Space, but not the only determinant of prospect properties. It is therefore likely that the longest views will occur in the circulation spaces approaching the living room. Once in the living room itself, the inability to see outside limits the length of the view to the dimensions of the room, with longer views available from the room periphery and glimpsed views down corridors. However, the formal features of Wright's architecture also contribute to this phenomenon.

Of the houses that show decreasing $RL_{(L)}$ trends, the *Robie*, *Schwartz*, *Millard* and *Storer* houses possess little in the way of an entrance vestibule, opening instead directly into a space which immediately allows for long views. Similarly the *Freeman* and *Jacobs* houses enter into long corridors that lead directly to the living room, while entering the *Affleck House* requires the visitor to pass a long corridor leading to the bedroom wing. The *Cheney House* entry incorporates a dog-leg into the entry sequence, but the effect is the same; a long narrow view terminating in the

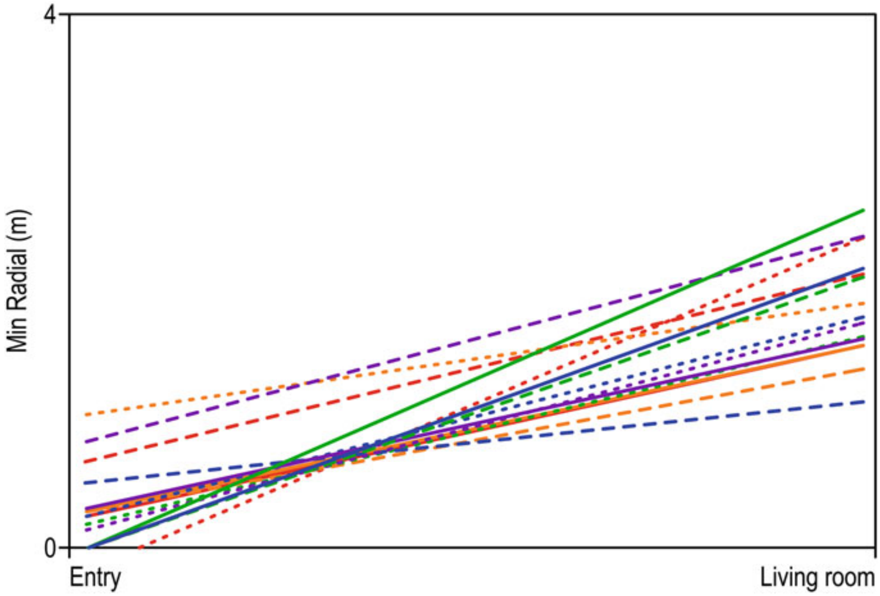


Fig. 10.95 Data trends of shortest view distances $RL_{(S)}$

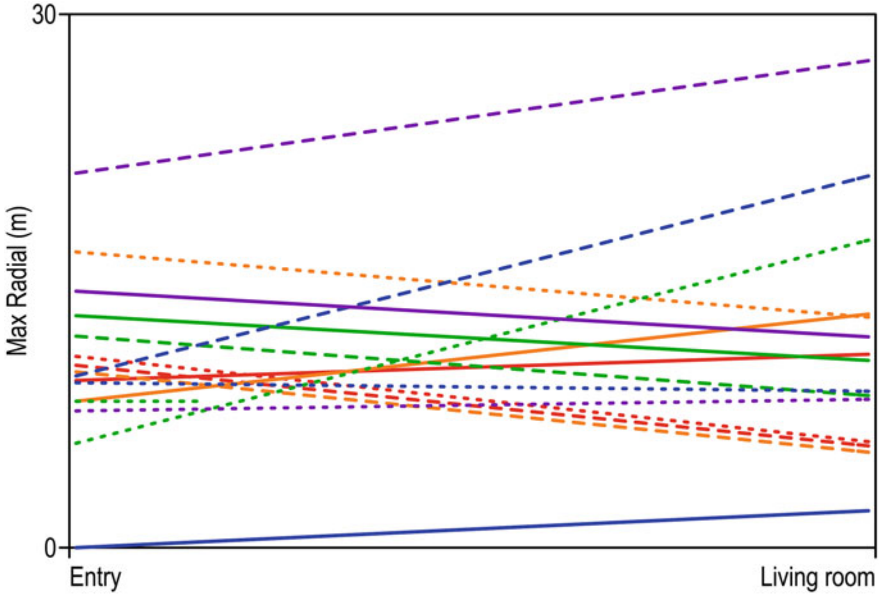


Fig. 10.96 Data trends of longest view distances $RL_{(L)}$

living room but not incorporating the room centre or hearth, from which views are shorter.

Of the total 60 indicators—derived from four measures of prospect and refuge in each of the fifteen of Wright's designs—48 (80%) conform to the results predicted in the first hypothesis of this chapter.

10.7.2 Hypothesis 2: Reduplication

Reduplication is the second most important characteristic of the Wright Space. Hildebrand (1991) argues that Wright enhanced the emotional power of his designs by creating forms that cause multiple prospect and refuge properties to change simultaneously and with common intent. House designs with a strong reduplication of prospect and refuge conditions will display strong positive correlations ($R^2 > 0.7$) between prospect and refuge indicators (A, H, $RL_{(L)}$ and $RL_{(S)}$).

Of all the designs analysed only three do not possess at least one strong positive correlation between two prospect-refuge measures (Table 10.18). The remaining twelve houses conform to the hypothesis and contain either strong or moderate positive correlations which constitute approximately 47% of the indicators.

Table 10.18 Overview of reduplication and substitution of spatial characteristics of Wright's architecture

House	Reduplication		Minimal correlation			Substitution	
	+ Strong	+ Moderate	+ Weak	0	− Weak	− Moderate	− Strong
Henderson	1	3	2				
Heurtley		3	1		2		
Cheney	2	2			1	1	
Evans		1		3		2	
Robie	1		2			3	
Millard	1	3				2	
Storer		2	2			2	
Freeman	2	1				2	1
Ennis	1	1	3		1		
Lloyd Jones	2	3	1				
Jacobs	1			3	1	1	
Schwartz		3				2	1
Lloyd Lewis	1	3	1		1		
Affleck	1	1	1		3		
Palmer	2	1	1		1	1	
Totals	15	27	14		10	16	2

In addition, approximately 20% of the data confirms a strongly negative or moderate negative correlation between prospect-refuge measures. This negative relationship exists where one prospect-refuge measure increases and the other decreases, effectively indicating a substitution of one form of prospect or refuge for another, such as when the architect compensates for a reduction in area by increasing ceiling height. The remaining 33% of the data indicates weak correlations where the prospect-refuge measures are relatively independent and neither enhance nor compensate for changes in the others. The *Evans House* and *Jacobs House* both contain flat ceilings of a single height which have zero correlation to the remaining measures.

Of the fifteen strong positive correlations, nine (60%) occur between area and another measure, and nine occur between height and another measure. Wright's preferred method (five strong correlations or 33%) of reduplicating prospect and refuge is through varying the height and the proximity to the nearest surface ($RL_{(S)}$), followed closely by varying height and area simultaneously (four strong correlations or 27%). Of the total ninety indicators—derived from six measures of reduplication/substitution in each of the fifteen of Wright's designs—fifty-six (62%) are positive correlations that conform to the results predicted in the second hypothesis of this chapter.

10.7.3 Hypothesis 3: Enticement

A third characteristic of Wright's architecture is an alleged capacity to entice visitors to move through space using formal and visual cues, and to come to a position of rest in the living room, near the hearth. This means that the trend line for D_M should decrease across the path, and that D_A should be in a forward direction, ideally within a range between ±75° of the direction of travel for the majority of the length of the path. The trend lines for the D_M data conform to this hypothesised condition in eleven of the fifteen cases, with the *Heurtley*, *Ennis*, *Lloyd Jones* and *Lloyd Lewis* houses being the anomalies and all displaying only weak trends (R^2 = 0.0152–0.2027) (Fig. 10.97). Of the conforming houses, three possess weak trends, three possess moderate trends, and four possess strong trends, ranging from R^2 = 0.0088 in the *Robie House* through to R^2 = 0.9303 in the *Jacobs House*. While the trend in the *Robie House* conforms to the hypothesised result, the strength of the trend is so low as to bear negligible resemblance to the actual spatial experience of the design and the decrease in D_M is minimal.

Drift angle data cannot be presented as a trend line; instead, the angle of each step along the path is recorded and the percentage of locations with a D_A value within ±75° of the direction of travel is calculated. Every house analysed contains at least one location where D_A is contrary to the direction of travel, and in the *Robie* (36.11% forward), *Storer* (44.74% forward) and *Lloyd Lewis* houses (46.81% forward), this lack of directional enticement (or apparent confusion) is the norm (Table 10.19). Half of the twelve houses that conform to the results predicted in the third hypothesis contain between 50 and 70% of locations with forward orientations, the remaining half feature a majority of locations (>70%) with a forward orientation.

On average, 73% of locations on the Prairie Style house paths possess a forward orientation, giving this style the most clearly directed path. The Prairie Style houses also show the greatest range of results, with individual houses having between 36 and 91% of locations with a forward orientation. The Textile-block houses are the next most clearly directed group, averaging 65% of locations with a forward orientation and they also display the smallest variation in the number of forward facing points (44–77%). As a set, the Usonian houses feature an average of 60% of locations with a forward orientation and a slightly greater range of variability (46–81%) than the Textile-block houses. This variation is due to the high percentage present in the *Jacobs House*, the prototype for the Usonian series. If this prototype were excluded the Usonian houses would offer the most consistent enticement qualities (46–65%).

Enticement arises from a combination of both drift angles and drift magnitudes. While these measures may be considered independently, they may be more informative when considered together. For example, those locations with high drift angles in the *Ennis House*—locations which may encourage departure from the path—are accompanied by weak drift magnitude, indicating that these distracting views possess only weak enticement, while the high drift magnitudes occur at locations with low drift angles indicating strong enticement to continue in the direction of travel. The opposite situation occurs in the *Lloyd Jones House* where the highest drift

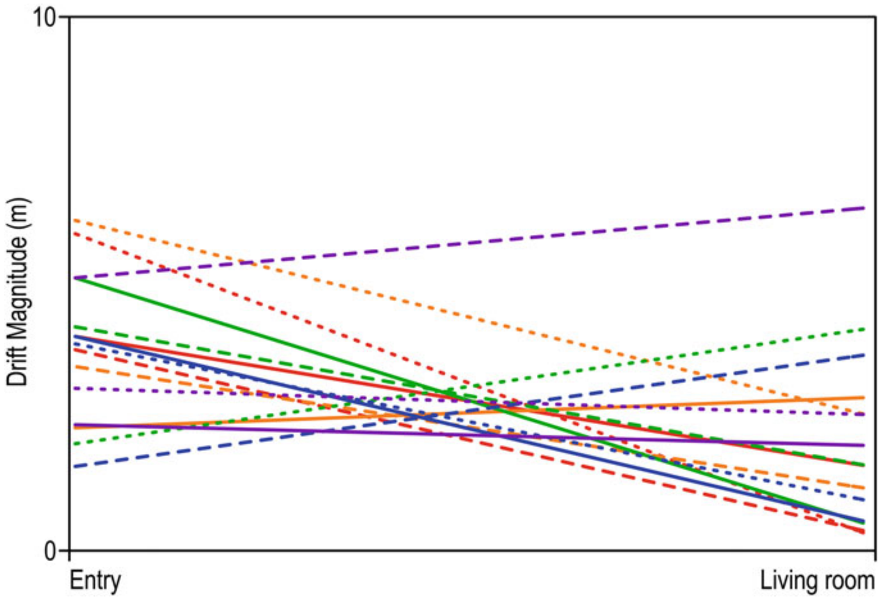


Fig. 10.97 Data trends of isovist drift magnitude (D_M)

Table 10.19 Percentage of the individual locations along each path with forward drift angles

House	% points of D_A within ±75°	% points of D_A within ±90°
Henderson	91.43%	94.29%
Heurtley	56.52%	71.74%
Cheney	89.47%	94.74%
Evans	90.00%	95.00%
Robie	36.11%	44.44%
Millard	66.67%	80.95%
Storer	44.74%	60.53%
Freeman	77.78%	88.89%
Ennis	75.00%	77.50%
Lloyd Jones	60.61%	60.61%
Jacobs	81.82%	86.36%
Schwartz	53.49%	60.47%
Lloyd Lewis	46.81%	61.70%
Affleck	54.29%	68.57%
Palmer	65.00%	75.00%

Percentage of locations ±90° are shown for comparison only

magnitude coincides with a drift angle of almost directly behind the visitor, indicating an instant where enticement strongly discourages continuing along the path. Of the total 30 indicators—derived from one measure for drift magnitude and one for drift angle in each of the fifteen of Wright's designs—documenting enticement, 23 (77%) support the third hypothesis.

10.7.4 Hypothesis 4: Complexity and Mystery

The final property that is expected in the Wright Space is that levels of mystery and complexity will decrease along the path from the entry to the living space and hearth. Thus, trendlines developed for *O*, *O*:*P* and *J* data should decrease in value from left to right, for this hypothesis to be true.

Partially supporting this expectation, occlusivity values decrease in only nine (or 60.00%) of the fifteen cases and offer a range of trend strengths (R^2 = 0.1650–0.6605) including five weak trends and four moderate trends (Fig. 10.98). Of the houses with trends that counter the hypothesis, only the *Jacobs House* possesses weak trend strength (R^2 = 0.0658) while the *Henderson*, *Heurtley*, *Ennis*, *Lloyd Jones* and *Lloyd Lewis* houses possess moderate trends (R^2 = 0.3244–0.6605).

Proportional Occlusivity (*O*:*P*) data provides results that better conform to the hypothesis, with mystery decreasing in twelve cases; the exceptions are the *Heurtley*, *Ennis* and *Lloyd Jones* houses, which all possess weak trends (R^2 = 0.1003–0.2432) (Fig. 10.99). Houses conforming to the hypothesised result

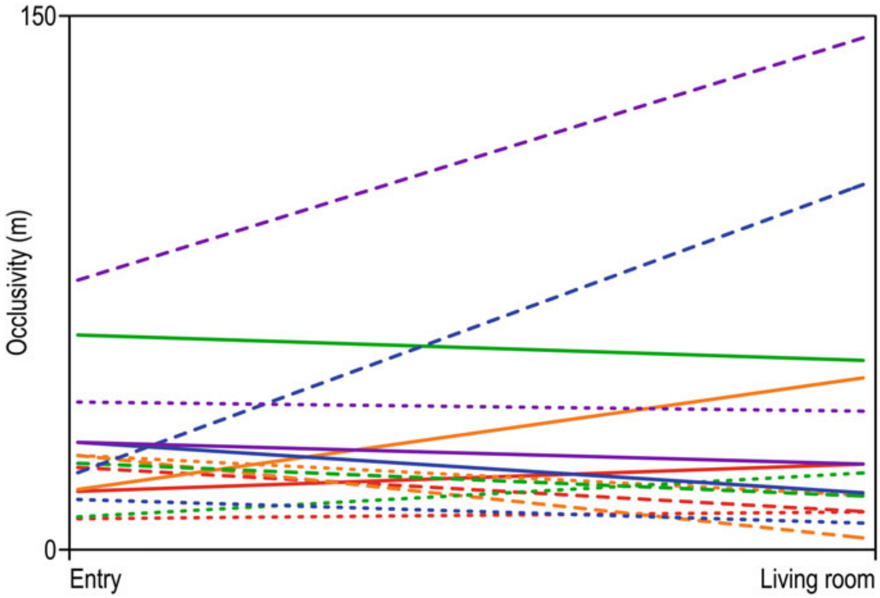


Fig. 10.98 Data trends of isovist occlusivity

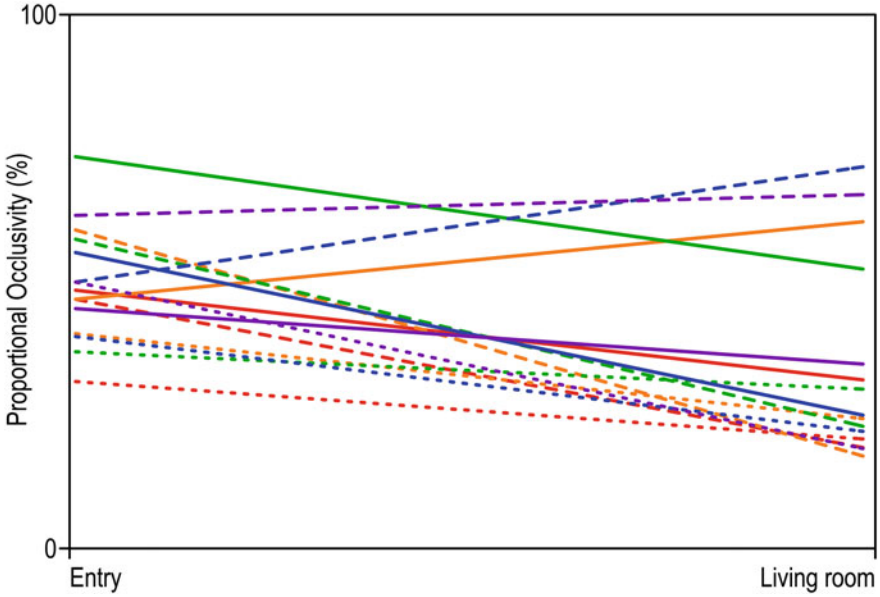


Fig. 10.99 Data trends of isovist proportional occlusivity

include predominantly moderate (5) and strong (6) trends ranging from $R^2 = 0.0369$ in the *Robie House* through $R^2 = 0.8783$ in the *Freeman House*.

In eleven cases the Jaggedness indicators conform to the hypothesis with exceptions again being the *Heurtley*, *Ennis*, *Lloyd Jones* and *Lloyd Lewis* houses, all of which display weak trend strengths ($R^2 = 0.0246$–0.3081) (Fig. 10.100). Houses with results conforming to the hypothesis also display generally weak trend strength with moderate trends in the *Millard*, *Storer* and *Freeman* houses and only the *Palmer* exhibiting a strong trend ($R^2 = 0.0240$–0.7607).

Of the total forty-five indicators—derived from three measures of mystery and complexity in each of the fifteen of Wright's designs—twelve (71%) conform to the results predicted in the fourth hypothesis. The Usonian houses demonstrate the greatest consistency in data trends associated with mystery, with twelve of the fifteen (80%) conforming to the hypothesis. Of the three non-conforming Usonians, the increase in complexity (*Lloyd Lewis*) and mystery (*Jacobs*) are virtually imperceptible and the trend strength is weak ($R^2 < 0.0659$). In the Prairie houses, eleven of the fifteen (73%) indicators conformed to the hypothesised result and nine (60%) from the Textile-block houses conformed. The lower result is due primarily to the *Ennis* and *Lloyd Jones* houses which appear to possess a different formal and spatial pattern for mystery and complexity to the remainder of the houses. Proportional occlusivity (O:P) appears to be a much better indicator of mystery than absolute Occlusivity (O) in Wright's architecture with twelve as opposed to nine

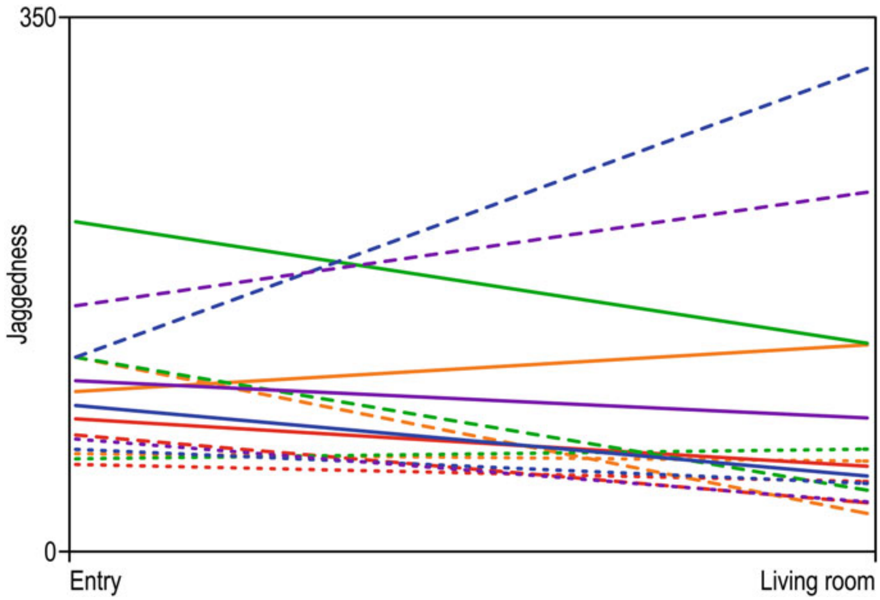


Fig. 10.100 Data trends of isovist jaggedness

data sets conforming to the hypothesised results. Given the variable sizes of the fifteen houses, proportional occlusivity is also, logically, the best basis for comparison.

10.8 Conclusion

The core of Hildebrand's (1991) argument is that in the early Prairie Style houses, Wright developed a unique design pattern to control the way vision is shaped by space and form and then utilised this pattern as a basis for the designs he would produce throughout the remainder of his career. This chapter's analysis of fifteen houses from three distinct phases of Wright's career uses quantitative data to assess this claim.

The first hypothesis proposes that a shift occurs from refuge-dominant to prospect-dominant conditions while moving along a path from the entry to the living room. This result is found in 80% of the data (and would be 88% of the data if the somewhat problematic $RL_{(L)}$ measure is excluded). The data supporting the second hypothesis, that Wright varied prospect-refuge characteristic simultaneously and cooperatively, to enhance the sensation of prospect or refuge is less convincing. While 62% of the data supports the hypothesis, only 47% of the data indicates a strong or moderate example of reduplication, and 33% of the data shows weak or non-existent relationship. A key finding here is that 20% of the data indicates that Wright substituted one prospect-refuge characteristic for another, a design trait that remains largely undiscussed in the arguments of historians and critics. However, this method for assessing reduplication is relatively unsophisticated and a superior option may be discovered through further research and the use of three-dimensional isovists or saliency maps (Bhatia et al. 2013). The third hypothesis states that Wright's architecture will entice a visitor in a forward direction, along the specified path, toward the living room and that this pull will decrease closer to the living room, a result which occurs in 77% of the data. Finally, the fourth hypothesis states that mystery and complexity will decrease toward the end of the path in the living room, a result which occurs in 71% of the data.

Of all of the houses analysed, only the *Palmer House* data conformed to all hypothesised results. However, this house is not an ideal or particularly strong representation of every characteristic in the pattern. The *Henderson*, *Cheney*, *Evans*, and *Freeman* houses are the next best exemplars of the Wright Space. The *Heurtley House*, which Hildebrand identifies as the first design to contain all thirteen prospect and refuge features does not conform to the hypothesised results for mystery, complexity or strength of enticement. Only two houses (the *Henderson* and *Lloyd Jones* houses) possess the reduplication of all prospect and refuge measures and therefore represent the intense prospect and refuge conditions Hildebrand describes.

In total 159 (71%) of 225 indicators broadly support the four hypotheses. This result does indicate the presence of a common pattern through Wright's designs, and that this pattern broadly conforms to the anticipated psychological cues required to evoke the much-debated feelings of emotional wellbeing. But before concluding that the existence of the Wright Space is overwhelmingly proven by this research, there are two final factors to consider when interpreting this result.

First, thirteen of the fifteen houses selected for the present analysis were ones that Hildebrand chose as exemplars of the Wright Space. It might then be argued that 86.66% of the results, not the 70.66% determined here, should have been the practical target for determining, conclusively, the veracity of Hildebrand's argument. As mentioned previously in this chapter, the set of houses analysed were ones which *should* reveal a pattern if it exists at all. The fact that this pattern was found, but was not as strong as might be anticipated, must be taken into account when considering these results.

Finally, while there is a pattern in the data, and it does conform to the anticipated spatio-visual properties, this is not evidence that the pattern is unique to Wright. Without a parallel study to compare isovist data derived from paths through other houses of each era, it is impossible to determine if this result is particular to Wright, or whether it is something that might be uncovered in an analysis of the path through any large house, from its vestibule to its hearth. These factors are discussed in past research using this method (Ostwald and Dawes 2013b; Dawes and Ostwald 2014a, b; Amini Behbahani et al. 2016, 2017), but remain beyond the scope of the present analysis.

Chapter 11
Conclusion

The idea of examining the spatial characteristics of Modernism for the purposes of investigating selected social, cognitive and experiential properties of architecture is not a new one. As Chap. 1 shows, multiple attempts have been made to draw attention away from debates about form, style and aesthetics in Modernism, and towards a discussion of space and the various human relations and conditions it supports. For example, in 1941, Giedion's *Space, time and architecture* sought to reconceptualise architecture in terms of human existence and interaction, social structure and progress. Writing from a marked Modernist perspective, Giedion set out to find order in a world that was struggling in the aftermath of two world wars and with technology driving rapid and often divisive changes in society. While he was undeniably one of Curtis's 'mythologisers' of Modernism, Giedion was also critical of Modern architects for being seduced by materials, technology and science at the expense of poetry, art and the human condition. Giedion's revised 1961 edition of *Space, time and architecture* even argues that '[t]he moment we fence architecture within a notion of "style" we open the door to a formalistic approach' (1961: xxxiii). The inevitable impact of this approach is 'fatigue', which comes from being overly focussed on peripheral issues, and 'boredom', which drives architects to move swiftly from one idea to the next, constantly abandoning the past. What is interesting in this argument—which partially prefigures Berman's (1988) thesis in *All that is solid melts into air*—is that Giedion's first edition in 1941 was already dismissive of form and style, yet he felt the need for an even more assertive rejection two decades later.

A parallel to Giedion's reworked argument is found in the updated edition of Colin Rowe's 'The Mathematics of the Ideal Villa'. Although written in 1947, the 1973 edition contains an abrupt addendum, where Rowe notes that his style of mathematical analysis could also be productively applied to other works. He then takes the opportunity to warn against the temptation of engaging too deeply in stylistic categorisation and the search for hidden proportions. He describes this approach as a 'Wölfflinian style of critical exercise' (Rowe 1947: 16), after Swiss art historian Heinrich Wölfflin, whose application of formal analysis often

M. J. Ostwald and M. J. Dawes, *The Mathematics of the Modernist Villa*,
Mathematics and the Built Environment 3,
https://doi.org/10.1007/978-3-319-71647-3_11

disregarded spatial and human factors. Rowe admits that the focus on ‘what is visible’ (1947: 16), that is, architectural form, has its appeal, but his acknowledgement is perfunctory. Rowe’s addendum reads as an *arriere-garde* action, a belated and possibly Pyrrhic defence mounted against those who had previously misread his intentions or dismissed his observations. The former interpretation also makes sense if you know that in the years after its publication, Rowe’s essay was often praised for uncovering unexpected formal parallels between the work of Palladio and Le Corbusier. Yet for Rowe, this was merely a ‘straw man’, a means of demonstrating the greater significance of space, time and movement (Ostwald 2001).

Unlike Giedion’s grand tome, the present book has no singular conclusion, no clarion call or triumphant revelation. Its purpose is not to question the importance of formal analysis, to challenge stylistic categorisation or attack those searching for hidden proportional systems. Instead, this book combines a set of computational tools and a mathematical mind-set to investigate issues that are normally the sole domain of historians and critics. This difference in intent also explains the character of this final chapter.

Rather than offering an alternative history of Modernism, this book presents a selective critical analysis of a set of related themes in a larger architectural movement. Its content is undeniably episodic in nature, with each section testing a particular group of ideas in an architect’s works. The major analytical sections (Chaps. 5–7, 9 and 10) actually examine fourteen different arguments about Modernism, each of which are framed as a hypothesis for testing using a computational or mathematical method. This final chapter briefly summarises the various outcomes of the book in qualitative terms.

11.1 Social, Cognitive and Experiential Properties of Modernism

11.1.1 Free Plan

One of the great technical advances of the Modern movement in architecture was the free plan. The free plan, the second of Le Corbusier’s ‘five points’ in his 1931 *Vers une architecture*, was initially celebrated for its capacity to liberate architecture from the constraints imposed by load-bearing walls. But, over time, its significance became tied to its capacity to create new social structures and support different ways of experiencing and understanding architecture. While Le Corbusier’s *Villa Savoye* is often regarded as one of the first examples of a free plan, its most dramatic and acclaimed expression is found in Mies van der Rohe’s *Farnsworth House*. However, there is on-going debate amongst historians about the evolution of Mies’s variation of the free plan and its actual, rather than intended, social, cognitive and experiential properties.

In terms of the evolution of the free plan, a point of contention is whether it arose spontaneously in the design of the *Farnsworth House* or evolved gradually throughout Mies's earlier works. As Chap. 5 reveals, if we examine Mies's domestic designs from 1927 to 1951, a gradual shift in social structure, as reflected in spatial topology, is apparent. In general, the earlier plans possess a more hierarchical social structure (being reliant on deep, branching networks of spaces), whereas the later plans have more open, social structures (with shallow, looped networks of spaces). While the *Farnsworth House* does possess the most 'open' or 'free' variation of the plan in Mies's domestic architecture of this period, the same socio-spatial strategy is also readily apparent in the *Lemke House*, and traces of it can be found in his earlier designs. Thus, the free plan did not materialise in a pristine, neo-Platonic state in the *Farnsworth House*; its lineage can be traced mathematically through Mies's works of the previous two decades. But regardless of its origins, is the social structure of the *Farnsworth House* really as significant as the theories suggest?

When considering the social structure of Mies's domestic architecture relative to the number of inhabitants these designs serve, the *Farnsworth House* is actually very similar to his previous works. Furthermore, if we examine the proportion of spaces in each house set aside for semi-public, semi-private, private and service functions, the *Farnsworth House* is again broadly similar to the others. Collectively, these results suggest that the most significant aspect of the *Farnsworth House* may be its program, not its form. The social structure of the design and its associated free plan are a direct consequence of its function as a 'weekend retreat' for the client. In contrast, Mies's previous designs were for larger families, some with servants and several with guest accommodation and entertaining areas. It is the limited program of the *Farnsworth House* that allowed Mies to produce such a minimal plan, and then the secluded site allowed him to expose this plan through the use of a masterful, transparent structure.

The question of whether or not the topology of the free plan supports social emancipation, as Mies and Le Corbusier separately suggest, has remained largely untested prior to this book. Through its flexibility and adaptability the free plan supposedly removes distinctions between spaces that serve primarily for inhabitation and those that are for circulation, creating a new sense of opportunity and independence. Testing this idea is not as simple as estimating the floor area set aside for 'corridors' in a house, and comparing how it changes, either as an absolute value or as a proportion. Even open-planned spaces require circulation, regardless of whether or not they are labelled as such on a plan. Conversely, several areas set aside for circulation in large houses (such as the porch or lobby) also serve important social functions. Through a topological analysis of Mies's architecture, his argument about the changing use of space as a consequence of the free plan is supported. However, the logical inevitability of Mies's argument about the free plan is also revealed, and ultimately the fact that in an open plan all habitable spaces also double as circulation spaces is not especially ground-breaking. A lack of walls may provide a greater sense of flexibility, but the space must be filled with the necessary trappings of life (like furniture) for it to function, at least partially reinstating the missing social structure and limiting choice.

A further curiosity of the free plan is that its lack of defined and enclosed spaces often leaves people feeling like observers or visitors in a building, rather than users or inhabitants. Indeed, the act of experiencing Mies's open plan from various static viewing positions has been likened to the experience of being in an art gallery or approaching a monument . Rather than needing movement to experience a building, Mies's open plan emphasises the potential of certain locations for surveillance or control. In this context, it is interesting that the *Farnsworth House*—being one of the designs that allegedly feature this rational, experiential property—actually has relatively few ideal viewing locations. This may partially explain the cognitive significance of these locations in the plan, although the emotional hiatus or inertia that these spaces evoke may also be traced to the impact of Mies's minimal, unadorned walls, which often feature striking art works or frame dramatic views of the landscape. Mies's plans may have some of the spatial properties of art galleries, but the fact that they sometimes also function in a similar way cannot be completely dismissed as an explanation for the particular experience they evoke.

11.1.2 Spatial Choreography

In architectural theory, the concept of spatial choreography refers to the attempt to control or influence human responses or behaviours through the manipulation of space and form. Many examples of this approach can be found in the Modern movement. For example, Le Corbusier described the imagined experience of the *promenade architecturale* in the *Maison La Roche-Jeanneret* and the *Villa Savoye*, and Alvar Aalto, Rudolf Schindler and Oscar Niemeyer have all offered accounts of the perceptual responses people will experience in their buildings (Pallasmaa 1996; Roberts 2003; Jones 2015). Such accounts differ from those of critics and historians, because architects' descriptions seek to explain the correct or ideal experience of their designs. However, despite the existence of these accounts, there are few detailed examples that explain precisely how space and form are meant to shape human behaviour and cognition. The primary exception is found in the work of Richard Neutra, which is covered in Chap. 6.

Neutra's books—including *Mystery and realities of the site* (1951), *Life and human habitat* (1956) and *World and dwelling* (1962)—provide a rich and detailed explanation of his approach to spatial choreography as part of his larger theory of Biorealism. They outline a complex design theory, wherein space and form are used to manipulate sensory and kinaesthetic response. The ultimate purpose of this approach is to shape each person's intellectual and spiritual reaction to the world. While Neutra's theory has many dimensions, three axioms can be distilled from it to explain the relationship between vision and movement, cognition and experience, and experience and nature.

Neutra's first axiom, often paraphrased as 'vision leads to movement', suggests that architectural plans should be structured around long, uninterrupted vistas through space, which encourage a person to first survey, then move through and explore a plan. Across the houses analysed in this book, long sight-lines dominate Neutra's plans. These interior vistas control the social networks in Neutra's architecture, defining spaces that are important for personal interaction, navigation and safety. These vistas typically bisect the core of each plan, passing through the edges of the major spaces. Moreover, the longest vistas are often criss-crossed by important secondary sight lines, meaning that a person moving through the primary interior axis has peripheral experience of the majority of each house. The power of Neutra's vistas resides in their capacity, *par excellence*, to impart information and understanding while controlling access.

Neutra's second axiom, which follows from the first, claims that 'experience leads to understanding'. In a practical sense, this claim is about the cognitive efficiency of a plan. As a result of his strategy of creating dominant vistas in each plan, Neutra's designs do typically feature heightened levels of cognitive clarity. However, there are instances where his plans are less efficient or effective in these terms. For example, the twin pavilion plan of the *Moore House* has a strong relationship with nature and is, partially as a result of this, a less efficient plan. The *Tremaine House* has a plan that is superficially similar to the *Kaufmann Desert House*, but it is actually more cellular, being reliant on walls that interrupt the edges of vistas so that they can frame particular views of nature. In the *Tremaine House,* the cognitive efficiency of the plan is reduced, while its connection to nature is enhanced. Thus, in some cases, Neutra appears to have prioritised the importance of his third axiom, 'creating a strong connection to nature', over his second.

Neutra's third axiom declares that vision and movement must not be restrained to the interior, but encompass the experience of the immediate site and its larger context. The evidence that Neutra took this position seriously is apparent in many of his designs, where spaces are rarely more than two topological steps from the exterior, and in most cases only a single change in direction is required from anywhere in a house to access the exterior. But more significantly, Neutra often designed major circulation routes through these houses that required a person to move outside to access rooms.

While the analysis undertaken in this book cannot confirm the actual impact of Neutra's spatial choreography on people, there is clear evidence that he used the strategies described in his books to shape his architecture. This is a rare example in which an architect's design approach, theories and buildings—or *process*, *position* and *product* as they are described in Chap. 1—are closely aligned.

11.1.3 Social Function

A central article of faith in the ideology of Modernism is that in architecture 'form follows function'. However, in the last four decades historians and critics have repeatedly used this standard in a subversive way, to reveal the pedantry and caprice of much Modern architecture. For example, the façade of Mies's *Seagram Building* has been pilloried for its bronze and steel detailing and expression, which actually masks a concrete structure. The many subtle decorative features in his *Barcelona Pavilion* have been similarly exposed. The detailing of Le Corbusier's *Villa Savoye* has been ridiculed for being crafts-based and bespoke rather then machine-made and mass-produced. For these reasons, in recent years public utterances of 'form follows function' are often elegiac in tone. Nevertheless, while its reputation may have become somewhat tarnished in architectural theory, this concept remains a touchstone for many designers.

In this book, a special type of function, concerned with the social structure of the plan is examined. The functional agenda of many buildings is actually implicit in the number of rooms they are required to contain, along with the size, distribution and relationships between these spaces. Thus, the concept of 'form follows function' also ties aesthetic expression to social structure. Indeed, buildings where refined formal expressions have arisen from an underlying social program are often praised, intellectually or morally, as being transparent or truthful. It is also often assumed that because the form of a building is restrained and elegant, then its social function must be similarly refined. A case in point is found in the work of Glenn Murcutt, which is examined in Chap. 7.

Descriptions of Murcutt's architecture tend to emphasise its aesthetic consistency, geometric purity and tectonic refinement. In contrast, Murcutt himself is often dismissive of observations about the formal consistency of his work, claiming instead that each design represents a considered, pragmatic and poetic response to its setting. The lacuna at the centre of this debate about the primacy of either form (as outcome) or context (as generator) is the social structure of Murcutt's architecture. On the rare occasion that his planning is mentioned, it is also described as polished and refined. The assumption is that, if the building's form is a model of sophistication and homogeneity, then the social structure must be both consistent and considered.

For the first issue—that of the consistency of the social structure embedded in Murcutt's planning—his early designs generally feature shallow plans, whereas the later plans are deeper and more complex. Nevertheless, in general Murcutt's planning conforms to a loose or weak social pattern wherein hallways are the most integrated spaces, followed by a cluster comprising the living room, dining room and kitchen, then finally bedrooms, bathrooms and service areas are the most socially isolated. While acknowledging that such a pattern exists, it is an unsatisfying observation, because it simply conforms to the most basic social structure found in many late twentieth century houses. Paradoxically, the one space that does not conform to this loose pattern is the exterior. In Murcutt's early architecture, the exterior is visible from almost every room, but access to it is tightly controlled. In his later designs, access to the exterior is not only more common, but in several designs movement outside is necessary to access parts of the house. Historians and critics do not generally note the changing accessibility of the exterior, but it is potentially the only aspect of Murcutt's social structure that demonstrates a deliberate or considered strategy. Otherwise, the plans of the majority of Murcutt's rural designs exhibit limited determination or deliberation in the social structures they feature.

If Murcutt's design process is actually embodied in his product, that is, if his designs are a true reflection of his process and position, then they represent a consistent formal response to context and environment. In contrast, the social structures embodied in his planning are most likely the least important characteristics of his architecture, something that Murcutt has never directly denied, but which has been largely overlooked by scholars.

11.1.4 Existence, Experience and Emotion

While the experience of Modern architecture is alluded to in Mies's theories of the free plan and Neutra's spatial choreography, in both cases it is primarily seen as either evoking an intellectual understanding of space or fulfilling the needs of a rational mind. Modernist manifestos may talk about the poetry of space, the spirit of the age or even, in a Heideggerian sense, what it means to 'be', 'live' or 'dwell' somewhere, but such experiences are rational or ontological. Peter Blundell Jones captures this type of spatial cognition when he notes that it is 'vital to our well-being that we know where we are and where we are going, in both an immediate, literal sense and in a longer-term, metaphorical sense' (Jones 2015: 4). While Jones is talking more broadly about the relationship between the body, space and movement, his explanation resonates with many Modernist views on architecture's purpose in shaping human experience.

Modern architecture is typically regarded as communicating first and foremost to the mind, as its aesthetic expression 'deals with movement, occupation, and daily activities' (Morgenthaler 2015: 3). Modernist manifestos assumed that society would be relieved of all primitive and base needs. No longer having concerns about safety, privacy and survival, humanity would only require intellectual stimulation. Even accounts of beauty in Modernism tend to be associated with the way light and shade can transform a simple Phileban form into a timeless temple to rationalism. Adolf Loos condemned decoration for many reasons, one of which was its vulgar appeal to primitive societies. A civilised society does not need decoration; white walls and pure geometry are enough to satisfy the desire for grace and elegance in a liberated world. Such arguments led to early European Modern architecture being understood as appealing to the mind, not the body, but it was a different story in America.

Frank Lloyd Wright's designs were neither white nor pristine. He employed natural materials and colours alongside masonry and concrete, to create a richly textured architectural experience. While his European counterparts liked to dramatize the difference between their machine-made forms and nature, Wright's buildings embraced their sites, in several cases creating floor plans that enveloped trees and rock formations. Wright's architecture did not float above the ground like

Mies's *Farnsworth House*; his terraces, landscaped walls and eaves reached out to ground themselves in nature. Where Mies and Le Corbusier employed large windows, like picture frames, to capture expansive views, Wright created windows that offered glimpses, tantalising the visitor with hints about the surrounding world. Furthermore, Wright's art-glass windows featured geometric abstractions of local plants and his furniture was sometimes built-in, nestling into nooks in the walls, or circling sunken living rooms. Where early European Modernists praised transparency and efficiency as properties of the plan, for Wright, space was meant to be explored, discovered and, most of all, felt.

The two great arguments about emotional responses to Wright's architecture involve the experience of the living room and of movement through the house. The first is concerned with the spatio-visual properties of three locations in Wright's living rooms, each of which are meant to evoke a slightly different mix of sensations and associated emotional responses. The first of the spaces, the threshold to the room, is said to exhibit a heightened sense of mystery and complexity, along with a stronger level of enticement, drawing a person into the room. The second of the spaces, at the centre of the room, provides a balanced experience of prospect and refuge, offering potential for both excitement and security. Finally, the location in front of the hearth is most conducive to feelings of safety, offering the greatest warmth and potential for concealment. In each of these locations, there is a spatio-visual corollary to the feelings that are meant to be experienced, thus allowing for certain properties of these spaces to be measured. But the complexity does not end with this part of the claim. There is also an ambiguity inherent in debates about the properties of these three locations relative to time. Is the emotional impact more profound at night, with the world shrouded in darkness, or in daylight, when exterior views complicate and heighten the sense of exposure?

These theories and debates are examined in Chap. 9, by comparing the spatio-visual properties of three spaces, in seventeen of Wright's living rooms, by night and by day. The primary question we ask is, is there any pattern in the spatio-visual properties of these three locations? If there is no pattern in terms or space, form and vision, then arguments about consistent emotional responses to space and form are clearly invalid. However, the results of our mathematical analysis suggest that these spaces do possess a higher than anticipated set of geometrically similar properties. In particular, Wright's Prairie Style works are highly consistent and the Usonian designs are only slightly less so. The Textile-block houses are the only set that doesn't conform as closely to the pattern.

Significantly, the 'Hollyhock House' (*Aline Barnsdall House*) is amongst the outliers in terms of spatio-visual properties. It has some characteristics similar to the Textile-block designs, but ultimately does not fit neatly with any set of designs. In contrast, the properties of the living room in 'Fallingwater' (*Edgar J. Kaufman House*) are most closely associated with the Usonian works. Of all of the seventeen designs analysed, the *Heurtley House* is statistically closest to the mathematical pattern in Wright's living rooms. While it is impossible to determine, as some critics do, that it is the most important of Wright's early works, it is certainly the most typical, in terms of the spatio-visual properties of its living space, regardless of whether the assessment is taken during the night or day. This last point returns us to the topic of time. Inclusion of external views does seemingly weaken the consistency of the pattern of experience in Wright's living rooms. This might imply that exterior views were of less importance to his choreography of emotional response.

The second argument about the experience of Wright's architecture is about movement through the plan, following a path from the entry to the hearth. Wright never offered an explanation of the properties of this path, but historians and critics have identified a pattern of emotional responses and the spatio-visual geometries that are allegedly responsible for them. The challenge for a historian approaching this topic is akin to the one faced by an architect when describing a universal emotional response. As Flora Samuel asks, '[w]hat are the implications of designing a *route* to be perceived one way, when we will all perceive it so differently?' She argues that this is actually a greater 'problem for the historian who, in describing one experience of the journey, gives expression to only one version' (Samuel 2015: 44). But despite the difficulty inherent in this task, as Jones notes, the 'experience of movement through space … has been neglected or side-lined in much architecture and planning over the past century', and perhaps because of this, there has been a growing 'sense of … confusion for many about where to be and where to go' (2015: 6).

In general, as Chap. 10 demonstrates, the experience of moving along a path through Wright's architecture has the following characteristics. First, there is a shift from very enclosed spaces to more open (from refuge-dominant to prospect-dominant conditions). Second, there is a general sense of enticement in the way Wright uses space and form to draw a visitor forward along the path, until finally the living room is reached and the strength of that pull is reduced. Third, paths generally commence in a space that exhibits a higher degree of mystery and complexity and thereafter they move towards a space that has a reduced level of occlusion and increased order. These three properties are broadly in accordance with parts of the dominant theory, but one aspect of Wright's architecture isn't. Reduplication—embodied in Wright's strategy of raising the height of a ceiling in a large room, or conversely lowering the height of a ceiling in a narrow space—is actually not as prevalent in his domestic architecture as the guidebooks suggest. When it does occur in a design, reduplication is noticeable and it may emphasise certain emotional responses, but it is neither as consistent nor widespread as anticipated.

Not all of Wright's pathways feature these spatio-visual properties. Indeed only one house, the *Palmer House*, actually fulfils all of the criteria, although the *Henderson*, *Cheney*, *Evans* and *Freeman* houses come close to fitting the ideal pattern. Conversely, the *Heurtley House*, which encapsulated so many of the theories about Wright's living spaces, has only a limited level of conformity with the theorised properties of movement, and only two houses are ideal examples of reduplication: the *Henderson* and *Lloyd Jones* houses.

11.2 Conclusion

For an architectural historian, the act of constructing a conclusion for an analysis of a larger movement is a deeply fraught process. As Curtis admits at the end of his *Modern architecture since 1900*, the difficulty with framing a fitting denouement for a book is that history 'is still going on' (1996: 686). While this is true, he argues it is both possible and productive, to 'outline the shape of an unfolding Modern tradition as it appears from the shifting perspective of an evolving present' (Curtis 1996: 686). Just as this is a legitimate approach for a historian, it is also valuable for scholars who wish to approach history with a different mind-set. The alternative perspective we bring to the present work—mathematical and computational analysis—is particularly relevant in our evolving present.

We live in an era that is, for many people, completely reliant on computers for communication, social interaction and recreation. Computers are ubiquitous in society, and mathematics provides the foundations on which the contemporary world is constructed. As such, the application of computational and mathematical methods to questions of human experience, understanding and interaction is timely and appropriate. Such methods may not usurp the traditional approaches of historians and critics, but as the present book reveals, their application can uncover new insights into architecture as a *product,* a *position* and a type of *provenance*.

Finally, while a critical re-examination of Modern architecture was the catalyst for this book, there was also an ulterior motive. The computational and mathematical techniques featured in this work may have been developed by a large number of people over the last three or more decades, but they have proven difficult for many scholars, practitioners and students to understand and apply. Clear descriptions of what these methods can achieve, how they do it, and what the results might mean, are relatively rare. Furthermore, the highly technical descriptions that do exist are often inaccessible for novice researchers. Our aim for providing Part I was admittedly secondary to the overarching desire to illuminate some of the dark corners of Modernism (in Parts II and III), but it was always central to our vision for this book. We hope that the material in Part I will assist readers to use mathematical and computational approaches to test, and even challenge, long held assumptions and beliefs about architectural history, theory and design.

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M. J. Ostwald and M. J. Dawes, *The Mathematics of the Modernist Villa*,
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