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Workplace Environmental Design in Architecture for Public Health

Impacts on Occupant Space Use and Physical Activity

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I dedicate this book to my parents
Themistocles & Ninetta and my brother
Michael

Preface

All fine architectural values are human values

Frank Lloyd Wright (1867–1959)

Walking is man's best medicine

Hippocrates (c. 460 BC–c. 370 BC)

Over the past few decades, studies in epidemiological, pathological, clinical, environmental and experimental fields of medicine have proved that physical inactivity represents a major contributor to many worldwide chronic diseases. Health-related research estimates that if this inactive lifestyle continues, currently healthy population will likely face a number of ailments and chronic diseases. It is suggested by health-related research studies that an increase of even 10% of population-wide daily physical activity levels would significantly benefit public health.

This research seeks to explore patterns of occupant physical activity and movement intensity within office buildings in the belief that office design substantially shapes the nature and frequency of intra-building activity. As the research expresses its statement of relations between activity and floor plans, it develops a vocabulary for describing a building layout's inducement of physical activity, designating for instance, spatial "attractors" and "rewards" for movement. This emphasis goes against the grain of current thinking regarding office layout, especially in the matter of IT (information technology) integration, which prioritizes the minimization of worker activity as a condition of workers' increased productivity.

In adopting health-related and social science monitoring techniques and calculations of human energy expenditure, this project draws on six data collections that involve direct observations, interview questionnaires, self-report diaries, accelerometer readings and wireless occupant location mapping. Exploring the relation between occupant activity within different buildings is diverse and complex as individuals and buildings may vary considerably. During this research, a number of challenges and limitations have been identified and are discussed in this book.

The novelty of this work is that it monitors free-living office environments and studies how architectural design may influence physical activity through *office task alone*.

In this research, statistical analysis of the data and a quantitative model (named "KINESIS" after the Greek word for activity and movement) have been carried out to explore and identify dynamics of human space use and energy expenditure during work-time. The results of the data analysis focus on spatial factors of the office architecture which include the openness of a layout (i.e. open-plan or cellular), the distance between office spaces (e.g. an individual's desk and the kitchen), the existence of stairs between office locations (e.g. individuals' desk spaces and the toilet) and the window to wall area ratio of a space that may form a trip destination.

Each of the above-mentioned factors has been shown statistically to significantly influence occupants' activity and energy expenditure. In agreement with the results of the statistical analysis, the KINESIS model demonstrates a new simple model which simulates the behavior of populations in a given office environment. The research also statistically tests design implementations and illustrates how levels of activity might significantly increase energy expenditure distributions over population levels, and consequently benefit public health, by architectural design alone.

This book is composed by the following parts:

Physical Activity and Disease: Theory and Practice sets out to demonstrate the relation between physical activity and the promotion of health. This includes presentation of the health-related approach associated with the increasingly sedentary lifestyles across the worldwide populations. It describes also how scientific research demonstrates the value of exploring the design for office site movement.

Space-use and the History of the Office Building represents an overview of the history of office architectural design from ancient to present times. Along with recent concepts, theories and practice, it also introduces ideas on how the workplace is currently changing and how it further develops to respond to the current trends in office working.

Research Methods introduces the reader to current methods of measuring and mapping movement in different environments and disciplines. Based on these, the methods selected for the purposes of this research are presented.

Identifying Influential Office Architectural Design Factors of Movement illustrates research data collection results on the basis of which statistical analysis is carried out. From this analysis a quantitative (KINESIS) model is designed.

Conclusion and further objectives are suggested in the final chapter of this book.

Cambridge, UK Stamatina Th. Rassia

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About the Book

This research supports that physical activity varies according to spatial characteristics. The ultimate goal of this research is to identify how occupant physical activity levels could be influenced by architectural design. International heart experts' suggestions (i.e. MRC; Adidas, Wellness Medical Center UK, Dugmore 2007; PricewaterhouseCoopers 2007) have pointed out the value of increasing daily physical activity levels even by 10% of the current. Health-related research shows the importance of increasing daily energy expenditure generally in a population (as stated in the work of Geoffrey Rose 1992). This population-wide activity increase could decrease significantly the incidence of heart attacks and diabetes (N.H.S. Department of Health 2000, 2003, 2004, 2008).

While investigating the relation between human physical activity and movement within offices, this research explores:

- The reasons why indoor workplace occupants move in space.
- To what extent can causes of movement (or lack of) be identified in relation to architectural design characteristics?
- How physically active do office-users appear to be in a working day?
- Can any plausible scenarios be envisaged to suggest possible influences of architectural design on workers' physical activity?

Contents

Symbols

Technical or quasi-technical terms used in equations that appear in this book are drawn from a variety of fields (including health-related, social science, physics and applications of architectural theory) and are explained here.

A	Proportionality factor which can be determined for the purposes of the KINESIS model equations by taking into account environmental, cultural and personal characteristics. In this research, this factor has been determined by its statistical analysis indications
a	Window to wall area ratio of a trip destination within the office
c	Counts/min (GTIM Actigraph monitoring output)
C	Levels of "voluntariness" of a trip to an office destination
d	Distance walked in meters
D	Horizontal stair distance in meters. In a typical staircase D is equal to 1.4 times h
E	Energy expenditure in Joules
E_p	Energy expenditure per person per day in the KINESIS model
E_s	Energy expenditure in Joules per stair climb
g	Gravitational acceleration (9.81 m/s^2)
h	While using the stairs, h is the height ascended in meters, where this is about 2.7 m per floor
m	An individual's body mass in kg
P	Power in Watts
s	Number of staircases. We consider staircases in one storey unit (number of floors)
U	Number of trips per person per day in the KINESIS model
v	Walking speed in m/s
Δh	Change in height of the center of gravity in meters from seated to standing position which is estimated to be 0.4 m

Introduction

Office Environmental Design and Public Health: The Challenge

We spend 90% of our lives indoors (cf. European Commission 2003; National Research Council 1981) yet while humans evolve through their lifestyles, into increasingly indoor creatures, the relation of actual buildings and workplaces to their users' activity, health and disease prevention is still open to research (Evans and McCoy 1998). Duffy and Tanis remarked in 1993 that the objective of the new workplace is to attract and retain the best staff with the aim of stimulating creative work. Creativity and productivity are dominant terms in office management vocabulary. Productivity "designs" hubs of creativity that seem to affect habits of space-use and tie workers down to their desks for long hours. According to literature surveys, office management strategies seem to focus on the efficiency, effectiveness of space-use and job-interaction and neglect occupant health and well-being (Evans and McCoy 1998; Leaman 2000; Kelly 2001).

The history of workplace environmental design has indicated a leading office design preconception for reduced activity around the worksite by having desks that are functionally self-contained (e.g. having a printer, a telephone headset and a computer screen on each individual worker's desk). In this way individual productivity and organizational profitability (cf. Duffy and Tanis 1993) are supposed to increase.

Worldwide reports generally indicate that office workers (International Standard Classification of Occupations 2004) are 60 to 70% of their office-time sedentary (Webb and Eves 2005). Among the U.K. office worker population (that is estimated at 15,866 million people, i.e. 54% of the U.K. adult employed population (International Standard Classification of Occupations 2004; Department Office for National Statistics 2000), 64% of men and 76% of women (Brassington et al. 2002) is classified as either sedentary or moderately active, the latter term designating activity on an irregular basis only. In addition, two-thirds of women and one-third of men reportedly experience difficulty in walking briskly up a slight slope for several minutes.

The focus of this research is to measure the relation between the design of office indoor architectural environment and human physical activity. Exploring and understanding the factors that influence walking in office buildings is critical to efforts to promote higher intensity activity in increasingly sedentary workforces (Centres for Disease Control and Prevention 2001). These factors are themselves influenced by a wide range of personal, environmental and socio-economic variables that form this interdisciplinary research. So far, studies related to this topic of research have been mainly psychosocial, based on self-efficacy and human perception (e.g. of the perceived distance to a walking destination, Vincent et al. 1967). Only a small number of studies have appeared to focus in objectively measured activity rather than people's beliefs, particularly in health-related research examining the environmental correlates of "walking for exercise".

Part I
Physical Activity and Disease: Theory and Practice

Chapter 1
Physical Activity and Health Promotion

1.1 Physical Activity and Public Health Recommendation

Studies over the past few decades in a variety of health-related disciplines (for instance, epidemiology, pathology, clinical medicine) demonstrate that physically inactive lifestyles represent a major contributor to individuals' and populations' health ailments (cf. Bucksch 2005). Public health ailments along with the incidence of a number of chronic diseases are considered to be effected by the prevailing worldwide trend in sedentary lifestyles (cf. Blair et al. 1996).

The significance of the issue of physical inactivity and its impact on health has been demonstrated since the 1970s and 1980s with exercise prescription striving to improve physical fitness by encouraging participation in exercise that is often of an 'endurance' character. Physical activity is still perceived as an important lifestyle component in improving long-term health (cf. Rowett Research Institute 1992), as the majority of Western populations such as the U.K. are classified as either sedentary or moderately active.

To prevent health problems caused by inactive lifestyles, public health recommendations such as the 1996 *Surgeon General's Report on Physical Activity and Health*, encourage people of all ages to maintain at least a daily total of 30 min of activity at a moderate intensity for a suggested minimum period of 5 days a week. Moderate intensity physical activity is equivalent to brisk walking. According to the U.S. Department of Health and Human Services (1996) suggestion, moderate activity intensity may correspond to a 60 kg individual spending on average 627.6 kJ over a generally stated as leisure-time activity over a day. This has been calculated by the U.S. Department of Health and Human Services (1996) based on averaged values for individual body mass and leisure-time activity frequency, duration and intensity. Since, however, this is a very general leisure-time recommendation, this research seeks to calculate Joules of activity based on its own measurements and energy calculation methods. Moderately intense activity according to health-related research may, for instance be equivalent to the activity

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of *carrying a light load* and being *slightly out of breath*. For example, it may involve *ascending stairs while carrying a bag*. Brisk walking ($\geq$1.5 m/s) has been shown to increase fitness, reduce body fat (cf. Bond Brill et al. 2002; Slentz et al. 2005), lower blood pressure (cf. Bond Brillet al. 2002; Dunn et al. 1999), increase high-density lipoprotein (cf. Bond Brill et al. 2002; Fogelholm et al. 2000; Kelly et al. 2005), and reduce risks of bone fracture (cf. Feskanich et al. 2002). Brisk walking has also been associated with the prevention of the incidence of chronic diseases (cf. Stampfer et al. 2000; Wannamethee et al. 2000).

Physical activity, has been associated also by the Allied Dunbar Fitness Survey of the Rowett Research Institute (1992), with a decreased incidence of rates of coronary heart disease, strokes, osteoporosis and high blood pressure. Although a brisk walk is readily available, as it requires no special equipment or training (cf. Hillsdon et al. 1995), it is estimated that only about 36% of men and 24% of women in the U.K. meet public health recommendations for physical activity by walking 5 day per week for at least 30 min per day (cf. Eyler et al. 2003; Rafferty et al. 2002). Sedentary people face 1–2 times greater risk of premature death (cf. World Health Organization 2002). Apart from morbidity and mortality (cf. Fox 1999), inactivity may also affect well-being (U.S. Department of Health and Human Services 1996) and the incidence of mental illnesses.

The benefits of highly intense and vigorous daily physical activity (such that induces sweating and shortness of breath) have been demonstrated in health-related literature to offer the best form of protection against heart disease or malfunction. However, a growing international consensus further stipulates that regular moderate activity and brisk walking may also confer health benefits associated with improved fitness, while reducing coronary risks. As vigorous activity levels may not be a realistic goal for office-related activity, moderate exercise can be achieved within a large number of indoor spaces. This is a type of activity that is also less deliberate than the vigorous as it does not require a special outfit, assistance or previous experience. Health-related research shows that the recommendation of 30 min of moderately intense activity has not yet been proven as a clinically significant threshold above or below which physical activity is associated with risk of disease. Thus we treat this recommendation as a general suggestion in combination to health scientists (N.H.S. Department of Health 2000, 2003, 2004, 2008) recognition of the benefit of increasing the physical activity levels of large populations.

1.2 Interdisciplinary Approach to Physical Activity

Health and environmental studies have been combined and recommendations have been made on how public health could benefit from exercise. The U.S. Department of Health and Human Services in their journal *Healthy people 2010* suggested that walking outdoors for even less than a mile to socially significant meeting points, such as to a local neighborhood shop, could increase population levels of activity and consequently health (cf. Frank et al. 2003). Research currently also suggests that the building sector in particular may contribute to occupants' relative inactivity. A number of public health experts have considered the value of office spaces providing—by design—the sort of environment that induce workers' physical activity and consequently health (Frank et al. 2003). Public health studies suggest also that office workspaces may themselves offer the scope to facilitate worker movement simply by encouraging users to take 'trips', for instance by simply walking or ascending and descending stairs.

National Statistics on Standard Occupational Population Statistical Analysis (2005–2006), as well as the Department Office for National Statistics (2000) indicated that the U.K. office workers represent one of the most sedentary and as such most vulnerable segments of the working population (cf. Webb and Eves 2005). U.K. National Statistics (O.N.S.) findings also estimate that adult workers in industrialized countries (this does not include the "developing" countries) form 60% of the working population.

Recent U.K. data have confirmed increase in trends towards sedentary occupation in offices as an effect of both organizational and individual preference as well as modes of work organization. In some cases, individuals work long hours in response to social pressures enjoining success. According to Treasury figures, average earnings, including bonuses, rose by 3.8% between 2005 and January 2006, but one consequence of financial benefit for workers, as suggested by the self-reports noted above, is increased time commitment to their jobs. In offices, working under stressful environments seems to be conducive to a tendency to lengthen working days, inactivity and increased health risk. A considerable number of health-related studies report that work-time and the layout of working environments (building elements) represent risk factors in the acute myocardial infarction (Rowett Research Institute 1992), independent of other established risks and occupational conditions, such as the Sick Building Syndrome (cf. Marmot et al. 2006; Leaman 1990).

The persistence and seriousness of the epidemic of diseases related to inactivity in the U.K., as well as in the U.S.A. and elsewhere, which has thrown the onus onto employers, regulators and the designers of office workspaces in seeking to inculcate habits of more active living into sedentary office workers and promote well-being. In Europe, the particularly extreme working hours (that are reported by the U.K. workforce) have also given rise to the European Community (EC) Directives 93/104/EC (1993) and 2000/34/EC (2000), consolidated into 2003/88/EC (2003), which limited work-time to a maximum average working week (including overtime) of forty-eight hours. The proposed minimum daily rest period stands at eleven consecutive hours in every twenty four period, with further breaks allotted when working days exceed 6 h. The number of rest hours given to office users (known as "leisure-time") has been supposed to promote activity in granting greater opportunity for worker to get "up and out". In a U.K. survey 20% of the population reported doing nothing in their free time (O.N.S. and E.S.R.C., U.K. Time Use Survey 2000).

Thus far, most research on architectural and building configurations for inducing exercise has been carried out by health-related researchers who have recommended stair use as a means of boosting occupant activity levels (Webb and Eves 2005). The current data on stairs has been largely established through the collation of findings on lifestyle activity (from the British Heart Foundation 1998; Department of Health (U.K.) 2004; Department of Health and Human Services 1996) as supplemented by empirical studies. In these studies, researchers put up posters encouraging site users to take the stairs. Researchers then measure stair use by photo-electric cells placed on stairways. A number of studies have also reported data relevant to the possible success of worksite interventions (cf. Webb and Eves 2005). Most study data considered "how" sites offered particular additional inducements for activity through improved aesthetics, music and artwork (cf. Boutelle et al. 2001; Kerr et al. 2004).

An office workplace intervention in the U.S.A. aimed at offering a realistic stimulant for daily office physical activity and introduced office treadmill-desks. This was implemented in 2005 by Dr. James Levine, an endocrinologist at the Mayo Clinic, U.S.A. Another study conducted by van den Auweele et al. (2005), aimed to influence occupational physical activity and workers' fitness by emails sent to each office-user that specifically asked them to stand up and move around the space in order to become fitter and healthier. The van den Auweele et al. (2005) work achieved only a temporary activity increase. For this reason, reminding emails so far do not seem to result in sustained population-wide physical activity increases. Therefore, the goal of this architectural research is to collect data in relation to space use in workspaces and gain further a better understanding of how population-wide levels of physical activity could be achieved by future architectural planning, research and implementation.

Part II
Space-Use and the History of the Office Building

Chapter 2
Office Building: A Brief Historical Overview

In exploring office architectural design and its impact on user activity, examples of the history of the workplace from ancient Egyptian, Greek and Roman palaces and administrative centers until the office of present time will be presented. Office architecture has undergone many interconnected phases and have withstood both discontinuities and inconsistencies. Influences from the past can be found in contemporary office design. Prevailing political and social conditions as well as the development of technology may explain changes in the form and use of space. Human movement has been taken into consideration during most of the office layout design stages, mostly to the extent of minimizing physical activity to the benefit of productivity. Concepts for workplace design are still changing and the office space is becoming a layout set to induce interaction and face-to-face knowledge and information exchange.

2.1 Ancient Times

In ancient Egypt (3200BC–525BC) (Hascher et al. 2002), Greece and in Roman times (around the 5th century BC), economy, power and authority directed administrative buildings' infrastructure, supplies and engineering. These consisted of well-defined cores, a center and courtsides that attracted central or peripheral movement. In ancient Egypt the hierarchy of spaces was very strong and centralized, in ancient Greece and in Rome administrative centers were spread, with head offices and political as well as social centers located in different areas of the cities. Office work in ancient Egypt was carried out in specific spaces assigned for different jobs such as for accounting, registration and for bookkeeping, just like the contemporary conventional office workspaces. Many ideas about the management of workplaces, however, stems from the ancient times and thinking. An example is "hot-desking", that is carried out today to resolve a need for mobile working and thus of non-personalized desk use. Foundations of this strategy is in the ancient

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Egyptian work fashion of clerks and scribes who were mobile and for this reason were provided with the freedom to organize their work from a variety of places suitable to their tasks. They relied on two wooden boards, an inkpot and quill (cf. Hascher et al. 2002). Ancient Greek and Roman head offices were also, as today, located in central cityscapes and were composed of cellular spaces adjacent to open-plan meeting spaces. Large organizations, such as publishers or dealers employed, hundreds of slaves for repetitive tasks. The scale of these workers' offices would be smaller and usually closely clustered with public and most-frequented spaces of the organization. Workers were usually given access from their workspace to the streets and other circulatory axes for reasons of convenience and sometimes access discernment.

2.2 Modern Era

Successive changes, the collapse of empire and the flourishing of private and public development, marked the beginning of the modern era. During this period, the state retained most of the power and the private sector involved mostly banks (from the Italian word *banchi*) businesses and commercial enterprises. The idea of office work developed until around the beginning of the 15th century when the requirements of the branches of international business organizations led to its increased use in highly ranking spaces such as the city palaces. Giorgio Vasari, in 1560, first designed the *Uffizi*, known in English as offices (Hascher et al. 2002) that were U-shaped three-story multifunctional galleries. These were large buildings, in which a vast range of office uses co-existed. The idea of commercial enterprise involved, during the 16th century, a distinct characterization of work, rank and job classification clustering and since 1694 and for 40 years, office design continued to evolve until the foundation of the first European state-central bank and its head offices. This was followed by the creation of departmental offices and immensely large banking halls with scriptoria, long rows of office desks that tied workers down to their desks and were arranged in linear sequence. This typology set the foundation of private organizations and professional businesses and greatly influenced a more sedentary office lifestyle composition where workers were required to perform repetitive tasks seated at their desks that was a trend which continued until the beginning of the 20th century.

2.3 From the 18th to the 20th Century

Economic growth and the increase in office construction was illustrated in the period from the 18th to the 20th century when office developments were rectilinear, linked by a central corridor, or designed around a core space or atrium (cf. Hascher et al. 2002). The general staff was located in large rooms where individuals with higher administrative positions worked separately. Segregated space-use distinctively marked the office building of the 18th century and further influenced the office planning of the 19th century (cf. Hascher et al. 2002). Power and status not only affected the societal structures, office relations and the layout of building interiors but also influenced the building fabric, its envelope and construction height, that developed into tower blocks.

In Chicago, where technology like the railway, the steel-frame and the elevator were largely developed, many high-rise designs were developed enabling maximum organizational profit by stacking working groups on top of each other (cf. Hascher et al. 2002). In exploring the design of the skyscraper the office layout changed from largely cellular to open-plan. High-rise buildings defined not only the interior design but also the urban context of the city prototype with the development of the known skylines of New York and Chicago. Louis Sullivan was a pioneer architect from America who influenced concepts of industrialization and studied the high-rise commercial building. Apart from Sullivan's views about tower blocks, it was shown that these suffered from poor environmental design conditions, ventilation and daylight (cf. Hascher et al. 2002).

In the late 19th century, the invention of the telephone and telegraph enabled northern U.S.A. city dwellers to work closer to home. The wider use of electric lighting, the typewriter and calculators made work more efficient. Office design evolution, however did not appear to develop in the same way worldwide. European workplaces were less often accommodated in high-rise buildings than in their U.S.A. counterparts. They were mostly open-plan and only sometimes designed to be segregated with large subdivisions. Design interest shifted, during this period, to aesthetics and to more advanced construction methods and planning technologies. In 1906 Frank Lloyd Wright designed the Larkin Building, which presented special focus in aesthetics, construction methods and technology for large buildings and skyscrapers. Concerns for the occupant's well-being and welfare also characterized this period legal obligations. The German sociologist Max Weber through his work *Wirtschaft und Gesellschaft* (1922) and the French engineer and director of mines Henri Fayol in his work *Administration industrielle et générale*s (1916) introduced this concept to office practice.

From 1900 to 1930, productivity and working efficiency were emphasized in the establishment of a new workplace, which became predominantly open-plan with glass partitions. Directors and managers were thus able to oversee the productivity of their staff (e.g. Frank Lloyd Wright, Johnson Wax Company, Buffalo, U.S.A.). Associated productivity with seated workers discouraged movement and interaction.

Frederick Taylor's theories, epitomized in his *Principles of Scientific Management* (1911), have been dominant in shaping workplace design since the 1920s, in breaking down complex tasks into discrete, repetitive activities. The implementation of Taylorian visions in the workplace have fostered the image of open-plan rows of subservient workers, who—it was presumed—could only waste their corporate employer's time by socialising and for this reason were closely supervised by an office manager who was usually located in a separate room.

According to this spatial organization, work became principally "task-focused" (cf. Hascher et al. 2002) leading employees to come together only insofar as they needed to use specialized equipment, initially typewriters and telephones and then computers, copiers, printers and fax machines.

World War II, as well as precipitating the worldwide economic crisis, caused a twenty-year building downturn, and as a result architects of the post-war period followed the pre-war design methods that were guided by the rules of functionality, which reached their peak in the 1950s. In 1920, artists and architects who represented the European modern movement, in admiration of the modern designs of the U.S.A., set out with the least resources to reproduce these examples. A few architects managed to propose designs such as the "crystalline glass tower" and the "concrete office building" of Mies van der Rohe that later, after the war, influenced U.S.A. corporate architecture. Le Corbusier's work in Brazil in 1936 was also highly influential in glass architecture around the world as it expressed wider ideals where the organization would be more transparent and democratic.

After the war, the economy was reconstructed. While the European designs featured dense cellular spaces, with rows of offices located around a central corridor, American and Asian architecture became predominantly open-plan in the belief that open-plan designs saved useful space. These spaces were often poorly lit. Furthermore, by the end of the 1950s and beginning of the 1960s the office users' needs within the space were re-evaluated to comply with the terms of the so-called "Human Resources" (cf. Hascher et al. 2002).

Steel and glass architecture became indicative of the international modern movement, with the image of the American corporate building. The first example of a modernist standardized view of an efficient corporate building was the Level House of Skidmore Owings and Merrill (1952). As glass architecture became widespread, in New York, new "sealed" predominantly deep open-plan, air-conditioned and artificially lit glass structures with elegant modernist interiors became the design focus. Natural light and ventilation became increasingly important. Luxury and autonomy began to be perceived in well-lit and well-ventilated spaces, achieved by suspended ceilings in open-plan office buildings.

2.4 From the 20th Century Office Site to the New Workplace

This is the era of technological advance and of the co-existence of different building typologies and space-uses ranging from high-rise buildings to horizontal development and from cellular interiors to open-plan. Modes of working also changed during this period. The managerial interest shifted from "task working" to so-called "knowledge working", where office users are encouraged to interact informally in order to exchange ideas face-to-face and increase their levels of creative work that is believed to ultimately benefit the organizational economy (cf. Hascher et al. 2002).

During the 1950s, the development of the open landscape of the office's "American century" was initiated by the Bürolandschaft that was developed in Germany (Hamburg). Its rationale was based on a new model of interior design that, in contrast to Taylorian views, promoted human relations and fostered egalitarian and non-hierarchical job interaction by freely arranging the furniture and the office uses within the largely open-plan layout. As a design strategy this aims to increase flexibility in office space use and facilitate occupant decision for communication and activity.

In the 1960s, the Bürolandschaft became very popular in many European countries, although since the 1950s, this planning model received wide criticism for the design forms that it produced. These focused mostly on traditional ideas of familiarizing the office-user with the occupied space. Herzberger's Dutch Centraal Beheer insurance company (1974) followed the concept of designing for a "family-like" workplace. In these worksites, occupants were located in the space in such a way as to have a better sense of space and a feel of being members of a wider working population rather than a crowd scattered in a space (as in previous design strategies). As a result of the sense of a collective working scale, the office layout soon became highly personalized (cf. Hascher et al. 2002). For example, occupants would bring pictures of their children or furniture from their homes to the office. Herzberger's building has been highlighted as a notable example of a densely designed European building that, although not as profitable and efficient as the large open-plan layouts, gave a sense of self in the organization. While "building block" modules became standardized, with the scope for customisation in the early 1980s, the notion of "universal planning" involving the minimisation of large variations in space standards and the increased use of "one size fits all" has been followed. The final fall of the Bürolandschaft in Continental Europe came in 1973 when the economic crisis made the high rents unsustainable. Following the fall of the Bürolandschaft, the office building culture returned to the design of conventional cellular room arrangements around a central corridor. The space became again more inflexible and monotonous. However, this time occupants would be provided with a sense of ownership of their office space. Attempts to increase flexibility led to a multifunctional space providing a recreational and almost urban experience within the workplace (with its cafes and relaxation points co-existing with the office environment, for instance the Stockholm SAS building (1988) designed by Niels Torp). The combination of cellular and open-plan spaces introduced common rooms that had a core service creating the Swedish 'combi-office'.

While the workplace design kept changing, U.K. and U.S.A. practices started to promote schemes where people would be more mobile and could work from outside the worksite. This aimed to increase spatial openness and decrease maintenance costs. The widespread use of mobile technology, the mobile phone and the laptop impacted on modes of working and the overall office environmental layout and space-use. Work is undertaken at the worksite and the café and to the worker's home. Tele-working and remote technologies aimed at a wider cost-cutting strategic plan for the office. At the same time job competitiveness in the 1990s more globalized market has considerably increased. Spaces were deep-planned, predominantly artificially lit and air-conditioned. For the first time, it became apparent that occupant health, satisfaction and well-being were affected by the design of the space. As a result, office design has been linked with job absenteeism and the incidence of the so-called "Sick Building Syndrome" (cf. Leaman 1990; Marmot et al. 2006).

Open-plan designs for flexible working such as that of the British Telecom business park have been finally linked with a specific "workstyle 2000" design initiative. "Hot-desking" is re-introduced (after its first appearance in ancient Egyptian times) as vital to the design of the contemporary office layout where occupants are provided with no explicit anchor points. The space becomes impersonal and group working is a constant within an open-plan department. Leading concepts are increased efficiency, productivity and information tracking with the aim of higher profitability, whether personal or organizational. Office interaction becomes more relaxed and informal. Communication and face-to-face interaction is encouraged by office management as it is supposed to boost workers' ability to perform *creatively* (cf. Hascher et al. 2002).

2.5 Current Thinking and Future Design Implications

Past organizational strategies for space-use regarded workers as "units for production", aiming to maximize their efficiency (cf. Hascher et al. 2002). These office users were required to remain at a given station and perform repetitive tasks. Today the worker is asked to carry out "knowledge" tasks (in Peter Druckler's formulation) that will increase productivity and creativity, interaction and face-to-face communication, which often involves walking around the office space. The term "knowledge worker" was introduced thirty years ago and has been criticized in 1993 by Knights, Murray and Willmott who argued that all human activity entails some form of knowledge. Blackler (1995) amplified this, saying that "all individuals and all organisations, not just so-called 'knowledge workers' (Hascher et al. 2002) or 'knowledge organisations' are 'knowledgeable'". Recent theories of workplace interaction, meanwhile, have emphasised that knowledge exchange formally connects information and increases worker productivity (Worthington 1997).

In 1985, it was suggested that "your work is where you are" (Stone and Luchetti 1985). This soon became the motto for a deployment of space in which workers followed variable patterns and provoked alternative ways of working that engaged in the so-called "alternative workplace strategies" or "alternative officing" concepts (Harvard Business Review 1985). This encouraged mobile working, even outside of the worksite where employees could work from an internet café, from home, from a hotel, from an office space other than the desk and more. Office workers, in this working mode, can be mobile, come together for teamwork in formal meeting spaces or informal spaces or even desks "islands" for informal communication as well as in spaces ascribed for focused individual work. The last twenty years have seen the emergence of new styles of workstation, mobile furniture, so-called "intelligent furniture" and distinct freestanding elements that lead to space-use diversity, flexibility and mobile working. To some extent, conflicts and crossovers between the two design schools—the regimented, optimally productive office and the alternative, virtually networked space—have also issued in the emergence of a wide body of thinkers, writers and researchers studying emerging workplace questions and trends.

The new office space is composed of multifunctional open-plan or cellular spaces resembling "cybercafés" or "monasteries". This analogy was suggested in 1998 by Holtham and Tiwari who believe that the medieval establishments may offer contemporary office design with long-standing planning concepts. For instance, the monastic "cells" are enclosed narrow spaces set to facilitate knowledge exchange, team briefings, individual quiet work (in smaller cellular spaces akin to "cloisters" and "carrels"), serendipitous meetings (in the cloister walkways) and private reflection (in the "cell" spaces available for focused personal work). In focusing on the dimensions of each office space and its assigned value for office working, the William Bordass Associates, Francis Duffy (D.E.G.W.) and Andrian Leaman (Usable Buildings Trust) have stated the importance of the relationship between the "actual plus ancillary" office space (i.e. the density of the space and the provision for circulation routes and actual office spaces). Duffy along with Worthington (in the book "Reinventing the Workplace", 1997) have suggested that the office space functions under four systems of relation, the "den", the "hive", the "cell" and the "club". The "den" is set to foster group work and interaction. The "hive" is always open-plan and as such facilitates and assists managers in supervising their employees, who are meant to be tied down to their desk producing useful work. The "cells" are enclosed spaces designed to increase individuals' productivity by clustering them according to their job description. The "clubs" are designed for individual interaction and process working. In 1997, Duffy indicated that currently most office layouts are hive-like resembling call centres. He also predicted a significant increase in the design of "dens", "clubs" and "cells" in future due to their diversity and potential for using space more actively and flexibly. The metaphors of "den", "cell", "hive", "carrel" and "monastery" work to reflect some emerging difficulties and managerial concerns. These spaces were designed to provide both places of reflection and unscripted interaction. The main idea is to plan for efficient and effective schemes that induce productivity, which usually entails the clustering of IT facilities or the provision of wireless networking, so that users remain perpetually "on call". Trends in the dematerialization of workspaces have led at least 10% of office workers (Kelly 2001) to work virtually, either from home or using only transient "hot-desks", which provide no anchor points to an individual territory.

Chapter 3
Current Office Design, User Activity and Occupancy Evaluation

Environmental and behavioral studies have identified and demonstrated correlation between building design and human behavior. Office buildings are regarded as "weak" program buildings (cf. Joseph et al. 2005) as they sustain a very wide range of activities and interactions. By contrast, activities in "strong" program buildings (for instance, hospitals) are more predictable and more structured (such as around doctors' and receptionists' offices as well as around wards).

3.1 IT Integration in Space: Impacts on Activity and Job Interaction

During the last decade, the individual workstation has been transformed with the integration of IT into a paperless office space. Ergonomic design has also been introduced in the office environment to propose workstations that are not owned by the office user but are used as stations where only a computer-screen is provided. Printing facilities are no longer positioned on an individual's desk but are located centrally at a print station or a printing room. The computer integrates most office functions making them faster and more standardized. IT devices such as PCs, laptops, wireless networks, computer programs and multifunctional devices (e.g. printers, scanners, plotters) are intended to simplify certain tasks thus driving productivity increases. The workstation is set up either as a *universal computer workplace* or as a *touchdown station* (cf. Hascher et al. 2002, p. 72) for staff equipped with personalized laptops whose work is frequently mobile. IT integration in office spaces transformed not only the ways in which people work but also workers' degree of movement and modes of communicating. Communication need no longer be exclusively face-to-face. Indeed, organizations may prefer, in terms of time productivity, that employees communicate at a distance through either centralized computer networks by email or by oral communication (i.e. mobile phones,

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networked telecoms). Emailing also serves to keep the office paperless and individual productivity standards high as colleagues can send messages to multiple recipients. While direct proximity to IT facilities is conducive to interaction from the viewpoint of the employer's desire for continuous work, it is clear that IT location reduces employee physical activity. Many attempts have been made by health and environmental scientists to reduce virtual communication within the worksite and increase job-related movement for interaction.

3.2 Effects of the Design of Offices on Occupant Activity and Occupancy Evaluation Method

The design of an office space may both demand activity (e.g. in the sense of forcing users to cross hallways or transepts to reach work areas) or invite it (e.g. by the provision of optional work routes offering visual or environmental stimuli). Surveys indicate that activity is most desired when it relates to communication and information exchange (cf. Allen 1977) usually in an informal environment associated with individuals' desk space.

In office planning, certain constraints, such as spatial provision per person, may have an effect on users' sense of space and behavior. These provisions can vary considerably according to the building location depending on the country, region, and cultural influences as well as trends it is set to comply with (cf. Bordass et al. 2001). In addition to workspace provision per person, the building provides workers with the opportunity to move for different purposes, such as for non-work related activity to the kitchen. According to William Bordass Associates (2001), the building amenities are divided in "actual" office spaces (such as the kitchen and the meeting room) and the circulation systems that are usually designed to involve physical activity and are called "ancillary" (such as the corridors and staircases).

Findings suggest that building circulation systems and in particular staircases are the predominant stimulant of office users physical activity levels. Stairs exist in almost every building and allow users to exercise without the need for specific equipment, change of clothes or undertaking lifestyle changes such as going to the gym. Several studies have indicated that relatively modest increases in stair use can have positive effects on health (cf. Joseph et al. 2005). Harvard alumni health studies (2004) involving more than 11,000 men have found that ascending at least twenty floors per week may reduce the risk of stroke by 20%.

Post-occupancy evaluation (P.O.E.) (Bordass et al. 2001; Leaman 2003) as well as post occupancy review of office buildings and their engineering (P.R.O.B.E.) strategies are currently set to add value in hindsight and provide foresight and insight (Bordass et al. 2001) to office user productivity and space-use satisfaction. These are currently widely used as reliable methods by which managers and designer groups meet occupants' needs (Bordass et al. 1994, 2001). They are designed to increase satisfaction, productivity and to focus on indoor environmental qualities. In doing so, P.O.E. focuses on increasing occupant well-being and avoiding the incidence of a number of building-related syndromes, such as Sick Building Syndrome. Sick Building Syndrome has been extensively researched and analyzed and is currently believed to be caused by poor Heating, Ventilation and Air-Conditioning (H.V.A.C.) indoor environmental conditions. Machine exhausts can extract compounds and molds in the air and are reported to account for a number of combinations of health ailments and allergic reactions. Current research for this reason also monitors environmental factors, such as the air-tightness of the ceilings, floors and walls (Bordass et al. 2001). It also (Leaman 2003, among others) takes into consideration spatial qualities (i.e. size, density, circulation spaces), operational characteristics (i.e. security, maintenance, flexibility in use, health and safety) and spatial provision for personal privacy and spatial control that may affect user well-being and satisfaction (Leaman 2001). To date the assessment of building performance in terms of its users' satisfaction and productivity is carried out with qualitative measures (such as interview surveys). Leaman has stated in his paper "Indoor Environmental Quality and Occupant productivity in CH2 Building" that it is possible that unrevealed useful information may be hidden behind occupants' reports. Given the role of office environment in the poor health of employees, it is aimed here to identify by data collection what changes in design and plan of offices could promote health by physical activity.

Part III
Research Methods

Chapter 4
Introduction to Methods for Measuring Activity

There is currently a range of technologies available to record movement and location in different environments. These correspond mostly to free-living (i.e. urban environments, sports grounds) or "controlled" health-related environments (i.e. health-related laboratories). Topological multi-agent behavioral models are also available to monitor and predict movement and space-use. These are well-established in various fields of research and scientific work remains further to develop them. Such models are mostly relevant to large-scale design environments (e.g. urban) and are mathematical, operating under functions of the field of topology.

Although studies have been carried out measuring outdoor and worksite physical activity, only limited work has been done on the actual topography of the indoor workspace use. Literature reviews have also shown that monitoring technologies for the latter are few. Thus for the purposes of this research (to measure office-user activity and location of movement within the topography of indoor office architectural environments), a survey of a number of available monitoring methods from various fields of study has been conducted and from those the most appropriate and reliable have been selected.

4.1 The Difference Between Space-Use Topography and Topology

Movement is defined, in this book, as activity within the topography of an office space. It has been identified that the topographical sense of occupant movement within the indoor office space may be mistakenly associated with the meaning of space-use in topological models. This distinction merits further analysis.

Duffy (D.E.G.W.; Duffy and Tanis 1993), Becker (Cornell University, Becker and Steele 1995) and Hillier (Bartlett School at U.C.L.; Hillier 1984) have

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examined the development of methods for the analysis of space-use (Hillier and Hanson 1984). The application of these methods in different environments (e.g. to worksites, Penn et al. 1997) has resulted in the development of a distinctive "space syntax" (originally coined by Bill Hillier, Julienne Hanson and colleagues) that describes and models space-use in terms of the ease of navigation offered by any setting where this is required (e.g. museums, airports, hospitals). Hillier's space syntax takes the form of a topological mathematical program, breaking spaces down into components and analyzing spatial connections as networks of options that are represented graphically in depictions of relative spatial connectivity, integration and isolation. Space syntax finds its readiest application in predicting correlations between spatial layouts and social effects such as crime (Hillier 2004), traffic flow, or sales per unit area. Planners in the public sphere as well as private interests such as retailers, have used this idea of space as forming a network in order to influence microeconomic activity and to maximize movement, while also sometimes seeking the clustering of similar actions according to patterns of large space and land use, particularly in cities.

Space syntax in contrast to the scope of this work that aims for example to identify the importance of ascending stairs in energy expenditure, operates with topological rather than the topographical models required in this research. The topological models have been resolutely two-dimensional, failing to factor-in the distinct, health-enhancing office space-use characteristics of, for example, ascending stairs. This topological system also seems unsuitable for the monitoring purposes of this research as its differentiation between spaces cannot clearly correspond and explain the actual topographical features of the office space that may, for example, be related to continuities and discontinuities of stair use and physical activity between adjacent indoor office spaces. This means that space syntax cannot by itself offer the account of information required by this research topographical enquiry. For Carlo Ratti (M.I.T.), space syntax has yielded a number of paradoxes in its postulation of space-use under certain geometric configurations. This has led to a heated academic exchange with Bill Hiller and Alan Penn concerning Ratti's questioning mathematical reliability (Hillier and Penn 2004). Recent research has sought to combine space syntax with geographic accessibility analysis through the application of Geographic Information Systems (G.I.S.). This development was presented in 2009 by the Swedish research group for "Spatial Analysis and Design" at the Royal Institute of Technology in Stockholm.

4.2 Physical Activity Measurement Methods: Accuracy and Cost

Measuring physical activity within the topography of an office space is a complicated task (as occupants move for different reasons) within short distances in spaces that although uniformly characterized as workplaces may vary considerably in terms of their indoor architectural design. A number of methods for recording physical activity are currently available to capture and assess physical activity in a variety of laboratory-based (where the environment in which the data collection is carried out is regarded to be "controlled") and free-living environments. These methods have been shown to vary remarkably in terms of their ease of use, cost and accuracy. The most accurate sensors so far seem to be the recently combined heart-rate and movement acceleration sensors. These monitors have been reported to offer more accurate results than accelerometers or heart-rate sensors alone (Corder and Ekelund 2008). Although recently proved to be accurate, heart-rate monitors, doubt has been cast on their capacity to measure low to moderate levels of activity (these of course, are the only levels of activity that may occur within an indoor office environment) and it has been shown in health-related research that increased heart-rate at these levels may not always be related to physical activity (but for instance to stress rates; Corder and Ekelund 2008; Cambridge University MRC Epidemiology Unit researchers' suggestions). Furthermore, it has been suggested (by this research MRC advisors, from their experience in monitoring physical activity and human heart-rates) that recording heart-rate in free-living environments, such as in schools and offices, may increase awareness of the participation in a health-related data collection and hence interfere with the reliability of the results.

These research literature reviews have identified a diverse number of tools that have been built to fit a variety of types of physical activity (cf. Celler et al. 2004; Corder and Ekelund 2008) however, the use of accelerometers (or activity monitors) seem to be more suited to the purposes of this research. Accelerometers are more sophisticated than pedometers, although the latter are cheaper to use (than accelerometers, heart-rate monitors and calorimeters, as shown on the Corder and Ekelund 2008) and can record movement in the form of step counts, they have no means of assessing physical activity intensity, duration or frequency of bouts of activity (as can accelerometers). Accelerometers are attuned to the dynamic component of physical activity and offer a time-sampling mechanism that can measure the duration and frequency of bouts of activity (Celler et al. 2004). They have been confirmed in children against indirect calorimetry and doubly-labeled water (Corder and Ekelund 2008) and have been found to have moderate to strong correlations for energy expenditure. Accelerometers however, cannot be used in water-related activities nor for assessing the physical activity associated with resistance exercise, weightlifting and cycling.

Analysis of the available methods for measuring physical activity has also indicated that self-reports (such as questionnaires and diaries) may offer a low-cost and straightforward method of data collection on physical activity. Self-reports fall within the general category of direct observation which, however, appear at the end of the Corder and Ekelund (2008) scale for cost and accuracy of results. The very low reliability of these methods is due to for example, the apparent space-user difficulty in accurately recalling the levels, duration and period of activity (over e.g. a day at work); and reasons of practicality where it may not be possible to carry out observation for as long as the rest of the population-wide methods of studies.

Although observation methods may offer useful detailed account of physical activity and space-use and have sometimes been applied to validate other methods, they may influence the Hawthorne effect, where participants might change their behavior as a result of knowing that they are being observed. This effect, however, may wear off after an initial period. In conclusion, according to studies on human psychology, the perception of what one thinks that he or she should be doing rather than actually doing may introduce bias in people's responses to questions. Introducing bias has been aimed to be avoided in this research. A number of interview questionnaire types have been explored. A popular and relatively reliable interview form related to human perception of physical activity is the International Physical Activity Questionnaire (I.P.A.Q. 2005) and was used for this research.

4.3 Mapping Human Location

Identifying factors that influence walking in office buildings is critical in this study that aims to record movement in addition to promoting higher-intensity physical activity. It has been identified that relatively little work has been conducted in measuring occupant location of movement indoors. Most work is focused in measuring movement within the outdoor and urban space. Urban space-use studies, for example have so far recorded a relation (Saelens et al. 2003; Sallis et al. 1998) between movement and street connectivity, traffic safety (e.g. by the use of CCTV), road accessibility and convenience (Frank and Pivo 1994; Humpel et al. 2002), urban "walkability" levels (e.g. by the use of a distinct "walkability index"; Saelens et al. 2003) and aesthetics [showing, for example, that people in urban spaces will move less towards large open green spaces with shrubs than to landscapes with trees (Humpel et al. 2002)].

While the assessment and measurement of the use of the urban environment can be objectively carried out and validated currently by the use of G.I.S. (Geographic Information Systems), this cannot be applied with the same accuracy in building interiors. Although G.I.S., radio frequency identification (R.F.I.D.) and electronic tagging can offer movement cartography monitoring, it seems that these mostly apply on transport models or in criminal investigation. The R.F.I.D., also called a "spy chip", is able to track people or products wherever they are and for this reason its use has been opposed on ethical and legal grounds resulting in their further exclusion from this research. Cost and accuracy have been the main considerations governing selection of the methods appropriate to recording individuals' movement location. Methods of identifying location on for example playing fields, and their adoption for indoor spaces have been examined.

The Active Bat (prototyped in 1989–1992), a technological predecessor of the "Ubisense", was considered. Both "Ubisense" and Active Bat technologies involve highly sophisticated installation systems suitable for permanent use in appropriate settings but not for short-term set-up for the purposes of trial or experimental run of data collection as required in this research. The Active Bat system is an ultrasonic indoor location system that relies on sensors installed throughout the ceiling of the office space. This system is set to produce an estimate of the location of every individual Active Bat. It functions and registers movement by multilateration (which is the process of accurately locating a beacon by gauging the difference in the time that its signal took to arrive at three or more receivers) and can track multiple Active Bats at the same time.

The use of Active Bats can be of particular assistance in health-related environments. They can, for example, be useful in hospitals in emergency where locating a member of staff or a patient is of vital importance. By using this system in workplace environments, it is possible to determine the location of office colleagues and other staff as well as their availability for a job interaction. As with the "Ubisense" use Want et al. (1992) and the Olivetti Laboratory reports, it is suggested that this system function could, if adopted, increase working efficiency and productivity, as office staff would spend less time trying to find a colleague or arrange a meeting and would therefore have fewer but more successful meetings. Since the Active Bat system is not accessible for wider use in office environments it is expected to be used in data collection only where available in this research.

Chapter 5
Selected Research Methods of Data Collection

5.1 Method

- Direct observation
- Interview questionnaire
- Diaries and Actigraph activity monitoring
- Active Bat location mapping

Research data-collection conducted comply with ethical considerations as stated by the Ethical Committee of the School of Biological Sciences at the University of Cambridge.

5.1.1 Direct Observation

Measuring physical activity within the topography of an office space has been shown so far to be a complex task. It involves short walking trips that do not comply with a tight mechanistic program of actions (i.e. offices have been defined as "weak" program buildings; Joseph et al. 2005) but are undertaken for office space-use and practice that may be personal or job related or both. For this reason, direct observation has been carried out to offer an intuitive judgment of otherwise undefined, often multi-purpose, activities. An advantage of this method of monitoring is that it indicates reasons for trips and destination choice. This type of information is unavailable to monitoring techniques, such as accelerometers. Additionally, two out of six research data collections enabled objective measurements of individuals' location and movement. Recording human movement by direct observation was undertaken manually by the researcher on tables and on floor plan copies of the selected data collection office-sites.

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5.1.2 Interview Questionnaire

Supplementing observation, short interviews were conducted to capture self-assessment and human perception of space-use and activity. Self-reporting questionnaires were solicited through a scheduled recall interview. As many studies have been carried out to identify forms of question that can extract objective and reliable answers, the short version of the I.P.A.Q. interviews attending to working day periods were selected. The I.P.A.Q. interview schedule was developed by a working group initiated by the World Health Organization (W.H.O.) and the Centers of Disease Control and Prevention (C.D.C.) as a common instrument to be used internationally in obtaining and surveying physical activity data (I.P.A.Q. 2005). Results drawn from comparison of 12 countries' self-reporting measures demonstrate its high reliability, suggesting an 89% agreement of answers on perceived with actual levels of physical activity (De Bourdeaudhuij et al. 2003). The I.P.A.Q. has two versions, short and long. Both pose recall questions to individuals' on their weekly physical activity. The I.P.A.Q. short version was adopted in this research as its participants requested non time-consuming questionnaires. The short-form of the I.P.A.Q. interview questionnaire has been assessed according to its revised (in November 2005) I.P.A.Q. scoring protocol resulting in the calculation of respondents' perceived time spent per working week in sitting or walking. From this protocol, participants' perceived activity rates were assessed. These could also, according to the I.P.A.Q. protocol suggestion, be classified as low, moderate or vigorous. In addition to the short version of the I.P.A.Q., further architecture-based semi-structured and unstructured questions were posed. The purpose of these questions was to gain a better understanding of, for example, occupants' satisfaction with the use of space.

5.1.3 Diaries and Activity Monitoring

G.T.I.M. Actigraph accelerometers, each weighing about 40 g and consisting of a waist belt, a USB connection cable and a piece of (not worn) computer software, were applied in order to monitor occupants' daily activity levels. Monitors were routinely set up to record intensity of steps and activity at intervals of 5 s. This method of data collection was adopted as cost-effective, reliable and widely tested in health-related studies (Corder and Ekelund 2008). Users were asked and agreed to wear this accelerometer while awake. The Actigraph accelerometer data output is given in counts per intervals and its internal data analysis can then categorize activity into three intensities: *light* (where the rate of activity is less than 1952 counts per minute), *moderate* (ranging from the minimum value of 1952 counts per minute to a maximum of 5724) and *vigorous* ($\geq$5724 counts per minute).

This equipment also offers rating of *light* and *health enhancing*. The latter is equivalent to the sum of *moderate* and *vigorous* intensity Actigraph counts of activity. In order to comply with public health suggestions for health enhancing activity, the Actigraph also indicates the number of minutes per day that are spent in *moderate* or *vigorous* intensity of activity. It then categorizes this activity into levels; *low* (<30 min per day), *medium* (30 min per day $\leq$ *Medium* < 60 min per day) and *high* ($\geq$60 min per day). Where activity levels are specified for periods less than a day, the criteria are modified *pro rata*. As health-related research (Cambridge MRC Epidemiology Unit advisors, N.H.S. Department of Health 2000, 2003, 2004, 2008) has pointed out that public health recommendations should be regarded as general suggestions only, in this research activity will not be classified but analyzed as a distribution of energy expenditure of a population. Although Actigraphs are relatively sophisticated and reliable devices (as compared with pedometers), they have no means of distinguishing the location of activity. Actigraph accelerometer outputs represent daily activity and for this reason office movement was recorded by the use of simple and straightforward tick box diaries that have been produced for this research. These diaries were used by the data collection participants in order to note the time spent inside and outside the office.

Additionally, the Active Bat (weight: 40 g, dimensions: 55 $\times$ 55 $\times$ 7 mm) (Want et al. 1992) was selected for its capacity to map occupants' location and activity, i.e. their walking routes, distance and duration. Four out of six of these data collections enabled direct observation in order to explore reasons, distances and routes of individuals' indoor office movement. Two additional research field-studies have, however, offered the possibility by the building infrastructure and logistics available (the Active Bat had already been installed in the building operation systems and had been mounted on the walls and ceilings) to make use of the centralized networks of the Active Bat system of beacons and receivers and thus to measure movement more objectively (i.e. than direct observation).

The Active Bat beacons that were agreed to be worn by the building users during the data collection periods transmit spatial coordinates and individuals' reference codes periodically to the receivers mounted on the building walls, ceilings, gateways (doors) and on corridors. While people walk relatively slowly within buildings, the Active Bat system can accurately locate occupants moving within the space. Provided an unobstructed line-of-sight (e.g. by not having very thick walls e.g. of width of a meter) between the Active Bat and the ceiling sensors, occupant position can be estimated to a margin of error in less than 3 cm (Addlesee et al. 2001; Harter et al. 1999). The readings were then assembled by a computer system designed to process and display users' locations on floor plans and by video representation.

As for reasons of privacy all data collection involved reference codes and not participants' identities and names. The Active Bat system can only track Active Bats and their reference codes that can by no means track identities. This complies with ethical requirements for individuals' privacy and anonymity. It also means that if an individual refused to participate in the research data collection, the beacon would simply be removed and placed on a desk. Thus no information would then be provided on office activity. Such issue, however, did not arise in this research data collection.

Chapter 6
Research Data Collection

6.1 Setting up the Data Collection

The program of this exploratory research is based on six workplace data collections (see Tables 6.1 and 6.2) that were carried out in the UK at the:

Site A Martin Centre, Cambridge
Site B Daneshill House 1st floor, Stevenage
Site C Daneshill House 3rd floor, Stevenage
Site D AT&T Laboratory Offices, Cambridge
Site E William Gates Computer Laboratory Offices, Cambridge
Site F D.E.G.W., London.

These sites were selected for their design characteristics (whether open-plan or cellular, conventional or irregular and unusual) and their space as well as staff availability for monitoring. In order to receive representative outputs, this research has aimed to involve more than half of each of its workplace environments' staff. Participant characteristics such as their job classification, age, gender, height and weight were compared and representation of sample ensured. The samples were also proportionate to the total of each office staff. If, for example, we have two managers in an office, thirty-six members of staff and ten secretaries, then this research aimed to involve participation from at least one manager, eighteen members of staff and five secretaries. The Site D (AT&T Laboratory) dataset represents about 90% of its users and the rest of the studies include about 60% of their total office user population.

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Table 6.1 Research data collection: case study detail

Site name	Office layout type	Research participants		Monitoring time		
		No. of People	Type of occupant	Days	Work-time Average hrs per day	Leisure-time awake Average hrs per day
Site A	Cellular	5	Research based	7	9	3
Site B	Open-plan	10	Commercial (planning industry)	8	8	5
Site C	Cellular	18	Commercial (planning industry)	5	8	4
Site D	Cellular	340	Research based	142	9	
Site E	Cellular	19	Research based	5	9	3
Site F	Open-plan	31	Commercial (planning industry)	11	9	3

Table 6.2 Research data collection: method

Site A	Direct observations	Interview questionnaire	Actigraph	Diaries	
Site B	Direct observations	Interview questionnaire	Actigraph	Diaries	
Site C	Direct observations	Interview questionnaire	Actigraph	Diaries	
Site D					Active bat
Site E		Interview questionnaire	Actigraph	Diaries	Active bat
Site F	Observations	Interview questionnaire	Actigraph	Diaries	

In order to avoid the Hawthorn effect all participants were introduced to the scientific merits of this study. They also attended an explicatory presentation that clarified the need for behaving normally during the measurement period. All data collection organizations and participants gave consent to their voluntary involvement and were free to seize participation should they be willing to. Reference code numbers were used for the participants and all ethical considerations for privacy were preserved and maintained private. All research participants' personal data remained anonymous as prescribed by the Ethical Committee of the School of Biological Sciences at the University of Cambridge. Throughout this work, and in line with ethical considerations, all monitored sites and research participants were given reference identity codes.

Following the generally advisable practice in health-related data collection, a preliminary study was carried out to identify any relationship between occupant physical activity and the architecture of the office space. This was the research pilot study, which took place in Sites A and B.

6.2 Site A and Site B: Pilot Study

The pilot study was performed at the ground and 1st floor of the Site A (Martin Centre, Cambridge) and on the Site B (1st floor at Daneshill House, Stevenage). The Site A data collection involved 5 participants and Site B involved 10 (selected according to job description and personal characteristics to constitute representative samples of the Site A and Site B staff). The layout of the Site A is cellular, with every room located adjacent to each other. It was being used for research and administrative work. The Site B layout was square and open-plan with an octagonal atrium space in the middle. Site B formed a corporate office environment.

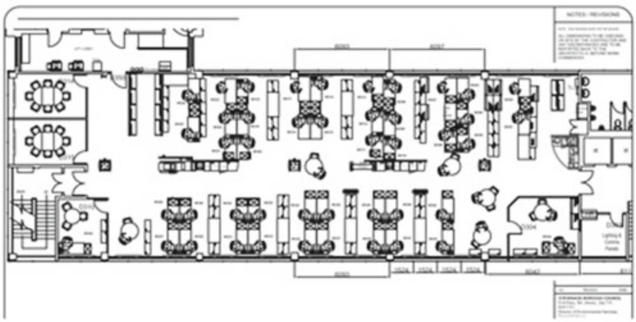
Site A 1st floor plan view. (*Source* Cambridge University Estate Management & Building Service)


Site B (*Source* Management office of the Daneshill House; Revival Project 2005)

Data collection method: Both data collections that comprised the research pilot study involved the use of direct observations, I.P.A.Q. interviews, semi-structured and unstructured questionnaires, diaries and G.T.I.M. Actigraph accelerometers.

6.3 Site C

Following the same research enquiry and method as before, the next site chosen was a more conventional office space than before, which was as such conceived to be corporate, open-plan and rectilinear. A suitable environment for this data collection was found on Site C (3rd floor of Daneshill House, Stevenage). It involved 18 participants selected according to job description and personal characteristics to constitute a representative sample of the Site C staff.



Site C (*Source* Management office of the Daneshill House)

Data collection method: The data collection involved the use of direct observations, I.P.A.Q. interviews, semi-structured and unstructured questionnaires, diaries and G.T.I.M. Actigraph accelerometers.

6.4 Site D

The research continued with collection of more objective data on occupant location of movement. This data collection was carried out on 3 out of its 4 floors of Site D (AT&T Laboratory, Cambridge). Although the Actigraphs were not available at the time, the Active Bat system was installed throughout the building and was worn by 340 users (about 90% of the Site D users). This data was offered by the Cambridge University Computer Laboratory administrative office to the researcher. The space, which was used for research and administrative purposes, was cellular and overall “L” shaped.

Site D 2nd floor (*Source* William Gates Computer Laboratory)

Data collection method: The Site D enabled only location mapping by the use of Active Bat monitoring.

6.5 Site E

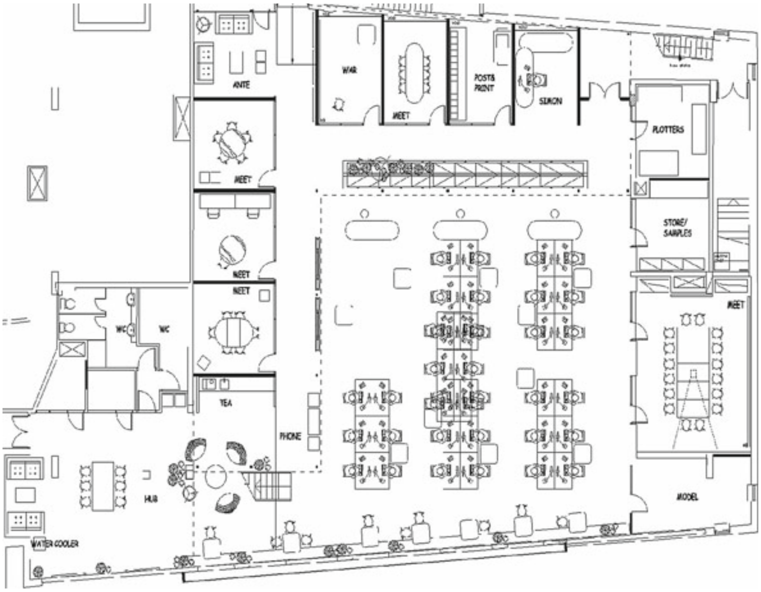
Additional data were collected at the Site E (William Gates Computer Laboratory at Cambridge). This site on the 2nd floor, like the Site D, is comprised of adjacent cellular spaces forming a rectilinear research and administrative workspace. It also had the Active Bat system installed in its infrastructure. The data collection involved 19 office users.

Site E (*Source* OpenRoomMap - The William Gates Building)

Data collection method: Activity was monitored by the use of both the Active Bat and the Actigraph accelerometer systems. The I.P.A.Q. interview, semi-structured and unstructured questionnaires were also administered in order to identify occupants' perception of their physical activity levels and space-use.

6.6 Site F

Further to the Site D and Site E data collections, the last data collection carried out was at the so-called “new workplace” of D.E.G.W that formed the research Site F. It is a square open-plan space with a mezzanine and was appointed for corporate office use. Data collection involved 31 participants who used the Site F spaces (i.e. mezzanine and its ground space) and it aimed to observe the location of occupant movement and measure physical activity levels in a less conventional and more flexible space than any of those previously monitored (i.e. providing no anchor points for about 30% of its users who were “hot-desking”).



Site F (*Source* D.E.G.W. Administration office)

Data collection method: This data collection involved direct observations, I.P.A.Q. interviews, semi-structured and unstructured questionnaires, diaries and G.T.I.M. Actigraph accelerometers.

Part IV
Identifying Influential Office Architectural Design Factors of Movement

Chapter 7
Data Collection Results

This chapter will provide results that have been obtained by the data and methods presented in the previous chapters. The data will be further statistically analyzed. Findings will be used to design the KINESIS model that will explore different scenarios of office user work-time activity.

- The research dataset indicate that the Site F population was more active inside the worksite than the rest of the research data collection participants (namely in Site A, B, C, D, E).
- The Site F population activity standard deviation seemed also, however, to be greater than that of the rest of the office users' across the research data collections. This can be explained by Site F office culture's fostering more irregular office space-use, "hot-desking" and working with less personalized anchor points (i.e. desk spaces) than the rest of the research spaces.
- Site F as well as Site E participants also, on average, met the public health recommendations for health-enhancing minutes of activity within the worksite but also, interestingly, during leisure-time.

S.Th. Rassia, *Workplace Environmental Design in Architecture for Public Health*,
SpringerBriefs in Public Health, DOI 10.1007/978-3-319-53444-2_7

Table 7.1 Average occupant activity levels inside and outside the research data collection worksites

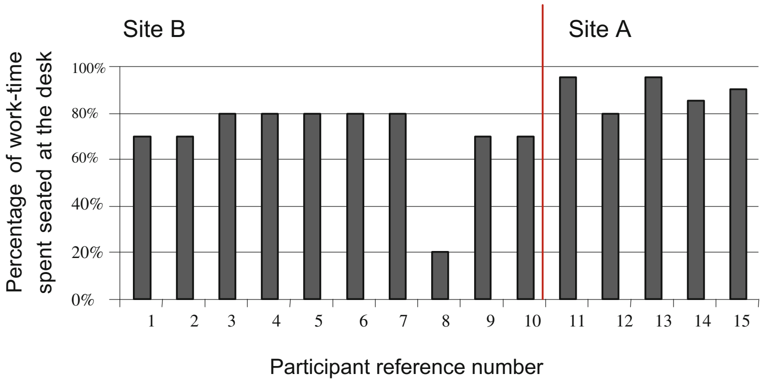
GTIM Actigraph physical activity monitoring sites	Time of the day	Number of research partcipants	Mean minutes ± Standard deviation
Site A	Work-time	5	18.4 ± 7.11
	Leisure-time	5	11.0 ± 9.44
Site B	Work-time	10	29.9 ± 14.7
	Leisure-time	10	16.5 ± 11.3
Site C	Work-time	18	22.1 ± 5.66
	Leisure-time	18	21.9 ± 12.5
Site E	Work-time	19	62.1 ± 21.6
	Leisure-time	14	47.9 ± 25.8
Site F	Work-time	30	66.4 ± 32.3
	Leisure-time	30	39.7 ± 22.9

Overall, in setting out to identify architecture-related movement influences and inhibitors a simple question was addressed to the office users which was, “Why do you move around the space”.

All staff answered to this question indicating that they would move in order mostly to communicate. In trying to identify whether any architectural attribute (including the lighting, the temperature, the layout) could affect physical activity, office users were asked to indicate any source of dissatisfaction. Temperature, lighting and acoustics were often cited as chief sources of discontent. Uniform lighting, the deep planned layout and the white walls were also cited as monotonous, clinical, apathy inducing fatigue. None of these constituted however, clear evidence that dissatisfaction effected on movement, for instance, in order to choose another more satisfying office space. Finally, key remarks on the site analysis (based on activity monitoring, observations and interviews, as well as diaries) are presented below.

7.1 Site A and Site B: Pilot Study

- 61% (i.e. 9 out of the 15 participants) of Sites A and B collectively believed their physical activity at work to be low.
- 70% of Site A and B users work-time was reported to be spent seated at the desk.



This chart shows the percentage of reported (IPAQ) work-time spent seated at the desk

- 85% of the Site B participants reported (informally) that they would take the stairs in order to meet a colleague if they were closer than two floors away. Otherwise they would either no longer make the trip or take the lift.
- Observation suggests that workers, whatever their immediate occupation, move mostly to meet informally.
- Site A and B participants visit the floor kitchens regularly to meet other office users. Although IT facilities were set to enable faster office communication, users seemed to prefer face-to-face communication.

- The open-plan job clustering in Site B fostered more employee interaction and information exchange across disciplines than the cellular Site A.
- Site B included a staircase in the middle of its atrium space. The atrium space was surrounded by glass, giving a reported feeling of a "fish bowl effect" that was informally suggested to cause a sense of exposure in an environment of co-workers. As no strong incentive to take this staircase was provided (all occupants were clustered on the same floor according to their job), no real need was provided for occupants walking up and down the internal stairs.
- Informal meetings around desk "islands" which were also situated around the open-plan atrium of Site B fostered more informal interactions.

7.2 Site C

Site C enabled the measurement of a more conventional open plan rectilinear office space. This space is on a higher floor, which was important because it enable a closer investigation of how office users would perceive the space and use staircases during a day at work.

- Site C participants visit the floor kitchens regularly to meet other office users. Although IT facilities were set to enable faster office communication, users seemed to prefer face-to-face communication.
- Workers were observed to move for "voluntary" or "imperative" purposes.
- "Voluntary" trips were observed to be usually to the coffee station, the office print room and others' desks. These involve ascending stairs to meet a colleague for work purposes of communicating at desk "islands". These trips are called "voluntary" because an alternative of not making the trip may be found; however, these will still take place.
- "Imperative" trips were mostly to the toilet, to the meeting room and to the manager's office.

Interview sought to determine whether any space use factors inhibit movement by annoying. Irritants and determinants reported included:

- Internal temperature
- Noise pollution
- Smell
- Color of walls
- Lighting
- Furniture
- Layout

Although it has been suggested that attributes of the office space may dissatisfy users, no evidence has been found to support the idea that dissatisfaction deters movement.

7.3 Site D

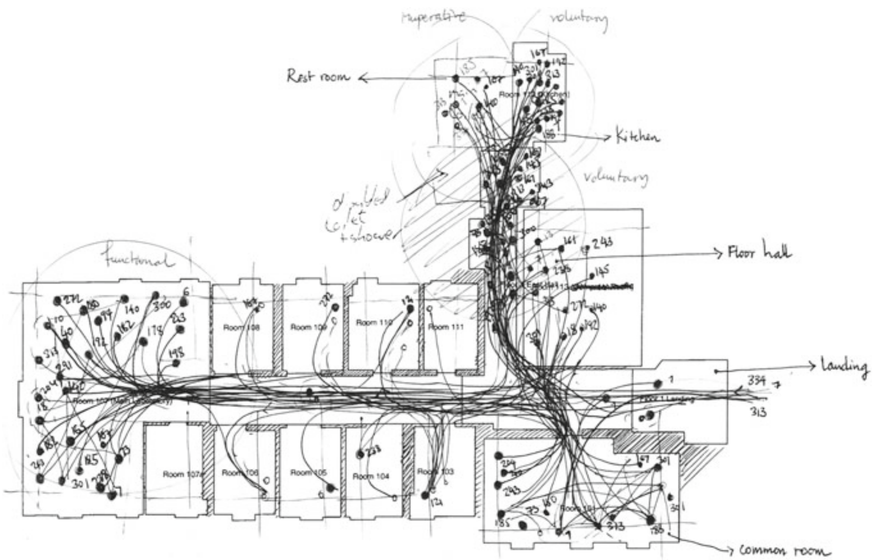
- This analysis has suggested that the probability of making a journey to a given distance in a day at work is higher for informal job communication than for any other reason.
- Trips to a colleague's desk or en route stops on the landing for brief conversation took place 2–3 times more than to any other place.
- Office users walked an average of 7 m to meet a colleague and would often stop at an average distance of 10 m for informal discussion on the landing.

An average of 1 daily trip would be made to the:

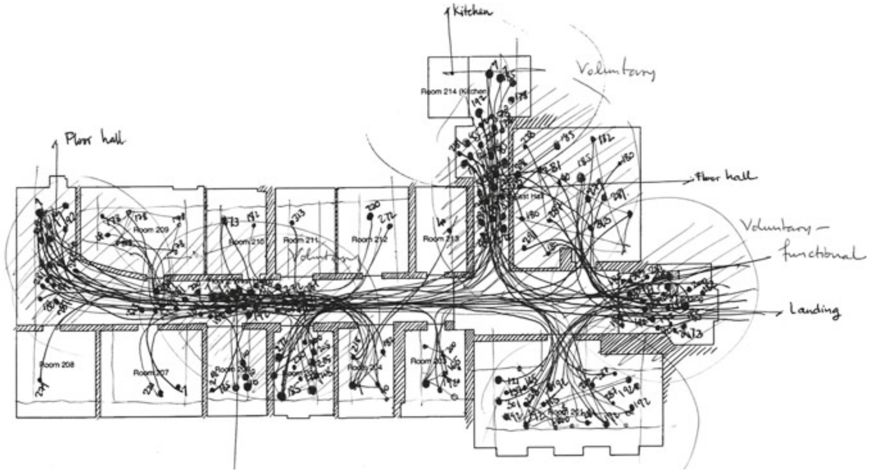
- Coffee station
- Reception desk
- Main laboratory: common room.

The average distance to these destinations was 10 m. Observations of the location of movement also shows that occupants walk mainly down the corridors towards the:

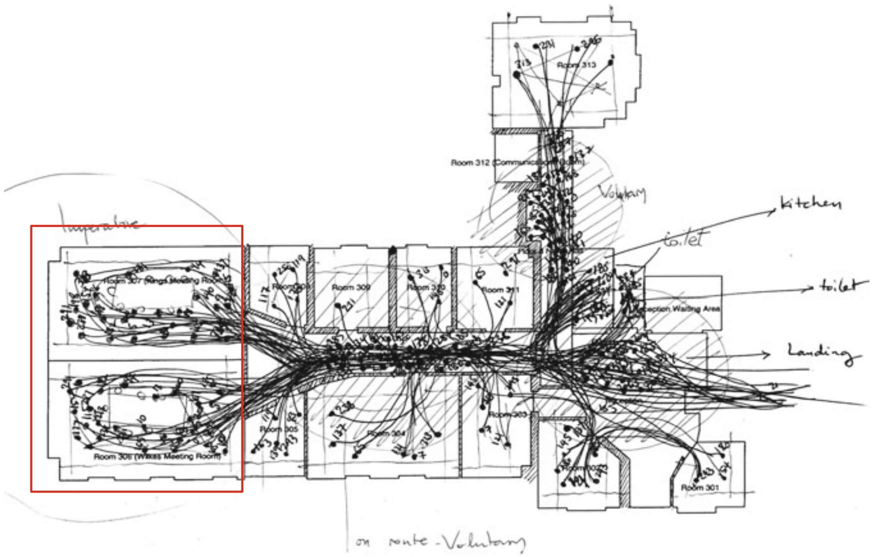
- Office kitchen
- Toilet
- Individuals' desks



Site D: 1st floor. Data extracted from objective location mapping datasets



Site D: 2nd floor. Data extracted from objective location mapping datasets



Site D: 3rd floor. Data extracted from objective location mapping datasets.
The *square shows* the location of the meeting rooms

- Site D shows that activity on the 3rd floor differed from that on the 1st and 2nd floor. This floor contained the two formal meeting rooms of the building. Informal and spontaneous communication and activity was found to take place on the 1st and 2nd floors.

- The movement patterns of the 3rd floor users were described mostly by a stop at the floor kitchen (also the “coffee station”) before a meeting, followed almost always by an en route stop for a brief informal conversation in the corridor and then a procession to the official meeting in one of the two assigned rooms.
- One trip per day would be made to the meeting room (e.g. for the office report of the day).
- Occupants would visit their floor toilet on average once a day. For this, they would walk an average distance of 9 m.

Special remark for Site D: Architectural practice can prescribe the distance walked to different spaces (such as to the toilet) from the architectural design stage.

7.4 Site E

In agreement with previous data collection interview results, site E participants’ self-reports have indicated that the most popular space for movement was their colleagues’ desk (often reported to be next door) for informal communication.

- 13 out of 19 participants mostly walked to meet their colleagues. The remaining 6 of the 19 participants almost always communicated by email.
- The research population all agreed that an average of 16% (about 1 h) of their work-time (about nine hours a day) would be spent away from their office desk.
- An average of 1 trip per day per participant was reported to be to the lounge one floor below as it was thought aesthetically pleasing. This trip was reported always to involve stair use.

It was reported that in 99% of trips from one office level to another, participants would take the stairs. The reason given was that it was:

- Simply quicker to take the stairs
- The lifts were not as fast as they should be, less conveniently located and further away from the stairs.

In only 1% of times would they take the lift and this because they would have to carry heavy laboratory equipment.

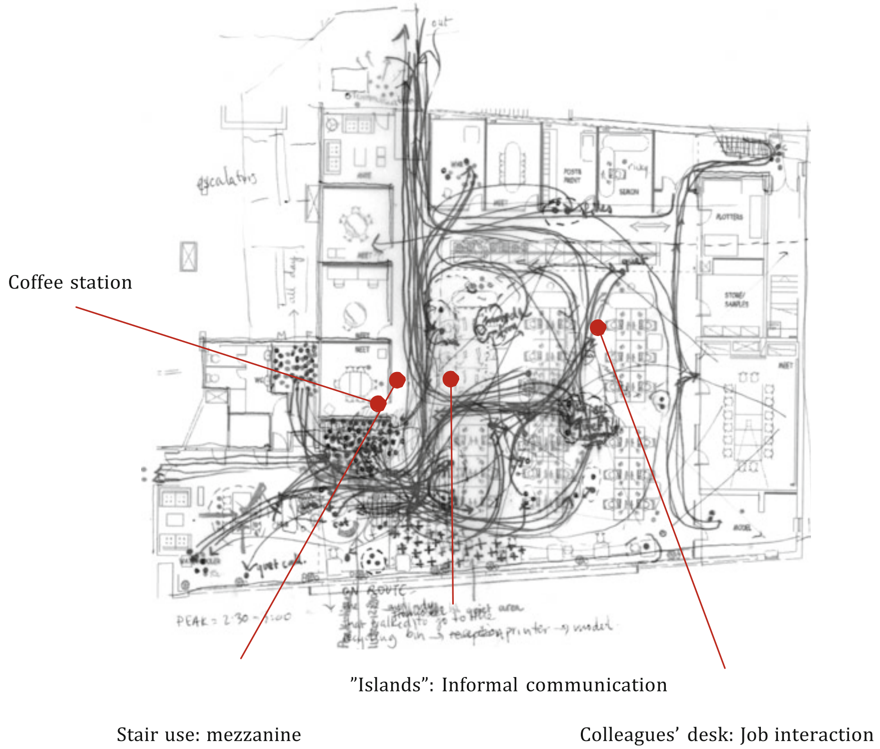
Special remark for Site E: This finding supports the conclusion that where lifts and stairs are equally convenient people will take the quicker route and if stairs is the preferred option, then this activity will be healthier. Given the above outcomes and as stair use is recommended by health-related research as particularly health-enhancing (Rowett Research Institute 1992), research participants were further asked whether ascending and descending stairs is understood as positive, necessary or unnecessary.

- Of the 18 participants interviewed (only one participant was not available to answer these questions due to a generally heavy workload), 78% reported stair use as quicker, as the lifts were relatively slow and further away than the stairs.
- 22% of participants regarded stair use as positive, stating that they would normally look forward to it during their daily office routine because it led to aesthetically pleasing lounge downstairs. None of the occupants reported stair use as a negative and unnecessary aspect of their office day.
- Overall, half of the participants regarded walking as generally positive and half as necessary as well. None regarded walking as unnecessary and they suggested that job related reasons or "stretching their legs" is necessary or "good for you" and thus would not wish to refrain from this activity.

7.5 Site F

Site F has been the most "flexible" site of the research. This is designed to promote a "new workplace" organization that has shown also to promote activity inside the worksite.

- 63% of their average daily health-enhancing (moderate to vigorous intensity) active minutes were recorder to be spent in work-time.
- Colleagues' desks, once again were indicated to be the most popular magnet of occupant movement that attracted an average of 3–4 trips a day. Out of these trips, on average, 1 trip per day was observed to involve ascending and descending the mezzanine staircase and 1 trip was part of a longer journey which involved many en route stops (i.e. to the kitchen, toilet or print room). 21% of these trips were made to destinations closer than 10 m away from the starting-point location.
- 39% of trips to the kitchen and 21% of the trips to the print room were found also to involve ascending and descending the mezzanine staircase as the mezzanine had no other kitchen or print room.
- 15% of trips to the kitchen and 7% of those to the print room were en route to other office destinations (for example, the meeting room, an individual's desk).
- Where workers were clustered according to job and seated within 3 m from each other, physical activity for communication seems no longer to occur.
- The most mobile people seemed to be those that were "hot-desking".
- Participants would visit the toilet on average once a day and 7 of 31 participants would take the stairs to the toilet.



Site F: Ground floor daily activity observations

These data observations invite categorizing movement according to purpose (i.e. "voluntary" and "imperative").

- It was evident that trips to the print room, less "voluntary" than for instance, trips to the kitchen, would not involve stair use.
- It was also observed that spaces that may offer a recreational sense of space (such as the kitchen or an individual's desk on another open-plan office level, e.g. the mezzanine) also encourage movement.
- An open-plan allowed staff to see whether any of their colleagues were in a communal office area (e.g. the kitchen) and this could trigger daily visits.

Chapter 8
Statistical Analysis

8.1 Models

The research monitoring was set to receive quantitative and qualitative data on occupants' daily office physical activity. Direct observations were carried out in order to identify research participants' daily activity patterns and were confirmed with the research questionnaire. As the accelerometers cannot determine the location of each individual's movement, this analysis has used observational data to indicate participants' movement location and assess energy expenditure. This assessment has been carried out by following the research physics-based energy calculation that is in three parts: getting up, which involves gravitational energy and has been calculated by the use of Newton's formula ($m \cdot g \cdot h$); accelerating, which involves inertial energy and has been calculated by the use of Newton's formula ($m \cdot v^2/2$); and walking, calculated by the use of Ralston's empirical equation (1958).

The energy calculated from Newton's formulas is useful mechanical output and thus for this analysis, a value of 20% mechanical efficiency (an appropriate moderately low figure for non-trained activities such as causal movement about the office; Whipp and Wasserman 1969) was used. This results in the metabolic input being 5 times the mechanical output. Note that Ralston's empirical equation already predicts metabolic input. Based on the above, for movement on the (x, y)-plane, the energy for getting up and walking reads as follows:

$$E = \left(\frac{(2.02 + (1.33 \cdot v^2)) \cdot m \cdot d}{v}\right) + \left(5 \cdot \frac{1}{2} \cdot m \cdot v^2\right) + 5 \cdot m \cdot g \cdot \Delta h \qquad (1)$$

where

- E is the total energy expenditure in J, as derived from Ralston's empirical equation (1958) which can determine energy expenditure at (x, y)-level walking

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SpringerBriefs in Public Health, DOI 10.1007/978-3-319-53444-2_8

speed and from stationary power consumption prior to movement, plus five times (given 20% human mechanical efficiency) the inertial energy for horizontal acceleration, plus five times (given 20% human mechanical efficiency) the gravitational energy.
- *m* is an individual's body mass in kg.
- *d* is the distance walked in meters, as measured by counting the observed trace of occupants' movement on each data collection office plan view. As the sample sizes of these data collections were not more than 31 participants each, they were also considered feasible to be carried out as objectively as possible. Unstructured questions also sought to confirm observed number of trips, duration and distance during the office day.
- *v* is walking speed in m/s, which in this analysis has been determined, for consistency, according to the observational data. Each individual's average walking speed was directly visually assessed, in meters per second, by the use of a chronometer that the researcher carried. This means that the researcher, at different times, would focus on each participant's activity and would count the scale, i.e. the number of steps walked in one second for each meter distance. Typically this speed would range from 1.2 to 1.5 m/s.
- *g* is the acceleration due to gravity (9.81 m/s^2).
- Δh is the change in height of the centre of gravity in meters from seated to standing position which is estimated to be 0.4 m.

When stair use was observed then for every staircase ascended, which is understood as a partly horizontal and partly vertical activity, human energy (J) was calculated as follows:

$$\mathrm{E}_s = \left(\frac{(2.02 + (1.33 \cdot v^2)) \cdot m \cdot D}{v}\right) + 5 \cdot m \cdot g \cdot h \qquad (2)$$

where

- *Es* is the total energy expenditure in J per stair climb. We propose that this energy expenditure is part gravitational and part "walking", derived from Ralston's empirical equation (1958) which, can determine energy expenditure at (*x*, *y*)-level walking speed and from stationary power consumption prior to movement, plus five times (given 20% human mechanical efficiency) the gravitational energy (as given by Newton's formula).
- *D* is the horizontal distance in meters, in a typical staircase *D* is equal to 1.4 times *h*.
- *h* is the height ascended in meters, where this is about 2.7 m per floor. This research conjectures that an individual moves forward at a walking speed of about 0.33 m/s.
- *m* is an individual's body mass in kg.

Model 1

The first model focuses on popular trip destinations and sets out to identify the architectural attributes that may influence or inhibit movement in a workplace. The number of expected trips to office spaces was modeled using Poisson regression, which models the number of occurrences of an event in time (in this case the number of trips to an office space over a day at work). The Poisson regression is a log-linear model. This regression analysis was adjusted for the clustering of observations between individuals and within buildings and was controlled for age, gender and weight.

Spatial characteristics that were observed to affect indoor office movement were taken into consideration in the statistical analysis.

- A space's distance from individuals' desks.
- The presence of stairs between the desk and the walking destination.
- The openness of each space (coded as a binary variable where "0" denoted open-plan and "1" non open-plan (i.e. cellular) spaces).
- The window opening area of each walking destination. This was observed to attract occupant activity for private telephone calls or informal meetings ("hot-desks" were also situated close to the windows). The statistical analysis includes value for the window opening area that was calculated for each office space according to the example presented in Fig. 8.1. This measurement was used because not enough evidence is currently available to specify a causal relation between window features, such as, natural light or the view outside, and space-user physical activity location and levels.

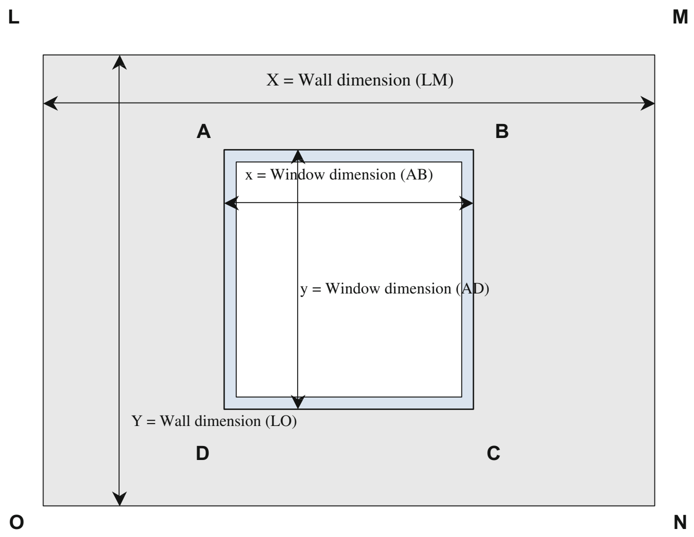

Fig. 8.1 Window opening area, which is described as the window opening to wall area ratio = (x · y)/(x · y)

Model 2
The second model acknowledges the observed fact that the number of trips to office destinations depends not only on destinations and their design characteristics but also on the complex dynamics of the voluntariness of movement between different worksite destinations. The office layout may be described as a system of interconnected *nodes* and *links*. The nodes are ascribed for different spatial voluntariness levels and the links that are designed to connect the nodes form walking routes.

This research conjectures that trips to "imperative" (least "voluntary") movement destinations, such as to the toilet, will be more resistant to different indoor office environments and will appear to be repeated relatively uniformly among all data collection participants. The reason for this suggestion is the purpose of visiting these spaces, that they attract movement for either physical (i.e. going to the toilet) or "imperative" job-related purposes (e.g. meeting the manager, attending a set regular daily formal meeting in the office). For this reason, it has been expected to use the "imperative" trips to the toilet as a robust baseline movement category with which any other more "voluntary" activity could be compared. "Voluntary" trips may be more dependent on architectural design attributes than the "imperative".

"Imperative" trips to the toilet and the meeting room were assigned with zero "0" voluntariness (as they attract the least "voluntary" activity, for physical or job-related reasons). "1" has been assigned for trips to "voluntary" movement attractors that may entail, e.g. job-related requirements as well as the choice whether to carry out a trip. Such trips include those to the workplace reception, "cells" for concentrated work, desks "islands" for informal communication, individuals' colleagues' desks, workplace print rooms. "2" was ascribed for "highly voluntary" trips to the kitchen. The kitchen seems to be the only place observed to attract more recreational than job-related movement as compared with any other indoor office space.

The research modeling was based on the measurement of:

- The odds of making a trip to a voluntary "1" as compared with an "imperative" (voluntary "0") trip destination.
- The odds of making a trip to a "highly voluntary" (voluntary "2") versus an "imperative" (voluntary "0") trip destination.

These models were investigated by using multinomial regression analysis, which models the probability of an event that has more than two alternatives (event of "voluntary" versus "imperative" trips and event of "highly voluntary" versus "imperative" trips).

8.2 Participant Characteristics

Each participant was categorized in the analysis according to job classification (i.e. by denoting "1" manager; "2" assistants; "3" general staff; and "4" facilities officers); age (i.e. "1" denoting 25–30 years old participants; "2" 31–40 years old;

Table 8.1 Research participants' characteristics as set for the statistical analysis

Characteristics		Variable	n (%)
Gender	*Binary*		
	Male	0	33 (51.56)
	Female	1	31 (48.44)
Age	*Categorical*		
	25–30	1	25 (39.06)
	31–40	2	20 (31.25)
	41–50	3	11 (17.19)
	51–60	4	3 (4.69)
	61–65	5	5 (7.81)
Job classification	*Categorical*		
	Manager	1	6 (9.38)
	Assistants	2	7 (10.94)
	General staff	3	48 (75)
	Facilities officers	4	3 (4.69)
			Mean (S.D)
Weight (kg)	Continuous		
			72.3 (15.1)
Height (m)	Continuous		
			1.7 (0.1)

"3" 41–50 years old; "4" 51–60 years old; and "5" 61–65 years old); individual's height (given throughout in meters); weight (presented throughout in kilograms); and gender (by assigning this as a binary variable where "0" is set to designate male participants and "1" female) (Table 8.1). This analysis considered potential perturbation effects (fluctuations) that could occur around its estimates due to the clustering of observations between different individuals using different buildings. This was achieved by adjusting the statistical models for each individual and for individuals within buildings (that may be, for example, open-plan or cellular). During the statistical modeling process, individuals were grouped into 5 categories using the quintiles of their mean daily energy expenditure.

8.3 Observation Clustering

The number of days during which observations were carried out varied among the data collection participants. For this reason, individuals were clustered according to the building that they used. This nested structure of clustering was followed throughout the statistical analysis.

8.4 Testing the Research Hypothesis

In order to test the normality of the research hypothesis, the Shapiro-Wilk test was carried out. This test is preferred to the Kolmogorov-Smirnov test as it offers higher statistical power.

In this analysis, normally distributed continuous variables were summarized as mean plus or minus standard deviation (S.D.). Non-normally distributed variables were reviewed using 1, 5, 10, 25, 50, 75, 95 and 99% of their cumulative distribution.

Variables that respond to a set of categories (categorical) such as, the "voluntariness" of space-use; the individuals' age group and gender; the participants' job classification, and the openness of a space [that is, whether open-plan or not (i.e. cellular)], were presented by using absolute numbers and percentages.

8.5 Results and Discussion

Remarks

- More than half of the observed daily work-time movement was to "voluntary" trip destinations and 22% was to "highly voluntary" (i.e. the kitchen) (Table 8.2).
- The most frequent trips were to colleagues' desks (attracting 1.5 ± 1.3 trips/day/person), to the kitchen (1.2 ± 1.0 trips/day/person), to the toilet (1.2 ± 0.4 trips/day/person) and the print room (0.6 ± 0.6 trips/day/person) (Table 8.3).
- Trips to the toilet are shown in Tables 8.2 and 8.3 to form not only the predominant daily "imperative" activity, but also a substantial part of the total daily activity (attracting on average 1.2 trips out of a mean 5.5 trips per day, Table 8.3).
- Trips to the "imperative" trip destination of the toilet (where the mean total number of trips was 1.2 ± 0.4 and the p-value for trend 0.32) occur on a more similar and robust basis across the physical activity groups than, for example, trips to the kitchen (where the mean total number of trips was 1.2 ± 1.0 and the p-value for trend 0.001), to colleagues' desks (where the mean total number of trips was 1.5 ± 1.3 and the *p*-value for trend 0.005) and the reception desk (where the mean total number of trips was 0.5 ± 1.0 and the *p*-value for trend 0.001) that seem to increase across groups (Tables 8.2 and 8.3).

Visiting a colleague's desk has been shown to be the most popular office activity. However, it was also observed that visiting a colleague is more related to office practice and management dynamics (which sets the location of occupants' home desk and often clusters them according to their job description) than to the architectural design of the space. For this reason, movement between colleagues' desks

Table 8.2 Participants' total number of trips to office destinations per day (categorized by quintile of individuals' mean daily energy expenditure)

Trip destination	Voluntariness status	Total number of tri ps observed		Number of trips observed in group 1[a]		Number of trips observed in group 2[b]		Number of trips observed in group 3[c]		Number of trips observed in group 4[d]		Number of trips observed in group 5[e]	
		Frequency	Percentage	Frequency	Percentage	Frequency	Percentage	Frequency	Percentage	Frequency	Percentage	Frequency	Percentage
Toilet	Imperative	221	23.02	45	30.41	39	25.16	40	20.83	48	23.76	49	18.63
Meeting room	Imperative	25	2.6	1	0.68	4	2.58	5	2.6	7	3.47	8	3.04
Reception	Voluntary	40	4.17	0	0	1	0.65	7	3.65	10	4.95	22	8.37
Cell	Voluntary	30	3.13	3	2.03	9	5.81	13	6.77	4	1.98	1	0.38
Desk	Voluntary	277	28.85	39	26.35	44	28.39	53	27.6	59	29.21	82	31.18
Island	Voluntary	52	5.42	9	6.08	10	6.45	8	4.17	12	5.94	13	4.94
Print room	Voluntary	105	10.94	18	12.16	16	10.32	25	13.02	22	10.89	24	9.13
Kitchen	Highly voluntary	210	21.88	33	22.3	32	20.65	41	21.35	40	19.8	64	24.33
Total		960	100	148	100	155	100	192	100	202	100	263	100

[a]Group of individuals whose mean energy expenditure belongs in the 1st quintile of the distribution of the mean energy expenditure per individual
[b]Group of individuals whose mean energy expenditure belongs in the 2nd quintile of the distribution of the mean energy expenditure per individual
[c]Group of individuals whose mean energy expenditure belongs in the 3rd quintile of the distribution of the mean energy expenditure per individual
[d]Group of individuals whose mean energy expenditure belongs in the 4th quintile of the distribution of the mean energy expenditure per individual
[e]Group of individuals whose mean energy expenditure belongs in the 5th quintile of the distribution of the mean energy expenditure per individual

Table 8.3 Mean number of trips to office destinations per day per person (categorized by quintile of individuals' mean daily energy expenditure)

Trip destination	Voluntariness status	Mean number of trips per day per person						
		Total (n = 64)	Group 1[a] (n = 11)	Group 2[b] (n = 10)	Group 3[c] (n = 13)	Group 4[d] (n = 13)	Group 5[e] (n = 17)	*p*-value for trend
Toilet	Imperative	1.2 ± 0.4	1.1 ± 0.3	1.1 ± 0.4	1.1 ± 0.3	1.3 ± 0.6	1.2 ± 0.4	0.32
Meeting room	Imperative	0.1 ± 0.3	0.0 ± 0.1	0.1 ± 0.1	0.1 ± 0.2	0.2 ± 0.3	0.3 ± 0.4	0.01
Reception	Voluntary	0.5 ± 1.0	0.0 ± 0.0	0.1 ± 0.3	0.4 ± 0.8	0.6 ± 1.0	1.1 ± 1.4	0.001
Cell	Voluntary	0.1 ± 0.3	0.1 ± 0.1	0.2 ± 0.4	0.3 ± 0.5	0.1 ± 0.1	0.0 ± 0.1	0.21
Desk	Voluntary	1.5 ± 1.3	1.0 ± 0.4	1.2 ± 1.0	1.2 ± 0.9	1.7 ± 1.3	2.2 ± 1.7	0.005
Island	Voluntary	0.3 ± 0.4	0.2 ± 0.3	0.3 ± 0.3	0.3 ± 0.4	0.3 ± 0.3	0.4 ± 0.6	0.46
Print room	Voluntary	0.6 ± 0.6	0.4 ± 0.6	0.4 ± 0.5	0.7 ± 0.6	0.6 ± 0.6	0.6 ± 0.8	0.45
Kitchen	Highly voluntary	1.2 ± 1.0	0.8 ± 0.5	0.9 ± 0.7	1.1 ± 0.6	1.2 ± 0.8	1.9 ± 1.4	0.001
Total		5.5	3.6	4.3	5.2	6	7.7	

[a]Group of individuals whose mean energy expenditure belongs in the 1st quintile of the distribution of the mean energy expenditure per individual
[b]Group of individuals whose mean energy expenditure belongs in the 2nd quintile of the distribution of the mean energy expenditure per individual
[c]Group of individuals whose mean energy expenditure belongs in the 3rd quintile of the distribution of the mean energy expenditure per individual
[d]Group of individuals whose mean energy expenditure belongs in the 4th quintile of the distribution of the mean energy expenditure per individual
[e]Group of individuals whose mean energy expenditure belongs in the 5th quintile of the distribution of the mean energy expenditure per individual

is expected to be further analyzed in future research. Based on the above, Model 1 focuses on the popular trip destinations of the kitchen and print room only.

8.5.1 Model 1. Results

Remarks

- The frequency of trips to the kitchen may be higher if it is open-plan as opposed to cellular (*p*-value: 0.05; Table 8.4).
- An increase of 1 m distance of occupants' initial location to the print room may be associated with a 5% decline in the daily number of trips to this destination (*p*-value: 0.03; Table 8.5).
- If stairs are used to reach the print room, the number of the daily trips to this destination may decrease (*p*-value: 0.16; Table 8.5).

In this work a trip has been defined as an occupant's journey within the office site. For reasons of clarity and eliminating noise from the statistical analysis, all trips have been defined as single destination ones that started from an initial office

Table 8.4 Poisson regression model results for participants' number of trips to the kitchen

Outcome	Covariate	RR (95% CI)	*p*-value
Number of trips to the kitchen	Open-plan (vs. cellular; binary variable)	2.21 (0.97, 5.04)	0.05
	Distance (m)	0.99 (0.97, 1.02)	0.62
	Stairs ≥ 1	1.03 (0.72, 1.47)	0.88
	Kitchen window opening to wall ratio	0.71 (0.41, 1.25)	0.24
	Age (categorical variable)	0.86 (0.74, 0.99)	0.04
	Female (vs. male; binary variable)	0.66 (0.47, 0.92)	0.02
	Weight (kg)	1.01 (1.00, 1.03)	0.04

RR rate ratio, adjusted for the clustering between individuals and within buildings

Table 8.5 Poisson regression model results for participants' number of trips to the print room

Outcome	Covariate	RR (95% CI)	*p*-value
Number of trips to the print room	Open-plan (vs. cellular; binary variable)	0.68 (0.17, 2.74)	0.59
	Distance (m)	0.95 (0.91, 0.99)	0.03
	Stairs ≥ 1	0.63 (0.33, 1.21)	0.16
	Print room window opening to wall ratio	0.94 (0.72, 1.22)	0.64
	Age (categorical variable)	1.00 (0.79, 1.26)	0.98
	Female (vs. male; binary variable)	0.78 (0.43, 1.42)	0.41
	Weight (kg)	0.99 (0.97, 1.01)	0.30

RR rate ratio, adjusted for the clustering between individuals and within buildings location and were directed to an office destination. More complex multi- destination trips have been broken down in distinct trips starting from different initial locations. This type of *en route* trip is expected to be analyzed in further research.

8.5.2 Model 2. Results

Remarks

- By increasing the distance of an individual's desk by 1 m from an "imperative" and a "voluntary" trip destination, the odds of making the trip to the "voluntary" destination (as compared to the "imperative") may decrease by 6% (p-value < 0.0005; Table 8.6).
- By adding one or more staircases en route to both an "imperative" and a "voluntary" trip destination we may discourage trips to the "voluntary" trip destination (as compared to the "imperative") by 61% (p-value < 0.0005).
- 10% larger window openings in "imperative" and "voluntary" trip destinations can significantly increase the odds of making a trip to the "voluntary" destinations (as compared to the "imperative") by as much as 153% (p-value < 0.0005).
- 10% larger window openings in "imperative" and "highly voluntary" trip destinations (i.e. to the kitchen) can significantly increase (by 128%; p-value < 0.0005) the odds of making a trip to a "highly voluntary" versus an "imperative" trip destination (Table 8.6).

Table 8.6 Multinomial regression results for participants' probability of a trip to "voluntary" and "highly voluntary" trip destinations as compared with "imperative"

Outcome	Covariate	RRR (95% CI)	p-value
Trip to a "voluntary" destination	Distance (m)	0.94 (0.91, 0.97)	<0.0005
	Stairs ≥ 1	0.39 (0.23, 0.65)	<0.0005
	Voluntary trip destination window opening to wall ratio	2.53 (2.22, 2.89)	<0.0005
	Age (categorical variable)	0.88 (0.68, 1.13)	0.30
	Female (vs. male; binary variable)	0.67 (0.35, 1.29)	0.23
	Weight (kg)	0.97 (0.95, 1.00)	0.03
Trip to a "highly voluntary" destination	Distance (m)	1.03 (1.00, 1.05)	0.02
	Stairs ≥ 1	0.58 (0.34, 1.01)	0.05
	Voluntary trip destination window opening to wall ratio	2.28 (1.99, 2.60)	<0.0005
	Age (categorical variable)	0.83 (0.63, 1.07)	0.15
	Female (vs. male; binary variable)	0.54 (0.27, 1.06)	0.07
	Weight (kg)	0.99 (0.96, 1.01)	0.25

RRR: relative risk ratio, adjusted for the clustering between individuals and within buildings

- By increasing by 1 m participants' initial location (i.e. their desks') distance from an "imperative" and a "highly voluntary" trip destination, the odds of making the "highly voluntary" trip (as compared to the "imperative") are likely to be influenced by 3% (*p*-value: 0.02; Table 8.6). The positive direction of this association may be explained by the fact that trips to a "highly voluntary" destination usually reflect the need for the reported change of sense of space.
- By adding one or more staircases en route to "imperative" (e.g. the toilet) and "highly voluntary" trip destinations (i.e. the kitchen) a significant (*p*-value: 0.05) reduction in the odds of making the trip to the "highly voluntary" versus the "imperative" trip destination may result (Table 8.6). The direction of this association appears as expected negative and indicates that a stair use may have a discouraging effect on participants' number of trips to the "highly voluntary" as compared to the robust and "imperative" trip destinations by 42%.

In further research where more data sets and larger populations could be tested, it may be possible to identify more variables regarding the probability of a trip to a type of destination (e.g. "voluntary") over the time spent at work.

In conclusion, work-time energy expenditure may offer in the future the possibility to increase median values of office user energy expenditure by architectural design.

Chapter 9
KINESIS Model

This research data collection and statistical analysis has explored how people move inside office buildings, where to and why. In real, practical situations, however, office design can be infinitely varied, which raises two questions: (i) is it possible to extract general laws about human movement in an office environment? and (ii) can we make them sufficiently precise and quantitative to be useful in practice e.g. as a tool in office layout design? To achieve this in full generality would certainly require an entire research program and is beyond the scope of this book. However, here we shall take an initial step in this direction by proposing a *quantitative model* that captures the main insights of the movement research data in the form of a set of equations, in order to allow us to apply these insights in an unambiguous way to new layouts. In particular, the purpose of this model is to have a practical way of estimating the total energy expenditure per person per day in a given office layout.

9.1 The Model

We model the total energy expenditure per person per day E_p to be the number of times U a certain trip is made per person per day multiplied by the energy cost.

E of making that trip:

$$E_p = U \cdot E$$

We divide trips into two categories: the first are those that are imperative, which the individual must make regardless of their distance, or any other variable. In this category we include trips to the toilet, to see the manager and to the meeting room. They occur due to physical need or office culture and are not therefore influenced by architecture. For the purpose of calculating E_p, the values of U for these trips are an input and cannot be calculated. Rather, they should be based on prior observations.

S.Th. Rassia, *Workplace Environmental Design in Architecture for Public Health*,
SpringerBriefs in Public Health, DOI 10.1007/978-3-319-53444-2_9

The second category includes all other trips. In order to calculate U we must identify which factors will be most important in contributing to the likelihood of a trip. From the statistical analysis of the previous chapter it became clear that four such variables emerged, which we now list:

(i) the trip distance d in meters
(ii) the number of staircases involved s
(iii) the ratio a of window area to wall area of the destination
(iv) a number C (=1, 2 or 3) characterizing the level of voluntariness of the trip, which is given by a pre-established table.

This leads us to the formula:

$$\mathrm{U} = A \cdot \exp(-0.029d + 0.12a - 0.48s) \cdot C$$

where

A is a proportionality factor which cannot be determined since it takes into account other environmental, cultural and personal characteristics, which are not controlled for.
This formula, is valid for trips where, $d < 50$ m and $s < 3$. In addition, we add the proviso that if the ratio a is smaller than 0.1, then we take $a = 0.1$.

A more detailed explanation of the origin of this formula will be given below. Here we only make a few preliminary remarks:

- Since the formula for U is valid only up to a proportionality factor A, it is only meaningful to compare ratios, which do not depend on A i.e., where all other factors apart from d, s, a, and C are kept constant.
- The statistical analysis has indicated the proportionality factor A = 5.25 ($\sim$5). For application to real environments A should be obtained empirically.
- We note that U decreases with the distance d and with the number of staircases s as expected although the particular functional form is not obvious a priori.
- The appearance of the window to wall area ratio codifies the psychological reward, which makes the destination more attractive (larger window area) and therefore increases the likelihood of the individual wanting to make the trip.
- Finally, C reflects the ability for the destination to attract the individual (e.g. a kitchen might attract more than the print room).

9.1.1 *Justification of Terms in the Equation for* U

In choosing an equation for U we start by making the assumption that the various variables affect U independently of each other, i.e. that U can be written as a product of functions each of which depends on a single variable. From the statistical analysis that involved 64 individuals and 4 different buildings, the average number of trips, as a function of each variable by performing Poisson regression adjusted for the clustering of observations of individuals and individuals within buildings, has been examined. Let us now consider each of these in turn.

Dependence on *d*

The Poisson regression adjusted for the clustering of observations for individuals and individuals within buildings described the relation of the number of trips per day per person as a function of distance by an exponential fit of the form:

$$\text{constant} \cdot \exp(-0.029\text{d})$$

This fit is highly significant with a *p*-value < 0.001 (Table 9.1).

Dependence on *a*

The Poisson regression of the number of trips as a function of the window to wall area ratio of the destination demonstrating an exponential fit of the form (Table 9.2):

$$\text{constant} \cdot \exp(0.12\,\text{a})$$
$$p\text{-value} < 0.001$$

Dependence on *s*

The Poisson regression of the number of trips per day per person as a function of the number of staircases in the route described the data by an exponential fit of the form:

$$\text{constant} \cdot \exp(0.48s)$$
$$p\text{-value} < 0.001$$

This data does *not* take into account trips made using the lift (Table 9.3).

Table 9.1 Poisson regression: occupants' number of trips to an office destination in relation to the distance from their initial walking location

Number of trips	Coef.	Std. err.	z	*P* > |z|	[95% Conf. Interval]	
d	−0.0285137	0.0058409	−4.88	<0.001	−0.0399617	−0.0170657
Constant	0.616697	0.1295092	4.76	<0.001	0.3628637	0.8705304

Table 9.2 Poisson regression: relation between *a* and the expected number of trips to an office space

Number of trips	Coef.	Std. err.	z	P > |z|	[95% conf. interval]	
a	0.123317	0.0198261	6.22	<0.001	0.0844585	0.1621755
Constant	−0.2199672	0.1447896	−1.52	<0.001	−0.5037496	0.0638152

Table 9.3 Poisson regression: relation between stair use and the expected number of trips to an office space

Number of trips	Coef.	Std. Err.	z	P > |z|	[95% conf. interval]	
s	−0.4841839	0.0542475	−8.93	<0.001	−0.5905069	−0.3778608
Constant	1.26	0.0898476	14,00	<0.001	1.08	1.43

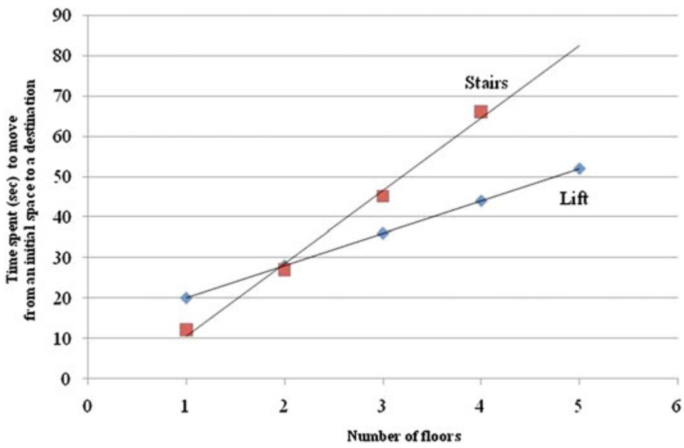

Fig. 9.1 Stair use as compared with taking the lift. The relation is based on the research data

The question naturally arises whether or not we are underestimating the number of trips to a given floor since here we are not taking into account the use of the lift. However we shall argue that, if the trip involves less than two floors, most people will choose to take the stairs instead of the lift, which would mean that, if $s < 3$ (the limit of validity of our model) then the great majority of trips are properly accounted for. Indeed there are two sources for this assumption, our own data and observations in the literature. In Fig. 9.1 we show that the time necessary to reach the destination is shorter by stairs if $s = 1, 2$ using our data.

Also the literature suggests that if waiting for a lift takes 12 s (Tyni and Ylinen 2006) and the staircase is closer to the individuals' desk, then they might be inclined to take (ascend) the stairs instead of the lift. Figure 9.1 suggests that if a trip destination is more than two floors away, then the staff are likely to prefer the lift. These two sources support our assumption faithfully in representing the dependence of the likelihood of a trip on s for $s < 3$.

9.1.2 *Method to Calculate* E *for a Given Trip*

Calculation of energy on this model is based on the physics-based energy calculation, which is in three parts: getting up, which involves gravitational energy and has been calculated by the use of Newton's formula ($m \cdot g \cdot h$); accelerating, which involves inertial energy and has been calculated by the use of Newton's formula ($m \cdot v^2/2$); and walking, that has been calculated by the use of Ralston's empirical equation (1958). As Ralston's empirical equation already predicts metabolic input, the energy calculated from Newton's formulas is useful mechanical output and thus for this analysis, a value of 20% mechanical efficiency, which is an appropriate moderately low figure for non-trained activities such as casual movement about the office (of a currently reported as poorly active worldwide office workforce; cf. International Standard Classification of Occupations 2004; Webb and Eves 2005; Whipp and Wasserman 1969). The equation derived for calculating human energy expenditure while walking on the horizontal axis reads as follows:

$$\mathrm{E} = \left(\frac{(2.0.2 + (1.33 \cdot v^2)) \cdot m \cdot d}{v}\right) + \left(5 \cdot \frac{1}{2} \cdot m \cdot v^2\right) + (5 \cdot m \cdot g \cdot \Delta h)$$

where

- E is the total energy expenditure in J, as derived from Ralston's empirical equation (1958), which can determine energy expenditure during (x, y)-level walking speed and from stationary power consumption prior to movement, plus five times (given 20% human mechanical efficiency) the inertial energy for horizontal acceleration, plus five times (given 20% human mechanical efficiency) the gravitational energy.
- m is an individual's body mass in kg.
- d is the distance walked in meters.
- v is walking speed in m/s, which has been set to 1.2 m/s.
- g is the acceleration due to gravity (9.81 m/s^2).
- Δh is the change in height of the center of gravity in meters from seated to standing position, which is estimated to be 0.4 m.

In order to also assess stair use, human energy exertion (J) has been calculated as follows:

$$E_s = \left(\frac{(2.02 + (1.33 \cdot v^2)) \cdot m \cdot D}{v}\right) + (5 \cdot m \cdot g \cdot h)$$

where

- Es is the total energy expenditure in J per stair climb. We propose that this energy expenditure is part gravitational and part "walking" which is derived from Ralston's empirical equation (1958), which can determine energy expenditure at (x, y)-level walking speed and from stationary power consumption prior to movement, plus five times (given 20% human mechanical efficiency) the gravitational energy as given by Newton's formula.
- D is the horizontal distance in meters, in a typical staircase D equals to 1.4 times h.

- h is the height ascended in meters, where this is about 2.7 m per floor where this research conjectures that an individual moves forward at a walking speed of about 0.33 m/s.
- m is an individual's body mass in kg.

9.2 Simulation

We will apply this model to a realistic layout and demonstrate how the model predicts changes in energy expenditure when the layout is modified in some way. To do this we will start with a standard layout and create new layouts each of which differ from the standard by changes in only one of the variables s, d, or a. For the sake of simplicity we will make changes uniformly i.e. in each new layout all trips will have the same variable changed by the same amount. For example, in one of the new layouts, all distances d are increased by a factor of 2 as compared with the standard. In another all destinations have their value of a increased by 20%. We then assume that the layouts are inhabited by a fixed, typical sample of individuals with known physical characteristics (body mass, etc.) and who are distributed spatially on a square grid in the open space. This is a uniform random distribution and differs from run to run. We then calculate the average number of trips and distance walked per person by averaging over runs, after which we use the model to calculate the energy expenditure in each of the layouts and compare it with the standard one.

9.2.1 A Standard Layout

Our main criterion for the standard layout was that it be realistic. We designed a functional and plausible office design environment layout (Fig. 9.2). It has been designed open-plan because it has been judged best to fit current ideas of cost-cutting office management and real estate (Table 9.4).

Spatial Distribution of Individuals in the Open Space
The model accepts as an input the number of individuals (which we have chosen to be 30 for all runs) and then, for each run, distributes them randomly inside rectangle A of Fig. 9.2 on a square grid of dimensions $(6 \cdot 12)$ so that each person occupies a node of the grid with the constraint that no more than one person can be on any grid point.

Population Characteristics
The characteristics of the population in the model come from the research data collection and correspond to data of real individuals. Individual body masses range from 50 to 102 kg, age from 21 to 67 years and equal gender distribution (50% male and 50% female).

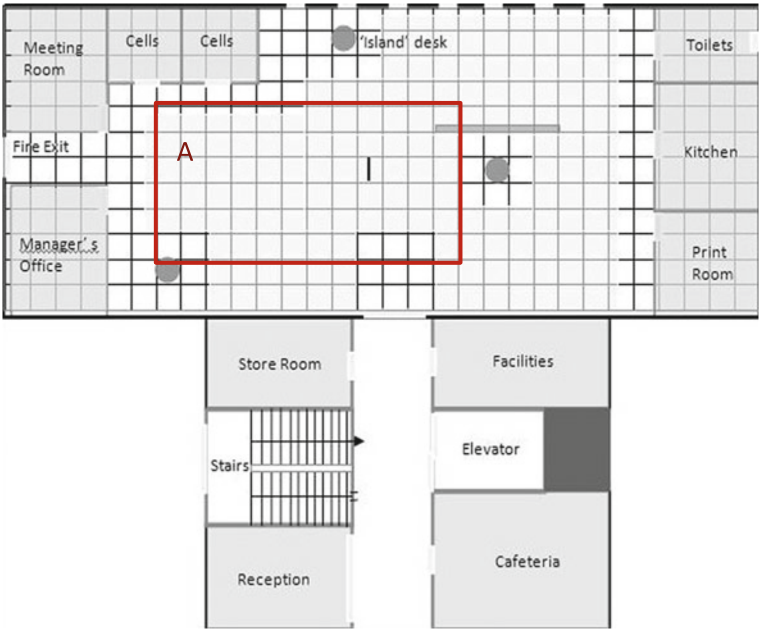

Fig. 9.2 Standard layout for the KINESIS model. The *rectangle A* indicates the area of the initial distribution of people (Rassia 2014)

Table 9.4 Standard layout for the KINESIS model

	Standard layout						
Spatial attributes	Kitchen	Print room	Cafeteria	Colleague's desk	Desk "island"	Reception	"Cell"
a	0.4	0.2	0.6	0.4	0.6	0.4	0.3
s	0	0	0	0	0	0	0
C	3	2	3	2	2	2	2

9.2.2 Modified Layouts

Five new layouts were created from the standard one:

- Small window opening (based on the research, this is considered as a smaller reward for physical activity): **a** decreased by 20%
- Large window opening (based on the research, this is considered as a higher reward for physical activity): **a** increased by 20%
- Short distance (change in the building form): **d** decreased by a factor of 2
- Long distance (change in the building form): **d** increased by a factor of 2
- Multi-storey (introducing vertical circulation): **s** increased by 2.

Results and Discussion

See Tables 9.5 and 9.6.

Remarks

- The simulation results agree overall with the previous chapter that an increase (or resp. decrease) in *a* leads to an increase (or resp. decrease) in number of trips and energy expenditure; likewise, the behavior with *d* is reflected as expected.
- As expected also, the number of trips decreased when *d* and *s* increased. What was not clear in advance was whether the energy expenditure would also decrease since individuals consume more energy when walking for a longer distance or using the stairs. KINESIS estimates energy expenditure increase by 18% from the standard when the distance increased and 40% decrease from the standard if an individual would have to walk up 2 staircases to find an office destination.

Table 9.5 Average work-time number of trips (*U*) per space and scenario

U	Kitchen	Print room	Cafeteria	Colleague's desk	Desk "island"	Reception	Cell	U total	U total difference from standard
Standard	2.10	1.29	1.70	1.76	1.75	0.88	1.64	11.13	
Large window opening	2.52	1.55	2.04	2.12	2.11	1.05	1.97	13.36	20%
Small window opening	1.68	1.03	1.36	1.41	1.40	0.70	1.32	8.90	−20%
Short distance	2.57	1.62	2.34	1.92	1.94	1.36	1.85	13.61	22%
Long distance	1.40	0.81	0.90	1.48	1.43	0.37	1.30	7.69	−31%
Multi-storey	0.89	0.49	0.65	0.68	0.67	0.34	0.63	4.26	−62%

Table 9.6 Average work-time energy expenditure (*Ep*) per space and scenario

Ep	Kitchen	Print room	Cafeteria	Colleague's desk	Desk "island"	Reception	Cell	Ep total (kJ)	Ep total difference from standard
Standard	732.73	508.32	903.48	296.87	335.08	625.41	351.20	3753.09	
Large window opening	879.28	609.99	1084.17	356.24	402.10	750.50	421.43	4503.71	20%
Small window opening	586.19	406.66	722.78	237.49	268.07	500.33	280.96	3002.47	−20%
Short distance	490.70	347.01	659.68	193.28	217.09	505.26	227.29	2640.30	−30%
Short distance	930.90	612.83	952.36	450.61	500.35	512.03	514.46	4446.54	18%
Multi-storey	433.73	288.71	470.34	242.44	256.43	303.67	254.54	2249.86	−40%

For 9 h day (equivalent to a working day) sedentary energy is equal to 3240 kJ

Chapter 10
Discussion

10.1 Architecture, Occupant Activity and the Management of Office-Space

Focusing, in this research, on increasing occupants' daily physical activity (i.e. the effort of movement by, for instance ascending stairs) has suggested the importance of designing for architectural "rewards" for movement. In relating occupant trips through the office architectural layout characteristics, this research considers spaces for their relation to spatial navigation and visual gratification that could offer a psychological and physical benefit. A spatial attraction of different activities and occupancy levels may lead to an indoor design articulation of office spaces. Attractors, links and rewards for movement follow the contemporary issues of flexibility of office occupancy and employee interaction.

The focus of this research on office layout in relation to movement may have consequences for office organization as a whole in understanding office management and work coordination. The rationale for this is usually functionality, with architectural planning envisaging economy in the sense of the minimization of movement. Traditionally, a company consists of a production apparatus, a marketing apparatus and development activities, with all functions being sited under one roof (cf. Hascher et al. 2002). On the production side, physical activity is minimized due to capital-intensive facilities of different enterprises that are merged into one space. When architecture follows management's lead in aiming to maximize organizational productivity, it tends to propose designs where occupant close-clustering is suggested according to job description in self-sufficient groups (with their own secretary helpdesks and IT facilities). This clustering can create social separations between working groups, partly through *force majeure* and partly to facilitate in-group communication and to strengthen employees' identification with their immediate team.

Structuring space and work relations very rigidly in clusters (Joseph et al. 2005) may often lead to suppressing circulation, especially through offering IT resources.

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IT integrates the office spaces and may transform them into higher density environments, placing all necessary tools for workers' production in close proximity. Work is then produced (whether through keyboards or printers) according to the formula of the least physical effort on the part of the workers. The time and energy saving for office workers, may then relate to a decrease in physical activity levels. This decrease in activity is implicit in the rationale of IT as shown by Redmond's (2005) Microsoft® Office survey announcement for office users' levels of work-time exhaustion. IT integration in office spaces and its consequences for industrialization show no signs of declining. To some extent, however, space-use efficiency and IT "information economy" have placed also a great premium on spontaneous, unscripted face-to-face communication where "meeting points and opportunities for unplanned communication are still as important as ever" (as stated by Thomas Arnold and Birgit Klauck in: Hascher et al. 2002).

Insofar as study observations support the hypothesis that the centralization of space management, together with clustering practices, are likely to decrease the number of steps taken by office occupants, designing configured spaces as decentralized could increase levels of activity. Ideally, architects would shape occupant movement by setting up a "game" in which users are rewarded for journeys by a sequence of visual or other functional rewards to find, for example, the printer or the kitchen. These trips could also serve other purposes, such as offering employees information regarding additional workplace senses of identification. This would mean that organizational patterns would "break" existing clusters into multidisciplinary groups. More radically yet, groups could be set up so that although most workers could be clustered, a number of workers could be located at a certain proximate walking distance from their closely interacting colleagues so as to induce movement for job interaction. This might stimulate co-workers to walk in order to carry out face-to-face communication and thus could, according to Hascher et al. (2002), induce team productivity.

The National Institute for Clinical Excellence has suggested that managers should improve working conditions to reduce job absenteeism, which on the real estate front translates into higher organizational profit (Bordass and Leaman 1993). Daylight, a view of the outside (through a window), fewer deep-plan spaces with functions that are not too far from each other are also supposed to induce productivity and organizational profit (Bordass and Leaman 1993). Saving finances and building energy may additionally lead to the design of open-plan spaces as opposed to cellular, where managers are usually, by design, able to keep track of closely clustered staff members' performance (Leaman's work at Usable Buildings Trust). However, aiming to induce productivity centrally by open-plan designs may cause office users a sense of a relative lack of privacy. According to Adrian Leaman's work (2009), especially when seated in the center of an open-plan space, this can cause worker dissatisfaction, complaints, the feeling of disturbance and the need to "escape". For this reason, the provision of comfort, the promotion of desk proximity and environmental control (Leaman 2000, 2001, 2009) seems very important when designing an office space. Overall, management in conjunction with Post-Occupancy Evaluation (P.O.E.) strategies concur that the space should be designed in a non-complex way to provide occupants a relative freedom to make decisions, be productive, healthy and remain satisfied.

10.1.1 Challenges

The exploratory nature of this research has provided an understanding of the ways office users move inside buildings and their levels of activity that could be stimulated by architectural design. In researching the topic of "designing for movement" a number of achievements have been made and limitations had to be faced.

In working directly to identify and explore ways to influence occupant energy expenditure and therefore the effort of making a trip without dissatisfying office users, it has been central in this work to identify what may affect human perception and the value of "rewarding" for movement. This has been a demanding task as human perception is a subject of human psychology, idiosyncrasy, previous knowledge and experience.

In exploring the relation between the activities of occupants within office worksites, it has been noticed that office buildings and their use can vary considerably. That is why precise and generic causal relations are difficult to demonstrate, validate and calibrate. As Gary Raw (Usable Buildings Trust), has noted, "people are the most valid measuring instruments: they are just harder to calibrate!".

Exploring the effect of buildings on human physical activity seems diverse and complex. As people may walk at different speeds and for different purposes, office environment layouts are very rarely the same. An office space may be designed for different managerial purposes where users may be clustered (e.g. according to their job requirements) or spread around the office site. Office layouts may be open-plan, cellular or a combination of both. They may also involve one floor only, an atrium or a mezzanine. Office spaces may be part of a high or low-rise building. Indoor office environments also seem complex as their spaces may be both job-related and recreational (Evans and McCoy 1998). In trying to identify reasons for occupant activity, Leaman's (2001) work for "what occupants want" has been reviewed, where he suggested that occupants may not be very concerned with, for example, the pleasantness of the space as, he suggests, they really would not wish to be there in the first place. This research based on its analysis understands that the aesthetic pleasantness and job-related space choice may be heavily dependent on individual preference, perception and personality. For example, the choice to move closer to a window (as observed, for example, in Site F) in order to carry out concentrated work, may be based on both job-related and aesthetic qualities offered, which may induce a different sense of space.

Although various means are currently available to measure physical activity and a number of studies on human perception and activity have been carried out to identify: what constitutes a "far" or "near" location of a walking destination (Stevens 1959; Scharf and Stevens 1961; Kunnapas 1960); the effect of aesthetic interventions (e.g. by changing the colors on the walls to a more vibrant tone) on movement; and the impact of spatial "cues" on human well-being (Evans and McCoy 1998) and activity, it still seems a demanding task to measure objectively indoor activity and its location.

The novelty of this research means that validation data are not available yet to back up or serve as a basis of comparison with the present study data. Furthermore, in breaking new ground, this research combined new techniques for recording activity and trip destination within office buildings, i.e. through interviews, observations and accelerometer readings. In building up a sufficiently multivariate picture of the relation between workers' activities and their workspaces, it has, however, been possible to develop a self-validation method for hypotheses linking office environment use to users' physical activity levels and energy expenditure. This has been achieved by synchronizing the use of the Active Bat and Actigraph systems as well as its data collection observations and interview results with its physics movement models.

Aiming to collect objective information on occupant movement within the office site, this work has incorporated the use of Actigraphs lent by the Epidemiology Unit of the Cambridge Medical Research Council. This equipment has been used as it is suggested to be more reliable (Corder and Ekelund 2008) in its outputs as compared, for example, with pedometers. However, these have also involved some non-negligible limitations. First of all, they have no means of indicating of the place where the wearer's activity is carried out. Its output is continuous and requires diaries to be filled in by the users in order to have a clearer indication of whether, e.g. an individual was moving inside the office or outside (or using the gym). Additionally, although use of the accelerometer may be more sophisticated than e.g. that of the pedometer, its output is dimensionless and given in *counts* measured for physical activity intensity on the horizontal axis. As the Actigraphs are uni-axial they cannot specifically and clearly demonstrate human energy expenditure in moving against the vertical axis, such as when ascending and descending stairs or simply getting up and sitting down. Note that ascending and descending stairs can increase the intensity of activity to a moderate level (Webb and Eves 2005).

Converting the Actigraph *counts* in a standardized dimension of Joules of human energy expenditure has also not been an easy task. Current literature demonstrates this, as discussion and research of a large majority of health scientists still seeks to identify the most appropriate and accurate method of assessing and converting Actigraph *counts* into Joules. The equation that has been most widely used in order to approach this convertion leads to the estimation of human energy expenditure in kcal/min. This is the Freedson equation (1998) and has been used in this research. This equation, however, measures only activity that is above the moderate threshold of 1952 counts/min. It measures activity above the R.M.R. and B.M.R. levels, and focuses on walking at a brisk pace and above, which is rare inside the workspace. For this reason, in order to calculate total individual energy expenditure over a day at work it has been decided in this research to calibrate Freedson's equation with the Ralston equation (1958) which provides an empirical method of calculating energy expenditure at walking speed and stationary energy expenditure prior to movement (of approximately $2.02m$, where m is the individual's body mass in kg).

Actigraph accelerometers have also been shown unable yet to determine specific muscular movement and individual mechanical efficiencies. Muscular movements require energy and moving against a force over a distance. Accelerometers cannot for example, show that an individual was weightlifting. It can neither measure the mass of the load lifted nor the effort expended. It will, however, provide an activity intensity and duration record.

This research sees its contribution in its self-calibration by endorsing the occupant location mapping Active Bat physics models in synchrony with the Actigraph accelerometers. The physics models are based on Newton's laws of motion and seem to be closely associated with the calibrated Actigraph accelerometer model (that takes into account energy expenditure at (x, y)-level walking speed and the stationary power consumption prior to movement). It should also be remembered that the human body does not work at 100% efficiency. Adding a value for mechanical efficiency has been the result of discussion with health advisors and was included in the research models as an estimated representative value for human medium-to-low mechanical efficiency (i.e. 20%; Whipp and Wasserman 1969) for, e.g. the relatively sedentary U.K. office workforce (Brassington et al. 2002). Calculating human energy expenditure by including values for mechanical efficiency is a topic for further interdisciplinary research.

It should be moreover mentioned that for logistical reasons (requirement for incorporation in the building infrastructure), the Active Bat system could not be widely used in all research data collections. Accordingly, the statistical analysis was based on observational data rather than objective location mapping. This might have resulted in some missed information. Also, by observation, it has been possible to gain a better understanding of reasons for occupants' movement around the office, that could probably not otherwise be suggested (i.e. "voluntary" vs. "imperative"). Statistical analysis that has measured open-plan and cellular, conventional rectilinear and more flexible spaces, has also further tested a way that could lead to higher levels of occupant energy expenditure by architectural design. Further work could aim to expand the current data collections in places where the Active Bat would be used. It could also work on larger datasets and delve into their computational and logistic challenges (that appeared during the AT&T Laboratory analysis) of extracting data from a large multivariate work.

Further work could also extend to measurement of greater ranges of mechanical efficiencies and walking speeds within a larger variety of office spaces and management cultures. Extending this work's statistical and KINESIS models at a theoretical and practical analysis level could lead to adapt to a design-time tool (such as the AutoCAD or a building energy model) for architects to estimate physical activity levels, energy expenditure and space-use from the architectural design stage.

In further aiming to benefit public health by design, it should be noted that there are currently no thresholds above which an increase in physical activity becomes clinically significant. Similarly, there is no threshold below which a lack of physical activity is associated with increased risk of disease and above which risk is negligible. The public health recommendation of 30 min of physical activity is offered as guide and health scientists emphasize the importance of increasing the distribution of energy expenditure nationally and not only of sedentary groups. In such cases, they suggest that fewer people will remain inactive as the overall population's daily energy expenditure increases (N.H.S. Department of Health 2000, 2003, 2004, 2008). This research has taken the general guideline into consideration and has recognized the need to avoid making any activity classifications or categorizations among its population sizes. In line with expanding this research to incorporate the above, new design ideas for flexible office working and higher productivity levels that may lead office design in the next few years to become less personalized, common and shared, and more network-based, could be taken as a further research challenge. This research hypothesis is that by designing for "rewards" (in terms of both health and satisfaction), the workplace may be given a new presence and a new multifunctional definition aiming for higher job interaction. Engaging and reinforcing the best aspects of an existing space, or making new interventions, could then have a beneficial effect on overall space-use and derived inhabitation capacity, effectiveness to promote physical activity and consequently public health.

Conclusion

The novelty of this work has been to study and measure how architectural design influences physical activity in offices. The aim has been to identify whether influencing population-wide levels of activity *through office tasks alone* may be possible. Monitoring evidence has shown that although a substantial part of the office day is spent seated at the desk (reported to be no less than a mean of 70% of the work-time), on average, physical activity during work-time may occur at greater levels than during leisure-time. An architectural vocabulary has been introduced to assign spaces with a value in promoting different purposes of activity. Activity purposes have been related to physical, job-related imperatives (e.g. going to the toilet, meeting the manager) or with more "voluntary" purposes (e.g. walking to colleagues' desks or to the kitchen). The statistical analysis and KINESIS model have suggested that the probability of a "voluntary" trip to an office destination is a function of the effort (distance walked and stair use) required and spatial "reward" (window opening) related to the trip destination.

In exploring the overall complexity of the topic of "designing for movement", this research has faced a number of challenges and has broken new ground by monitoring human physical activity in office buildings. Future research will aim to validate, extend and expand existing models; focus on a larger variety of environmental design layouts; design and test different KINESIS layouts and combinations, and assess different office management cultures and larger samples. A further question is whether the new workplace design for flexible working and incentive schemes, as currently promoted, can provide a solution to consuming less building energy and expending more human energy. A preliminary assumption, especially regarding the minimization of the use of lifts and the increase of natural lighting by larger windows, is that building efficiency, space -use effectiveness and public health can be achieved by design.

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Glossary

Technical or quasi technical terms drawn from a variety of fields (including health-related, social science and applications of architectural theory) are presented here. Starred (*) words below have been introduced for the purposes of this research.

Architectural design Indoor environmental layout characteristics (e.g. open-plan or cellular, existence of stairs, window openings).

Attractors* These are office space configurations that have been shown to invite users' movement. In the cases of the sites under investigation, these were the kitchen, coffee and tea stations, toilets, print room, common areas and other offices in which users congregated over the day at work.

B.M.R. Basal metabolic rate: The minimum amount of energy required by the human body for lying in a state of physiological and mental rest.

B.M.I. Body mass index: A statistical method of comparing an individual's height and weight in order to identify potential weight-related problems such as obesity. The B.M.I. is given mathematically by the ratio of the individual's weight (kg) divided by the square of the individual's height (m).

Cellular office space An office layout composed of adjacent enclosed spaces.

Desk "Islands" Desks placed haphazardly or informally within the office space to enable quick and informal meeting.

D.I.T. Diet induced thermogenesis: Also called post-prandial thermogenesis (P.P. T.) or the thermic effect of food (T.E.F.). It accounts for about 10% of the total energy intake of a mixed western diet and it is the amount of energy used in digestion, absorption and transport of nutrients.

Dynamics of movement The variety of physical activity levels and intensity during time awake or a set research time-span.

Dynamics of space A system of dependent spatial attributes that can direct individuals' or groups' work-time physical activity.

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Energy expenditure (E.E.) Humans oxidize (metabolize) carbohydrate, protein and fat to produce energy and maintain body functions (e.g. breathing and heartbeat). Energy expenditure can be measured in joules (J), kilojoules (kJ) or calories (cal) and kilocalories (kcal). As the nature of "work" is constantly changing, with the use of technology and the growing use of machines that replace human activity from the building site to the household, bathroom or kitchen, these activities become less time-consuming and less human energy-demanding.

G.I.S. Geographic Information Systems.

H.V.A.C. Heating, Ventilation and Air-Conditioning: This acronym is used in work related to indoor environmental comfort.

Home* This is an individual's office workplace.

IT Information Technology.

Leisure-time Time spent away from the office worksite. This may include travel (e.g. to and from work), lunch (away from the office worksite), exercise, sleep and household activities (e.g. cleaning, gardening).

Link* Indoor office circulation routes and zones. These may be corridors, stairs, atrium stairs and elevators.

MET The Metabolic Equivalent of physical activity intensity, a term commonly used in health-related sciences to express metabolic rates.

Movement* The physical action of walking from e.g. an individual's office desk to destination. It is defined as an activity within the topography of an office space.

Office hours Hours spent within office configurations performing tasks.

Open-plan space An office layout where all office spaces and functions co-exist in a single space that is unobstructed by designed partitions such as walls.

Physical activity (P.A.) "*Physical activity is any bodily movement produced by skeletal muscles that results in energy expenditure…*". (see: U.S. Department of Health and Human Services 1997)

Power The rate at which a human body expends energy at a given time. This in the metric S.I. system is expressed in Watts , that is Joules per second.

R.M.R. Resting metabolic rate: The minimum metabolic rate required by the body in order to support its basic physiological functions, including breathing, blood circulation and all the numerous biochemical reactions needed to sustain life. The R.M.R. generally accounts for 60–75% of human total daily calorie expenditure.

Rewards* Architectural design rewards for occupant movement are mostly visual or social and provide some interest, encouragement and satisfaction to the office users who perform a task around or near them.

S.I. The international system of units which is abbreviated from the French *Système International d' Unités.*

Trip* This is an occupant's journey within the office site. This journey is assumed to always start from an initial office location (i.e. a desk) and end at another office location (i.e. the kitchen, another person's desk). We have assumed all trips within the worksite to be single, from location A to B, and not en route (multiple destination). For reasons of clarity and of eliminating noise from the research statistical analysis, it has been agreed that multiple-destination trips will be broken down into distinct trips starting from different initial locations. This more complex type of journey is expected to be analyzed in further research.

Voluntary trips* Trips that have an alternative of not being made; however, they are carried out. Levels of voluntariness may range between three categories ("highly voluntary", "voluntary" and less "voluntary").Less "voluntary" trips mainly due to physical or job related purposes (e.g. going to toilet, meeting the office manager) are also defined in this work as "imperative".

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