Movement and Orientation in Built Environments: Evaluating Design Rationale and User Cognition

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Movement and Orientation in Built Environments: Evaluating Design Rationale and User Cognition

Veracruz, Mexico
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An **EDRAMOVE** intensive in collaboration with the **SFB/TR8 Spatial Cognition, Germany**

***Organizers*:** Saif Haq, Christoph Hölscher, and Sue Torgrude

***Reviewers*:** Simon Büchner, Reginald Golledge, Magda Mavridou, Riklef Rambow, Alasdair Turner Jean Wineman, Craig Zimring

Although architects shape human movement and cognition through the process of designing buildings, their conceptions about these basic processes may not match those of the users. Movement and cognition in built environments is usually investigated from the perspectives of either the user or the designer. This intensive will provide an open forum to bridge these perspectives in an effort to link design and research. Specifically, this workshop will feature:

- Studies about the intentions that architects have regarding shaping human movement and human cognition in space as well as investigations into relevant knowledge employed by designers for these activities.
- Studies about human movement and spatial cognition, both in real settings and under controlled experimental conditions (e.g. virtual reality studies)
- (Technical) design support tools to improve the planning process and evaluation of future buildings with respect to anticipating and shaping human movement.
- Evaluation techniques: observations in the field, spatial analysis methods of existing and planned building layouts, agent studies.
- Cognitive mapping research: impact of environmental structure on navigability, memorability, perception and appreciation.

Most importantly, it will provide a forum for sharing and 'linking differences' of various approaches to studying and applying design rationale and stake-holder cognition, with special emphasis on human movement and orientation.

The electronic proceedings documented in this volume include extended written contributions representing 9 oral presentations and 3 posters accepted for the EDRAMOVE intensive session.

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Learning and Navigating Built Environments: How Spatial Cognition and Behavior Relate to Environmental Form

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1 Introduction

How to understand the interplay between people and their built surroundings and then how to inform planning and design with that research are questions I am addressing with my background in cognitive psychology, computer science, and human geography. Large outdoor environments like urban squares, city neighborhoods, and university campuses are of particular interest, I believe, because many competing interests and constraints must be balanced, and oftentimes development only proceeds in piecemeal fashion. Sets of buildings can be similarly complex—consider a hospital, an indoor shopping mall, an airport, or simply the phrase "a building complex."

In my studies of these settings, I pair behavioral measures of users with models of those environments' physical form. Previous research has described the cognitive architecture of spatial cognition, yet much of this work has ignored people's surroundings and the role that physical barriers, architectural details, landscape features, and such play in navigation, orientation, memory encoding, learning, and other components of spatial cognition and behavior. Modeling the salient details of environmental form has allowed me to retain the careful controls of experimental psychology while also considering environmental context with formal, quantitative methods.

I would like to present a pair of empirical studies, which are representative of my broader work. Automated computer systems collect data from human participants; models of environmental form, constructed for the study areas, provide quantitative measures; and these two sets of results combine to explain—at least in part—the interplay between people and their built surroundings. Cognitive scientists have an established theoretical interest in these matters; planners and designers can also benefit from applying such techniques for automated data collection, quantitative data analysis, and environmental modeling.

[1] The U.S. National Science Foundation supported the preparation of this paper through the Interactive Digital Multimedia IGERT (grant number DGE-0221713) and a Graduate Research Fellowship. Additional information on the two studies is available on-line at: http://drew.dara-abrams.com/research/

2. Students' Spatial Knowledge of a University Campus

2.1 Introduction

Through contact with an environment, people acquire spatial knowledge. This study considers the relationship between those internal representations and external structure by pairing behavioral measures of spatial knowledge with quantitative measures of physical form.

A set of computational techniques known as space syntax can be used to model the form of an environment. These models rest on a simple distinction between "open" space, which is permeable to sight and/or movement, and "closed" space, which blocks sight and/or movement. Visibility graph analysis (VGA), one such technique, evaluates the visibility/accessibility between grid points in open space, producing a graph that represents an environment's topological connections.

To investigate whether these models schematize environments as people do, I used VGA to model a university campus and then compared measures extracted from that model with tests of students' spatial knowledge of campus locations.

2.2 Methodology: Measuring Students' Spatial Knowledge

A total of 57 undergraduate students at the University of California, Santa Barbara (UCSB), participated. Each completed a demographics questionnaire, three tests of spatial ability, a pointing task, a map arrangement task, and a building familiarity questionnaire.

The pointing task asked participants to imagine standing at a given building and to point to another (off-screen) building by rotating a 360-degree panoramic photograph. The map arrangement task asked participants to create a map of the campus by "dragging and dropping" 39 properly oriented "cutout" building pieces on to a background image that included the outline of the campus lagoon along with the coastline that bounds two sides of the campus.

2.3 Methodology: Modeling the Campus Environment

I mapped visibility on the ground plane of the UCSB campus and then performed VGA on the base map using DepthMap (software from Alasdair Turner, University College London), which laid a uniform grid over the map. A graph was then created, with nodes representing grid cells, and DepthMap's VGA algorithm connected the nodes for those grid cells that were mutually visible. For each building, I manually averaged measures over a one-cell buffer.

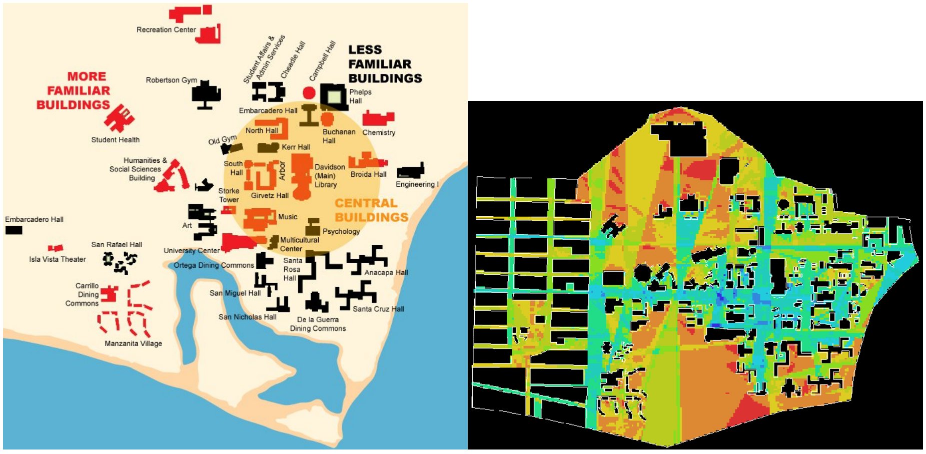

Fig. 1. Left: The 39 buildings included in the study. Right: A visibility graph of the "open" space on campus. Entropy, a measure of complexity, is plotted, with redder colors indicating more spatial organization, and bluer colors indicating less.

2.4 Results

Regression analysis showed that the VGA measures significantly predicted performance on the tests of spatial knowledge, above and beyond other effects. Participants more accurately placed cutout pieces for buildings with higher clustering coefficient measures and lower control and controllability measures. And participants pointed with more accuracy from buildings with higher entropy measures and lower relativized entropy measures. Participants with higher sense-of-direction performed significantly more accurately, and those with better perspective-taking abilities pointed more accurately, yet these individual differences were independent of the VGA predictors. Participants were more accurate for buildings they rated as more familiar, but again, this effect was independent of the VGA predictors.

2.5 Conclusions

This study demonstrates that a model of environmental form can be used to predict the accuracy of people's spatial knowledge. The model presumably highlights environmental features relevant to spatial cognition. That different sets of measures predict performance on the pointing and map arrangement tasks begins to suggest which properties influence which cognitive tasks, a question I intend to probe further with experimental manipulation.

3 Learning the Layout of a New Building

People's spatial knowledge is only considered at one static point in time in the first study. With this second study, I have considered the acquisition of spatial knowledge over a period of months. At UCSB, the main psychology building was recently expanded with the addition of an east wing, separated from the main building by a courtyard. The two buildings, both of which are three stories tall, are connected by causeways on both upper floors. When the addition opened, faculty members and graduate students found available to them a total of four staircases, two elevators, and two elevated causeways, not to mention angled and orthogonal hallways in two buildings. Mary Hegarty (professor, Department of Psychology, UCSB) and I followed faculty and students during their first year in the newly expanded complex. At three time points, participants wrote route directions between specified rooms, one always in the old building and one always in the new. By plotting out the directions, we could identify whether participants chose to follow the shortest path or whether they instead apply a different wayfinding strategy.

Wayfinding strategies that people use in indoor environments and those that they use in outdoor environments have been enumerated by others' research. Of particular relevance here are those identified by Hölscher, Meilinger, Vrachliotis, Brösamle, and Knauff (2005): The central point strategy tells you to first travel to the part of the building you are most familiar with and then proceed from there; the direction strategy tells you to begin by heading in the direction of your destination; and the floor strategy tells you to first move to floor of your destination. In the case of the psychology buildings, the central point strategy guides people down and out to the central courtyard, and so I here instead call it the ground strategy.

As can be seen in the plots on the following pages (Figures 2, 3, 4), participants used all three of the strategies. Use of the ground strategy fell as people became more experienced with the buildings, but use of the direction and floor strategies depended more upon individual preference.

Similar to the first study, I have also modeled the physical form of the psychology buildings. Comparing the set of routes with the measures of a visibility graph analysis suggests the basis in floor plans and architectural details of how route choice preference develops over time. These results, and others, I would like to share with workshop attendees.

Fig. 2, 3, 4 (on the following pages). Routes selected by the study participants. In each figure, the routes are color coded by strategy (direction = blue, floor = purple, ground= orange) and the percentage of participants using each strategy is plotted in the bar charts at bottom.

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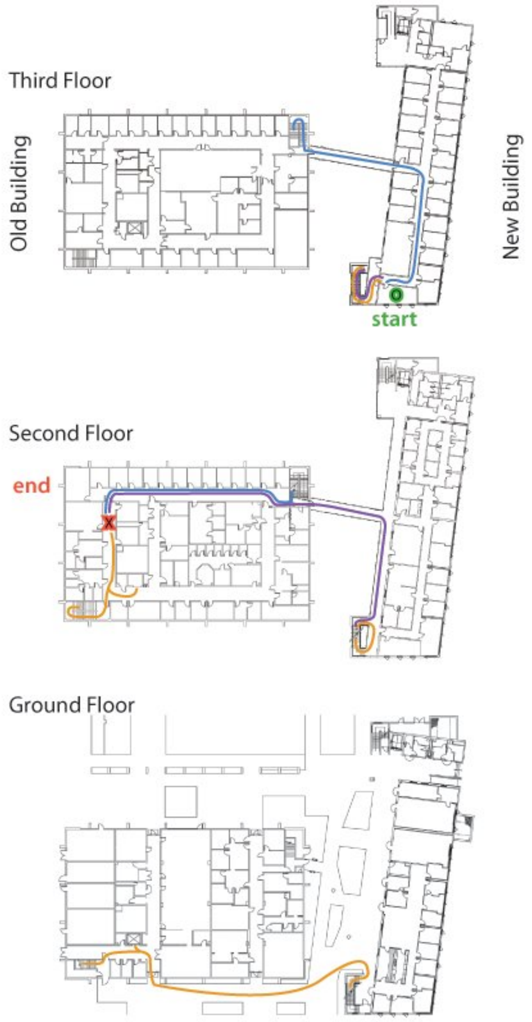
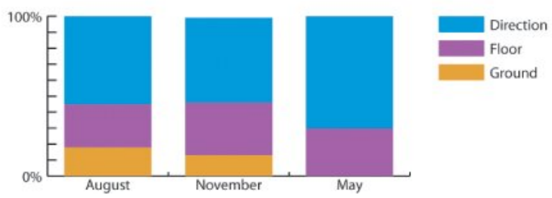
Route 1



Third Floor
Old Building
New Building
start
Second Floor
end
Ground Floor

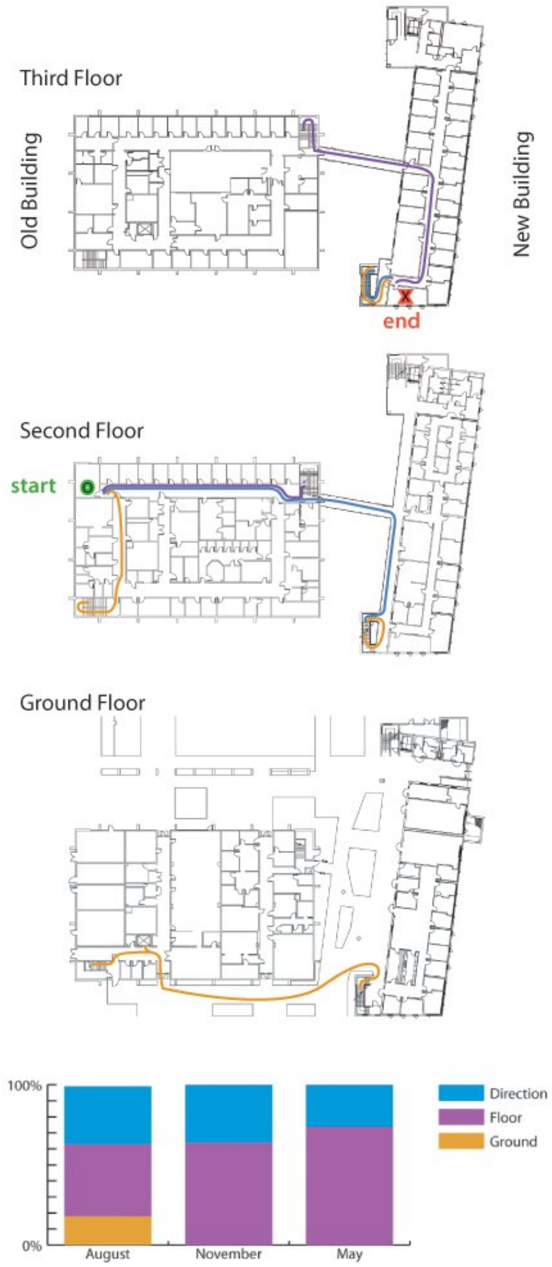


100%
0%
August
November
May
Direction
Floor
Ground

Route 2


Third Floor
Old Building
New Building
end
Second Floor
Ground Floor
start
100%
0%
August
November
May
Direction (Other)
Direction (Back)
Direction (Side)
Direction (Front)
Floor (Front)
Floor (Back)
Ground

Route 3


Third Floor
Old Building
New Building
end
Second Floor
start
Ground Floor
100%
0%
August
November
May
Direction
Floor
Ground

The Architects' Understanding of Human Navigation*

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1 Introduction

Orientation can be a challenging task for visitors of complex public buildings like airports and hospitals. The common way of putting the issue in the field of human spatial cognition is to ask what makes a building difficult. But investigating what constitutes the legibility of built environments seamlessly leads to the role of the architectural designer who shapes this very environment to a large extend. Describing the properties that make built space adequate for human spatial cognition on the one hand and understanding how these properties can be achieved within architectural design on the other hand are inextricably linked.

Architectural design processes have been studied intensively in the Design Cognition community (see for example Akin, 1986 and Goel & Pirolli, 1992). Some researchers touch wayfinding issues in architectural design: Weisman, 1981 for example identifies factors of architectural legibility, Arthur and Passini (1992) give a prescriptive model for systematic wayfinding design. While wayfinding cognition and design cognition are both investigated as separate topics, the reasoning of architects when they actively create wayfinding-friendly designs is not well understood. As a consequence of this situation, there is a lack of theoretical background for effective tool support and professional training. The fact that wayfinding is mostly treated implicitly in the discipline of architecture tells its own tale.

Nevertheless, it is theoretically possible that architects are able to create navigation-suitable designs although rarely reasoning explicitly about the users' navigation. Goldschmidt (2003) identifies both declarative and procedural knowledge as important in the design process.

Whereas *explicit* wayfinding design knowledge refers to everything that designers do with the intention to improve their designs in terms of navigability *implicit* wayfinding design knowledge subsumes all aspects in architectural design which have wayfinding related consequences but are not considered as such by the architectural designer. To address such implicit and wayfinding related design knowledge the present study discusses real life example cases. Brösamle and Hölscher (2007) discuss the role of example cases and design tasks for the investigation of implicit design knowledge in more detail.

* We would like to thank our interview partners for their helpful information and patience.

Brösamle and Hölscher (2007) found that wayfinding difficulties in an existing building could quite often be identified based on building plans alone. With respect to the anticipation of user behaviour, however, the conclusions were largely inconsistent among their informers. The study concludes that the systematic anticipation of the users' situation immersed in a complex building is a demanding task for the designing architect. The present study therefore focuses on techniques and concepts in architectural design which are used by architects when they reason about the wayfinding complexity of built space. Conclusive remarks evaluate these techniques and concepts in the light of existing wayfinding cognition research.

2 Methods

In a series of semi-structured interviews we discussed concepts and techniques in architectural design in relation to navigation and orientation. Twelve architectural designers and planners volunteered to participate in our study. They all have been working in architecture companies for several years, some of them had closer contact with formal analytic techniques, e.g. space syntax (see for example Bafna, 2003). In order to account for implicit wayfinding design knowledge we asked our informers to give critique on two different example cases and to discuss possible wayfinding difficulties in these cases. Both cases where based on real buildings with known navigation difficulties. For each case the discussion started with a general *investigation phase*. Subsequently, the interviewers prompted for wayfinding related issues by posing *navigation-related questions* on possible navigation difficulties and requested informers to anticipate the behaviour of users in the building.

Data Collection and Analysis: During the interviews videos of the sketching area were recorded in order to capture drawing actions and pointing gestures on the drawings as well as verbal utterances. The audio tracks of the videos were transcribed and the resulting transcripts were related to the sketchmaps. This was done by numbering each sketching element and tagging the corresponding positions in the transcript text. The interview material was then segmented and analyzed according to semantic content, use of examples, provided definitions, metaphorical expressions and reference to spatial elements in the drawings.

3 Results

Investigation phase: Participants analyzed the presented example cases primarily along the main circulation. This is mainly reflected in the extensive use of circulation-related vocabulary and frequent reference to main corridors, axial lines and other elements of the circulation systems. When drawings or overlay diagrams where produced, these often refer to corridors, stairs and visitor flows (Fig. 1). Some informers verbally stated having analyzed the building from the main entrances along the main circulation as if they would enter it themselves. Functional categories, e.g. use, played an important role in this first investigation phase as well (see also Brösamle & Hölscher, 2007).

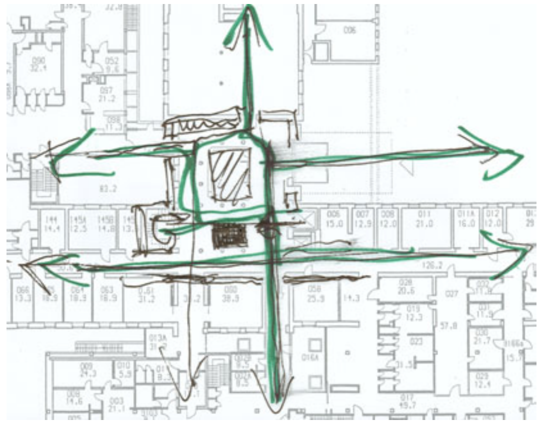

Fig. 1. Informer analyzes main pathways and visitor flows.

Navigation-related questions: While the terms “circulation” and “use” are widely mentioned spontaneously in the investigation phase *visibility*-related utterances mostly occured in those situations when the interviewers actively drew the informers' attention to navigation and orientation issues.

When asked to analyse floor plans in terms of legibility our informers often did this by evaluating the visibility of different navigation options from possible locations and views a user might have when immersed in the building. For example, they realize that the visual contact to an important junction is broken by some part of the interior. However, the anticipation of possible usability issues from a users perspective is not done consistently across informers. Rather, locations looking interesting from the plan view are considered and in a second step the visibility and occlusion of relevant objects from this location are evaluated. The result strongly depends on the chosen location and (at least in our interviews) locations were seldom considered in a systematic fashion.

Verbal comments emphasize atria and other open spaces across levels as a means to increase visibility and thus to communicate a building's structure to its visitors. Atria are not thoroughly recommended by all our participants, though.

Finally, there is a tendency among our participants that those who are involved in hospital design provided more detailed analyses of usability-related factors compared to those who are not.

4 Discussion

The tools and techniques in architectural design focus on the building, in particular its structure its form and other properties. This building-centred view is reflected in the frequent use of categories that are strongly related to the organization of the building in space. Working in plan, making sections, representing spatial and functional relations in bubble diagrams all have in common to look from an overview-like perspective which presents many parts of a building simultaneously. Exactly this property makes them powerful tools for understanding spatial configurations or aggregate movement of people.

However, the resulting understanding of architectural space tends to be static, like the spatial relations they represent: Movement is frozen in aggregated flows which then are treated as location factors rather than moving individuals with personal goals who encounter different situations in every location. Penn (2003) elaborates on the non-trivial interpretation of configuration in relation to individual spatial cognition. The parallel presentation of spatial elements does not neatly support the architect in anticipating the complexity of the scenes encountered by users immersed in the building.

The experienced architect will of course be able to anticipate views within a building based on floor plan representations and the like. Our results nonetheless suggest that present design support techniques are not suited for systematic evaluation of the users' situation in multiple locations. Thus, architectural design may be improved in this respect – whether in form of more effective diagrams and software supporting the architect or in form of specialized training for those architects who are working on complex buildings.

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Mental Model-Centered Design for Built Environments

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Abstract: In this contribution, we argue that understanding model preferences in human mental spatial reasoning can eventually help improve both the design and the use of built environments. We present a design support tool prototype that interacts with the designer by checking for model preferences in the spatial instantiation of design constraints and suggests alternative placements where such are appropriate. We then discuss the applicability of the underlying methodology for supporting preferences in the spatial mental models which users of built environments exhibit when conceptualizing these environments. A framework is proposed for systematically evaluating designs with regard to how well users can conceptualize the corresponding built environments. We suggest that integrating this framework into the design process can lead to buildings for which correct mental conceptualizations are comparably easy to construct and maintain. Users may ultimately benefit from better building use and designers from being able to construct more usable buildings.

Keywords: Spatial mental models; mental preferences; design support systems; building use; cognitive factors in human-computer collaboration.

1 Introduction

Declarative knowledge about the spatial configuration of objects in a scene is often mentally integrated and processed in terms of spatial mental models (SMMs, Tversky, 1991). Such mental structures are, for example, useful for describing how spatial facts can be mentally inferred from a set of premises. They also may serve as modeling paradigms for shedding light on the working principles of the involved mental processes. It has been shown for several domains that general preferences exist in the construction of SMMs, that is to say, in the case of configuration problems with more than one valid solution not all of these solutions get constructed equally often. Some solution models are being preferred over others (Knauff et al., 1995; Schlieder, 1999). We have argued in the past that investigating such preferences holds formidable potential not only for understanding human problem solving in various domains (including architectural design, Bertel et al., 2007) but also for eventually creating human-computer interfaces that allow for a closer and more effective coupling of mental and computer-based reasoning processes (Bertel, 2007, 2005).

In the following, we will first show how results from a study on model preferences in mental spatial reasoning have influenced the creation of a design support tool prototype. The presented approach focuses on introducing preferences in the designer's mental representations of a built environment into the design process. Second, we will argue that the demonstrated methodology should be transferred to address in a similar fashion the mental representations which the user of a built environment constructs of it. The goal is to give the user's mental preferences in conceptualizing the built environment a proper place in the design process, thereby enabling the construction of buildings which are easier to understand, use, and describe. Third, we will present a set of starting points towards realizing these aims; in particular, we will describe a conceptual framework for systematically evaluating designs with regard to how well the built environments which they would entail could be conceptualized by users.

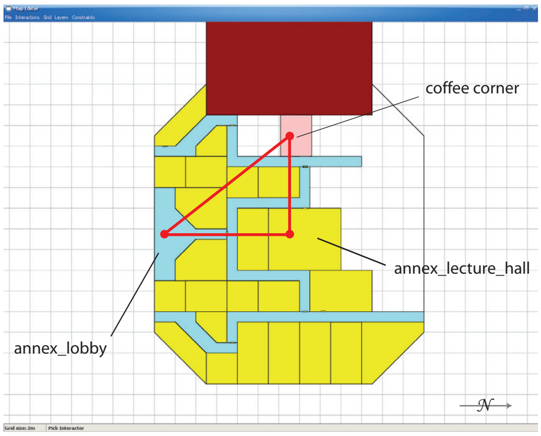

Fig. 1. An object placement (here '*coffee corner*') is suggested by the design tool; the suggestion is based on the preferred direction model for configurations in which the relations *coffee corner northwest-of annex_lobby* and *annex_lecture_hall north-of annex_lobby* are given.

2 Designer's perspective: Mental models of spatial configurations

Part of the task of designing a built environment is to find a spatial model in which a set of spatial constraints can be instantiated to sufficient degrees (in particular: in a conflict-free manner). Often, such spatial constraints pertain to directional or distal requirements between parts in the structure to be designed, or they involve topological conditions. Figure 1 shows the result of an object placement in our design tool prototype.

In a nutshell, during the design process the architect constructs SMMs of the overall layout of a built environment or parts of it in her head while sketching or drawing. Due to the nature of SMMs, in the designer's head mental spatial preferences will be effective in this construction process, for instance regarding the instantiation of direction or distance variables.

Although a trained architect usually will elaborate on various alternative design solutions to a given problem, the knowledge about the effects of spatial preferences in human mental model construction provides a fruitful basis for developing intelligent interactive assistance systems. Assistance systems of that kind, first, can help the designer overcome potential design biases imposed by her model preferences; second, they can inform a computational planning component about human design preferences (e.g. with respect to spatial configuration) in such a way that computationally generated design suggestions are constructed to be in line with human expectations based on such model preferences.

Our design support tool prototype interacts with the designer such that it permanently checks for model preferences in the spatial instantiation of design constraints. Based on the results of this check alternative placements of spatial entities are suggested. The presentation of potential alternatives is organized according to conceptual neighborhood structures (Freksa, 1992). That is, the system organizes alternative design solutions according to their conceptual similarity with respect to each other. By these means, the virtual space of possible solutions is explored in a systematic and mentally well conceivable manner (see Fig. 2).

3 User's perspective: Mental models in built environment usage

Although facilitating the process of design for the designer is a worthwhile endeavor in itself, the eventual goal of all building design is, of course, to create buildings which best fulfill their intended purposes. In the case of buildings that are intended to be used by people the degree to which their purposes can be fulfilled naturally depends on how well people can use them (i.e. how well they can navigate and orient in them, describe them, communicate about them, etc.). One crucial factor common to human performance across all such abilities is the degree of overlap between the SMM that a user constructs of a building (or, rather, of some part of it) and the building's actual structure: the higher this overlap, the higher the potential for good and unproblematic usage.

In the light of our previous discussion of preferences in SMM construction, we argue that preferences that exist on the part of a building's users should be considered for and influence planning decision already in early design stages. Two examples shall serve to illustrate our point:

First, imagine a human wayfinder who studies the map of a building which has been hung at the main entrance in order to establish a path between his current position and the location of a particular room. Depending on the complexity of the route, he may simply memorize in a verbal fashion a particular sequence of wayfinding decisions (e.g. *first left, straight, left*) or he may try to memorize a floor plan layout. Likely, during such actions he will read off a number of spatial facts from the plan and integrate them more or less consistently into his mental representation of the building, i.e., into a SMM.

Any preferences in reading off such spatial information, in conceptualizing it and in integrating it into a model will then influence the structure of the resulting mental representation. Where this representation significantly differs from reality, building use will be impaired; where such differences are systematic one may have leverage to influence design processes so as to avoid constructing configurations that are easily misconceptualized. As an example, design methods may favor certain angles in corridor bends over others that have been shown to often lead to misjudgments with regard to the orientation of a building's main axes.

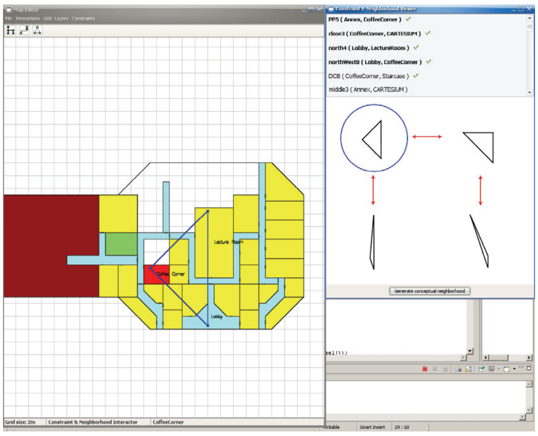

Fig. 2. Another view of the design tool. *center right:* A conceptual neighborhood for four different direction models; *center:* the object placement that corresponds to the currently selected model; *top right:* the results of an overall design check for certain spatial constraints.

Second, for a variation, imagine that instead of reading a map our wayfinder gets verbally instructed on his route by a second person. This process again entails the construction of SMMs with preferences playing a role in the model construction, and the story continues just as above…

We believe that the designer of a built environment should either be made aware of the configurations that are prone to later misconceptions by building users, or that design support tools should automatically avoid such configurations where possible. By this approach, building users may ultimately benefit from better building use and designers from being able to construct more usable buildings.

4 Model fit: Evaluation of expectations

The right question to ask now is – given that one already has sufficient knowledge about conceptualization and model construction preferences in a population of building users –: How can we make sure that these preferences are well appreciated in the design phase and that the resulting design does in fact avoid configurations which are easily misconceptualized? Here, a specific evaluation scheme for designs is needed. As movement in a built environment is at the core of how a user (e.g. a wayfinder) experiences it we see the necessity for suitable evaluation schemes to be similarly based on human movement patterns (i.e. on routes though the environment). Specifically, we propose that for each design to be evaluated a set of routes be defined that capture the most important (e.g. the most frequent) movement patterns in the environment. For these routes, qualitative descriptions are generated that include the necessary information on decisions to be made by a wayfinder who travels along a route from start to end. A standardized description process should be used for all routes; for performance issues, it should ideally be one that is capable of generating route descriptions which can be conceptualized as easily as possible, taking into account structural and functional issues of route and communication complexity (e.g. Richter, 2007).

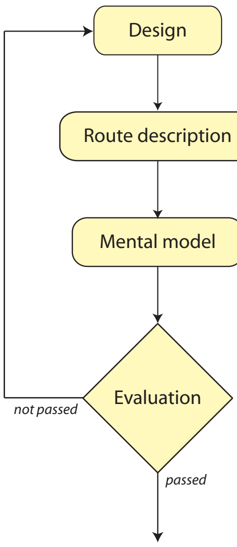

Fig. 3. The proposed evaluation scheme for designs.

Next, each route description is fed into a generative process that creates an SMM based on the spatial information contained in the route (or in route segments, in case of long or complicated route descriptions). This generative process is the one that takes into account the known human preferences in model construction: For each route description only the preferred SMM is constructed so that a set of *n* route descriptions will eventually lead to the production of *n* SMMs.

As a next step, for each SMM, the spatial configuration specified by it is in turn compared to the spatial configuration specified by the design. The comparison process is qualitative in nature and it measures the degree of structural correspondence between the SMM and the design. It produces two main outputs: A value from applying the measure and a list of structural components that mismatch. After comparing the design to all generated SMMs, the individual correspondence measures are integrated and a global expectancy value is computed. This value signifies how well a design structurally corresponds to what a user can expect of it based on knowledge from route description and SMM construction processes that feature preference-based instantiations. A synopsis of structural mismatches can be used to identify critical parts in the design in case it needs to be modified. Fig. 3 gives an overview of the complete evaluation scheme.

On a general note, the proposed approach will likely not favor designs that lead to the simplest models or the shortest route descriptions. Rather, it will favor designs that lead to models whose construction and maintenance requires minimal cognitive effort.

5 Discussion and outlook

In this contribution we argue for considering preferences in spatial mental models both in the designer and in the user of a building right from the beginning of the design process. However, there are a number of open issues that need to be addressed towards realizing the described ideas in an intelligent interactive assistance system.

On the one hand, it is not completely understood (1) which spatial relations a potential user might use to construct a mental model and (2) how these relations refer to the constraints the architect has to consider during the design process. Some suitable kind of formal language is required to capture both, the specifications to be met in the resulting design and the constituents of the resulting spatial mental models in the user of the building. It seems that this issue has to be addressed in a joint interdisciplinary effort pursued by architects, cognitive scientists, and computer scientists.

On the other hand, we expect that the structure of the mental model constructed in a user's mind should vary depending on the task the user is confronted with. So, for instance, the task of reaching a specific location within the building vs. the task of describing a route to another person might lead to quite different spatial mental models.

Another issue to be addressed in the course of this research is how spatial mental models related to a given building vary between different individuals. Since it is known that mental spatial capabilities may be quite different in different people (e.g. Hegarty & Waller, 2006), we also expect that the grade of detail and the overall structure of spatial mental models should be different in people with different spatial abilities.

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Do you know your way? A mixed-method study on the use of virtual environments in wayfinding research.

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Abstract: This paper compares wayfinding behavior in virtual and real environments in order to reveal the theoretical basis for comparison while simultaneously producing applicable implications for designers and architects. The constructed virtual environment was modeled using standard design tools available for most practicing architects and mimicked the parallel real environment upon which it was based. Methodologically the study builds on existing research on wayfinding in both real and virtual environments, implementing both previously used and new methods.

Key words: wayfinding, orientation, virtual environments, design evaluation.

1 Introduction

Spatial behavior is not a new topic in the social sciences. Tolman [1] introduced the term "cognitive map" to describe a mental construct of routes, paths, and environmental relationships which, in his research, determined animals' responses to the environment. Some time later, Kevin Lynch [2] coined the term "wayfinding" in his well-known book The Image of the City. The phenomenon was "a consistent use and organization of definite sensory cues from the external environment in order to find one's way in it" which is "fundamental to the efficiency and to the very survival of the free-moving life" (p. 3). Wayfinding is different from following a known route. As the term implies, in wayfinding the route is not known, even though the origin and/or destination points are. The term is used both for traveling to novel and known destinations, as long as it involves finding the way to it. It is different however from exploratory movement, which involves surveying, without any particular spatial goal [3] [4].

Research on movement through space found that wayfinding behavior is partly influenced by design decisions [5] [6]. What is more, authors who tackle the issue agree that facilitating people's wayfinding involves more than signage since placing signs cannot overcome flaws in the architecture that cause confusion and make orientation difficult [7]. It is therefore important to study the mental processes of orientation as well as wayfinding behavior in the context of the structured environment putting particular emphasis on designed features of the environment.

Virtual environments (VEs), as artificial representations of environment with which users can interact, are particularly valuable and often used in research on wayfinding. The main advantage of using VEs in research is that they allow easier changes than are possible in real, built environments. Depending on how they are displayed, VEs can be either immersive on non-immersive. The latter are usually displayed on computer monitors. The former allow for the immersion of their users, either by employing various devices such as head mounts or using room walls as the display (see, for example [8], for more on types of immersive VE and their use in psychology).

Today, various forms of artificial representations of environments are used in architectural practice allowing designers to present their work to clients in a form of fly-through clips rendered on CAD (Computer Aided Design) models. These representations are usually not VEs per se, as they do not allow the user/client to have interactions with them. It was my intention to create a VE starting with a CAD model so that not only the findings but also the tools used in this research could be directly applicable in architectural practice. For the same reason (as well as the limited funds available for this project), the VE was non-immersive being displayed on a computer monitor. This method seemed most readily available in architectural practice where it is rare to find tools for creating immersive VEs. The aim of this study was to test if wayfinding in such a particular type of VE and real environment are comparable and if VE could be used for testing a building's wayfinding systems. In other words, this study explored the capabilities of using VE to assess a building' s wayfinding characteristics which could then provide an opportunity to redesign as needed before beginning construction. If the wayfinding behavior and navigation in virtual and real environments was shown to be similar, one could conclude that VEs can be used for assessing a future building's wayfinding system.

A number of studies have used VE in research on orientation and wayfinding. Ruddle et al. [9] for example, replicated Thorndyke and Hayes-Roth's [10] experiment from a real environment (RE) in which participants were estimating relative distances. Other researchers have looked at the usefulness of VE for learning environments and training purposes [11] [12]. A few studies have also focused on the same issue that this study has addressed, namely the comparison of wayfinding in a VE and a RE, addressing the ecological validity of research on wayfinding in VE.

Why address the same issue if a number of studies have already demonstrated that the patterns of movement are comparable between a VE and real environment (RE) [13] [9]? A closer review of the literature revealed three strong tendencies in the research on wayfinding in virtual settings. First, a possible limitation of the existing research – often acknowledged by authors – is that such studies do not consider salient characteristics of the environment such as ambient light and landmarks (see for example [13] [14]. Second, often the virtual environments do not fully account for signage, focusing instead on the structural elements of the environment. Lastly, the bulk of the research on wayfinding in VE employs a quantitative approach, and only a few studies take a qualitative approach (for a comprehensive review see [15]). This study confronts these issues by including more detailed physical characteristics in the VE that have been shown to be relevant to wayfinding in the RE, along with the use of a mixed-method approach involving both qualitative and comparable quantitative methods.

2 Methods

The study consisted of two phases: (1) an experimental one in which performance in a wayfinding task was measured and videotaped in a VE and a RE and (2) a qualitative phase in which the process of wayfinding was described by participants in think aloud protocols, delivered while they were watching the videos of their walkthroughs. This was followed by an interview. The methodology was first pilot-tested which led to change in the goal on the search and a review of the interview. A time limit of eleven minutes for the task in both conditions was chosen based on the performance of participants in the pilot study.

The chosen setting was a floor of The Graduate Center of the City University of New York in midtown Manhattan. This site was selected because users often describe it as confusing and difficult to navigate and its size and layout are representative of typical office buildings in New York. Based on the floor's layout, I built a three-dimensional virtual model of the floor that included exact elements of the environment such as textures, colors, and signage. The floor was modeled in standard architectural software – AutoCAD, 3ds Max Studio, and SketchUp [1]. The model was next imported to and edited in an Unreal Game Engine Editor[2] which allowed for game-like movement in the modeled space. I consulted on the accuracy of the model with actual space users and their feedback was incorporated. However, because this research was aimed toward the application of evaluating designs prior to their occupancy, I chose not to include elements in the VE that would indicate that the space is actually in use. Therefore personal items or virtual representations of other people were not included.

For the main study, 34 participants – 24 females and 10 males – were recruited from undergraduate schools within the CUNY system through a flyer that was posted on information boards and sent via email to assistants teaching undergraduate students. The participants had reported varied experience with VEs (mainly gaming environments) and had made no prior visits to the building. They were randomly assigned to the two conditions. In the first, experimental phase of the study, those

[1] Sketchup is available at http://sketchup.google.com/

[2] The software is available online for download for educational purposes at Unreal Game Engine website: http://www.unrealtechnology.com/features.php?ref=editor

assigned to the RE group were asked to find an elevator in the actual physical space (one floor of a university building) and the other 17 persons were asked to find it in the VE. The participants assigned to the VE group had a training session in which they were allowed unlimited time for practice. During this session, they became acquainted with movements through a different virtual setting in order to familiarize themselves with navigating through the VE by operating a mouse and a keyboard. In both groups, each participant started his or her task at the same point in space. Their wayfinding efforts were timed and videotaped on a hand-held camera. In the actual building, an investigator followed the participant and, in the VE group, the investigator videotaped the monitor of a computer standing a few feet behind the participants conducting the task. This choice was dictated by the need for keeping the experimental conditions between the groups relatively constant.

In the second, qualitative, phase of the study, together with each participant, I analyzed the video recording of his or her tour. As participants watched their walkthroughs, they were asked to comment on their thoughts and behavior while conducting the task. This method allowed gathering detailed information on the wayfinding process (retrospective think aloud protocols) without impeding their performance which is often pointed to as a limitation of a congruent think aloud protocol method [16] [17]. This was followed by an interview about the participants' experiences of wayfinding in the building.

3 Results

Following Ruddle and Lessels' [15] classification of metrics used in wayfinding research, this study produced data on all three levels used for evaluating wayfinding: (1) performance, (2) physical behavior, and (3) cognitive rationale. The performance level was evaluated based on the time and distance taken to complete the task. The physical behavior level was assessed by cumulating paths taken in both environments into two composite maps. Finally, the qualitative methods allowed a comparison at the cognitive rationale level. These different types of data allowed a thorough comparison between the two conditions. The results will be presented in this order as well. First I focus on the performance and physical behavior data that were acquired through quantitative methods; by comparing the time of task completion and the cumulative paths of the two experimental groups. The next section, on qualitative results, includes the cognitive rationale level of analysis along with other significant dimensions that emerged in the analysis of human-environment transactions. Because this paper aims to be applicable to the evaluation of environments as they are being designed, a separate section of the qualititative results analysis is devoted to the environmental dimensions across the two experimental groups. Finally, the qualitative results section includes other themes that emerged in the analysis of the data. The overall aim for data analysis is to compare wayfinding across the two experimental groups.

3.1 Quantitative results

All participants in the RE group completed the task within the assigned time limit. Sixteen out of seventeen completed the task in the VE group. The time taken to complete the task was measured based on the video recordings. For the one participant who did not complete the task, the maximum time limit was entered as their data.

Table 1. Descriptive Statistics for Time (in sec.) taken to complete the task in both groups

	N	Min.	Max.	Mean	Std. Dev.	Skew-ness	Std. Error	Kur-tosis	Std. Error
TIME (RE)	17	64.0	665.0	168.06	152.286	2.530	.550	7.026	1.063
TIME (VE)	17	117.0	1050.0	387.53	317.121	1.016	.550	-.436	1.063

After logarithmic transformation:

Log Time (RE)	17	1.81	2.82	2.12	.279	1.304	.550	1.087	1.063
Transf Time	17	2.07	3.02	2.45	.345	.433	.550	-1.414	1.063

Table 2. Independent Sample Test

		Levene's Test:	t-test Sig.	t	df	Sig. (2tailed)	Mean Diff.	SE Diff.	95% Conf. Interval	
Transf Time	Equal variance assumed	2.45	.13	-3.11	32	.004	-.335	.108	-.550	-.116
	Equal variance not assumed			-3.11	30.6	.004	-.335	.108	-.554	-.116

Participants in the RE group took on average 2 min 48 sec, while in the virtual environment the mean time taken was 6 min 27 sec.[3] The average time taken to find the elevator proved to be significantly different between the two groups ($t(32) = -3.111$; $p = 0.004$). In other words, there was a considerable difference in the performance of the task between those doing it in the VE and the RE. This finding would imply that time taken in a virtual model could not be used for predicting the time that one would need in a real environment.

The individual paths were mapped onto a cumulative map. The combined paths yielded from both conditions differ considerably. Since the cumulative maps reveal different movement patterns in both groups, one has to conclude that paths chosen in a VE could not be prognostic of movement patterns in real environments.

At the behavioral level, it was also informally observed that the participants conducting the task in the VE were not looking around as often as in the real setting. As the available video data do not allow for quantitative comparison (due to the fact that, in the RE the researcher was following the participant and thus was not always able to record the participants eye movement), a preliminary analysis of this issue has also been conducted from the description of the behavior delivered by participants. Those in the RE reported looking around more often than VE. This finding is also confirmed in existing literature. For example Ruddle et al. (1999) shows that participants in a non-immersive VE tend to look less around than when navigating in an immersive VE.

[3] Due to the highly kurtotic distribution of the data in the first group, the average means could only be compared after logarithmic transformation of the variable TIME taken into LogTIME.

Figure 1: Movement patterns in the real (top) and virtual environment (bottom). All participants started in the elevators lobby. Their goal was to find the 7th elevator, located in the bottom right corner of the floor plan

3.2 Qualitative Analysis and Results

The interviews and think aloud protocols were transcribed in full and coded. The codes used fall into the following categories: human, environmental, and specific differences between performing the task in the VE and the RE. These were developed based on existing literature on wayfinding and spatial orientation in built environment as well as derived from the data gathered. I acknowledge that both wayfinding behavior and experience involve an interplay between the actor and the environment and the distinction used here serves only as an organizational tool. A more specific description of each code and the reason for their application can be found in the following sections. The analysis of qualitative data has been conducted based on the categories across the two experimental groups.

3.2.1 Human Dimensions

For this section, I look at wayfinding as it was described by the participants. A number of codes have been developed based on existing literature on this topic (ie.[3] [5]). First I look at strategies employed by participants in both the VE and the RE, comparing between groups. Other relevant categories here are: prior experience and expectations.

Strategies. A frequent strategy employed by participants was to go around the perimeter of the floor or try the different corners of the building. This strategy was used in both the VE and the RE by about one third of all participants. Another frequent strategy used was to follow the exit signs and other signs, and especially to follow the room number sequence. However, sign usage was not a prevailing strategy as the participants were told that the signs would not be pointing to the elevator. Other strategies were applied locally, at decision points rather than generally to the whole task. One such mini-strategy would be to choose routes that seemed shorter. It was more often employed in the real than in virtual setting. Going to the right side was also noted by participants in both groups. Very often, however, the participants in both groups did not have an easily verbalized strategy and could not give any (rational) explanation for their particular decisions, other than their instincts.
While discussing their strategies, the participants frequently talked about their expectations regarding the space and where the elevator would be located. Often, they also referred to schematas based on their knowledge and prior experience, when speaking of the expectations. What is interesting, the schematas acquired in other actual buildings were equally often applied in the virtual setting.

Difficulty. Participants were asked about the difficulty of the task as well as a general difficulty of finding anything on that particular floor. After piloting the interview I also added a question about an anticipated difficulty for other people, as the pilot revealed that some participants would evaluate the environment as confusing and/or frustrating, but would at the same time state that they did not find the task difficult. This tendency was confirmed in a few interviews in both conditions, with some participants claiming that the task was not difficult but the setting was confusing and that they felt lucky to have found it quickly.

It was almost equally expressed that if they were looking for something else it might have been more difficult, as they wouldn't have available schematas. Even though, some participants in both groups found the task easy they thought the environments was confusing and projected that it would be in general difficult for other people to find anything there.

Frustration. Frustration in both groups was often caused by the experimental conditions such as the time limitation and taking part in the study. Frustration was relatively more often expressed in the virtual setting.

3.2.2 Environmental dimensions

Following existing literature on environmental features relevant to orientation and wayfinding (i.e. [18] [19]) the environmental dimensions were coded: signs, complexity, visual access, and distinctiveness. A separate category landmarks – closely related to distinctiveness was also included.

Signs

Exit signs. A separate code for exit signs was used as it became an emerging theme in the think aloud protocols and interviews. Exit signs differed substantially in their design from other signage system elements. They proved to be a useful clue for approximately half of participants in both groups, who were using them as an indication of where the elevator would be located. However, some participants did notice the exit signs but did not think that they could used as a clue for where the elevator was located. Sporadically participants in both groups, would purposefully avoid following the exit signs.

Other signs. Other signs present in both environments included room numbers placed by each door office, department boards placed above main office doors, and directional signs placed at the openings of hallways. Two information boards mounted at the ends of elevator lobby were not included in the virtual environment due to the high number of convexes that would require a larger processing power than that which was available for this study. Despite participants having been informed that there were no signs that would point to the elevator, a number of students still looked at the information boards looking for any relevant information.

Department boards were used in both conditions as deliminators of specific regions of the floor. This, along with the expectations that an elevator would not be located in an office, led the participants to avoid those regions. Room numbers for smaller offices served the same purpose in both environments. They were also used as an indication of direction, or to be more precise, the number sequence was interpreted as an evidence for where the particular hallways would lead to.

In both the virtual and real settings, the numbered signs were considered most useful in terms of mentally marking the space as the participants were walking through it. The bigger directional signs pointing to room numbers especially served as landmarks for both groups. In general, however, since the participants were informed that there are no signs that would point them to their destination, participants in both conditions did not pay much attention to signage. They would have had, as expressed in both groups, if their task had been different.

Built environment

Complexity. The complexity of the layout was an issue for both groups. In both conditions, participants pointed to the configuration of the space and the numerous possibilities they had when they were choosing their paths. The number of rooms and the size of the floor was also often mentioned by both groups as the environmental features that contributed to the perceived complexity of the environment.

Distinctivess. In both groups, participants were pointing to the lack of distinctiveness of different areas and elements of the floor. Most often, participants would note that everything looks the same, sometimes pointing to the colors used in the environment as being invariant. The lack of distinctiveness was noted as an issue in both the real and virtual settings but was more commonly mentioned in the VE.

Landmarks. The virtual environment did not include all the elements of a real environment. In particular, it did not have any signs of the space being occupied, having only the designed features. Interestingly, no personal elements of the space (such as, for example, markings by the doors or plants) were used as landmarks by the participants who were conducting their task in the actual building. In general, relatively fewer landmarks were mentioned in the interview when compared to the virtual group. It could be hypothesized that this was caused by the fact that the participant in the first group relatively rarely got lost and went straight to the destination (see the cumulative paths map). The few landmarks that were mentioned by the first group included the directional signs, water fountains, computer monitors located at one end of the main elevator lobby. Interestingly, the black, abstract sculptures located along hallways which were probably intended by the designers as landmarks, were not mentioned by the participants as significant markers of the space. In the virtual environment, on the other hand, landmarks were mentioned more often. The participants in the second experimental group frequently noted red sofas located in the psychology department. (Not surprisingly, this was not a landmark for the first group because only few passed by the couches). They also pointed to other landmarks such as some directional signs and monitors mentioned by the RE group.

Visual Access. Visual access, meaning the degree to which different parts of the building could be seen from a particular area, was an important yet not often expressed issue in both groups. Only a few persons mentioned that visual access and the openness of the space was important for them when performing their task. It was mostly associated with how the space was experienced and only partly a contributing factor for the cognitive rationale of making path choices. In other words, the closeness of the building space caused frustration, thereby making the task more difficult. As these were only a few spontaneous responses concerning visual access all participants were further probed about whether, in terms of their task, it made any difference, if the doors were solid or glass. A number of responses in both groups emphasized the visual accessibility that a glass door would provide.

A concurrent code emerged in the analysis of these particular responses. A number of people noted only to the amount of space they were able to see but also to the affordances of the spaces. They would talk about what solid and glass signified, what function the spaces behind them would serve and what degree of privacy they would manifest. In this sense, again, the visual access provided by the environment influences not only the cognitive rationale and decision-making but also how the space is experienced in the process of movement.

(Re)design Recommendations. Despite the fact that participants pointed to a number of architectural features that impeded their wayfinding, when asked for any (re)design recommendations the majority would point to providing a better signage system as the best solution. Following further probing, a number of design recommendations where made:
- change of layout and its complexity,
- enhancing the distinctiveness of different section by introducing color variation, and
- putting up landmarks.

These recommendations were sparse but consistent across the two groups.

3.2.3 Other emerging themes

Body. Lastly, I looked at the difficulties and differences experienced in the virtual environment as opposed to the real environment. Students who were assigned to the VE group pointed to the general difficulties of doing the task on a computer and associated them mainly with not being physically in the environment. A number of responses emphasized the role of body in experiencing the space.

Presence of others. The social dimension of the experience proved to be important for a few users in the RE group. Having other people present seemed to influence the decisions on which path to choose.

3.2.4 Discussion of the qualitative analysis

Thorough analysis of the qualitative data gathered in both groups reveals many similarities in wayfinding in both virtual and real environments. In both, users employed similar strategies and based them on knowledge they gained through previous experience in actual buildings. Similar difficulties were pointed to in both environments and, most importantly parallel characteristics of the environment were identified as sources of these difficulties. Both the virtual and real environment were similarly used and evaluated in terms of its wayfinding ease. The differences that emerged in these data point to differences in how space is experienced. Users emphasized the role of body in moving through space as well as presence of other people. The cognitive rationale level proved often to intertwine with this experiential component. Though perhaps less easily verbalized, these comments cannot be ignored. Participants talked about their decisions not being rationally justified, but rather simply resulting from their instincts and what they felt like doing in a particular time and space. Some spaces were experienced as welcoming; while other spaces made the participant feel confined. Despite that this kind of rhetoric is not prevailing in the more cognitive tradition of research on wayfinding, it might prove useful to include it in future studies in this topic.

4 Conclusion

The preliminary findings are partly consistent with existing research. The performance measures indicate that the time taken by users in the VE was significantly longer than in the real environment. The cumulative paths yielded from both conditions differed considerably which contradicts studies demonstrating that movement patterns in virtual and real conditions correlate [13]. Movement in this study was task oriented while Conroy's research looked at a non-task oriented behavior in an art gallery. This might be one possible reason for the differences in the findings between the two studies, yet further investigation of this issue is necessary. The comparison of aggregate paths along with the analysis of the qualitative data suggests the critical role of body in experience of wayfinding and movement in complex environments, which has been also recently pointed out by other researchers [4]. The results are also consistent with other studies which point out that in a VE, people tend to travel in paths that are generally straight [20], a pattern that is not persistent in real environments navigation.

Finally, the qualitative analysis of think aloud protocols and interviews demonstrates major similarities in the cognitive rationale behind the wayfinding behavior in both conditions. These findings allow for a tentative implication that virtual models could be used for assessing wayfinding systems of future buildings. Even though the virtual environments might not prove to be useful in predicting wayfinding performance and movement patterns in quantitative terms, qualitative data that can be gained through using VE in the architectural programming phases of a project seem to be sufficient for evaluation purposes and useful for redesigning buildings before they are constructed. It remains to be seen if this will be the case in more interesting, differentiated environments.

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Neural Responses during Navigation in the Virtual Aided Design Laboratory: Brain Dynamics of Orientation in Architecturally Ambiguous Space

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Abstract: The cues that assist people as they navigate spaces and form memories of places, have direct relevance to the design of buildings, neighborhoods and urban settings. The means by which mental representations of cognitive maps are formed has been the subject of study by architects, psychologists, and neuroscientists alike. This project united the expertise and methods of these disciplines, exploring the brain's response to architectural cues, and wayfinding strategies in order to gain further insights into the processes associated with wayfinding, the feeling of being lost, and successful re-orienting. Brain activity was recorded while subjects moved through a realistic, human scale, 360 degree immersive 3D virtual environment. Event-related spectral perturbation of independent components (ICs) derived from independent component analysis (ICA) suggested differences in brain dynamics when subjects knew their orientations versus when they were lost. Ongoing studies continue to explore the synchronization of virtual reality (VR) scenes, paths of movement through, and high density electroencephalographic (HD-EEG) responses as a novel means to measure the neural foundations of navigation function in full-scale realistic environments. Unlike magnetic resonance imaging, which records earlier brain responses in prone, immobile subjects, this pioneering technology relates navigation events to concurrent brain responses while subjects move freely within the VR cave.

Keywords: navigation, orientation, wayfinding, virtual reality, electroencephalography, allocentric, egocentric, route following.

Background

A deeper understanding of the brain processes underlying the formation of memories may provide new clues to the design of more effective wayfinding strategies for complex built environments. Several decades of brain research describe the neural bases underpinning the formation of memories of space and place. Animal studies in the 1970s first demonstrated "place cells" within the hippocampus were responsive to both memories of events and of memories of a place. Cells within this region of the temporal lobe were responsive to an animal's previous experience in a specific location, direction, and orientation (O'Keefe & Nadel, 1978). Recently Moser and colleagues discovered that memory of space also activates a hexagonal network of "grid cells" in the nearby entorhinal cortex in response to landmarks and self-motion, forming a neural system that associates memories of places and events (McNaughton et al., 2006). This process is thought to be involved in the transformation of place memories along with associated visual scenes, objects and events, to create a mental image of an environment, commonly termed a 'cognitive map'.

Human brain recordings reveal similarities to animal studies. Brain activity measured via high-density electroencephalography (EEG) has been used to distinguish synchronous activity of distinct cortical brain sources involved during different navigation strategies. The alpha frequency band (8-13 Hz), has long been thought to reflect cortical readiness to process incoming information, and has been observed during complex maze tasks and during route planning periods. Moreover, recordings from patients undergoing surgery for epilepsy were consistent with animal studies, demonstrating similar place responsiveness to virtual scenes (Ekstrom et al. 2006) and (4-8 Hz) theta band activity during navigation tasks. The study of patients who become disoriented in urban environments and inside buildings may provide considerable insight into the neural processes that support the learning of spaces, and formation of memories as one moves through spaces, as well as the navigation strategies that lead to the formation of cognitive maps. Neuroimaging studies of patients with temporal lobe disorders demonstrate that some are unable to recognize or perceive landmarks. Others have no deficits in object or spatial perception, but cannot associate landmarks with directional information, relying heavily on maps and plans that they may draw for themselves (Aguirre & D'Esposito, 1999). Factors that influence memory—including dementia or Alzheimer's disease—can also selectively affect memory involved in navigation tasks. With such knowledge, the selection of architectural cues may be better able to address the brain's process during navigation.

Multiple processes are involved in storing and retrieving memory of routes between spaces and the geometric relationship of places. Subliminal recognition of visual object cues, and differential processing of relevant versus irrelevant landmarks are likely involved. Two commonly held theories have been proposed to describe how people navigate. Egocentric referencing pieces together memories of places along the route of travel, and was initially thought to be the basis from which geometric or allocentric "birds-eye" cognitive maps are formed. However, a cognitive sequence from egocentric to allocentric mapping may not be necessary, and that subjects differ in their relative degree of reliance on body-centered versus environment-centered reference frames (Wolbers et al. 2004) . During a computer navigation task, Gramann et al. (submitted) found blocking of posterior alpha activity during turns in those subjects using an allocentric reference frame, compatible with more intense cortical activation of occipitotemporal, parietal, and retrosplenial cortical areas supporting visuospatial orienting. In contrast, subjects using an egocentric reference frame had stronger alpha blocking in or near the right primary visual cortex. These findings are consistent with functional brain imaging studies and support the use of high-density EEG to track cortical patterns during navigation.

Such research suggests direct implications for design in that wayfinding systems may need to serve both of the above navigation strategies in order to meet the needs of different users. Navigation paths through complex settings such as large commercial buildings, urban environments, and academic schools and centers have great need for improved navigation cues. Wayfinding systems have value beyond the reduction of stress or anxiety so often experienced when one feels lost. Studies have noted the significant value of staff time recovered when users can find their own way through large campuses. McCarthy (2004) found that staff time used giving directions to lost patients was associated with 4,500 hours each year and an associate cost equivalent of $220,000 per annum. There is also a vital need for accurate and rapid wayfinding for both patients and medical staff in hospitals that tend to have highly complicated layout of pathways reflecting dense functional programs, rigorous operational requirements and requirements for the separation of public, private, and professional spaces. Of importance is consideration of the risk and benefit of design that makes obvious navigation paths obvious for the separation of clean spaces, particularly during infection outbreaks, such as in the SARS epidemic.

Methods

An increasing number of virtual reality studies have been conducted to predict how people move through spaces and remember places. Many such studies rely on theoretical modeling systems and others on simplified images of navigation paths that test wayfinding theories. In order to further investigate human navigation strategies, this study developed an interactive cave environment that presented realistic scaled renderings of actual architectural environments. Separate experimental conditions were created to compare behavior and brain dynamics in environments with no prominent visual cues versus environments that included rich visual cues. A wayfinding task was designed to test neural responses to ambiguous spaces (with no visual cues to direction or orientation) versus unambiguous spaces (where landmarks, architectural features, interior finishes, or color provided clear clues). Visual ambiguity was systematically controlled by varying the symmetry of the surrounding environment, lighting effects and shadows, or other visual cues that might serve orientation. The unambiguous rooms included exterior and interior statues and colored doors that clearly marked the entry to three rooms, each with different furnishing and functions. The ambiguous space comprised a double loaded corridor devoid of wall color, shadows, or objects. Thus, a subject positioned in the back corridor had no visual cues as to their location or orientation within the building, or the arrangement of the adjoining rooms.

Subjects were instructed to learn and memorize the location of all rooms and corridors during free exploration, and to demonstrate their knowledge via drawn plans before and after testing began. Each subject then completed 96 trials in which they navigated from the front lobby (unambiguous) or back corridor (ambiguous) toward stated goals in the adjoining rooms (in pseudo-random order). Tracking of the movement path assessed subject orientation via measures of behavioral responses including navigation errors, time to goal, and length of path to goal.

The interactive Virtual-Reality Aided Design (VAD) laboratory comprises a circular 15 panel dual projection 3D immersive environment that surrounds the subjects and enables interaction and movement within the rendering of built spaces. The test environment comprised a realistic, full-scale 3D rendering of the actual building on campus that houses the 360 degree 'StarCAVE'. Software was developed to playback the scene viewed by the subject as they moved through the virtual exercise.

High-density 256 electrode EEG was recorded using active electrodes (Biosemi, Netherlands) providing sufficient signal to noise ratio without interference from complex magnetic and electrical systems running the CAVE environment. The amplifier system was positioned in a backpack and connected via one fibre optic cable to a recording system outside the cave. The virtual environment was adapted to subject's movement by means of a electromagnetic motion capture system recording subjects head and hand movements. Software was developed to synchronize online 256 channel EEG, motion from sensors attached to the head and hand of the subjects, and the VR-data stream to track movement along the routes, the virtual cues and scenes observed as the subject moved through the rendering, and the physiological brain responses as the landmarks were encountered. All data streams were synchronized online and in real-time via a UDP network allowing for interactive rendering of the virtual environment while subjects navigated through the rendering. With such methods modifications to the visual features of cues and their location relative to the path and other cues can be explored in terms of their effectiveness in wayfinding design.

EEG data were analyzed by means of independent component analyses (ICA) and clustering on source location and time course of brain dynamics during orientation, using the software package EEGLAB developed at the Swartz Center for Computational Neuroscience, UCSD (Makeig et al. 2007). New signal and image processing systems allowed brain and muscle activities to be independently analyzed and localized as subjects moved during the task (Gramann et al. 2008).

Findings

An initial group of subjects were used to test and develop the system itself, and provided valuable information about procedures necessary to synchronize VR, EEG, and behavioral protocols. Analysis of the map drawings demonstrated slight improvements of map accuracy after the experiment as compared to the initial drawing. However, the environment used was relatively simple and subjects were able to draw an accurate map after a few trials of self exploration. The number of incorrect turning decisions showed a trend to be higher in subjects preferring an egocentric as compared to subjects preferring an allocentric reference frame. However, due to the small sample size the difference reached no significance.

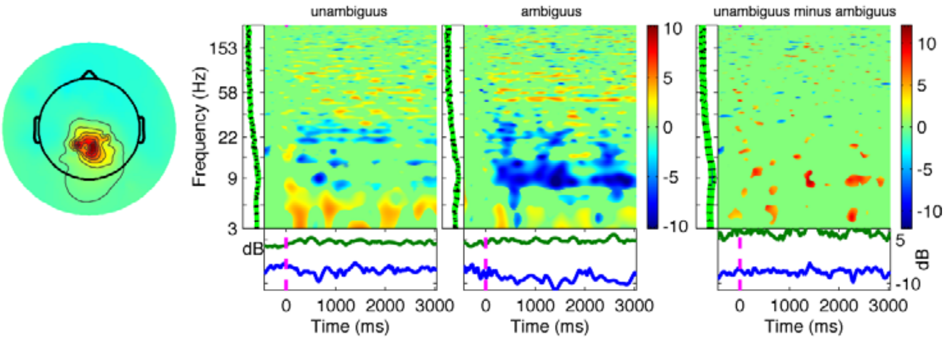

Figure 1. Independent Component Analysis of EEG responses in parietal brain region. Condition 1 shows event-related spectral perturbation (ERSP) for trials when the subject was cognizant of his position within the environment (front corridor) as compared to Condition 2 when the subject had no landmarks available for orientation. The left-most column shows significant differences between the two conditions (bootstrapping with $p<0.05$). ERSP in dB for frequencies from 3 Hz to 250 Hz in log-scale for a component localized in or near the superior parietal cortex (Precuneus, BA 7). Red colors indicate significant increases and blue colors indicate significant decreases in spectral power from baseline (time period before onset of the trial). Green colors indicate no significant difference from baseline activity.

A wide-spread cortical network was involved in navigation from a first person perspective including occipital, occipitotemporal, parietal, and frontal areas. Brain dynamics in a subset of these areas revealed significant differences between oriented and disoriented trials with most pronounced differences in the lower alpha and theta-band. When comparing the brain dynamics for epochs with starting positions in the ambiguous environment with starting positions in the unambiguous environment the results revealed differences in or near the parietal and occipito-temporal regions as indicated by equivalent dipole models using realistic boundary element head models (BEM). Figure 1 below exemplifies the difference in a wide range of frequencies for a component localized to the parietal cortex for a subject being disoriented as compared to when he knew where he was in the environment. (See Figure 1.)

Conclusions

The results indicated a progressively subtle use of visual cues as subjects navigated the ambiguous space. In the case where obvious cue were not presented, subjects looked for any distinguishing features that might indicate location, including shadows around doors, or patterned finishes. This suggests a continuum of cue effectiveness dependent on the surrounding context and the opportunity to repeatedly search for cues.

Brain dynamics accompanying navigation in the 360 degree VR environment from a first person perspective involved a network of cortical areas known to subserve spatial orienting. Differences in brain dynamics dependent on the ambiguity of the starting position were found in parietal and occipitotemporal cortex with significant stronger synchronization in the theta and stronger desynchronization in the lower alpha band. This pattern likely reflects the involvement of the parietal cortex in utilizing visuo-spatial information from a first person perspective and the involvement of parietal and occipitotemporal areas in processing heading changes and planning of future paths. Interestingly, disorientation was associated with increased alpha desynchronization likely reflecting increased attentional demands for processing less informative visuo-spatial information.

With further understanding of the neural sources associated with wayfinding, this interactive and synchronized VR / EEG system offers a novel means to test the effectiveness of cues to visual and spatial relationships in a virtual environment while mapping brain and behavioral strategies that may provide greater knowledge of cognitive mapping processes (Gramann et al., 2005; Gramann et al., 2006).

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Getting from A to B and Back: A Representational Framework for Pedestrian Movement Simulation in a School Environment

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Abstract. The paper presents some techniques developed in order to explore the relationship between school design and pupil movement outside of formal teaching activity. The aim is to integrate configurational analysis with agent-based modeling techniques through a representation that allows for multiple assumptions. Ultimately the desire is to evaluate how cognitive assumptions of spatial navigation will affect the outcome of OD models aimed at predicting crowding. The paper considers various techniques of spatial representation, simulation and network analysis and proposes a way of combining these in a new way for use in pedestrian movement consultancy in schools.

1 Introduction

The main purpose of the research is to combine Space Syntax logic with origin destination modeling and to provide an alternative assumption of pupil route choice to those currently used in origin destination models. In this context, the paper presents the development of techniques suitable for use in this application. The process has to be appropriate to school design and to have as its aim the accurate prediction of crowding in the proposed design. A number of ways of representing the spatial layout of a school building will be evaluated and a technique used in robot navigation will be proposed as being the most suitable for the above stated purpose. The aims of this paper are therefore to explore and evaluate the most suitable spatial representations on which to base agent-based simulations that will be carried out in future research. More specifically they are to explore and present a way to incorporate space syntax intelligence into traditional origin destination models. One of the key contributions is a technique that enables the user to combine typical measures in the origin-destination (OD) paradigm with those present in the space syntax paradigm. The scope of the paper does not include testing of the representations or simulations based on them. This part of the research is still in progress.

2 Spatial Representation

2.1 Context

Most pedestrian movement consulting is carried out either through spatial network analysis or through simulation. Different tools and techniques exist for both modes of production. Both classes of method, however, require a mapping from the design or layout of the building to some representation that is a suitable input for the model. In many cases, the space is filled with cartesian-coordinates at discrete intervals, the coarseness of which can often be set by the user. The resulting representation is a grid or mesh, similar to those used in finite element analysis or CFD. The grid is then represented as a graph whose nodes are the nodes of the mesh and whose links connect each node to its neighboring cells, see Figs. 1 and 2. The criteria for determining neighborliness depends on the different implementations and interpretations that are currently available. Examples of grid cell representations used as a basis for analysis and simulation include [1–3]. Alternatively, there are many variants that use other spatial discretization methods that use lighter-weight representation for better scalability in large complex buildings, urban areas, entire cities or even nations, see Figs. 3 and 4. Examples include [4–7]. We will call the latter type topological representations and the former topographical.[1] Topological models differ widely in how they are constructed but, like topographical representations, they too result in a graph where connectivity between nodes represents connectivity between different spaces. In this case, however, the nodes, rather than being placed evenly in a grid-like fashion, are fewer and spaced farther apart, their location determined by other factors. In both Space Syntax and origin-destination modeling paradigms, one can find evidence of the two types of representation: topological and topographical. The axial line map [8] and the network model [4] are both examples of topological representations in each field respectively, and Depthmap [1] and Exodus [2] are both members of the topographical representation typology in the the two domains respectively. Each paradigm finds a use for both types of representation while focusing on different metrics within their field of interest.

	Space Syntax	**Origin-Destination**
Topological	Axial Line Map	Network Models
Topographical	Depthmap	Evacuation Models

Table 1. Topological and Topographical Models in Space Syntax and Origin-Destination Paradigms

Looking at topological models in greater depth, we can categorize them into two different types, planar network models that generally belong to the origin

[1] However, both types are in fact topologies in that they can be represented as graphs and analyzed topologically.

destination modeling paradigm (fig.4), and non-planar, axial line graphs (fig. 3) that belong to the Space Syntax paradigm. In general, planar network models are used to represent regional systems, with a node for each city and links between the cities representing an abstract shortest path to them (i.e. Christalle's central place theory [6]. However, they may also be more faithful to spatial constraints at a micro level. These include ones that use road centerlines as their representation [9, 10]; ones that use networks generated by hand [4]; and automatic methods of generating networks based on the voronoi diagram or medial axis transform [5]. While all these representations differ widely from each other, they share the property of being planar. They are based on the cartesian notion of nodes representing points in space connected by links representing access routes in a more or less precise manner. The axial line graph in Space Syntax, however, belongs to the category of non-planar topological network models. The main distinguishing feature of this type of representation is that the nodes in the graph represent lines of sight (or linear spaces) and the links represent intersections between these lines. In other words, the planar representation described above has been inverted. Critically, for their category, the graphs generated from this type of representation are not constrained by planarity. Batty explores the implications of this in [11]. The key conjecture of the paper is that in order to render space syntax representations tractable to origin-destination analysis and simulation, a translation needs to occur. He proposes a means of translating from the Space Syntax representation to a planar, origin-destination one. The proposition of this paper (explored in section 3) is to translate the other way. (see Fig. 5).

2.2 Analysis

As mentioned in section 1, one of the aims of this paper is to evaluate the suitability of different spatial representations for consulting on pupil movement in schools. Suitability can be evaluated by speed, tractability, ease of use, value in the consulting sector and accuracy of representation and fidelity to results. However, before accuracy and efficiency can be evaluated empirically, an initial assessment of the different forms of representation needs to be done to determine the most productive and tractable process that allows both origin-destination and space syntax techniques to be combined. Topographical representations have an obvious fidelity to the space they are representing, with only the granularity of the grid being the limitation on accuracy and potential cause of measurement error. The topological representations are also able to represent all parts of the spatial system in question, but by using different discretization heuristics. In some cases (e.g. Christalle's central place theory [6]) spatial constraints are not even modeled; in others, they are and are drawn by hand [4] or automated [12, 5]. This makes their appearance and graph theoretical properties differ widely inter- and intra-category. For example, a road centerline network and an axial line network of the same urban area will seem qualitatively different from each other and have a different graph (c.f. Fig.s 3 and 4). When faced with a number of representational options, the problem arises how to compare or combine the

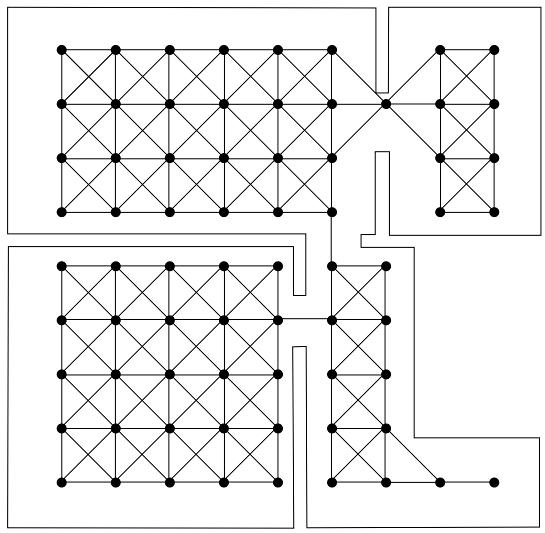

Fig. 1. Illustration of the topographical representation of a set of architectural spaces, as used by programmes such as Exodus [2] and Simulex [3].

output of different analyses or simulations when the fundamental, underlying representation of the spatial system might be varied and incompatible. Furthermore, different representations are favored for different applications. When attempting to combine different methods, therefore, it is important to choose the underlying representations very carefully. As explained in section 1, one of the main aims of the ongoing research is to compare and combine cognitive models of spatial interaction with physical and metric ones. A representation that can accommodate both types of analysis is needed. Planar network models

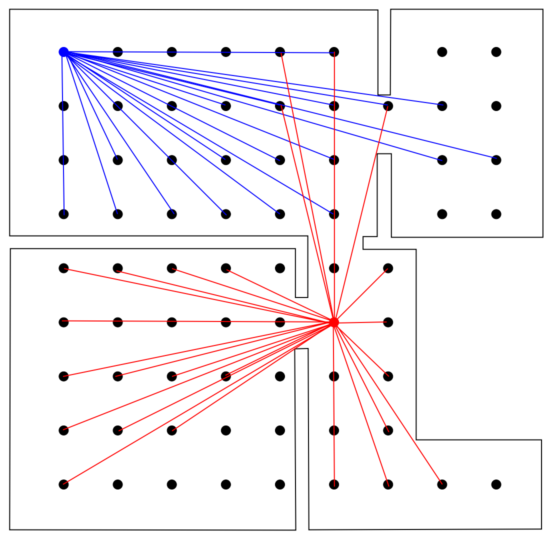

Fig. 2. Illustration of the topographical representation of a set of architectural spaces that takes into account the visible space from each node, as used by programmes such as Depthmap [1]. For clarity, only the connectivity of two nodes is illustrated.

are most often used to calculate physical and metric models of spatial interactions, whereas non-planar, Space Syntax axial line maps are more often used to calculate cognitive and inherent graph theoretic properties of the space. Future simulations will later rely on different elaborations on Dijkstras shortest path algorithms in order to determine which route choice decisions produce the most true-to-life results. Therefore, one needs to consider the suitability of applying the shortest path problem in both topographical and topological representations.

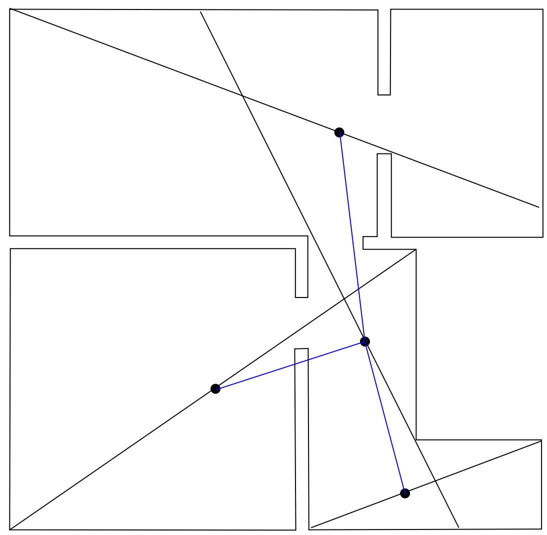

Fig. 3. Illustration of a topological representation of a set of architectural spaces, in this case the axial line map, with its graph representation in blue. The graph is planar but this type of representation is unconstrained by planarity.

The shortest path calculation can have a calculation time of between $O(V \log V)$ to $O(V^3)$. Topographical networks can have upwards of 100,000 nodes, which is at least an order of magnitude larger than topological representations. There is, therefore, a huge computational advantage in using topological models over topographical ones in order to compare and combine the different route choice methods. A further consideration in the choice of representation and the means of generating it is that in consulting, generating networks by hand is also one of

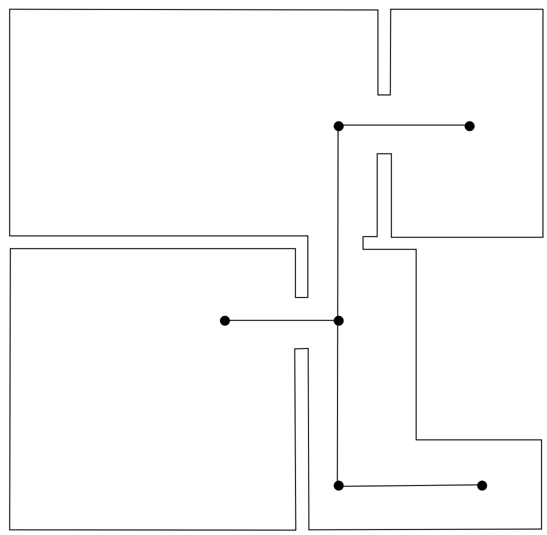

Fig. 4. Illustration of a topological representation of a set of architectural spaces as used in transportation planning network models [6] and recently in complex buildings [4]. This type of network is always planar.

the most labor intensive and time-consuming aspects of the consulting process. This is why techniques have been developed to automate the process both in Space Syntax, and in robot navigation research [5, 12].

2.3 The Chosen Representation and its Application

Having considered the reasons for choosing a topological, planar representation, the exact type of representation used will be presented here. The type of topolog-

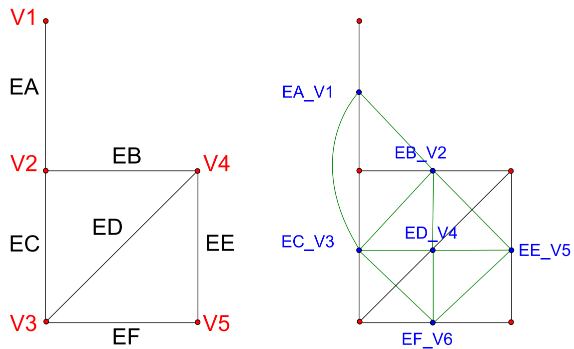

Fig. 5. Diagram of planar network versus non-planar network after Batty [11]. The network on the left is the base, planar network and the network on the right shows the derived inverse network, which is unconstrained by planarity, even if it is planar in this particular example.

ical representation that has been chosen for development is Wallgrün's simplified generalized voronoi graph(GVG)[5]. Wallgrün proposes using a graph of the generalized voronoi diagram (GVD) as the route graph[2] for robot navigation. This is the GVG (see Fig. 6). The GVD is simply a version of the standard Voronoi diagram [14] that is applicable to all shapes, not just points. Wallgrün's hierarchized GVG goes one step further by simplifying the resulting graph using a relevance measure applied to all nodes in the network (see Figs. 7 and 8). The level of simplification can be defined by the user to create a cleaned-up topological representation of the space in question that encompasses all the possible routes an agent can take in it, with few redundant nodes. Wallgrüns representation has been chosen as the base representation as it provides a consistent, automated methodology for constructing network models of any type of space and is particularly well adapted to complex shapes that are often encountered in modern buildings. The introduction and development of Wallgrün's representation as a basis for simulations could significantly reduce the amount of man-hours required to carry out pedestrian movement consultancy. Such a representation has been created of a case study school - Corby City Academy - and future research will test its suitability with respect to other modes of representation.

[2] A route graph for our purposes is defined by Werner [13] as a spatial representation of the environment that encompasses all the different paths an agent can take while navigating that environment.

So far in the research, a number of tools have been developed to use the Wallgrün networks in analyzing and simulating built spaces. The process proposed is outlined below:

- Create a single complex vector polygon of the walkable space for each floor of the building.
- Create the polygons that represent the holes in the space.
- Export the polygons created into the format required by Wallgrün.
- Run Wallgrüns algorithm to produce the hierarchised, GVG based route graph.
- Import the route graph created into Rhino for further manipulation.
- Export the network as a Pajek graph file with any necessary additions, changes or annotations added.
- Import the Pajek file into the simulation environment.

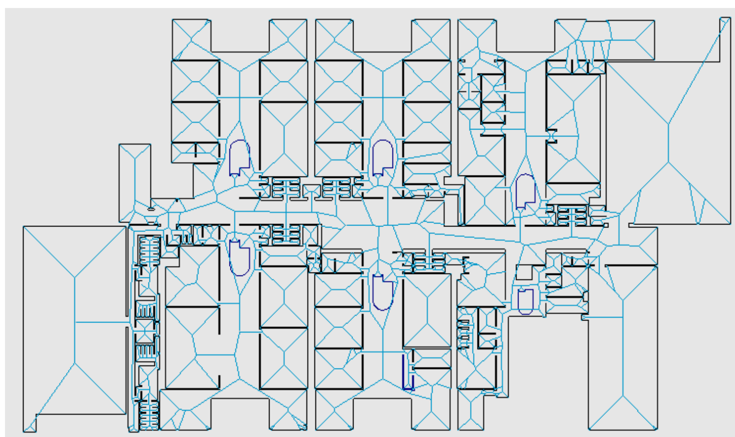

Fig. 6. GVG of a school building, by JO Wallgrün. This representation shows no simplification. It is just the graph of the GVD.

3 Mapping from Planar to Non-Planar Representation

3.1 Underlying assumptions of OD and SS paradigms

As mentioned in the introduction, the aim of the paper is to take the base representation chosen in section 2 and create a new data structure that allows the interrogation of the network using both least distance/time/cost algorithms and least angle algorithms. Currently, the OD paradigm uses a least distance, least time or least cost algorithm to determine the route choice of its agents. This implies firstly that agents are always perfectly capable of determining the

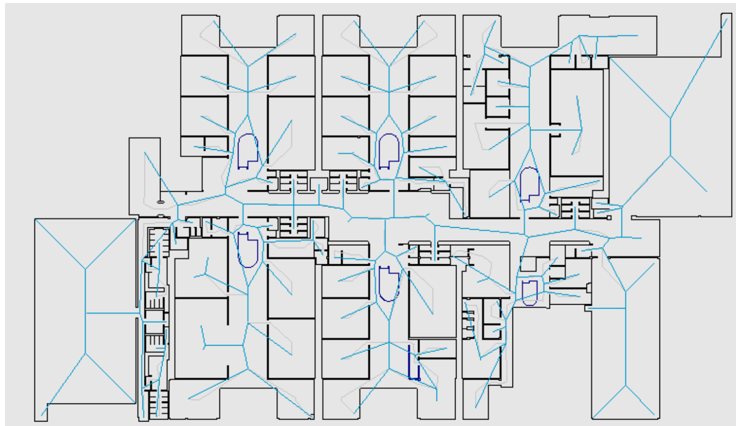

Fig. 7. GVG of a school building, by JO Wallgrün. This representation shows an intermediate level of simplification with a few redundant vertices remaining that would be extraneous for simulation purposes.

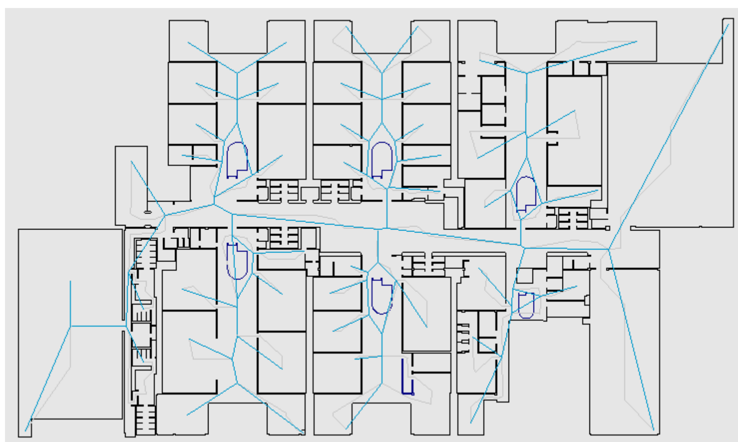

Fig. 8. GVG of a school building, by JO Wallgrün. This representation shows the maximum degree of simplification of the graph while still covering the major spaces in the school.

best possible option in whichever terms are pre-picked, and rationally choosing to take that option regardless. The assumption is that all agents have perfect knowledge of the system and that with that knowledge they make perfectly rational and predictable choices. However, suppose that they either don't have full knowledge of the spatial system in which they navigate, or that they don't make perfectly rational choices. How would this affect the outcome of the model? Research in spatial cognition [15–18] suggests that people exploring a spatial system try to conserve linearity as much as possible when navigating from A

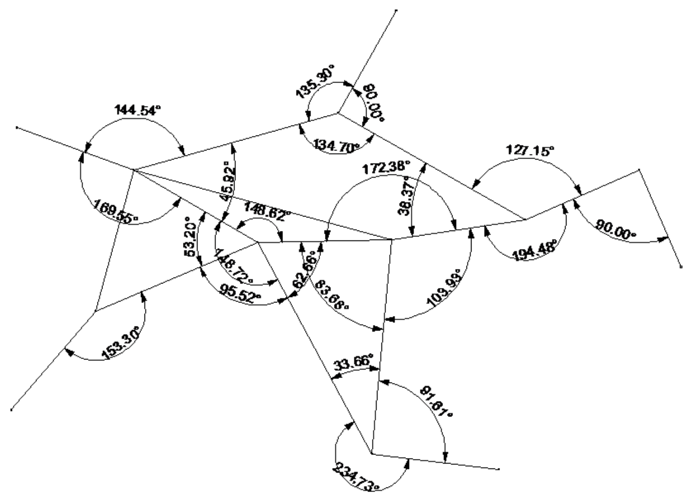

Fig. 9. Sample planar network with angle dimensions added between links.

to B. Miller's theory that the human memory can remember 7 +/- 2 things [19], implies that route simplicity may also be an important factor in route choice. We might suppose then that even with complete knowledge of the system, not all agents will choose their path based on one metric such as least time or distance, and that it is possible that further optimizations in accuracy may be achieved. It is therefore proposed to develop alternative route choice selection procedures that loosely follow the space syntax paradigm, as well as others, to be explored in the future. The overall purpose is to test the assumptions in an agent-based simulation of pedestrian movement and assess the most true-to-life ones. However, to do this, it is first necessary to convert the space syntax measures into the typical representations of an OD network. This is not straightforward, as Batty [11] mentions that the two network representations differ from each other

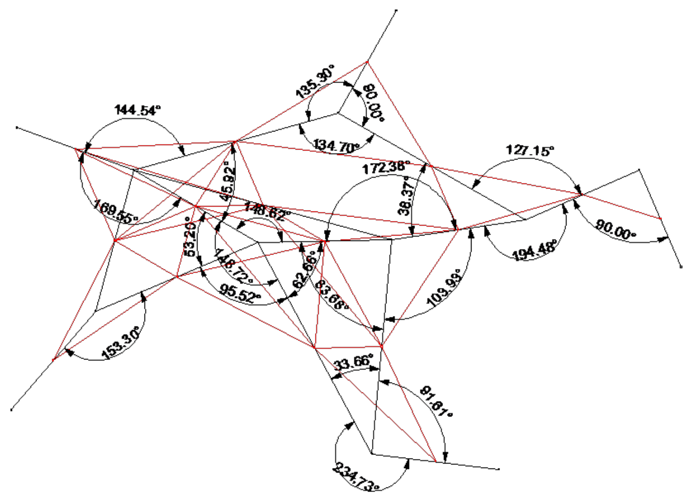

Fig. 10. Inverse, or angle graph (in red) of sample planar network inblack. The resulting graph is non-planar in this example.

in an inverse manner. It is, therefore, necessary to create a unifying framework for analysis. Batty's approach is to take the space syntax representation and render it tractable to OD analysis. The approach taken here is the inverse: taking an OD network and rendering it tractable to space syntax analyses. The type of analysis chosen, angular analysis, is set out in [16]. Turner [9] and Dalton et al. [10] have already explored the potential of this approach for street networks with promising results.

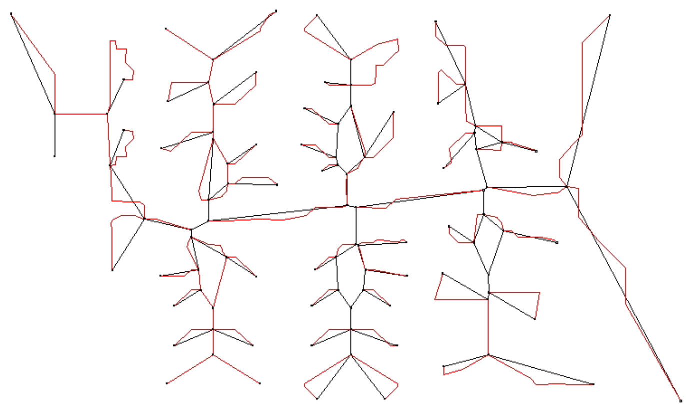

Fig. 11. GVG of a school building, by JO Wallgrün.

3.2 Technical Process

The approach that has been adopted in order to convert a planar network model into an axial network, suitable for angular analysis is to create an inverse network from the base representation. This is done by creating a node for each link in the base representation, and connecting all nodes by a link in the derived representation where there is a node connecting the base links in the base representation. Figure 9 shows a sample planar network, with the angles between each link indicated. Figure 10 shows the resulting inverse or angle graph derived from it. This is along the same principle as demonstrated in fig. 5. In the procedure, the links in the derived network are given a weighting equal to the angular deviation of the two incident links in the base representation. Figures 11 and

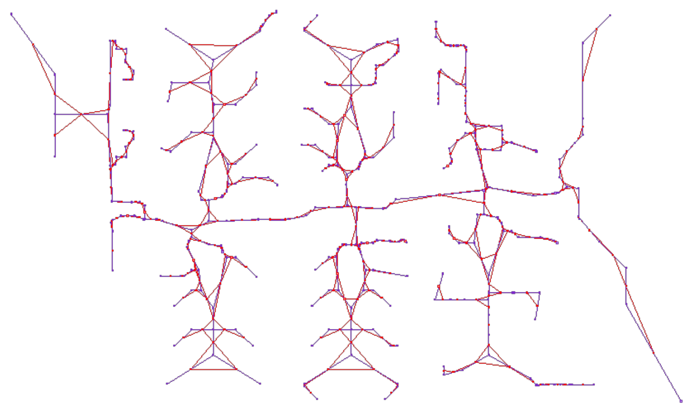

Fig. 12. GVG of Corby City Academy (in purple) by Wallgrün, with inverse graph generated and overlaid (in red).

12 show the base and derived networks respectively for a case study building: Corby City Academy.

The consulting process that is used to assess crowding takes an architects plan of the proposed building layout, generates a network of spaces from the plan and uses this graph as the underlying data structure for the scenario modeling of pupil movements in the building. Many representations can be used for this, but the one chosen here is Wallgrün's hierarchized, simplified GVG [5] (see Fig. 8). However, it is augmented with an additional, inverse data structure capable of storing angular values for route distance estimation (see Fig. 12). This allows the graph to be analyzed both in the traditional origin-destination shortest-path concept as well as the space syntax framework of changes of direction and angular direction changes. In this way, it integrates angular analysis [16] and OD modeling. Future research will evaluate the accuracy and suitability of this representation over the axial line representation proposed by Batty, which could equally be used to reach the same goal. Apart from being non-exhaustive, the representation techniques proposed here only form a part of the consulting process. Any number of simulation methods could be applied on top of this representational foundation; however, they are outside the scope of this paper.

4 Conclusions

The technical process presented in this paper aims to provide an enhanced level of understanding of crowding in a school environment given the introduction of cognitive navigation strategies instead of and alongside conventional OD assumptions of least cost/time/distance strategies. This is made possible by the use of a hybrid representation that incorporates a base planar network and its inverse. Future research will focus on testing and evaluating the strategies and representations outlined in this paper.

Acknowledgments

Thanks to Ruth Conroy-Dalton, Alan Penn, Shrikant Sharma and Robert Hart for valuable intellectual input and expertise. Thanks also to Jan Oliver Wallgrün, who provided the GVGs of Corby City Academy. This research was supported by the EPSRC and co-sponsored by Buro Happold and Node Architecture.

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Effect of Wording of Fire Warning Announcements on Evacuation Behavior in Subway Stations

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1 Introduction

The new subway lines in central Tokyo run very deep (nearly 50 meters) below ground, and their stations are connected to one another by underground paths that are spatially quite complicated. Passengers must travel long distances from ground level to the platform as well as from station to station, making them susceptible to stress caused by claustrophobia and worries about safety. For this reason, design features of underground pathways have been extensively studied in relation to subjective distance and depth perception (Ohno, 2006). The issue involves not only such psychological factors, however, but also the crucial concern of safety.

Generally speaking, fire protection has not been considered as great a priority in subway stations as in other urban public facilities because they are assumed to have fewer fire hazards. However, several major subway disasters have occurred in recent years, such as the fire caused by a suicidal man at a subway station in Taegu, Korea, that took 192 lives in 2003 and the terrorist bombings on the London Underground in 2005. A subway fire is potentially much more dangerous than those in other structures because 1) the complicated spatial layout causes mass confusion for passengers unfamiliar with the surroundings, 2) smoke and heat not only become trapped inside but flow in the same direction as the evacuation route (i.e., upward), and 3) there are limited access routes both for evacuees to go out and rescue teams to go in.

Since people tend to follow the flow of the crowd in emergencies, it is important for them to be led in the appropriate direction in the early stages of evacuation. Although in the case of subways, station staff are expected to provide this guidance, the number of personnel available in any one place is limited, and those who are on hand may not always be fully informed of the overall situation. One possible solution is to make better use of loudspeaker systems, recent technological advancements in which afford precise control of the area and direction covered by individual units, making it possible to tailor warning announcements to the layout and signs of specific locations in the station.

Given the above, the present study experimentally examines how the wording of broadcast warning announcements combines with the effects of nearby spatial features and signs to influence evacuation behavior at subway stations. Most previous research on fire evacuation behavior either rely on case studies (e.g., Sime, 1986) or assess building safety performance using computer simulation (e.g., Kakei et al., 2000). Proulx and Sime (1991) conducts experiments to test the effectiveness of verbal evacuation instructions, sharing research interest with this study, but does not take into account the influence of the surrounding physical setting. Thus this study should prove of value both for its use of on-site experiments as well as its attention to specific spatial conditions faced by evacuees in an emergency.

2 Method

A series of experiments was conducted in an existing Tokyo subway station at five settings, each with a different stair and sign layout. For each session, the subjects (13 male and 8 female university students) were asked to listen twice through headphones to a recorded announcement played over a portable voice recorder, then to start heading in whichever direction they believed safest. Experimenters followed them to record their behavior until they started to go up/down a stair, at which point the subjects were asked why they chose that route. To avoid the effects of order as well as of prior familiarity with access routes, the subjects were divided into two groups with the experimental order and the initial paths taken into the settings varied for each.

3 Experiments

3.1 Experiment 1: Fire warning announcements without directional instructions

This experiment examined how spatial features and signs in each of four settings (see fig.1) affected evacuation behavior when subjects heard a warning announcement that did not give any directional instructions ("A fire has broken out. Please evacuate immediately").

Table 1 shows the routes chosen by the subjects and why. The reasons given were classified into three categories: 1) behavioral history, relating to the initial path the subjects took to the experimental setting (e.g., going back the way that they came or, less typically, heading in another direction because they did not remember seeing any exits along the first route), 2) safer-seeming spatial features (e.g., upward stairs, wider- and brighter-looking spaces), and 3) one or more signs indicating a nearby exit. Some subjects mentioned reasons that belonged to two categories.

In setting 1, where upward stairs and exit signs were to be seen on either side—where, in other words, there were almost no asymmetrical spatial features—subjects tended to choose their way according to behavioral history. In setting 2, upward stairs (C) were chosen by 18 out of the 21 subjects. In setting 3, where there were no upward stairs, 12 subjects chose path (A) based on spatial features and 9 chose downward stairs (C) because signs indicated an exit, but none chose (B). In setting 4, 15 subjects chose upward stairs (A) according to spatial features, while 6 chose path (B) because of the exit sign.

The above results suggest that most subjects chose their evacuation routes systematically according to physical cues in the given situation: spatial features played a prominent role, with upward stairs being preferred over downward ones, while exit signs influenced decisions to some extent.

3.2 Experiment 2: Fire warning announcements with directional instructions

3.2.1 Announcements that direct subjects downstairs

As mentioned earlier, the underground paths connecting stations of different train lines are spatially quite complicated. In some cases, a warning announcement may need to direct passengers downstairs to lead them to the nearest exit. Thus this experiment examined how evacuation behavior was affected when instructions led subjects downward, a direction avoided by almost all of them in the previous experiment. Subjects in group 1 heard the announcement "A fire has broken out. Please proceed to the Ma Line station [one of the names shown on a nearby sign]" at setting 2, and the announcement "A fire has broken out. Please go downstairs first, then proceed to the Ma Line station" at setting 3 (see fig. 1). Group 2 heard the first announcement at setting 3, followed by the second one at setting 2.

As shown in table 2, 15 out of the 21 subjects experienced feelings of uneasiness and resistance when, after hearing the first announcement, they discovered that they had to go downstairs, but the second announcement with additional information warning them that they would be heading downward mitigated such resistant feelings for more than half of them.

3.2.2 Announcements that lead subjects in the same direction as the location of the fire

Station signs typically contain directions for places that are relatively far removed. If a fire is at one of these distant locations, a warning announcement may need to direct passengers partly toward the source of the emergency on the way to the nearest exit. Thus this experiment examined how evacuation behavior was affected when instructions seemingly led subjects toward a dangerous place. Settings 4 (see fig. 1) and 5 (see fig. 2) were used for the experiment. In setting 4, if passengers know that the fire is at the Ch Line station to which route (A) leads, they may also regard route (B) as dangerous because it goes in the same direction as (A) when viewed from the start point of evacuation, although in reality (B) leads to the closest exit. Similarly in setting 5, if the fire is at the Mi Line station some hundred meters away, passengers may avoid route (A) because the sign indicates it leads to the station, although the nearest exit actually lies along the same route, immediately beyond the staircase. Accordingly, subjects in group 2 heard the announcement "A fire has broken out near the Ch Line station. Please evacuate immediately" at setting 4 and the announcement "A fire has broken out near the Mi Line station. No other places are in danger, so please use the nearest exit to evacuate safely" at setting 5. Group 1 heard the first type of announcement at setting 5, followed by the second type of announcement providing more information at setting 4.

As shown in table 3, 13 out of the 21 subjects experienced feelings of uneasiness and resistance when they heard the first announcement, but only 5 felt the same way upon hearing the second announcement with additional information, which seemed to be successful at mitigating their reluctance.

4 Conclusion

The following results were obtained by the study:

After hearing announcements that do not give any directional instructions, subjects tend to choose their way according to prominent spatial features (most notably upward stairs) and exit signs or, in the absence of such physical cues, to rely on their own behavioral history.

Subjects tend to feel uneasy about and sometimes distrust announcements that direct them downstairs, unless the instructions indicate that going downstairs first is necessary to eventually reach the exit.

Similarly, when subjects hear an announcement that leads them in the same direction as the location of the fire, they tend to feel uneasy and reluctant unless they are given more details about the situation.

These results point to possible problems with recently built or remodeled stations in Tokyo that are designed to have one concentrated ticket area shared by several subway lines of different depths, so that some platforms have only downward stairs leading to the exit. Such unintuitive layouts may result in dangerous confusion for evacuees in an emergency situation.

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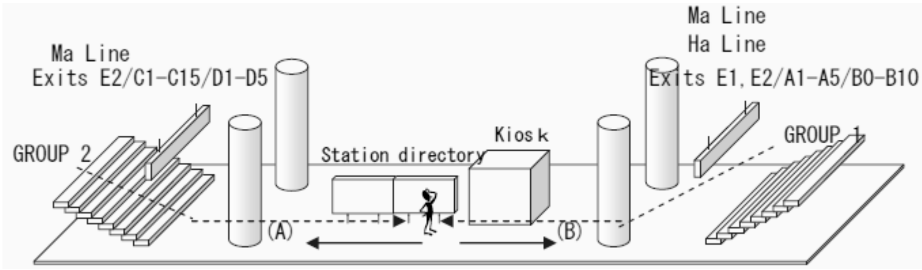
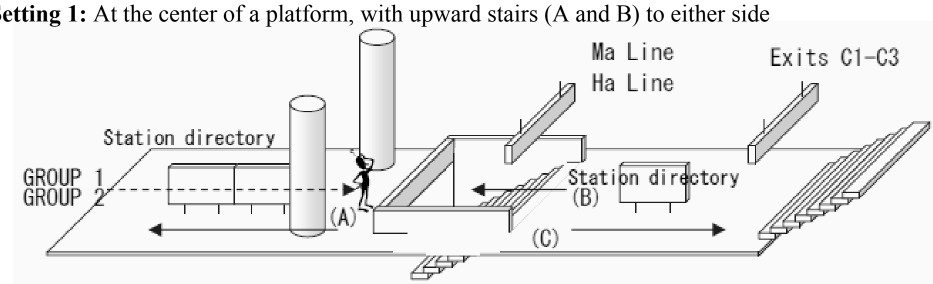
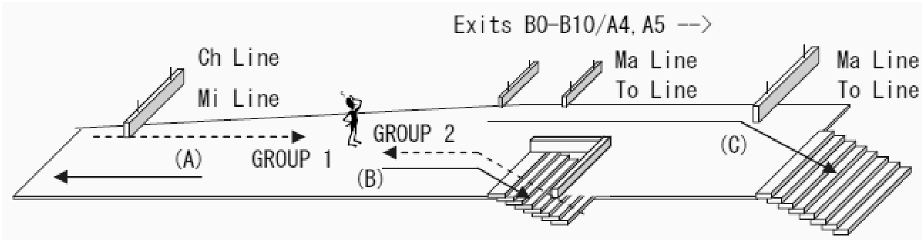


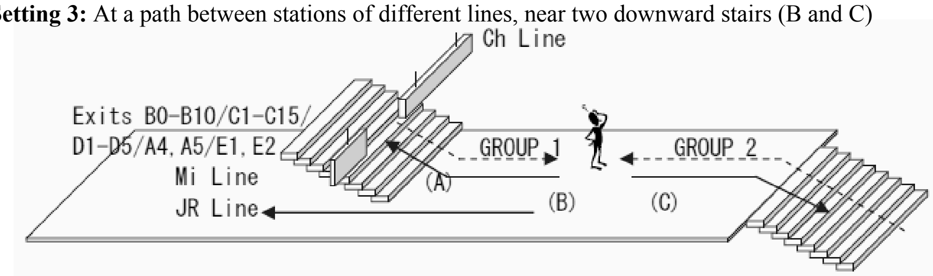
Setting 1: At the center of a platform, with upward stairs (A and B) to either side



Setting 2: At the end of a platform, near both downward (B) and upward (C) stairs



Setting 3: At a path between stations of different lines, near two downward stairs (B and C)



Setting 4: At a path between stations of different lines, near upward (A) and downward (C) stairs

choices ——▶ **initial route into setting** - - - - ▶

Fig. 1. Experimental settings 1-4

Table 1. Routes chosen by subjects and why

Subjest		Setting 1		Setting 2		Setting 3		Setting 4	
Group	No.	Choice	Reasons	Choices	Reason	Choices	Reason	Choices	Reason
1	1	(A)		(C)		(C)		(B)	
	2	(B)		(C)		(C)		(B)	
	3	(B)		(C)		(A)		(A)	
	4	(B)		(B)		(C)		(A)	
	5	(B)		(C)		(A)		(A)	
	6	(A)		(A)		(C)		(A)	
	7	(B)		(C)		(A)		(A)	
	8	(B)		(C)		(C)		(A)	
	9	(A)		(C)		(C)		(B)	
	10	(B)		(C)		(A)		(B)	
	11	(A)		(C)		(A)		(A)	
2	12	(A)		(B)		(A)		(A)	
	13	(A)		(C)		(C)		(A)	
	14	(A)		(C)		(A)		(A)	
	15	(A)		(C)		(A)		(A)	
	16	(A)		(C)		(A)		(A)	
	17	(B)		(C)		(A)		(A)	
	18	(B)		(C)		(A)		(B)	
	19	(B)		(C)		(C)		(A)	
	20	(B)		(C)		(C)		(B)	
	21	(B)		(C)		(A)		(A)	

behavioral history spatial features signs

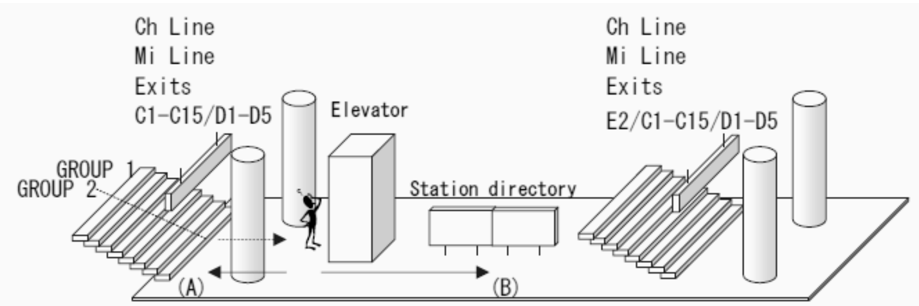


Fig.2. Experimental setting 5

Table 2. Subjects' responses to announcements that direct them downstairs

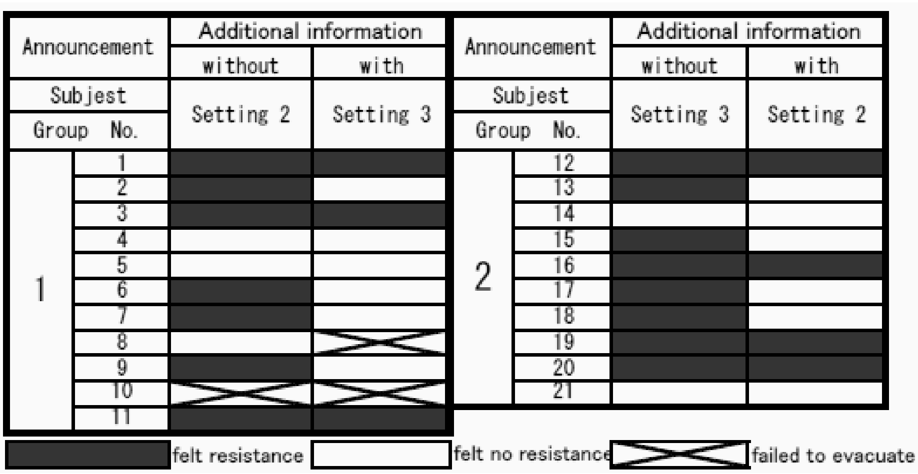


Table 3. Subjects' responses to announcements that lead them in the same direction as the location of the fire

3d isovists and spatial sensations: two methods and a case study.

Christian Derix, Åsmund Gamlesæter, Pablo Miranda Carranza.

Abstract. In our contribution to the 'Linking Differences—Defining Actions' workshop, part of the EDRA 39th Annual Conference, we will explain the work on three-dimensional isovists developed at the Aedas R&D group. This work is the result of a collaboration between the R&D group and the New York based architecture office Davis Brody Bond, also part of Aedas, for the design of the World Trade Centre Memorial Museum. We will introduce the design context that prompted the development of 3D Isovists, and the 2 basic methods and their variations developed as part of the research.

1 The WTC Memorial Museum.

Museums have traditionally been sites of deployment of spatial effects; from the exercises on monumentality of Schinkel in the Altes Museum to Libeskind's spatial drama in his Jewish museum, the design of experience has often played a role as important as the actual functions of housing and display of exhibits. If in traditional museums the experiences created had the function of providing the conditions in which the collections and exhibits (artistic, archeological...) would be perceived, in many contemporary museums this experience has become their central reason and purpose; this is particularly true in exhibitions that provide interpretative insights in to historically dramatic events.

The mission of the WTC Memorial Museum was, according to Davis Brodey Bond, to honour the victims, survivors and rescuers and to tell the stories of the events of September 11, 2001 and February 26, 1993, the first terrorist attack of the Twin Towers. The particular circumstances of the museum, been placed on the site where the events it commemorates took place, create specific and somewhat unusual conditions for this project : In a typical museum the space contains the exhibits; in this case, the exhibit contains the space. The Museum as an extant site already exists; The main spaces, limits, and materials are already there, and they need to be edited and presented so they can be weaved in to the interpretative narratives of the visitors.

The WTC memorial museum has been designed thus as an interpretive procession through the remains of the Twin Towers; the main architectural concern has not been only the effective display of the exhibits (artefacts and remains from the actual attacks) but the design of the museum as an affective experience . This experience is articulated as a series of spatial sensations of absence and presence, produced through the changes in size of the visual field, along the designed itinerary . The arrangement of these spatial events, their relation to the ruins of the WTC, and their capacity for recollecting the historical event of its destruction, were some of the main concerns of the design by Davis Brody Bond.

2 Three dimensional Isovists.

The goal of the research carried by the Aedas R&D group was to develop a number of computational methods, algorithms and software tools that would correspond to the ideas behind the WTC Memorial museum project. These methods would allow to represent, test and validate some aspects of the proposal, and allow to visualise those intended effects related to changes of the visual field in a precise form.

The principle used for the study of these spatial sensations was based on the idea of an isovist. Our work concentrated on three-dimensional implementations of the isovist concept. An isovist is defined as the portion of space visible from a given point; generally this implies two types of isovists: two-dimensional and three-dimensional. A Two dimensional isovist consists of the area visible from a point, defined in two-dimensional representations like a plan or a section of a building, urban area or landscape. A three dimensional isovist consists of all the volume visible from a point in space. In general two-dimensional isovists are those most commonly used, particularly in plans. The reasons for this are many: usually two dimensions are enough to define the salient features of the isovists, and much of the analyses relate to the navigation and movement through space, movement which is mostly also two dimensional. The calculation of two dimensional isovists is also in general faster and simpler to run in a computer than their three-dimensional equivalents.

However, the analysis of three-dimensional isovists can describe, visualise and represent qualities of relevance which are lost in two dimensional analyses. These qualities are specially significant in spaces in which the horizontal is not always the dominant direction of movement, as for example spaces with ramps, stairs and escalators or uneven terrain. They are also important in spaces in which the vision of features such as the vertical references of tall buildings in the distance or signs placed high, is of importance. In short, three dimensional isovists are relevant in analysing architectural spaces in which their three-dimensional visual experience is of significance.

The study of isovists in architecture was first proposed by M.L. Benedikt in his paper 'To take hold of space: isovists and isovist fields', in 1979[1]. One of the most important contributions since then is the use of isovists combined in Visibility Graphs proposed and developed by Alasdair Turner and Alan Penn as part of the Space Syntax[2]. Whereas the Geometrical Isovists (polygonal in the case of 2D and polyhedral in the 3D case) give relevant data about the qualities of the shape of visible space from a particular points of view, visibility graphs make explicit the visual relations of different locations in space, and overall quantitative analysis of those relations. In the work at the WTC Museum Memorial we have implemented both approaches (polyhedral isovists and visibility graphs in 3D), and tested them in the spaces proposed by Davis Brody Bond.

In the case of the project for the WTC Memorial Museum, the spatial experiences sought after involved the control of changes of the visual field in terms of size, direction and shape, both horizontally and vertically. This search demanded the use of three-dimensional isovists in order to grasp and define the qualities of those experiences correctly. The complexity of the space and the planned itineraries at different levels communicating through ramps and sloping floors, escalators and stairs prevented the use of two-dimensional methods. These would have not captured the complex relations created in the exhibition space in which the exhibited artefacts and remains are perceived obliquely in the space, from the ramps, balconies and cantilevers.

Isovists are geometrical abstractions that relate to the visual experience of space; they are projections from one point in all directions, and are therefore not constrained by a field of vision (unless specifically bound), or include many other characteristics and limitations resulting from embodied vision, and that may be in many cases important constituents of visual experience. Isovists are simply the portion of geometrical space visually affordable from a given point. This means that an isovist can be understood in two different ways: either as the space visible from a point, or as the portion of space from which that point is visible. Isovists can therefore provide information on the visibility of a portion of a building form a certain point, in terms of how much surface may be visible or the angle of incidence of the view on these surfaces. They can also define how visible an object may be on a space, as well as information related to the shape and changes of shape of the visual space.

3 Algorithms.

The special conditions of the WTC Memorial Museum prompted, as explained above, the development of three-dimensional isovist calculation algorithms. There are a number of methods for the calculation of two dimensional isovists, to which members of the research team have previously contributed: processes based in computational agents, discrete visibility graph calculation inside CAD packages or fast polygonal methods using existing two-dimensional graphic libraries have been presented in different conferences and papers[3]. However, there are few methods and precedents for calculating three-dimensional isovists. For the WTC Memorial Museum we have worked both on three-dimensional implementations of the basic discrete method, as well as implementations of polyhedral isovist calculation methods. The first discrete types have been developed using the C# language as plug-ins for the modelling package Rhinoceros. The Polygonal method has been implemented using the Java language and the OpenGL graphics library through Java OpenGL (JOGL).

3.1 Discrete point calculations.

The algorithm used for the construction of the visibility graph is in principle quite simple: all space is filled with points and their visibility relations are calculated. This is done by casting rays between all points and establishing edges in the graph, only when those rays don't intersect any object in the model the space. Further network calculations can then be performed in the resulting graph. The easiest, but often quite useful calculation is simply the count of other nodes visible from a given point. This will show an estimate of the amount space visible from a point, and when displayed together, it shows what Benedikt described as the isovist fields.
We have tested three variations of this method, depending on the way points (nodes on the graph) are placed and distributed through space:

3.1.1 Surface method.

The surface mapping algorithm divides all surfaces in a 3D model (Breps in the case of the C# implementation running in Rhino) into approximately equal size rectangular patches. The visibility of the centres of these patches are then tested against each other. The method for this is simple: rays are cast between the centres of the patches and edges created when these rays don't intersect any other surface in the model. In the specific context of the WTC Memorial Museum, in which walls, floors and ceilings constitute the exhibits, this proved of great interest, and allowed to evaluate the visual exposure and range of different parts of the building.

3.1.2 Spatial method.

The spatial variant consists of a straight forward implementation of the 2D Visibility graph algorithm in to 3D. However, there is a substantial difference; whereas in 2D plans usually the visibility graphs correspond with the positions from which the space will be perceived, in 3dimensional space this is only the case of nodes placed above the floor surfaces, at a distance equivalent to the height of a person's eyes. These spatial visibility fields show the changes in size and shape of three dimensional space, and its gradual or sudden expansions and contractions. In fact this type of calculation gives more an idea of how open a space is. The results thus are more abstract than the 2D equivalent, and can be interpreted as spatial qualities of the space, instead of been directly related to spatial functional organisations. It is important to highlight this difference, which points to a possible complementary use of isovists for describing and visualising more vague spatial qualities, additionally to their main use in the analysis of the organisation of space.

A further variation of this second type is that of calculating the amount of spatially distributed nodes visible from patches on surfaces (generated like in the first method described). This amounts to the open space affordable to each point on the surface.

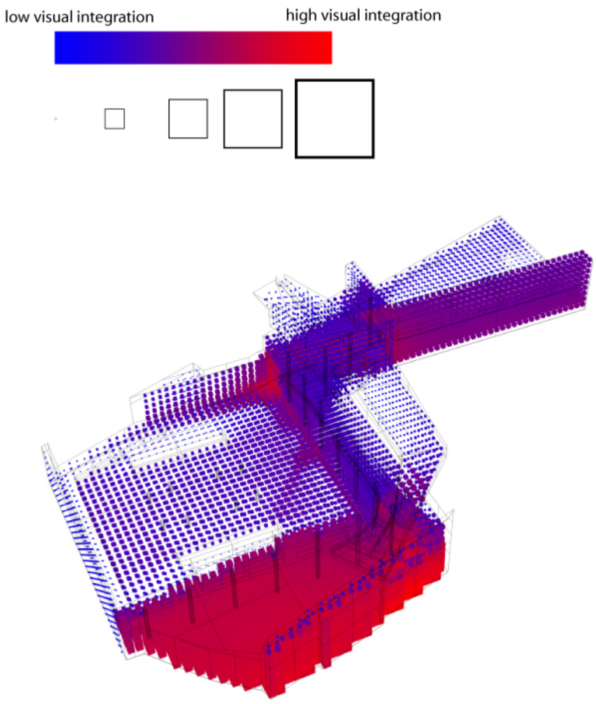


Fig. 1. Spatial method: amounts of visible space from each point, visualized both as colour gradients and box sizes.

3.1.3 Radial Polyhedral method.

This a further discrete method for calculating an approximation of the polyhedral isovist. Points on a sphere are projected radially until they hit planes on the 3D model, and the original sphere is distorted accordingly
In this case a number of radii are projected from a point until they hit a surface. Then these points are joined according to their proximity in terms of angular distances, to produce a closed volume. The resulting volume can be used for the calculation of its centroid (the direction or weight of the isovist), its volume, and other measurements used in analysing the shape of polyhedral isovists.

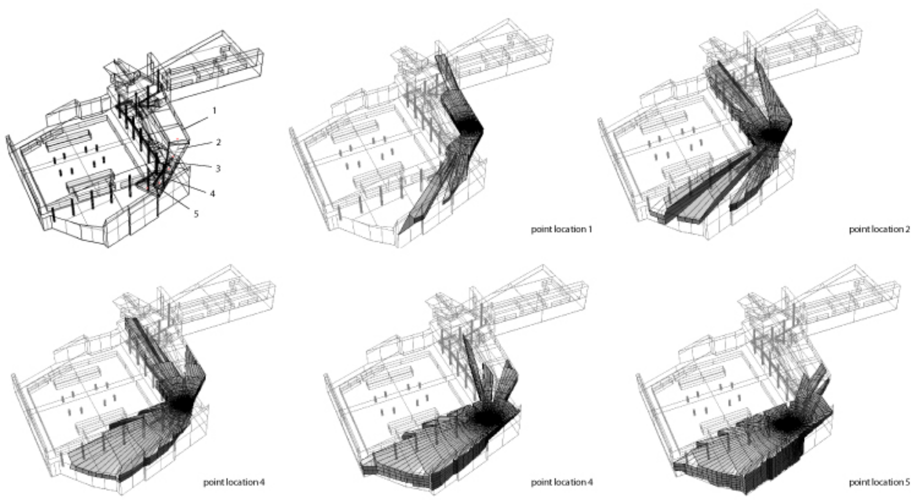


Fig. 2. Radial-polyhedral method: isovist sequence through the main ramp pf the WTC Memorial Museum.

3.2 Polyhedral Isovist calculation.

We have implemented also a polyhedral calculation method; this is in principle, an extension of the 2Dimensional methods for calculating polygonal isovists. But even if conceptually 2D and 3D calculations are similar, their actual implementation differ substantially, due to the added geometrical complexities of the three-dimensional problem. We have chosen triangular primitives or 3D faces for calculating this type of isovists. The method is as follows: We consider every triangular polygon and we project them (from the point we are calculating the isovist from) in to every plane formed by any other triangular polygon. We check for clipping, and if this is the case we subdivide the triangle in smaller ones. We substitute the original clipped triangle by the new ones and continue, until we have run through all the original triangles. The results of these calculations are triangular meshes defining accurately the polyhedral isovist. This can be used for the calculation and analysis of the shape of the visual field. We have used this polyhedral calculation for defining accurately the isovist fields for the whole museum; we have also employed simple calculations about their shape, such as volume, centroids, and the direction of the isovists, as simply the vector between the point it is calculated from and the centroid. We hope to be able to develop further calculations based on the form of the isovist. The calculation is fast enough to run in real time for small and simple 3D models. This allows to also evaluate the changes of the isovist and the evolutions of the visual field along a path. In complex models the isovists along a path can be calculated first and displayed as an animation afterwards. This proved particularly useful in the WTC Memorial Museum project, which is in fact a planned itinerary through an existing space. The animation of the isovist, and the consideration of its changes in time, is also an important aspect that we would like to expand.

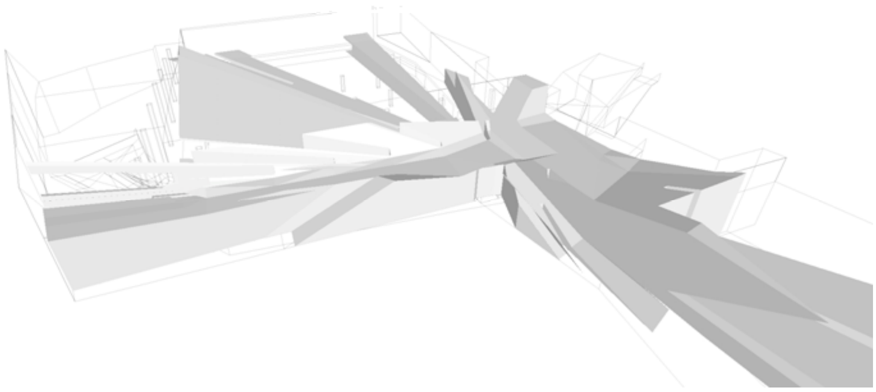


Fig. 3. Polyhedral method: isovist under entrance space to the WTC Memorial Museum, showing the complexity of the space.

4 conclusion.

Our work on three-dimensional isovists has only started. We have defined the basic algorithms and methods on which we are hoping to build on future work. Because they define basic geometrical features of spaces which relate quite directly to their visual experience, we expect to be able to use these methods in the generation of of spaces in which visual perception and its effects can be calculated .

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Problem Seeking
Visualization Method for Active User Involvement

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Abstract. Problem Seeking is an excellent method to visualize and to structure the needs of the user. The process will lead to the statement of a problem and the requirements to be met in providing an architectural or urban solution, and accompany the complete planning process. It enables the planner through an open minded communication to achieve the highest level of efficiency and, more important, acceptance of all participants. Two case studies are used as examples: Dar es Salaam, Tanzania - the unplanned settlements and the harbor zone, and the Municipality of Junik, Kosovo – an Urban Reconstruction and Development Plan.

Keywords: Visualization, communication, active user involvement, urban planning, history

1 Introduction

Problem Seeking is an excellent method to visualize and to structure the needs of the user. The process will lead to the statement of a problem and the requirements to be met in providing an architectural or urban solution, and accompany the complete planning process. It enables the planner through an open minded communication to achieve the highest level of efficiency and, more important, acceptance of all participants.

Problem Seeking is a type of figurative language which illustrates every project phase to help integrate the users on an improved more active basis and to overcome language barriers. Over the course of a project, a very personal relationship develops between all participants.

In multilingual projects, such visualization methods with figurative representations are immensely useful for triggering a lively dialogue. The desires and requirements of the future users are collected in the form of individual cards that are allocated to certain subject areas and then figuratively visualized, so that the participants are able to monitor the progress of the project. From the very first, the planning progress has a "real" dimension that is clearly perceivable by the users.

2 Dar es Salaam – Unplanned Settlements

Especially Dar es Salaam is an excellent illustration of the interplay between architecture and society, that is, the extent to which planned space influences society and, conversely, to which building and design are always responses to societal changes and expressions of functional and societal correlations, making them essential tools for influencing our environment in a positive manner.

2.1 Sustainable Dar es Salaam Project – Background

1993 the UN-Habitat "Sustainable Dar es Salaam Project" (SDP) was created as a coordination and integration project executed by the local administration and based on the financing and technical contributions of the United Nations Center for Human Settlements (UNCHS-Habitats) for the development of the Sustainable Cities Program (SCP). Renew the city center, eliminate environmental dangers, promote the economy, and, in particular, improve living conditions in the unplanned settlements were the goals. As success was fairly limited until 1996, with nobody feeling properly responsible and an acute lack of cooperation and coordination between the individual authorities, the UN decided to systematically support three, instead of the original nine projects in Dar es Salaam in order to demonstrate their feasibility. One of these projects was Hannanassif, an unplanned settlement. The project implementation was based on three principles: to include all parties, to carry out a careful analysis of the area, and to set up working groups that would draw up action plans for concrete implementation measures.

Finally, after seven years of experiments, in 1999, a special "Strategic Urban Development Plan" (SUDP) was drawn up with the goal of improving living conditions for all parties concerned. This plan is fully flexible and develops over time according to the demands and requirements of the residents. It is an integral part and by-product of the Environmental Planning and Management approach as suggested by UNCHS. The need to consider a new urban management approach had been recognized, to be able to involve the population from the bottom up and develop an independent programming of equipment, services and housing together.

In the meantime, in 1994 the university had started an annual intensive planning seminar with students from Milan, lasting three to four weeks in which lecturers and students from the UCLAS (University College of Lands and Architectural Studies) of the University in Dar es Salaam and from the Technical University in Milan took part.

What makes this approach so outstanding is that the plan then was integrated in the syllabus of the University of Dar es Salaam, UCLAS, thus directly involving future architects and urban planners. During her work as a lecturer at UCLAS between 1998 and 2001, the author had the opportunity to witness the practical, down-to-earth schooling enjoyed by the students and to support it with visualization methods for a better involvement of the user. The school defined the goals and linked them with the government program. Students were given grades based on their achievements. Semester coursework at UCLAS refers to real planning areas and the city authorities are involved in the progress as much as possible.

2.2 User Participation

The driving element is the participation of the population groups that are affected and the realistic implementation of small and extremely small-scale projects in the individual districts.

In order to get a better idea of the most pressing needs in these problem zones and to familiarize the students with the area, field surveys were organized and suggestions drawn up for improvement that are represented to the public and implemented in cooperation with the local population. To aid communication with the locals, specific visualization methods were used, Problem Seeking for example, a type of figurative language and models illustrating every project phase to help integrate the users on an improved more active basis and to overcome language barriers. Over the course of a project, a very personal relationship develops between the students, supervisors and residents. There is a strong support structure in place for the implementation process, and even when students move on to other projects, contact is maintained with the residents involved in previous projects to monitor their satisfaction levels and to see whether any additional requirements need to be met.

In multilingual countries, such visualization methods with figurative representations are immensely useful for triggering a lively dialogue. The desires and requirements of the residents are collected in the form of individual cards that are allocated to certain subject areas and then figuratively visualized on posters. As these posters remain in the assembly house, residents are able to monitor the progress of the project, especially when photographs, drawings and models are added to the posters. From the very first, the planning progress has a “real” dimension that is clearly perceivable by the users.

Fig. 1. Problem Seeking method to visualize the ideas and needs of the user.

2.3 Method

Lecturers from both universities had started to visit the unplanned settlements regularly and especially the lecturers from the Dar es Salaam University had started to form a kind of relationships with the inhabitants of these areas.

Based upon that new program and the experience of the university during the summer sessions the fieldwork with the inhabitants was intensified and as much student projects as possible were undertaken to improve the situation in the unplanned settlements as well as to test new virtual projects for the city center in Dar es Salaam.

The described project "Hannanassif" is one of these projects for unplanned settlements in Dar es Salaam. The inhabitants were very open for collaborations with the university as they already had seen that there was always a benefit for them. Students and lecturers were welcomed and shown around, as they were known to always have an "open ear" for problems and also were willing to find a solution. When we started a new project we always did a lot of field trips, talking to the inhabitants, gaining there trust, and slowly the new project developed, based on the most important needs of the user. The card technique of the Problem Seeking method was very helpful as well as the use of a lot of pictures and drawings to explain which solution we had in mind and how we planned to realize that.

2.4 Implementation

One of the largest problems for the population of unplanned settlements is the lack of drainage. The large amounts of water that follow sudden, heavy rainfalls cannot be absorbed by the ground, which is either completely dried out or swampy. The situation is exacerbated by the continuous construction of new buildings, making for a densely packed surface area, and a lack of waste removal mechanisms. Drains are therefore essential for the settlements. It must be ensured that residents are still able to access their own living space, and, most importantly, that waste is not disposed of via the drainage system but in designated areas outside the settlement. For these reasons, it is vital that the project is monitored with photographs and explanations even after the drainage system has been completed and that residents are informed of the importance of keeping the drains clean.

Market stalls serve to ensure the fairly self-sufficient goods supply in the settlements and are also a way of providing at least some income. Suggestions include design improvements using simple materials, some instruction on hygienic matters, and a pleasing overall design. In this context, it is particularly important to use existing material that is easy to get hold of and cost-efficient. Delineated areas are useful to create playgrounds for children or to separate the individual stalls. Tires are an excellent way of achieving this and can also be used for seating.

Fig. 2. Selling of groceries before and after improvements with new stalls – new children's areas

The cooperation between the university and the users meant that knowledge and research results could be implemented directly on site. The residents of the unplanned settlements benefited from their improved living conditions, while students were able to apply their theoretical knowledge on a practical basis. The close cooperation between all parties concerned ensured that simple, cost-efficient solutions were drawn up and implemented. The experiences of the users were invaluable for implementing ideas and encouraged an exceptional level of creativity.

3. Dar es Salaam – Harbor zone

Based on the experience in the unplanned settlements, a combined planning method was developed to draw up suggestions for the reconstruction of the harbor area of Dar es Salaam to be carried out in small steps. On the one hand, this planning method is based on the history and understanding of a city or an area, which is researched via an analysis of its urban development and through discussion with local residents, using visualization methods, especially Problem Seeking. On the other hand, the method rests on a rational-scientific analysis, by using methods like observations, black plans and Hillier's space syntax method, which produces evidence for architectural and urbanistic interventions.

3.1 Visualization of the whole process

This approach has proven extremely useful as changes and developments can be discussed on a visual level and thus placed in a consensus that is acceptable to all parties concerned. The people who would have to live with the planning results later on are involved in the overall process as much as possible and from a very early stage, so that planners are able to understand their requirements and wishes and react to them appropriately, thus also ensuring the necessary acceptance for bringing about changes. All steps are visualized in a simple manner, and can be presented at any point. The results were pooled and suggestions for selective interventions drawn up that were illustrated by sketches and pictures. It is an essential characteristic of these representations that they do not suggest architectural solutions and in fact permit many different interpretations.

3.2 Small steps as a concept for the refurbishment

The preservation of the center and its traditions should be an essential concept for helping the city to find its own identity. Existing attractions, such as the museum and the botanical gardens, should be integrated in the new concept. These areas, as well as parts of the Indian old town, boast beautiful old buildings that have also been defined as worthy of preservation at other points in the city's urban planning history and are crucial for the development of its identity. These historical buildings must urgently be restored and given new functions, preferably of a public nature. It is crucial that an end is put to the ethnical segregation that resulted from the colonial city structure and was exacerbated by the construction of the Mnazi Mmoja Park. The goal of any further development must be to blur these borders once and for all and unite the city's population and space. Mnazi Mmoja Park should be activated as a public recovery and green zone and linked to the town center with additional pedestrian connections. Suitable attractors should be developed there and throughout the city, not only for the inhabitants but also as magnets for tourism. This will improve the economic situation and help create worldwide attention.

The harbor zone has been defined as extremely important throughout the history of urban planning in Dar es Salaam and should therefore definitely be included in further planning measures. The area where the piers for sailing ships were once located, adjacent to today's commercial port, remains largely unused. This creates an opportunity to transform a rarely used area of the harbor into a lively, urban extension of the city, directly at the waterfront.

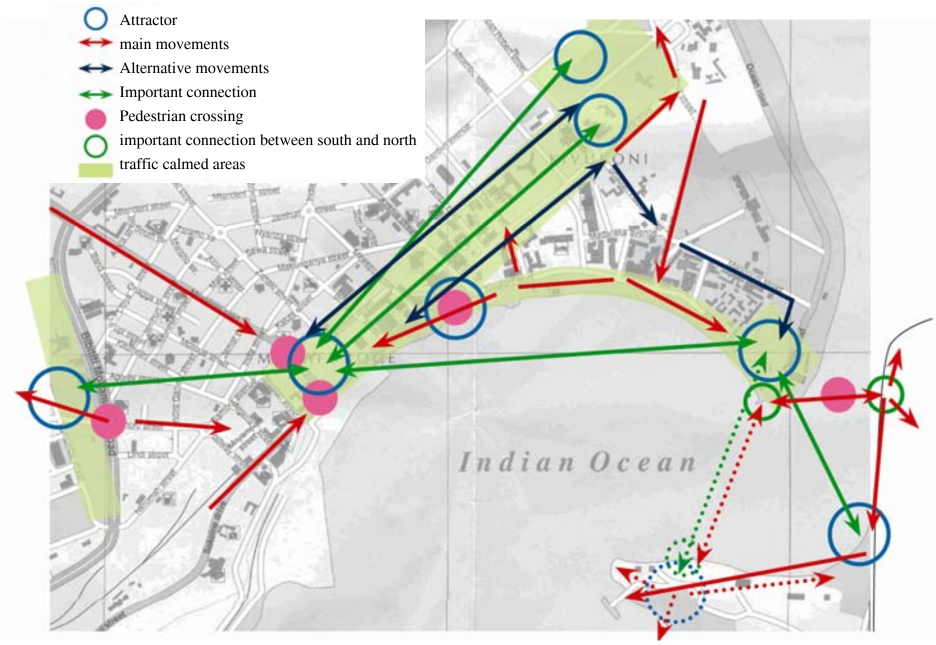

Fig.3. Graphically summarized diagram as basis for step by step recommendations for the future of the harbor zone.

4. Municipality of Junik

The municipality of Junik, situated in the Western part of Kosovo, has a long and very traditional history and was quite often in the middle of different conflict zones.

Fig.4. Location of Municipality of Junik in Kosovo

The author worked as an urban planner for Cultural Heritage without Borders in cooperation with students from the University of Prishtina. In a period of three weeks the area was investigated and interviews were conducted with the inhabitants. All remaining kullas were surveyed in special sheets, pictures and drawings were added and maps were drawn as a basis for the future redevelopment plan for the area.

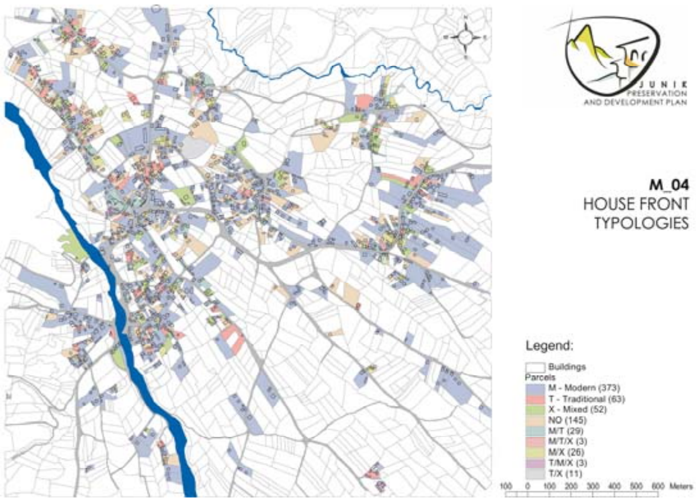

Fig.5. Map of house typologies with remaining traditional houses (63)

Together with the inhabitants a development plan was created, which is based on the region's history and old traditions. Junik is the heart of the "kulla" buildings, stone fortresses, which have been destroyed systematically in the recent war to obliterate traditions and history of the people of Kosovo. Together with the inhabitants new functions and possibilities were researched and ways uncovered to keep the remaining buildings and to refurbish those already in ruins. These discussions were all protocol led with the Problem Seeking method.

Fig.6. Problem Seeking method used for all discussions in the workshops

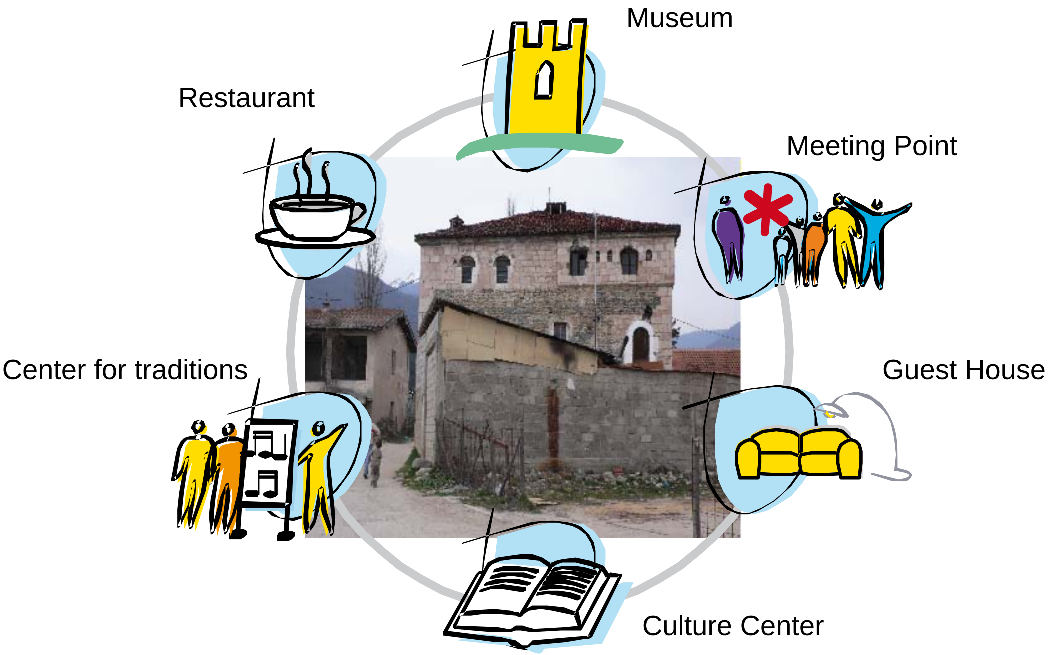

Fig.7. Problem Seeking method to visualize the ideas the inhabitants had for the refurbishment of their kullas.

Cultural Heritage without Borders refurbished one of the remaining kullas to give an example of what can be done with these houses to keep them and to help to preserve typical traditions of that region.

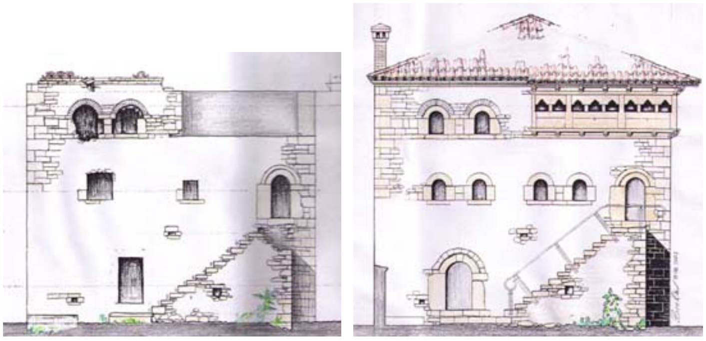

Fig. 8: Kulla e Junikut – drawing before and after refurbishment

Fig. 9: Kulla e Junikut before and after refurbishment

5. Conclusion

Good planning relies on different methods. Profound knowledge of a place, and the systematic investigation of the characteristics of a city in its historical context are essential in this process. The morphology of a city, its identity, results from its inhabitants. Urban life cannot be controlled through rational planning methods alone. Every location in a city, every shape, every stone tells a story and adds to the overall picture of a place. Locations have a potential for memory. These aspects give a city its unmistakable identity. The reality of urban life is shaped less by what we actually see than by the invisible treasure of its hidden meanings.

Cities and municipalities like Dar es Salaam and Junik must be given the opportunity to develop and make visible this sort of "meaning", not only for the benefit of the population, but also to position themselves appropriately and in sufficient time on the global stage. Restructuring offers a chance to unite the individual centers and points of attraction that developed in different cultures in a joint network of attractive, citizen-based zones and make a global connection possible via meaningful expansions. It is vital to take up the opportunity to provide locations for the underprivileged population groups and integrate them. Spaces and functions must be created that permit the joint interaction of all cultures and social classes and that bring locals closer to visitors. How this is perceived and experienced is part of actively shaping our future. This is true for everyone – residents, visitors, and planners – but in particular for the "users." It is, therefore, vital to integrate users in the planning process from the very start and to make them active participants with the aid of visualization techniques.

The method introduced here is one of many small steps, and involves a great deal of joint action and active participation on the part of residents themselves. This is a way to overcome past problems of implementation. For Africa in particular, where we find poverty side by side with a strong momentum for change, such an approach seems more promising than large-scale projects imposed from the outside, which meet with little acceptance and are often abandoned before completion. This visualization method is intended to promote enthusiasm on the one hand and to serve as an orientation tool on the other. The method outlined above wants to suggest a direction, a practical approach; a possible path towards change.

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Movement Dynamics and Shopping Patronage: A Syntactic Profiling of Shopping Centers in Business Districts

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Poster Abstract

Movement and spatial configurations seem to play significant roles in the performance of urban systems. Particularly noticeable is the case of shopping centers and their relative locations within an urban setup. This paper delves into some of the mechanisms underlying the performance of such centers within a restricted setting. The syntactic profiling of shopping centers in Yaoundé (Cameroon) is used to illustrate the intricate dynamic forces involved in shaping a shopping environment. Space Syntax predictive models of movements correlated with the underlying land use and gate-count observations on selected streets of the CBD area, point to somewhat diametrically opposed use of space by pedestrians and vehicles. This apparent novelty is explained, using statistical variables of the local morphology. The paper argues that although both land use and the configuration of street networks contribute to the movement equation in the downtown area, the performance or patronage of shopping centers is influenced more by the availability of suitably located interchange nodes that allow movement to be switched between the two systems. It concludes by a discursive analysis of some major factors that may make or mar effective movement systems and efficient location of shopping outlets

Emergent circulation patterns: Generating movement networks for buildings using stigmergy

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Abstract. This work explores the flocking behaviour of agents based on stigmergy, and tries to bring this emergent behaviour into architectural design context. According to the proposed scenario an agent colony is not solely a passive mechanism to analyse space but can also proactively modify its environment. Stigmergy based building algorithms are considered to be an adequate way to achieve meaningful spatial outcome. It is suggested that stigmergic agents can be directly involved in creative design routines.

Key words: Stigmergic building, generative architecture, circulation patterns

1 Introduction

This study is about linking ideas and models from the field of distributed computing with architectural thinking. Many algorithms well-known in artificial intelligence and artificial life studies can be more or less directly used in solving architectural problems. Some earlier studies conducted in CECA [1, 2] have brought generative modelling in architectural context; this work focuses on agent modelling for architecture. Although flocking and optimal path formations are widely explored subfields in agent programming [3, 4], there is no established application of these systems in use in architectural design communities or practices. Most of the work in the field still tends towards analysing existing or planned environments [5]. Only lately, few design-oriented people have made remarkable efforts in deploying agent-based modelling techniques for generating 3D structures and design solutions [6, 7].

2 Proposed computational model

The ongoing research explores the stigmergy-based [8] movement and building behaviour in computational agent colonies. The concept of stigmergy has been used earlier by Bonabeau et al [9] to generate 3D form. Bonabeau et al suggest that, given the right set of 'stigmergic' rules, agents can generate highly ordered structures. This work, however, focuses on generating circulatory network for buildings. For this purpose, a specific agent based simulation has been devised. The concept of proposed simulation model is fairly simple: agents, immersed into 3D environment, react to environmental stimuli by releasing 'pheromone' and by triggering processes that change the environment.

2.1 Testing movement patterns

Locomotion is the first and the most important component of the proposed model as the circulation core in the built structures is its direct resultant. The algorithms for steering individual agents are based on OpenSteer [10] engine with some additional routines to facilitate path recognition and following. Agents interact with their own trails emitting and sensing 'pheromone' in the environment. It has been found out that the sensory configuration has the major role in both of these models, and only a limited set of configurations lead to circulation patterns that can be useful in the architectural design context.

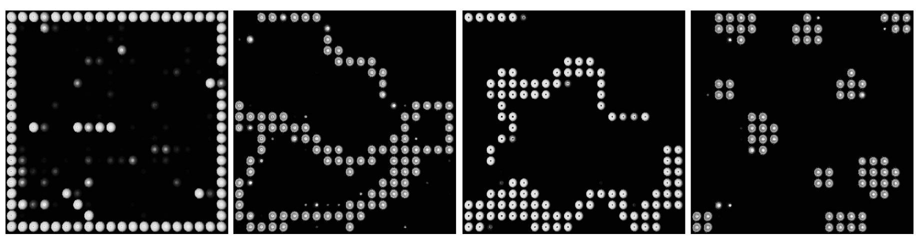

Fig. 1. Stigmergic movement patterns of agents with different sensory configurations. In these tests agents have three sensors with the angle between side sensors (from left to right): 45, 90,135,180 degrees

2.2 Environment

The agents move freely around in excitable lattice of 'nodes'. Each node in the lattice stores a set of values that agents sense and modify. Whereas the above shown tests are carried out in two-dimensional environment, the final model is constructed in 3D. The agents are not forced to 'walk' on planar surfaces but can 'fly' around freely. Without any environmental constraints the formed trails can also whirl freely in three dimensions. In order to constrain agents' movement to planar layers it is suggested to use differentiated lattice where certain layers of nodes in the lattice are less excitable than others and are therefore less attractive to agents.

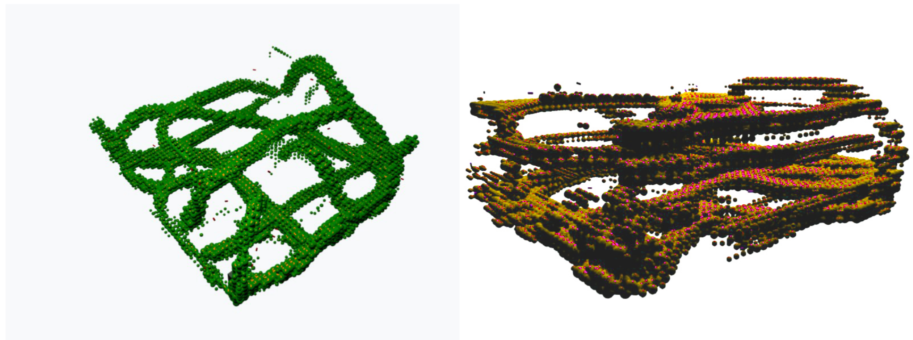

Fig. 2. Circulation (pheromone trails) in continuous and 'layered' environment

2.3 Generating spatial layouts

The objective of the final model is to establish a dynamic and adaptive system for generating building forms. All generated building forms have a range of spaces represented as extruded polygon objects and a defined circulation network where each space is accessible from the circulation. When the right conditions are met, agents trigger a diffusion algorithm [11] to create new spaces.

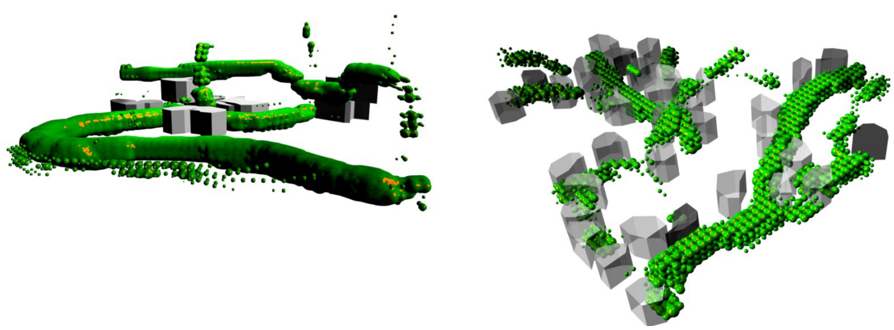

Fig. 3. Generating spatial representations. Spaces (block objects) are placed only to locations that are accessible to agents (green trails)

2.4 Formation of vertical 'stair-core' circulation

On their way agents cannot penetrate 'space' objects in the environment and are forced to choose an alternative route when they confront one. Circulation patterns tend to become more complex when movement is coupled with building routines and the motion of agents is guided by the changing environment. When

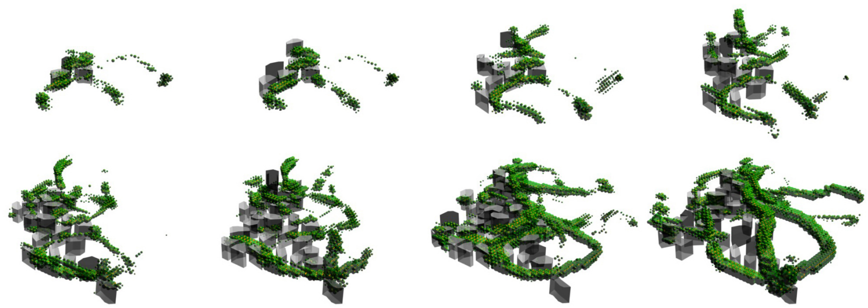

Fig. 4. Circulation network formation

an agent collides with an object it tries to avoid it by randomly choosing an alternative course, sometimes leading to the emergence of vertical circulation. It seems that the vertical movement happens in places that are overcrowded by objects encouraging agents to move to the next level.

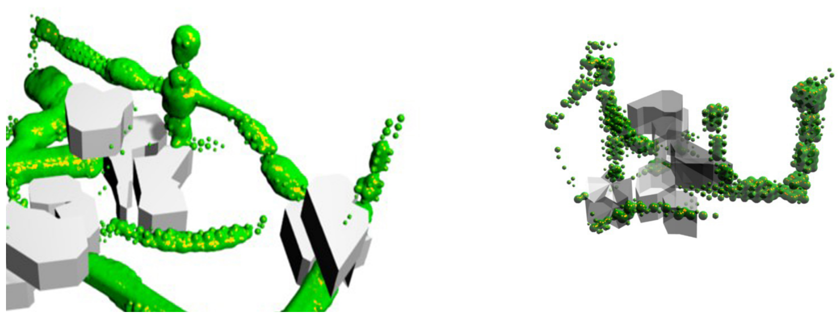

Fig. 5. Emergence of vertical 'stair-cores'

3 Summary

The proposed model demonstrates a dynamic system that can be used in early stages of design process. The greatest benefits of the model are its flexibility and ability to adapt to different environmental configurations. It is argued that due to the dynamic nature of the model, it can generate numerous architectural solutions and suggest not only the layout of spaces, but also the spaces needed for pedestrian or vehicular traffic. The flexibility is facilitated by two kinds of behaviour in the model. Firstly, there is a dynamic process that constantly tends towards optimal movement of agents. Secondly, there is a feedback process going on between agents and objects in the environment. The resulting spatial structures are therefore never controlled by the circulation or by the spatial configuration alone, but emerge dynamically with the respect to the existing environment.

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Lighting in the Built Environment: Human Perception, Behavior and Movement.

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Abstract. This research focuses on the understanding human movement through lighting. People have always been attracted to light, either by fire, candles or, more recently, electronic light. From this point of view, the question arose whether, in a retail environment, one's behavior is influenced by lighting. Hence, the first focus of the study lies on how humans behave (move) under certain lighting conditions: way-finding as well as their walking speed are included. The second focus of this study deals with the perception of space under certain lighting conditions, on a more emotional based approach. A theoretical background serves to develop several hypotheses. The experiments are organized in a controlled environment, which is a simulation of a supermarket.

Key Words. Lighting, Consumer behavior, mood, retail design

1 Introduction

The goal of this research is to develop guidelines for designing lighting in the retail environment. Two statements lie on the bases of this topic. Firstly, lighting can be designed to guide people's movement through space. Secondly, lighting can be designed in such a way it has a positive influence on the appreciation of a space, via the perception of that space. To back these statements up, a theoretical framework has been developed. This framework is based on research in commercial spaces and workspaces. The choice to undertake this research in commercial spaces is twofold: a thorough research indicated that commercial spaces are ideal environments to experiment in with lighting, humans, their behavior and emotions; furthermore, since most research has been done in office settings and there is a gap in research for retail settings, it is only logic to develop hypotheses -for retail settings- based on what is already been studied –in office settings.

Regarding retail environments, the following has been studied. Research showed that shop environments create a ‘retail experience’ that strongly influences consumers' purchase behavior [1][2]. Moreover, keeping shoppers longer in stores is likely to result in increased browsing behavior, which in turn is likely to cause increased impulse purchasing. And even up to two third of purchase decisions are made in store [3][4]. Consequently, shop interiors are extremely important and through their interior variables have an individual effect on the consumer. Kotler [5] therefore, coined the term ‘*atmospherics*’ to describe “*the effort to design buying environments to produce specific emotional effects in the buyer that enhance his (/her) purchase probability*”. Many design elements in combination or separately exert this influence on behavior in general. In this paper we want to limit our research to the factor ‘light’; how light influences behavior; and what kind of behavior precisely we are talking about.

There are three parts in this study and presently the second part is being undertaken. The first part included a survey of the literature, and in depth interviews with selected experts. As a result, certain hypotheses were developed (see point 3). The second part is an experiment in a controlled environment –simulation of a supermarket- and subsequently in a real shop environment. Finally, the third part will be the development of guidelines for lighting design in commercial spaces, based on the results of the experiments. The link between research and design will be developed in the final phase.

2 brief survey of the theoretical framework

The environment response model of Greenland and McGoldrick [6], mapping the influences of the shop environment on its visitors, distinguishes three stages in the user reaction in shop and service environments: a cognitive, an emotional and a conative stage (graphic 2).

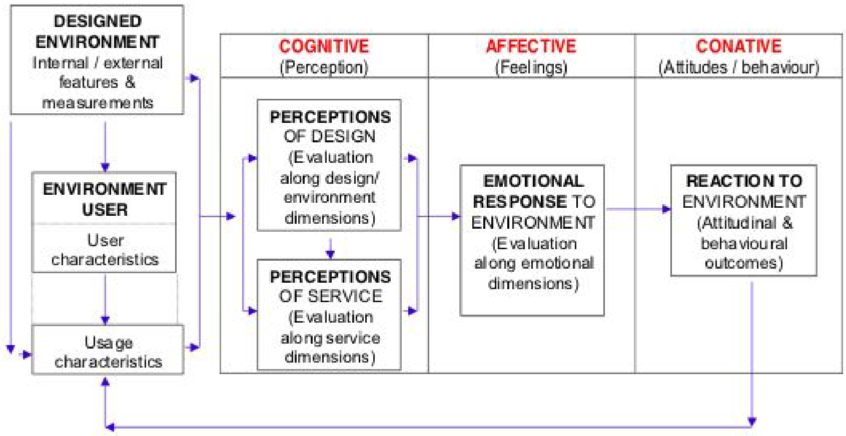

Fig. 1.

Environment response model of Greenland and McGoldrick

This model can be applied for lighting research as well, since lighting can be seen as a component of the shop environment. Greenland describes the cognitive stage as an action or faculty of knowing and perceiving the architectural environment. The emotional factor in his model contains all feelings elicited by the environment, e.g. arousal, pleasure, etc. The third possible influence, 'conotative', concern attitudes and consumer behavior. Both the emotional and conative factors are hard to separate and will influence one another. This research aims at finding more information about the interaction between these two factors, while focusing on lighting research.

Bitner [7] also developed a theory of how consumers respond to a retail environment. She described how consumers responded to a retail environment in a cognitive, emotional and biological way. What is called the biological response here is a slightly different approach to consumer behavior than the one Greenland and McGoldrick made. Bitner refers to a more natural approach of humans in retail environments, which is clearly separated from the emotional influence. Regarding to lighting, the biological factor got another dimension since the focus has shifted to the hormonal reaction of humans to lighting, which lies far beneath the range of this study because this reaction only occurs after a long and intense exposure to specific lighting conditions.

So, discussed here are the short term biological effects of lighting on people: the way people behave under certain light conditions, which route they take and with which speed.

When reviewing the literature regarding the influence of lighting within retail environments, several aspects have been studied. Consumer behavior on a very basic level: Taylor and Socov's research [8] showed that light influences the route consumers take through the store. This study indicates that people are drawn to light and that they, therefore, will choose the more illuminated path when passing an obstacle.

A second aspect addresses a more product-based level, which in turn also influences peoples' behavior. In this context LaGuisa and Perney [9] stated that light could draw attention to products. Areni and Kim [10] did similar experiments with wine bottles in a store. Under 'bright lighting' conditions bottles were more often examined and touched than under 'dim lighting' conditions. Magnum [11] took this one step further and showed that lighting influences the attractiveness of products in a store. Along the same line, Summers and Hebert [12] showed that more belts were touched and picked up with the addition of display lighting. Subsequently, they constituted consumers spent significantly more time at the display with the additional accent lighting.

A third aspect regarding light in retail environments comes from an environmental psychology based emotional model. Mehrabian and Russell [13] developed this model to study environmental stimuli within retail environments and their influence on the consumer. They proved that emotions, evoked by shop environments, are related to consumer behavior, and one step further, to buying behavior [14][15]. But each of them only make assumptions about the lighting specifically, and remain very vague about its possible influence on consumer behavior. What we do know is that lighting has an influence on the perceived price level of a store [16]. What most of us already assumed has been supported by research: bright lighting conditions, in combination with orange colored walls induce the feeling of low price perceptions. Soft lighting conditions on the contrary appear to increase the height of the price perception.

The biological influence in retail environments has not received the same academic attention as the influence of lighting in working environments. Studies in psychology showed that individual personality traits can influence reactions to environments [17]. Furthermore, Knez and Kers [18] found that age and gender interacted with the illuminance and the color temperature of the lighting, causing different kinds of mood shifts, in working environments. Kuller [19] showed differences in reactions to lighting, based on cultural backgrounds. Also, the spectrum of the lighting plays an important role as well. Studies about this give controversial results [20][21][22][23][24]. These aspects are taken into account in the development op this study.

3 Hypotheses

Our hypotheses are based on existing literature on mood, consumer behavior and lighting. Each of those three has been the topic of research, but a connection between them has never been explored:

- It is known that the visual environment, as well as the atmospheric elements, are able to influence the mood of people [25][26][27][28][29].
- Lighting is an atmospheric element of the environment as explained before.

So, the interior design and within that, the lighting, may become an important actor to induce the right mood that influences buying intentions and shopping experience in general. Consequently the next main hypotheses is stated:

H1a: Lighting has an influence on the mood of consumers in retail environments.

Gardner‘s review [30] revealed that there is a direct and indirect link between mood states and behavior:

H1b: Lighting has an influence on the people’s behavior as measured by their purchase behavior.

It is proven positive affect, of any kind, encourages a shopper to stay longer in store [31][32]. As mentioned above, lighting can induce positive affects. So, the next hypotheses is stated:

H2a: Lighting has an influence on people’s behavior as measured by the time people tend to stay in the shop.

H2b: Lighting has an influence on people’s behavior as measured by the wayfinding as well as ones walking speed in a retail environment.

There has been one study that found no direct influence of lighting on mood, but it only reported a difference between the perceptions of the light in the room [33]. An earlier study shows the same results [34]. Knez indicated that these results, and the divergent results of his previous studies as well, might be inconsistent by the use of an inferior measuring model. He points to a need for more precise and sensitive models to measure the influence of lighting on mood. When reviewing the methodology used in both studies, the same method to measure mood is exploited (namely the PANAS: a self-report of positive and negative mood method). Both researchers also acknowledge this method might not be effective for mood-measurement in lighting research.

Furthermore, Knez emphasized the problem of today’s psychological lighting research: we still do not know if the light effects cognition via emotion or if the light effects emotion and cognition independently. Therefore it is necessary to measure both mood and behavior. A model is developed, based on the SOR-model – stimuli, organism, response - of Mehrabian and Russell [13], to analyze both mood and behavior. Following measurements will be conducted: observation, time measurement, products bought and questionnaires. The questionnaires are used to measure both mood – via the PAD-model (pleasure, arousal, dominance) of Donovan and Rossiter [35]) - and wayfinding. Figure 2 shows the model used.

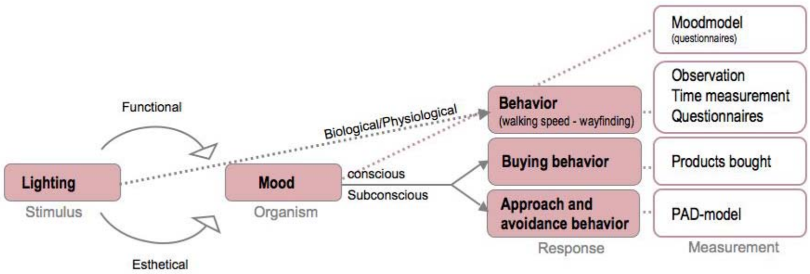

Fig. 2.

Conceptual model developed based on the SOR-model of Mehrabian and Russell

Note here that the persistency of lighting and its effects might be relative to all the other factors that can change behavior, perception and movement. Lighting is considered as just one of the many interacting factors that determine the outcome. This is taken into account.

4 Experiment

Partly quantitative, partly qualitative empirical experiments will be undertaken to verify or falsify these hypotheses. The experiments will be set-up in our retail-lab. The research is based on the ‘research by design’ method: it starts with empirical research of human behavior in relation of light and specific interior settings. These settings are modified during the research process in accordance to the empirical data.

The experiments in the lab environment have a strong internal validity, so the results of the experiment in a proper retail environment will increase its external validity. Therefore both experiments enhance each other and they will provide results that form a translation of how research can be implemented and translated in the design process.

The difficulty lies in isolating lighting from all other aspects that play a role in the perception and experience of a retail environment. By controlling and monitoring every possible detail in the lab environment –smell, temperature, products, people- except the lighting - that is an independent variable - we are able to attribute any change of behavior and/or mood to the lighting. This method can be used for most of the aspects isolated from architecture. But, dissecting retail architecture into several parts only works in one direction: architecture is more than the sum of its parts. It is important to take count of this holistic nature of architecture. Therefore, results of research on isolated matters, should always be set back to its context before they can become fully supportive in the design process. The designer must be aware of this and needs to develop the ability to select and merge valid information into a holistic concept.

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