Spatial Cognition for Architectural Design

SCAD 2011 Symposium Proceedings

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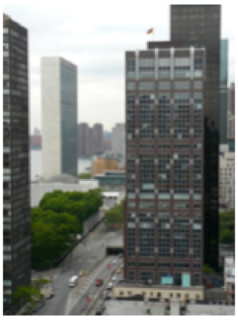
Proceedings

Symposium on

Spatial Cognition for Architectural Design



SCAD 2011
A symposium of researchers, educators, and industry practitioners.
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Public Panel Discussion

This public panel discussion on "*Understanding People, Spaces, and Spatial Cognition*" provided an opportunity for a wide audience to experience and understand the latest advances and current trends in the theory and practice of architecture design and its education, spatial cognition, and spatial computation. The panel engaged in discussions and debates on the core themes of the symposium. The aim was to identify how interdisciplinary application of knowledge may provide real benefit for the theory and professional practice of architecture design, and eventually, tangible benefit for the quality of everyday personal life and work.

Understanding People, Spaces, and Spatial Cognition

The Interaction of Architecture, and the Cognitive and Computational Sciences

The physical space in which humans live and work has far reaching implications on the nature and quality of everyday life and experiences. As Winston Churchill put it: 'We shape our buildings, thereafter our buildings shape us'. Understanding the space surrounding us has been a challenge for many disciplines. Architects shape space by designing buildings and cities. Psychologists and cognitive scientists investigate how humans understand space and how they behave in space. Computer scientists need to find ways of representing and computing with space, e.g., about its structure and perceived behaviour and function, within systems for design creation and analysis. People, i.e., users of designed spaces, serve a crucial role by the specification of design requirements at an abstract level.

Traditionally there has only been limited overlap between such disciplines and design stakeholders. What is missing is a holistic design creation and deployment paradigm encompassing every facet and stakeholder (e.g., users, designers, engineers, policy makers) in the design process. It is time to actively foster interdisciplinary connections to better understand the relations of design spaces & design practice, human spatial cognition, and spatial computation for design.

Bridging disciplines requires asking questions about the relation of art and science of design, analytic perspective vs. the synthesis of design creation, empirical evidence vs. design intuition, as well as technological support vs. creative autonomy. The panelists discussed how cross-disciplinary perspectives can be developed and what hurdles need to be tackled.

Panel Discussion Hosts

Busso von Alvensleben
Consul General of the Federal Republic of Germany in New York

Dr. Joann Halpern
Director, German Center for Research and Innovation
New York, USA

Dr. Eva-Maria Streier
Director, German Research Foundation (DFG)
North America, New York Ofice, USA

Panel Moderator

Dr. Eva-Maria Streier
Director, German Research Foundation (DFG)

Panel Members

“Contemporary architecture design tools regard eventual design products as isolated ‘frozen moments of perfection’. Even within state-of-the-art design tools, aspects such as commonsense, semantics, structure, function, behaviour, people-centred design –concepts that are implicitly known to designers– are yet to come to the fore. This panel discussion has been convened with the aim to initiate a dialog on a holistic approach - primarily encompassing architecture, cognitive science, psychology, computer science, and social science - for the creation and analyses of architectural designs.”

Towards a Holistic Approach for Spatial Design
Dr. Mehul Bhatt
University of Bremen, Germany

“Understanding how humans react to buildings, for example how they move through it to find their way, is a key aspect for taking a user-centered perspective. Psychology and cognitive science can provide valuable input to an emerging evidence-based movement in architecture.”

Dr. Christoph Hoelscher
University of Freiburg, Germany

“Today, by merging building and information technologies, including the personal computer, internet, handheld and wearable computers, sensors, BIM, BACnet, IFC, and intelligent computer applications that harvest, mine, and package relevant information, we are at the cusp of a new and powerful shift in the way we build and evaluate [building designs]."

Prof. Ömer Akin
Carnegie Mellon University, USA

"In designing spaces and structures, architects interact with external and internal representations of shapes and forms they generate in an incremental and iterative process to ensure a good fit with needs, requirements and desires. One of the affects of computational tools on this process is a vast expansion of the range of geometric potentials, coupled with a fairly poor proficiency to control the qualities of the resultant spaces and structures for proper use and well-being of humans. Not anything we can concoct with the help of computational power is worth actualizing; our challenge should be to match human-centered control capabilities to the generational power of computational design capacities."

Prof. Gabriela Goldschmidt
TECHNION - Israel Institute of Technology, Israel

"The real world and real patterns of human behavior require a real method of evaluation of the resources embodied and required in the maintenance and transformation of our built environment. This method of evaluation needs to bring together the world of science with the world of design so as to provide a holistic understanding of the qualities that each individual designed object possesses, and in turn, which qualities the environment as a whole has. The proposed method of evaluation is based on human cognitive modes and creates neither a virtual world nor a set of indigestible concepts and neologisms."

Prof. Wilfried Wang
University of Texas at Austin, USA

Introduction and Symposium Overview

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1. Introduction

The SFB/TR8 Spatial Cognition and the Spatial Intelligence and Learning Center (SILC) have initiated the symposium Spatial Cognition for Architectural Design to bring together cognitive scientists and architects to build a bridge across disciplinary boundaries and help identify common issues around the themes of space, cognition and design.

The symposium – held at the German Research council office in New York City, Nov. 16-19 2011- addresses the theoretical and methodological achievements of the cognitive and computational disciplines in the domain of architectural design. A dialogue between scientists from design research and educational disciplines as well as professional architectural design practitioners began with the aim to identify how such interdisciplinary application of knowledge may provide real benefit for the theory and professional practice of architecture design. Principal issues highlighted in this workshop include:

- cognitive systems. current topics in spatial cognition, e.g., guided by cognitively-driven approaches to user-centered building design
- artificial intelligence. state-of-the-art in spatial computing for design, e.g., emphasizing the role of specialised spatial representation and reasoning in design in particular, and knowledge representation and reasoning and artificial intelligence artificial intelligence in general
- intelligence-based design. architecture design education and professional practice focussing on paradigm shifts such as intelligence based design
- assistive technologies. fundamental questions concerning next-generation design assistance systems, e.g., focussing on multi-modal design analysis, and behavioural & functional simulation, and interaction design issues

The symposium emphasized interdisciplinary exchange and aimed to address questions concerning the translation of cognitive and computational research and theories into professional architecture design practice and education.

The symposium featured a total of four keynote talks as well as numerous short and long presentations and two tutorials. While most presentations were given from an academic perspective, the New York based designers Anthony Deen and David Gibson reported about their applied projects. To connect to local architecture professionals and the general public we included a public panel discussion hosted by the German Research Foundation and the German Center for Research and Innovation (GCRI) in New York City.

More information about the tutorials, keynotes and panel sessions as well as participants and the detailed program are documented on the symposium website:

http://www.sfbtr8.spatial-cognition.de/cosy/Events/SCAD-11/

Northumbria University (Prof. Ruth Dalton, Usability of Spatial Environments (USE) Research Centre), the SFB/TR8 and SILC jointly sponsored an architecture competition with the title "Designing from the Inside Out – Envisioning an Academic Interchange". This competition highlighted design criteria like making a building easy to navigate, a topic that links cognitive science and architectural design perspectives. The winners of the competition were invited to New York City to discuss their designs with academics and to present them in an exhibition alongside the public panel session.

More information about the competition and exhibition can be found here:

http://cognition.iig.uni-freiburg.de/martinb/inside-out/home.htm

The main part of this SFB/TR8 Report features working papers that participants submitted for the event. The contributions vary in their length, disciplinary perspective and methodological approach, and together they capture the diversity of the participants as well as the scope of the research community currently developing at the interface of cognition, space, architecture and design. The symposium served a platform for long and detailed discussions and participants agreed that further meetings and publications would be a fruitful enterprise. A summary of the public panel session and the four parallel discussion sessions on the final day of the symposium are also included.

The editors envision this current volume as a stepping stone towards future activities, including a follow-up book project to introduce the scientific agenda of this symposium to a wider, cross-disciplinary audience.

2. Scientific Agenda

The symposium strived to:

- Initiate communication between cognitive scientists, computer scientists, and designers & architects
- Identify which scientific results / knowledge from disciplines such as spatial cognition and computation might have an impact or relevance for designers

The symposium served as a platform for cognitive and computer scientists to:

- present / translate basic discourse to an applied field
- perform a reality check, as this interaction with designers and architects may challenge cognitive science assumptions about the usefulness of tools, and analytical theories

The symposium provided an opportunity to professional architects / designers to:

- present contemporary design challenges, paradigms, and case-studies
- learn about state-of-the-art research on space in computer and cognitive science, psychology etc.

- shape research questions and influence development of assistive technologies for design analytics
- get involved with opportunities for research at the intersection of social science and technology

3. Focus Themes

3.1. Spatial Design for Architecture

Design for architecture is concerned with `space': empty space, spatial structures, and the process of structuring. Spatial designers, architects, and engineers organize empty space by building-up structures and artefacts of our everyday existence and structuring transforms and organizes empty space into something of a desired form (e.g., a balanced room, a visually pleasing scene), function (e.g., easily navigable) and semantic connotation (e.g., of a `place'). Within design science and the philosophy of design in general, form, the associated utilitarian notion of function, and the relationship between the two are ontological constructs that have served a pivotal role by providing a point of interface between disparate focus groups involving users, designers, and engineers. Within the theory of architectural design in particular, conventional morphological analyses involving the elements of form, empty space, enclosure, behaviour, and function have been the fundamental underlying constructs.

Whereas the philosophy of form and function is a well-researched topic, the practical relations and dependencies between form and function are only known implicitly by designers and architects. Specifically, the formal modeling of structural form, i.e., their shape, layout, or connectivity, and resulting artefactual function within design, and practical design assistance systems remains elusive. Interdisciplinary studies concerned with `language and space', `spatial memory', `spatial conceptualization', `spatial representations', `spatial formalizations', `spatial reasoning' are extensive and enormous to say the least. However, attempts to understand the nature of creative spatial thinking and design processes for architecture within a unified cognitive and computational framework have not been given due consideration. This may be achieved from the viewpoint of dimensions such as psycho-spatial conceptualizations, visual, diagrammatic, and qualitative spatial representation & reasoning, learning for design, spatial communication, qualitative modeling & reasoning, and a specialized understanding of spatial computing for design.

Basic questions raised:

- How do architects think about form and function while they are designing? What is the role of spatial reasoning in different stages of design?
- What do architects want to be told, or not told, by an intelligent design assistance system?
- What kind of behavioural and functional analytical capabilities may be identified? Are there clearly recognizable gaps in the state-of-the-art?
- What are the emerging paradigm-shifts in the practice of professional architecture design, e.g., with respect to design tools, procedures, and learning modalities?

3.2. Spatial Cognition in Design

Spatial Cognition is concerned with the acquisition, organization, utilization, and revision of knowledge about spatial environments, be it real or abstract, human or machine. Within spatial cognition as a discipline, research issues range from the investigation of human spatial cognition to the development of cognitive, formal, and computational models of spatial perception, modeling, and reasoning from a multi-disciplinary perspective, e.g., involving disciplines such as cognitive science, psychology, linguistics, computer science, mathematics. Cognitive scientists have developed a range of methods to gather evidence about human behaviour and cognitive processes in such environments, especially with respect to way-finding, orientation and cognitive mapping. Recent years in architectural design have seen the rise of evidence-based approaches. In this context, cognitive science can provide both experimental procedures (e.g. virtual reality experiments, agent-based simulations), expert appraisal of designs (cognitive walkthrough methods) and theoretical frameworks for such evidence-based design. One challenge for architectural designers is to anticipate the behaviour of people in buildings and urban environments, e.g., including public spaces such as hospitals, airports or offices.

Design cognition, and the study of the design process in general, are mature research areas with clearly identifiable state-of-the-art benchmarks from disciplines such as artificial intelligence, cognitive science and computer science. One crucial objective of spatial cognition for architecture design is to build on existing foundations and paradigms in the study of design cognition in general, and to identify and explore areas of synergy: what kind of insights from `spatial cognition' may be applicable to design cognition in general, and vice-versa.

Basic questions raised:

- How can architects be supported? How would architects like to be supported? Should cognitive science research provide inspiration and new theoretical perspectives to designers?
- How can basic research in human spatial cognition be translated toward a constructive assistive role in architectural design e.g., by informative processes, design case-studies, new investigative methods for designers, development of cognitively motivated assistive technologies?

3.3. Spatial Computing for Design

In the last two decades, several interdisciplinary initiatives comprised of computer scientists, engineers, psychologists, and designers have addressed the application of artificial intelligence techniques for solving critical problems that emerge at several stages of the design process: design conceptualization, functionality specification, geometric modeling, structural consistency & code-checking, optimization, collaborative (design) workflow management, design creativity, and a plethora of other issues have been addressed.

Spatial computing for design is essentially concerned with developing the spatial informatics that is necessary to represent and reason about spatial structure. In particular, it is concerned with spatial structure as it exists with respect to the spatial and linguistic- conceptualization of a human, and its formal and computational characterization within a spatial design assistance system. A crucial aim in spatial computing is to address `space' from a cognitive and formal modeling and computational viewpoint, i.e., space, as it is interpreted within the computer science disciplines concerned with the investigation of artificial intelligence and knowledge representation in general, and formal methods in spatial representation and reasoning in specific. This capability is especially useful, for instance, for analytical tools that can be used to study the relationship between the form and function of spatial structure. As a field, spatial computing for design is also characterized in two ways: firstly, by the scientific questions that it must address from a representational and computational viewpoint and their relationships to the domain of artificial intelligence & design in general, and secondly, by the outcomes that a paradigm such as this is expected to produce. As concrete products, spatial computing aims to develop tools, systems, and frameworks for design systems that go beyond contemporary technological design paradigms and practices, and steer their movement toward the desired enabling technologies of the future. The symposium aims to initiate discussions focusing on the role of spatial computing in particular, and the spatial informatics underlying spatial design assistance techniques in general, vis-a-vis their interrelations with cognitive and psychological perspectives on the process of spatial design.

Basic questions raised:

- What is the critical impact of relatively recent (e.g., past 10 years) artificial intelligence research in design computing?
- How may design computing benefit from general formal methods in knowledge representation and reasoning, e.g., specifically concerning visual, diagrammatic, spatial, and temporal reasoning for future CAD / CAAD systems?
- How to best approach the development of multi-modal computational frameworks for design synthesis and analyses?
- In view of the state-of-the-art in spatial computing for design, what are the envisaged paradigm shifts in CAAD, and construction and architecture informatics?

Acknowledgments

We thank the Spatial Cognition Research Center (SFB/TR 8; Universities of Bremen and Freiburg, Germany), and the Spatial Intelligence and Learning Center (SILC, USA) as well as German Research Foundation (DFG) and the US National Science Foundation (NSF) for their support in enabling the symposium and this proceedings volume. A special Thank You goes to Stefan Altevogt and his team at the DFG New York office for all their help with preparing and running the event.

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Session Reports

The black-curtained studio: Eulogy to a dead pencil

Gabriela GOLDSCHMIDT
Technion – Israel Institute of Technology

Abstract. The major and most frequent learning experience in the architectural studio is the desk crit, wherein teacher and student discuss the current state of the student's design work. The discussion is frequently accompanied by sketching on top of the student's drawings, mostly but not exclusively by the teacher, to help illustrate and elucidate the points of discussion. Such rapid free-hand pencil sketches have been made throughout the history of architectural education. Digital design has changed the studio landscape and desk crits are now often conducted with digitally projected images only, which are discussed with no sketching to accompany the projections. We claim that sketching during the crit has an important cognitive role as it is instrumental in the construction of shared mental models of the project under discussion and supports deep, double-loop learning. The absence of the pencil from the studio is a mistake that needs to be corrected as nothing else can emulate the cognitive affordance that sketching promotes.

Keywords. Desk crit, digital design, mental model, pencil, single/double-loop learning, sketching

Introduction: The age of the paperless studio

Computers and digital technologies have made their way into architectural design already half a century ago. For a long time architects dreamed of 'automated' design, while in fact available technologies excelled in two areas only: drafting and three-dimensional modeling. By the 1990s CAAD (Computer Aided Architectural Design) tools had replaced manual drafting throughout professional practice everywhere, and renderings based on 3-D digital models started replacing physical models. CAD (and CAAD) research, now mostly referred to as 'digital design', has always continued to seek more significant ways to utilize computation in design; this was done following various approaches, from those pertaining to the generation and control of form to those mostly preoccupied with different aspects of building performance, such as energy efficiency for example. The two types of approaches are combined at times and have been called by some 'performalism' [36], the term denoting a combination of form and performance.

The latest and most salient impact that digital design has had on architecture is the ability to venture into new and seemingly limitless geometrical gestalts. Imported into architecture mostly from engineering design, applications allow the design of curved surfaces which enclose complex free-form spaces. Forms thus designed are often referred to as 'biomorphic', a name that hints at the wish to be able to emulate natural forms. A particular family of those forms was proposed by Greg Lynn, a pioneer in this field, who developed the 'blob' theory behind them [49]. Frank Gehry is probably the architect most associated with contemporary digitally produced free-form architecture (he started with software obtained from Dassault

Systems in France, called Catia, which was originally developed for the design of fighter aircraft).

Students in schools of architecture are fascinated by the ability to do away with rectangular and flat-surfaced geometries and are happy to embrace the digital technologies that give them the freedom to create buildings the forms of which are limited only by their own imagination. Moreover, they use all the advanced IT and modeling tools for their representations including film and animation (some of them end up, after graduation, working in the new media and film industries and not in architecture).

The increasing power and sophistication of digital tools (hardware and particularly software) has resulted in more reliance on monitor representations and less use of traditional manual representations on paper. In extreme cases designers stopped using paper and pencil altogether, although most still make freehand sketches, at least in the early, conceptual phase of a project. Naturally, young designers and students were – and are – most radical in espousing the changes; they are well versed in digital technologies and feel that paper representations are old fashioned, redundant and even obsolete. Under the deanship of Bernard Tschumi, the Graduate School of Architecture, Planning and Preservation at Columbia University instituted the first ‘paperless design studio’ in 1994 [10]. Several young faculty, including Lynn and Rashid, were attracted to this experimental line of work in the studio, which also inspired similar experiments elsewhere. The paperless studio has not become a universal mode of work in design studios but most schools have at least some such studios, and in other settings the use of paper representations has also dropped dramatically, as students prefer to conduct their discussions with teachers and critics on the basis of digital images, while the mode of designing – in between sessions with teachers – is by and large based on digital tools, albeit not exclusively so.

In this paper we make a clear distinction between the mode of designing and the techniques it uses, and the mode of representation utilized in the dialogue between students and teachers in the design studio. We address the ‘desk crit’ (critique), a ‘one-on-one’ conversation between student and teacher which takes place in almost every studio session, that is, two to three times every week. The crit is where the teacher coaches the student and it is the single most important element of architectural education and training. The claim of this paper is that in the transition form paper-and-pencil based desk crits wherein the discussion is accompanied by sketching to crits based on a conversation pertaining to projected digital images, with no sketching, something important is lost. The loss is related to learning opportunities: the sketching mode utilizes two channels of communication – conversation and spatio-visual action, which we know is conducive to learning, among others according to the dual-coding theory (e.g., [54]) – whereas the projected images mode, although pertaining to visual material, uses only the conversation channel in the crit, with no active action in the spatio-visual channel. This results in crippled instruction wherein the role of the teacher is inaptly reduced to that of a critic rather than coach, and therefore it is suspected that learning, too, suffers a setback.

After brief historical accounts of paper-based representation in architecture and studio instruction, the paper devotes a section to the desk crit. Next we turn to theories derived from psychology and education, namely mental models and single versus double-loop learning. We claim that sketching during the dialogue in the desk-crit helps student and teacher create a shared mental model of the student’s project, which is essential to the student’s progress. We also propose that sketching facilitates both single and double-loop design learning but it is particularly significant in affording double-loop learning. We conclude with a call for the resurrection of pencil and paper in the studio.

1. Brief history of paper, pencil, drawing and sketching in design

The history of architecture is of course longer than the history of architectural representation, and certainly representations made prior to construction. However, representations in the form of plans and major facades, and three-dimensional views of buildings, were made since antiquity. There are paintings depicting buildings, of course, but also drawings and engravings on clay (as early as the second millennium B.C.), on stone, wood, bamboo, woven textiles, papyrus and parchment, and later also on hand-made paper.

1.1 Paper, sketching and drawing

Paper was invented in China in the second century A.D. [40] and it took a thousand years for it to arrive in Europe; hence, we have no surviving drawings on paper before the Middle Ages. The quality of hand-made paper was poor and the cost high and therefore paper was used only scarcely to trace plans and other drawings. The turning point came during the Renaissance, in the middle of the 15th century, when paper manufacturing mills in Italy started producing paper in an industrialized manner. The reason for this development had nothing to do with the needs of artists or architects; rather, paper was now required by the new book printing industry that spread rapidly in Italy and then throughout Europe following Gutenberg's invention of movable type printing (circa 1440; see [23]). Artists and architects did not take long to discover the benefits of industrially produced paper for their purposes. In addition to being in good currency, paper was now strong and affordable, and provided an excellent medium to practice a new mode of representation: the sketch. Architects did not produce sketches before the Renaissance: they had model books and they visited their sites frequently, where they made design decisions *in situ* as master masons. But the norms had changed and now architects had a cultural 'license' to be more explorative and invent solutions that did not replicate so closely what had been done in the past. This required extensive experimentation by drawing and the newly found industrially produced paper was an ideal medium for this purpose. Preliminary sketches became excellent means to revise and rework compositions and design details, and they allowed, for the first time, to explore interior spaces of the designed buildings. The new often crude rapid sketches were called *pensieri* or thoughts in 15th century Italian [52], the name being indicative of the explorative nature of sketches and their decisive role in the development of design ideas. The architects of that era were in fact the first sketchers, in the sense in which we use the term today. Suffice it to mention Leonardo da Vinchi and Michaelangelo to illustrate this point.

In addition, scientific and technological innovations that grew out of the needs of practice did not skip the world of design. In circa 1420 Brunalleschi invented the mathematically based rules of perspective [66], and a few decades later perspective gave rise to the system of orthogonal (or orthographic, or parallel) projections, whereby buildings (and other artifacts) could be represented with great precision on three planes, making it possible to draw accurate plans, sections and elevations. The invention is attributed to Raphael [37], who had a number of building sites that were geographically dispersed and he was too busy to visit them all in order to manage construction as a 'master mason', as had been done hitherto. By sending sets of plans, sections and elevations he was able to manage construction remotely. This marks the beginning of design as a separate activity from construction – a 'noble art' as compared to a craft, and we cannot underestimate the tremendous magnitude of this change [67]. The efficacy of the new representational system, pioneered in the early 16th century, was so great that it became the standard mode of representations for buildings and their spaces and these conventions did not change to this very day. It is hard to estimate what would have been the fate of the sophisticated representational system had there been no paper to trace the drawings on. The synergy between these various inventions and technological developments, coupled with the open and accepting spirit of the Renaissance, all converged to establish a new era of architectural representation.

Although paper was produced at varying thickness, it was always opaque. Translucency, when required (e.g., in order to copy a drawing), was achieved by oiling opaque paper and then drying it. This was a messy process and the level of transparency was low. Translucent paper, including *tracing paper* which was extremely popular with architects in the 20th century, grew out of an early version reminiscent of tissue paper that was first industrially produced only in the 19th century[1]. Architects, designers and artists started using it after the first third of the 19th century as it allowed manipulations such as rotations and mirror images, but primarily overlaying and retracing, which is most useful at a preliminary conceptual phase, for the purpose of making revisions and changes.

1.2 Pencil

Until the beginning of the 16th century drawing implements on paper were primarily charcoal and ink applied with a brush. Charcoal was used mostly by artists; ink was used by both artists and architects. Where precision was a priority, a metal stylus was used first to mark lines on paper, and then ink was applied to make the lines dark and visible. An implement known as *pencillum* was in use since antiquity: it was a hollow stick with a metal stylus at one end and a fine brush at the other end [55].

The first graphite deposits were mined in England in the early 16th century, but it took a few decades before the right chemical composition and the wooden casing were combined to produce a pencil; its earliest documentation is to be found in a book by Konrad Gesner dated 1565 (ibid.). The mechanical pencil, later to become a hallmark of architects, did not make its appearance until some time in the first third of the 19th century. For about 100 years inventors kept refining it, first introducing a lead propelling mechanism, then a push button clutch (1879), and finally adding a spring to this clutch. The first such all-metal pencil, called *Fixpencil*, was introduced in 1929 by the Swiss company Caran d'Ache[2], which remained the best known supplier of architects' pencils. Alongside the pencil, ink continued to be used, culminating in the invention of the *rapidograph* in the early 1950s. Rapidographs are pens with ink barrels and detachable round tips which come in varying diameters, allowing the production of different fixed-width lines. They were used for technical drafting until computer aided drafting rendered them obsolete half a century later.

2. Brief history of studio instruction

Today's studio, the core of every single educational program in architecture throughout the world, is largely inherited from its predecessors, the Atellier at the Ecole des Beaux Arts, and the Vorkurs, the Basic course and subsequent workshops at the Bauhaus and the Vkhutemas.

2.1 Ecole des Beaux Arts

[1] Marjorie Cohn, former curator of prints, Harvard University Art Museums; personal communication.
[2] http://www.joonpens.com/Caran%20d'Ache_history

The history of university-level professional education in architecture is relatively short. Before World War I, the great majority of schools of architecture in the western world were modeled after the French *Ecole Nationale et Spéciale des Beaux Arts*, which was founded in 1819 by the *Academie Royale d'Architecture.* (Earlier training had been provided by the Academie itself, established in 1671 under the auspices of Louis XIV). Its main purpose was to serve the needs of French aristocracy [15, 22]. Throughout its long existence, Beaux Arts education promoted the value of historical precedents and the primacy of the great classical traditions, namely Greek, Roman and Italian Renaissance architecture. The Beaux Arts educational system was extremely influential and many a school in Europe that followed its tradition were hence identified as Beaux Arts schools (to distinguish them from schools of other 'denominations'). Leading 19th century American architects had studied at the Ecole des Beaux Arts in Paris [18] and a Beaux Arts diploma was in good currency in the USA well into the 20th century [24]. European Beaux Arts schools of architecture were widespread until the 1960s and even beyond, alongside other types of schools, notably the 'Polytechnic' institutes and schools that reflected the ideology of the Modern Movement. In France the Beaux Arts system was abandoned only after the uprising of 1968.

The Atelier. Throughout its existence, the Ecole des Beaux Arts was ran like a confederation of *Ateliers*. Each Atelier, headed by a *Patron*, usually an accomplished architect, had its distinct character. Aspiring students joined the Atelier of their choice where they trained, usually for long months, towards the Entrance Competition. The competition consisted of three parts. Two were '*Esquisse*' (Sketch) problems, that is, the execution of design and rendering tasks in the Atelier, within a limited period of time; the third part was a comprehensive written test that examined the candidate's scientific knowledge [15, 22]. If successful the candidate was officially admitted to the Atelier, were his studies normally lasted for quite a number of years. Drafting and rendering competence was a key to success in most tasks the student was faced with throughout his training.

2.2 The 1920s

An alternative model of architectural education was launched in the 1920s in Europe in two avant-garde institutions, the *Bauhaus* in Germany (established in 1919) and the *Vkhutemas* (Higher State Artistic and Technical Workshops) in Russia (consolidated in 1920). In both institutions architecture was a unit alongside other units devoted to arts and crafts[3]. The foundation of the new schools resulted from novel cultural attitudes and from reforms in education in contemporary arts, design, and architecture in the aftermaths of World War I and the Russian Revolution. These reforms, which rejected classicism, were strongly motivated by a social and political agenda and by a wish to empower the arts, the crafts and design through the use of industrial and technological advances. Experimentation and creative initiative were central to the educational philosophy of the Bauhaus and the Vkhutemas, as opposed to the conservative approach of the academies embodied in Beaux Arts education, which emphasized classicism and trained students by teaching them primarily to master styles of the past. Although the innovative Bauhaus and Vkhutemas were both shut down prematurely due to the political circumstances of the 1930s in Europe (the Vkhutemas was dissolved in 1930, in part due to internal difficulties; the Bauhaus was closed by the Nazi authorities in 1933). The

[3] At the Bauhaus, the architecture department opened only in 1926, after the school moved from Weimar to Dessau. However, informal architectural experimentation and discussion groups were active in the Bauhaus already earlier.

Vkhutemas was a much larger school than the Bauhaus, numbering an average of about 1,500 students at any given time [11] as opposed to a total of 1250 students who attended the Bauhaus throughout its lifespan of almost 15 years [25]. However, both schools enjoy a lasting influence on architecture and architectural (and design) education (e.g., [50]).

Vorkurs and workshops at the Bauhaus. Successful applicants to the Bauhaus were first admitted for a trial period of six months, during which they had to take the *Vorkurs* (preliminary course). This was an introductory arts and design hands-on experiential course in which students experimented with spatial expressions of design ideas, using and exploring a variety of materials. Success in this obligatory course and a high level of independent work during those six months were the criteria for final admission, after which the student was allowed to join the workshop of his or her choice. The workshops were colored by the agendas and pedagogical beliefs of their masters but students were nonetheless required to produce independent accomplished design work. The workshops were highly experimental in nature [9].

Basic course and workshops at the Vkhutemas. Following the Revolution, art education throughout the Soviet Union was entirely reorganized. Consequently, the various art schools and colleges were replaced by *Free State Art Studios* [43] where, in accordance with the spirit of the Revolution, the intention was to admit all applicants who were interested in receiving artistic education, irrespective of their previous education [48]. The Vkhutemas was created as a fusion of two Free Studios in Moscow, as part of this post- revolution reorganization [43]. Entering students were faced with the demands of the highly acclaimed Basic Course (which originally lasted two years but was later shortened to one year and finally to one term). The Basic Course had a lot in common with the Bauhaus' Vorkurs. Vkhutemas teachers were part of the avant-garde in the Soviet Union and work carried out by students in the studios that succeeded the Basic Course closely reflected the contemporary spirit of innovation, particularly as manifest in the constructivist movement.

2.3 The university context

The second half of the 20th century has seen a phenomenal growth in higher education, for which the university has become the prime vehicle. Many new universities were founded around the globe. The great majority of schools of architecture, whose number has surged proportionally, operate today as academic departments within universities, sometimes independently but often in partnership with other departments (e.g., planning, construction, environmental studies, civil engineering, or art). Despite the many differences among schools of architecture and their institutional contexts, almost all of them share similar goals. The programs they offer are based on training principles that were, to a significant extent, inherited from the Beaux Arts and the Bauhaus-Vkhutemas traditions [33]. The omnipresent design studio, central to the curriculum of every school of architecture, is a direct descendant of the Beaux Arts' Atelier. A strive for originality and innovation and the legitimization of exploration and search by trial and error have been handed down from the Bauhaus and Vkhutemas.

Professional architectural education has attracted the attention of several researchers; a number of studies have been devoted to its core element, the studio, and its pedagogy (e.g., [21, 31, 38, 46, 58, 59, 65]). The rationale for the studio system in a contemporary university is based on the 'problem-based learning' approach to professional training, also found in disciplines like medicine, engineering or law [46]. Kvan elaborates: "The essence of problem-based learning is the setting of a problem and allowing the student[s] to direct their own learning through the seeking of solutions to the problem. Under the watchful eye of a teacher, they engage in a search for solutions, learning not only the facts of the situation and the solutions but also the process. For example, they may embark on proposing solutions at first, only to discover that they must instead engage in the search for the issues and then for the solutions" (ibid., p. 346). All students attend one major studio each semester where some 25% of the required credit points are earned. In line with the school's orientation, students take additional studio or quasi-studio classes in the framework of obligatory and elective courses. The rest of the curriculum is based on courses pertaining to building technology, structures and materials, history theory and criticism, art, social and psychological topics, and a variety of other theoretical and practical subjects. Every school hopes to turn the studio into a locus of integration, where the student can apply knowledge gained in the various courses. In reality, this is not always easy to achieve [39]. Needless to say, new curricular components continue to be added to professional education all the time in order to keep up with dynamic social and environmental sensitivities and awareness as well as technological and scientific developments, of which digital design is a prime example.

With the advent of computational design tools and their integration into the studio, papers were published that describe experiments regarding such integration (e.g., [3, 12, 26, 51, 53, 56, 64]). Almost all of these publications look at production methods, students' satisfaction, and various parameters of the output. Many of the authors are interested in collaborative work of various kinds and manners in which computers facilitate it. However, none of these studies focus on learning processes, in particular within the framework of the desk crit, which is so central to studio education. Because of its utmost importance, we dedicate the next section to the desk crit; later we shall examine changes affected as a result of the use of computational devices in the crit.

3. The desk crit: Foremost learning setting

The architectural studio is a territory – a space, but also the common name of the central courses in the architecture curriculum. Throughout a professional degree program a student takes a sequence of up to 10 major, semester-long studios. The studio consists of a group of students (10-20) who work on one or more design projects under the tutorship of a teacher in a designated studio space. The studio class is in session two or three times every week and in between sessions students work in the studio individually or in teams towards the next review or crit. Some of the studio sessions are dedicated to formal reviews, which may be attended by guest critics in addition to the teacher(s), but the vast majority of studio sessions are devoted to desk crits, wherein the teacher visits each student (or team) at his or her desk to review the project's progress and help the student develop it to the best of the student's abilities. Figure 1 depicts a typical contemporary studio in a school of architecture.

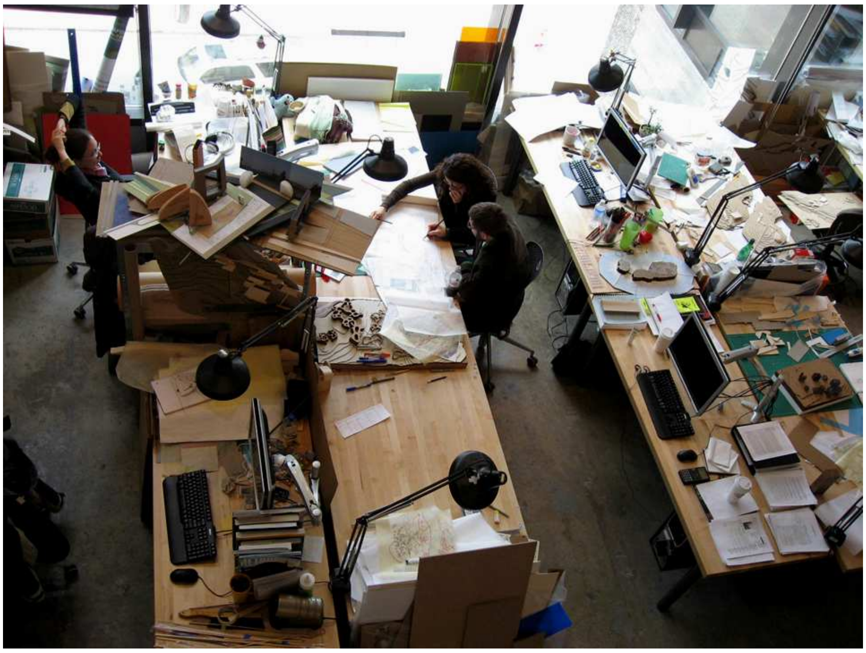

Figure 1. Architecture studio, Yale University, 2009. Center: Desk crit – student and teacher at the student's desk. Left: A student at her desk, surrounded by drawings and models.

3.1 The traditional desk crit

The desk crit (critique) is the primary professional training locale. It consists of a conversation between student and teacher in which the former presents the current state of his/her project and the latter asks questions and offers various comments. The reference material are the student's drawings and models, and the teacher's comments may include correction of mistakes, proposals of alternative solution directions, demonstration of relevant design problem solving methods, elicitation of examples and precedents, explanation of design norms and rules, explication of general issues regarding design philosophy and theory, and more. The conversation is informal and the student may ask questions and raise discussion topics. Research has shown that although students are unaware of it, teachers and not students are the ones who raise most topics in desk crits [34, 35]. In a traditional studio the teacher, who comes equipped with a pencil, often accompanies the discourse with rapid sketching on top of the student's drawings or on an overlaid sheet of translucent paper, to illustrate and elucidate points of the discussion, whether raised by him/her or brought up by the student. Addressing the desk crit, Kvan [46] points out: "Face to face, we [teachers] encourage progress and we guide by numerous non-verbal interventions in a conversation… By working alongside a student, the tutor demonstrates the processes of exploration and solution finding…" (p. 350). The student, a partner in the discussion, may also engage in sketching to explain his or her own ideas or questions. Sketching as part of the dialogue has a very important role as it expands the discussion and gives concrete form to issues that may otherwise remain quite abstract and hard for the student to grasp. For example, a conversation may touch on the question of privacy and sketches that illustrate how features of a certain layout contribute to privacy or conversely hamper it, assist in the comprehension of this matter. As we shall see in the next section, sketching during the crit is also essential to the construction of a mental model of the project that the student and teacher can share, thus ensuring that the teacher's comments are understood by the student as meant by the teacher and that they may serve the student in developing the project further. The role of sketching in the desk crit, then, is to facilitate and amplify cognitive activity that is essential to a fruitful exchange between teacher and student. Figure 2 shows conventional desk crits, carried out with printed drawings and overlays, in which teachers and students in three different studios engage in sketching to illustrate the points under discussion.

Figure 2. Desk crit with paper and pencil
a) Teacher draws (1st year) b) & c) Teacher and student draw (5^{th} year)

Schön [60] claims that "Skillful designing is a kind of knowing-in-action", a process that is "learnable, coachable, but not teachable" (p. 158). This explains the teaching, or shall we say coaching, model in the studio: the student practices by engaging in design and reports his or her progress regularly to the teacher/coach, who reacts to what is presented, thereby transferring both WHAT and HOW knowledge. As we have already seen, the knowledge transfer consists of clarifications, analyses, suggestions, examples, alternative approaches or solutions and so on, which are administered in a conversational format in which the student must be an active participant in order to ensure that learning is taking place. Good teachers/coaches do more than provide just very direct and perforce limited feedback pertaining to what the student has presented; rather, they generalize, they sidetrack to touch on design traditions, rules and conventions, they put things in context and show the relevance of a concept or a solution in other situations as well. The idea is to allow the student to carry the gained knowledge over to other work in the future. This is not easy to do, as pointed out by Argiris [5]: "We know from research on human problem solving that the thinking that is involved in creative activities is complex; to make it manageable, it is kept tacit. Consequently, the student and the faculty are rarely allowed to realize that they know much more than what they believe is obvious. Exploring what is under the top of the iceberg is necessary if learning is to take place and practice become more skillful" (p. 573). Again, instant visualization in the form of rapid sketches is of great help in this matter.

Another advantage of sketching during the crit has to do with reasoning. Cognitive science claims that two types of reasoning, rule-based and similarity-based, are used in problem solving. In yesteryears it was believed that there is a clear hierarchy whereby similarity-based reasoning is inferior to rule-based reasoning, and typical mostly of young children. More recently the primacy of rule-based reasoning is no longer universally accepted and researchers are interested in the relationship between the two modes of reasoning in adults as well [63]. According to Sloman [62] we are endowed with two independent (but interacting) cognitive systems, each dedicated to one mode of reasoning: one associative and similarity-based, the other symbolic and rule-based. Other researchers have advanced the view that if indeed there are two systems of reasoning, they are equally important to processes of problem-solving and learning (e.g., [27]). Since architects reason and think visually in the process of designing, images are very important in the crit as well, wherein they support mostly similarity-based reasoning. The teacher cannot possibly come prepared with a stock of all the images he or she will need in conversation with students – it is impossible to know ahead of time what topics will need to be discussed with each and every student. Therefore sketching is a very handy solution to the need to come up with the right representations, right on the spot. Moreover, a sketch can be abstracted to the bare minimum of elements needed in order to convey an idea, and in rapidly producing such a sketch the sketcher can emphasize certain things beyond what would be possible in a ready-made image such as a photograph or complete drawing, which could be computationally downloaded. By sketching the teacher transcends the functions of authority and coach to also perform as role-model [31]. Kaufmann [44] added that there is a correspondence between the novelty of a task (problem) and the functional usefulness of the mode of representation employed in problem solving, as illustrated in Figure 3. The modes are linguistic representation, visual imagery representation, and overt exploratory activity, which best serves highly novel tasks. Learning to design, designing, and critiquing designs, are novel tasks, and sketching is the embodiment of overt exploratory activity in these contexts; therefore it is superior to passive contemplation of (projected) images in a desk crit.

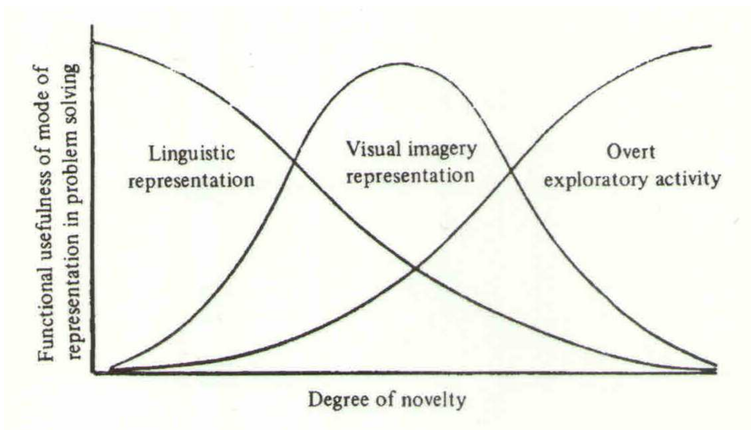

Figure 3. Functional usefulness of modes of representation relative to task-novelty. Source: G. Kaufmann, 1980 [44]

3.2 The pencil-less crit

The ‘talk-draw’ desk crit is no longer the sole norm in the studio. As soon as various CAAD, simulation and a score of modeling and evaluation programs (e.g., SketchUp, Autocad, Revit, 3D Studio Max, Rhino and more[4]) became sufficiently widespread and mainstream, teachers and students alike started using them in the office and studio respectively. Before long, students started arriving in the studio with memory sticks (and later with notebooks) instead of drawings and models, and every studio has projection equipment so students can present their work digitally during their desk crits. Drawings are printed out and brought to the studio only upon the teacher’s explicit insistence which is often met with disapproval on the students’ part.

What does a desk crit look like when paper drawings are not present? The student projects his or her drawings on the wall (or screen), including three dimensional simulations that replace physical models. In the past few years, studio classrooms had to be fitted with black curtains on their windows to allow better viewing conditions. The presenting student or students control the presentation with a keyboard and mouse; teachers join them in watching the screen. Since there are no paper drawings the pencil has become obsolete. Figure 4a depicts a typical desk crit which is conducted with digital projections and Figure 4b captures a review in which images are projected in an entirely dark room.

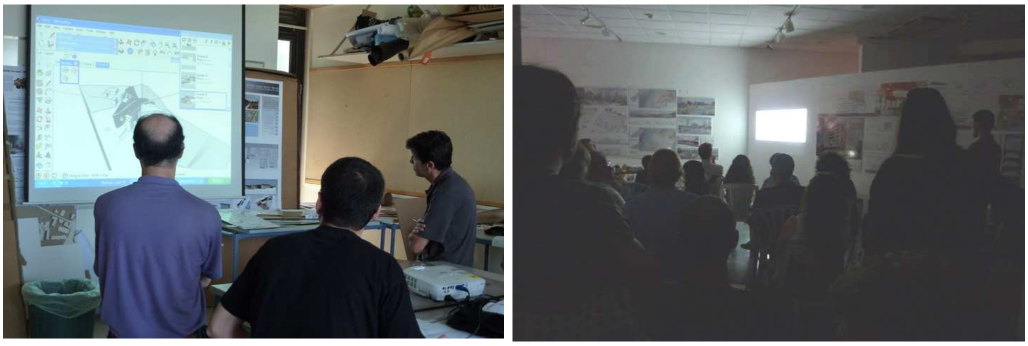

Figure 4. Projected images in the studio, without paper and pencil
a) Desk crit (4th year). Center: student; left and right: teachers. b) Design review (5th year).

In studios that claim to teach 'digital design' (such as the paperless studio at Columbia University) a radical approach does away with the 'project concept' altogether, and with it the notion of representation is effaced: "The educational process [of digital design] need not necessarily be 'project oriented' in the conventional understanding of the term… Teaching may in turn be '[digital-] model oriented" [53, p. 111]. "…root concepts such as representation, precedent-based design, typologies, and other principles of the past generation are in the process of being replaced today by a new body of design concepts related to models of generation, animation, performance-based design and materialization" (ibid., p. 105). Among the new concepts that digital design brings with it, one of the most important is the primacy of 'formation process' over 'representation'. There hardly is a design problem, and the user is virtually non-existent. There are some performative goals, there are digital models to choose from, and one creates something within the bounds of the state of the technology. For the most part no solutions are sought (since no architectural problems are posed), only exploratory

4 For a comprehensive list of software used in digital architectural studios see [13]).

studies are expected, that yield virtual structures of one kind or another. Why is it done? Primarily, because it is simply possible to do so. Is there a goal? The goal is to expand the boundaries of design and design production. The desk crit, of course, does not touch on ‘obsolete’ notions such as spatial adequacy, human satisfaction or fitting into urban patterns. Visual representation and certainly sketching as a means of thinking and communication are not necessary according to this view – they belong in the ‘old’ world. Sketching has been shown to support cognition while imagining and manipulating form and shape? This is not relevant, according to the ‘new’ approach; other means can be used to support alternative cognitive faculties, in a different way.

Digital design can be interesting and exciting. As taught today it often misses the point, as students spend most of their time learning how to use the software and preparing glitzy presentations and in that they resemble Beaux Arts students a century ago. In more cases than not, students do not really understand the deeper rationale behind digital design thinking. They are unable to connect the experience with their previous design education, as expressed by a graduate of a digital design studio who reflected about the experience: "The design process is becoming more complex, yet it is shortened thanks to the computer. The role of the human hand in design is disappearing… [there is] a dazzling virtual world. So dazzling that from time to time one cannot help wondering whether 'place' and 'space' are still relevant"[5].

Our claim is that giving up paper and pencil and therefore sketching in the desk crit deprives teacher and student of a cognitive affordance that is conducive to achieving the crit's goals, regardless of the means of form generation. In sections 4 and 5 we explain why, by delving into psychological and educational theories that are relevant to effective teaching and learning in the desk crit setting.

4. Sharing mental models

The concept of 'mental model' was conceived by Craik [16] and (re)introduced into cognitive psychology by Johnson-Laird [41, 42]. A mental model is a knowledge-based simplified internal representation of an aspect of the world that we hold in our mind; it is a dynamic mechanism that has a heuristic function in that it provides information about past, current and future states [19, 57, 68]. Mental models help us interpret, explain and reason about and anticipate situations, events, the environment and objects, thus guiding our behavior. We also develop mental models of ourselves and our interaction with others and with systems [28]. When people collaborate with others toward a common outcome, they bring to the process their diverse individual mental models of the outcome as well as of their collaborators and the process they (will/should) undergo. They must perforce develop shared mental models of the outcome and of the collaboration in order to coordinate their expectations to succeed in their joint mission. Shared mental models are therefore particularly important in teams, where they are studied copiously (e.g., [14, 45, 47]). Badke-Schaub et al. [8] described shared mental models in the context of design teams. They stress that the need for sharing is domain-specific; the weight of different models (task, process, context, competence etc.) varies and so does the manifestation of models. Process, for instance, is highly important in collaborative tasks such as flying an airplane (pilot and co-pilot, or navigator) or performing surgery (surgeon, other doctors, nurses). In a design team this may be less crucial; instead, reaching a shared mental image of the outcome, which is initially unknown or vague or has several acceptable alternatives, is of high importance. In the desk crit a process model is also of great importance.

[5] Adi Efraim, Students' representative, text of speech at Technion graduation ceremony, 2011.

The modality of mental models is also a function of the discipline in question. In many cases language dominates the construction and communication of a shared mental model, such that agreement is reached through conversation, or written and oral instructions or commands. In the case of design visual representations are very often indispensible to the creation of a shared mental model, since such representations are necessary to reach the goal, which is a specification of the designed entity at some level, conceptual and preliminary or accurate and detailed. This view is in line with our former assertion that visual representation is linked with associative, example-based reasoning that is typical to designing. Goldschmidt [32] used two examples to show how design sketches produced by team members on the same sheet of paper led to a shared design concept on which the final outcome was later based. In one case the team consisted of three industrial designers who co-designed a bicycle rack (Delft protocols; see [17]). The other example was taken from records of a desk-crit in the architecture studio and we shall use it here, too. The two actors, student and teacher, are seen as a team whose aim is to enable the student to reach the best possible design outcome and also deepen his knowledge while at it. For the critique to be effective the student must understand precisely what the teacher means; in other words, the two must develop a shared mental model of (at least) the task. In the current example the student presents plans of a small complex of low-rise dwellings units that share an entry court. The teacher is not satisfied with the layout and discusses its shortcomings with the student, the chief one being the loss of privacy for the individual units. The main topic is the court and the way it serves the dwellings that surround it. To better explain his points he sketches as he talks, first on top of the student's drawings and then on a fresh sheet of sketch paper. Figure 5 shows samples of a drawing by the student (5a); a sketch by the teacher on top of a drawing by the student (5b), and a supplementary sketch by the teacher (5c). The experienced teacher uses fast pencil strokes, curved lines and hatching which are not meant to outline spaces (as in Figure 5c), but rather stress more abstract ideas he expresses verbally, such as: ".. I see also that you enter at the far end, that is, after you have such a nice court, which is common [to four dwellings], actually nobody uses it (Figure 5b)… [it is better to provide] a private yard which is an entry court… and maybe there is this typical thing here, a colonnade along the inside edge…" (Figure 5c).

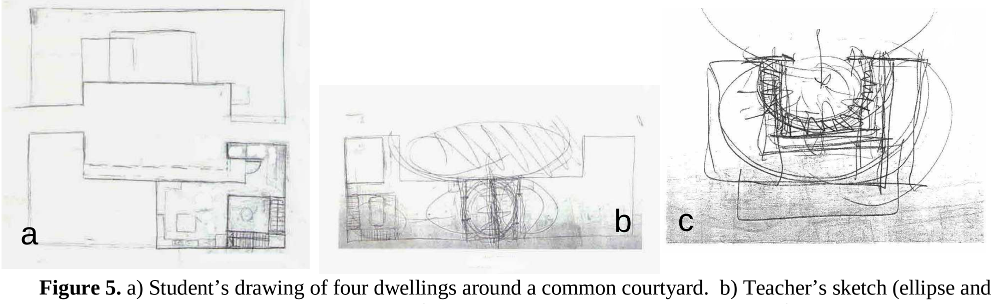

Figure 5. a) Student's drawing of four dwellings around a common courtyard. b) Teacher's sketch (ellipse and hatching; square and circle underneath) on top of student's drawing. c) Teacher's sketch of dwelling with private entry court lined with colonnade.

The teacher manages to drive home the points he raises and his proposed way to proceed with the project is accepted by the student; at the end of the crit the teacher asks: "Do you agree with such a search?" to which the student replies: "one hundred percent". Teacher and student have thus constructed a shared mental model of the anticipated outcome of the design process, namely, the development of dwellings that have a private entry court each, which is accessed from a larger open space shared with more units. This was achieved with the help of the drawings the student brought to the studio and the sketches made by the teacher during the crit.

5. Single and double-loop learning in the studio

An important assumption in studio learning, and possibly in other kinds of learning as well is that we learn from the struggle to reach a good solution. Since design problems are ill-defined and ill-structured (e.g., [1, 29, 30]) the designer must conduct a search and there is no guarantee that a satisficing solution (to use Herbert Simon's term; see [61]) will be found right away. "Skillful designing depends on a designer's ability to recognize and appreciate desirable or undesirable design qualities" [60, p. 159] and this entails a search. In the studio, it is the teacher's responsibility to help the student, who is not yet a skillful designer, come to such recognition. When qualities in the student's scheme are undesirable, the teacher can help the student recognize it and indeed that happens often. Likewise, desirable qualities must be fortified. The question then is what needs to be done in order to maximize learning? To answer this question we refer to Argiris and Schön's theory of single-loop and double-loop learning[6].

Argiris and Schön's [6] theory was developed in the framework of organizational learning, but it is also applicable to studio learning. Initially they were interested in theories of action, and differentiated between various kinds of theories in use that people hold, which guide their behavior in general and in problem solving in particular. This led to the concepts of governing variables and action strategy, to be consolidated into single and double-loop learning. In a nutshell, the theory proposes that in acting, people bring to bear *governing variables* which represent beliefs, values and principles to which they subscribe, and *action strategies*, which govern their de facto behavior in a given situation. When action is taken and unintended consequences are encountered (along with intended consequences), these consequences may be perceived as problematic if they are undesirable. For example, a student designer may choose to cluster several dwelling units around a common court as an action strategy, wishing to enhance social interaction, which is seen as a governing variable. Once he produces a plan according to this principle, it turns out that in his proposal the individual dwellings lose their privacy. This is an unintended and undesirable consequence (see Figure 5) and when this is pointed out in a design crit in the studio the teacher, who surfaces the problem, must suggest ways to solve the problem.

Argiris and Schön (ibid.) propose that resolving a problem of this nature is a learning experience, which may take the form of either single-loop learning or double-loop learning. *Single-loop learning* occurs when we return to the action strategy, make changes in it, and achieve an outcome that conforms with our governing variables without negative unintended consequences. In the case illustrated in Figure 5, this could have been achieved, for example, with separating walls that would enhance privacy. But this is not the only possibility: one can return to the governing variables and question them. When this is done, deeper questions must usually be asked. For example, in the case of the common yard with four dwellings around it, the question may be asked: is it appropriate and reasonable to expect that the residents of these units would want to socially interact with one another? Or might this be a romantic idea that is irrelevant to today's urban lifestyle? The designer may want to reconsider and possibly change the governing variables, which would open up other action strategies with consequences that

[6] The terms single-loop and double-loop learning were coined by Ashby [7]. Argiris and Schön who adopted them connected them with the concepts of Governing Variables and Action Theory, in the context of Theories in Action.

would hopefully not include undesirable ones. This would fall under the definition of double-loop learning. Figure 6 illustrates the concept of single-loop and double-loop learning.

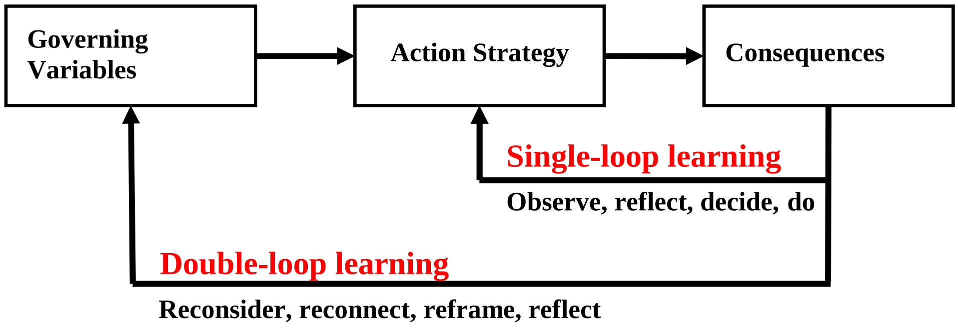

Figure 6. Single and double-loop learning. After: http://lornemitchell.com/blog/wp-content/uploads/2010/12/Single-Double-Loop-Learning.jpg

Under double-loop learning one must reframe the problem in order to expand the solution space. When we reframe the problem new variables may come into play and new priorities may arise. This necessitates a shift in our mental models of the situation and the preferred solution direction: prevalence of private open space over shared open space with neighbors. We can talk about it in the studio, but how is the privacy concept to be translated into action without starting from scratch, that is, on the basis of plans already drawn? The teacher uses his pencil while talking to demonstrate to the student how this can be achieved, not in an entirely abstract mode but based on the student's drawings. Building new mental models, then, is part of double-loop learning, as shown in Figure 7, which is a more articulated version of the difference between single and double-loop learning. In our case the metal model was of the expected outcome, but other mental models are also involved; a model of the user and social norms is but one example.

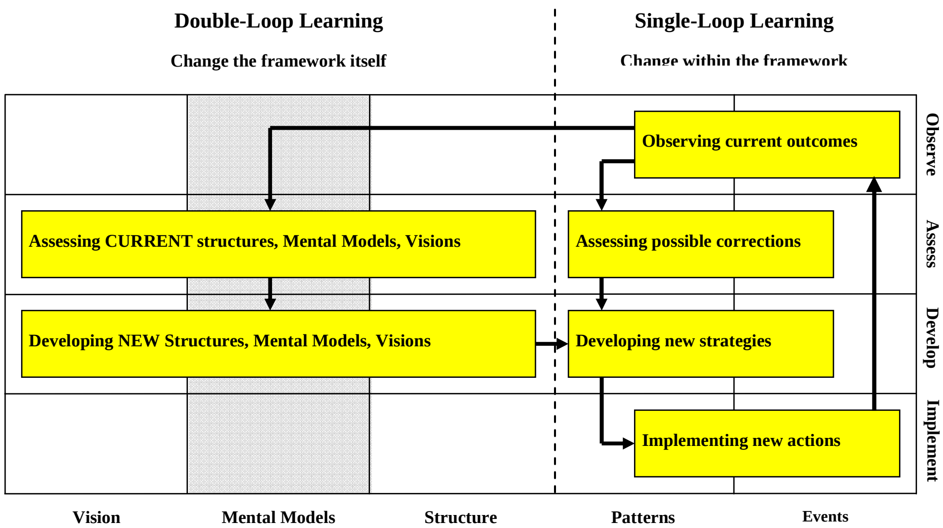

Figure 7. Single and double-loop learning with emphasis on mental model shifting. After: www.learning-org.com/.../LO22409DoubleMatrix.jpg; adapted from J.J. Shibley, The Portland Learning Organization

Double-loop learning is considered to be a more effective way to achieve long-term and deep learning where radical changes are required in the governing variables, whereas single-loop learning is efficient in routine and repeated problems for which the use of pre-established schemata is most helpful. In pushing the student to reconsider the allocation of open space and demonstrating how this can be done in a project that should not be discarded and started over again but rather transformed and developed, the assumption is that the design student will not only achieve a better project but will be able to make better judgments regarding the factors that should govern adjacencies of dwellings and the distribution of small-scale open space in residential projects he is likely to undertake in the future.

We must now address the question: is using sketching in a crit a mandatory consequence of the application of single or double-loop learning? In the case we have been looking at, the teacher could have talked about the concept of privacy without sketching and a devil's advocate may argue that this would oblige the student to develop a new layout by himself, which may have educational advantages. There are two answers to this claim. First, the teacher in our case did not sketch a complete solution (Figure 5c) but only illustrated a design principle, without which it is difficult to imagine a new mental model being constructed. Second, the teacher, we remember, is a coach. A coach demonstrates, models, exemplifies and gives instructions, and verbal (or written) instructions and explanations are not enough in the case of design. Argiris [5] asserts: "Architectural thinking can be divided into things that can only be drawn and things that can only be talked about. Formal [form related] concepts can be drawn; images about how clients would use the building should be talked about" (p. 620). In double-loop learning in the studio, then, sketching is an important component, especially in the service of creating shared mental models. Figure 8 is an adaptation of the single and double learning model to the studio crit.

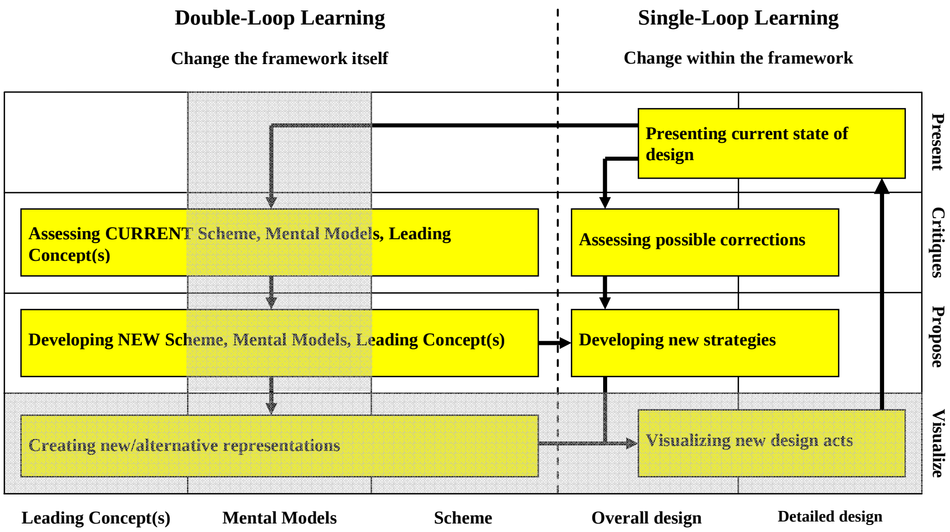

Figure 8. Single and double-loop learning – Adaptation to desk-crit in the design studio. After: www.learning-org.com/.../LO22409DoubleMatrix.jpg; adapted from J.J. Shibley, The Portland Learning Organization

We conclude that including sketching in the desk crit as a matter of routine is essential to the development of shared mental models by student and teacher, which in turn are conducive to double-loop, deeper learning experiences.

6. The pencil: Death, and plausible resurrection?

Students who refuse to work with paper and pencil wonder what the point is, since in practice they will be required to use the computer as of day one. They are naturally obsessed with anything new and technology-related, seen as superior by definition; it is easy for them to reject that which is culpable of being 'old' and therefore doomed as obsolete. It is certainly not my intention here to criticize digital design, nor am I opposed in the slightest to the use of digital tools in the design process by students. My objection is solely to desk crits that although referring to projected images, are conducted verbally only without the benefit of sketching on the fly.

Suppose digital design indeed divorces itself from the notions of place and space, precedent and typology, hierarchy and a host of other notions that have been entertained in architecture from time immemorial. Suppose it is also sensible to have students use the latest modeling, simulation and evaluation tools in producing their designs, as part of their preparation for future practice. What they produce, however, and bring to the studio, are still images of buildings and structures meant to inhabit human activity and systems (e.g., transportation) that serve society. These are not meant for construction; the students are novices and their design exercises are learning experiences, primarily through regular feedback from teachers along the process. Performance criteria may be measurable without any images (but frequently images do serve at least to substantiate the claims). Materiality, however, is hard to imagine without visualization and it needs to be discussed in the desk crit. The effective teacher still has to accompany commentary with examples, alternative approaches and so on to drive home his or her points in a 'show and tell' mode. What should such teacher/coach do: grab the mouse, intervene in the underlying data the student has used in producing the images, and talk about the consequences? Not only is this technically not reasonable but more importantly, it is not exactly conducive to a focused, uninterrupted, instructional dialog about whatever values and concepts the teacher and student consider important to discuss. The outcome is still meant to be (a representation of) something tangible, and as such what is discussed in the studio are interim and partial representations that are meant to come closer and closer to a satisfactory complete and final outcome, through incremental learning.

Rapid sketching still serves this need better than any other means available to us, among others because it is a platform for what Kaufmann [44] called 'overt exploratory activity'. Nobody confirmed this more cogently than William Mitchell [2], an esteemed pioneer of digital design: “Mitchell does not advocate the paperless studio, and does not view it as the most productive approach for developing the design process. He believes that traditional design media and techniques remain valuable for many purposes. For example, he states that it is important for students to create models with their hands, which allows them to appreciate the importance of craftsmanship in the creation of high-quality architecture. He adds that freehand sketching remains an enormously important activity in the design process, and studies have shown that it is much more than a passive manner of depicting a preconceived idea in the mind of the designer. It is a technique that involves numerous cognitive cycles that significantly help the designer develop his or her design” (p. 3). What is true for designing is also true for the process of teaching/learning in the design crit, which is seen as a special case of a design partnership. When the desk crit is deficient in this respect the students themselves feel that they acquire technical skills but they learn little about architecture. In doing away with sketching one confuses between contents and its comprehension and learning, and between a technologically based design paradigm and careful coaching based on unchanged cognitive structures. If anything, radical new paradigms such as those proposed by digital design require double-loop learning, which may be even more dependent on sketching as such learning calls for more radical transformations of the student's governing variables as well as action strategies, through shifts in mental models. Therefore statements such as “Any approach at a new pedagogy predicated on new forms of digital thinking must necessarily move beyond the formal *syndrome* [emphasis mine, G.G.] of representation…” [53, p. 110] are erroneous and potentially harmful.

With the increase in use of digital tools by students they appear to gradually loose their drawing and sketching skills. Al-Qawasmi & De Velasco [4] quote from a survey[7] conducted a few years ago among 800 leading U.S. architecture firms that were asked to evaluate fresh recruits – graduates of schools of architecture. Among other deficiencies the survey reports that “14% of [new] employees cannot hold a pencil with dignity” (p. ix). This means that a growing number of students cannot really participate actively in a crit that includes sketching (although they are probably perfectly capable of comprehending the teacher’s sketches, if such sketches are produced). Fortunately, the design education community (engineering, industrial design and architecture) is awakening to the loss caused by diminishing sketching skills and in several institutions manual sketching courses have been reintroduced (e.g., [20]), with highly satisfactory results in terms of design projects’ quality assessment. The general design affordances brokered by sketching are very important of course, but since we focus on the design crit, suffice it to say that the ability to lead a more effective dialogue with a teacher during the crit by using sketching is a treasured skill that supports learning and the loss of which should be deplored. Recognition of this loss and the initiation of ‘rescue’ programs to counter its negative impacts is a very positive rehabilitative step.

The digital studio cannot have the abolition of paper and pencil as a valid goal. Rather, it is an extreme manifestation of a stance that rebels against architecture as we know it and as we teach it, in favor of a different world of the artifact and its design. This rebellious movement has not replaced the studio, the teacher/coach, or the desk-crit; the learning that it has induced has by and large not transcended the technical realm and it has not found a way to emulate sketching during the design crit as an educational means. The baby should not be thrown out with the bath water!

Human cognition does not change so rapidly, even when technology is capable of extending it. de Verre et al. (ibid.) propose that “Efforts must be made to decrease the reliance on CAD which (although invaluable in the detail design process) imposes a structured methodology upon the user, restricting exploration and abstraction; stifling creativity. Sketching and ideation, are not only the tools of creativity and communication, but can also be a motivating factor in learning, resulting in more creative engineering graduates” (p. 425). We could easily replace ‘architecture’ for ‘engineering’ graduates, the statement still applies. It emphasizes communication and learning and this ties it to the desk crit. Having looked at the need for constructing shared mental models, and the learning benefits embedded in particular in double-loop learning, we understand why giving up the pencil in the studio is a mistake, a result of short-sighted over zealous adherence to the latest alluring technological prowess. The old is not always obsolete and least so when proven cognitive empowerment devices are concerned. The pencil should not vanish from the studio, and in the desk crit it should maintain the key role it has had for hundreds of years.

[7] The survey is conducted annually by ‘Design Intelligence’ and ‘Almanac of Architecture and Design’.

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Challenging prevailing ways of understanding and designing space

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Abstract. This paper aims to demonstrate the potential of disability to question prevailing ways of understanding and designing space in architecture. Drawing on a range of empirical material collected in studying how disabled people experience and understand the built environment, the paper points out how these people's perspective may invite architects to understand and conceive space in novel ways. Examples include designing new spatial configurations, using building materials in unusual ways or expanding the notion of building materials, but also rethinking the design process by searching for and using novel design procedures and tools.

Keywords. Architectural design, disability, experience, space

Introduction

Across the board, architects tend to associate disability with accessibility norms, which they experience as limiting their design freedom and hampering their creativity. In a study by Gray *et al.* [1], for instance, "*built environment professionals expressed the opinion that codes and guidelines restrict their creativity and "take away the challenges of the designer to come up with intelligent solutions*." In our research, however, we turn this association upside down. We start from the observation that, because of their specific interaction with space, disabled people are able to appreciate spatial qualities that architects—or other designers—are not always attuned to. This holds for people living with sensory impairments such as blindness or low vision, but also for people living with particular mental conditions like autism spectrum disorders or dementia. How these people experience and understand space, so we argue, may invite architects and other designers to conceive space in novel ways—both in terms of *what* they design and in terms of *how* they design. Accepting this invitation has fundamental implications for practice and education in architectural design. Particularly relevant in the context of this symposium, however, are the implications for practice in design research.

After a brief introduction into the different ways in which disability is being and can be understood, we build up the paper in three parts. In the first part, we point out how people living with different disabilities or conditions experience and understand space, and how this understanding may question prevailing notions of space in architectural design. In particular we demonstrate how in disabled people's experience

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of space boundaries are reshuffled that architects tend to take for granted. Subject to this reshuffling are boundaries defining space, but also boundaries between body and world. Together, these findings reveal the relativity of prevailing ways of understanding space in architectural design. As such they invite architects/designers to perceive space in novel ways, and challenge them to broaden their horizon.

In the second part, we illustrate what happens when designers take up this challenge, and consider disability as an opportunity to expand their notion of space, rather than as a problem to be solved. To start with, we look at the implications of this expansion in terms of what is designed. Based on a set of examples, we show how starting from the experience of disabled people may lead to rethinking space, *e.g.* by conceiving a new spatial configuration, by using building materials in novel ways or even by expanding the very notion of building materials.

In the third part, we look at the implications of this expansion in terms of how architects design. We show how rethinking space from the perspective of disabled people challenges and impacts the design process, and triggers the search for and use of new or adapted design procedures and tools.

We conclude the paper by wrapping up the major findings and discussing their implications for practice—the practice of design research.

For this paper, we draw on a range of empirical material collected in studying how people living with various conditions experience and relate to the built environment, and how architects respond to this experience. People involved include persons living with a sensory impairment, persons living with a physical/motor impairment, and persons living with specific mental conditions. In order to gain insight in their spatial experience, we combined in-depth interviews with photo- and video-ethnography, we analysed accounts written by disabled people, and we conducted building visits in their company.

1. Conceptions of disability in a nutshell

Conceptions of disability tend to be dominated by a medical discourse, which considers disability as an individual, physiological, disorder to be treated or cured. The disorder is situated in the person and the solution to the problem caused by the disorder lies in treatment or cure to restore the body's function. In this view, disability is defined by means of measurable criteria and arbitrary thresholds. Blindness, for instance, is defined by the World Health Organization (WHO) as having a visual field of maximum 10 degrees or a visual acuity of less than 1/20 in the better eye with the best possible correction (to see with the same details what a sighted person can perceive from a distance of 20 meters, a blind person must stand at a distance of no more than one meter) [2].

Critiques of such conceptions place the body in a socio-material context by recognizing the interplay between physiological condition and features of the society in which one lives. Embroidering upon the definition of blindness, for instance, Ruth Butler and Sophia Bowlby argue that the threshold at which a person considers oneself visually disabled varies across individuals and may also differ from how others perceive them [3]. This move to embrace disability as a social issue can be traced in the new UN Convention on the Rights of Persons with Disabilities [4], or in the International Classification of Functioning, Disability and Health of the WHO [5]. The latter makes a distinction between an "*impairment*": a problem in a body function or structure; an "*activity limitation*": a difficulty encountered in executing a task; and a "*participation restriction*": a problem experienced in involvement in life situations. In the WHO's words, "*[d]isability is not something that only happens to a minority of humanity. The ICF thus 'mainstreams' the experience of disability and recognizes it as a universal human experience*" [4].

The cultural model of disability embraces both the medical and social dimensions of disability, and yet moves a step beyond by acknowledging the potential of disability to question normative practices and prevailing frames of reference in society [6,7]. In an article entitled "Culture as Disability", Ray McDermott and Harvé Varenne describe this potential of disability as follows: "*In cultural terms, the difficulties people in wheelchairs face with curbs and stairs tell us little about the physical conditions requiring wheelchairs or cart, but a great deal about the rigid institutionalization of particular ways of handling gravity and boundaries between street and sidewalk as different zones of social interaction*" [6].

In this paper we aim to demonstrate this potential of disability in relation to architectural design. In particular, we aim to reveal what the spatial experience of disabled people tells us about architects' prevailing ways of understanding and conceiving space, and how their perspective invites us to reconsider aspects of the design process that architects—as well as design researchers—tend to take for granted.

2. Methods and material

In this paper we draw on a range of empirical material that was collected in studying the spatial experience of people with various abilities and conditions. People involved include persons who were born blind or lost their sight, persons having difficulty walking or using a wheelchair, and persons with a diagnosis on the autism spectrum. Their perspective is studied in different ways, using a mix of different methods.

In order to study the spatial experience of people who are blind, photo and video ethnography is used to facilitate observation and communication: blind children are asked to take pictures in and around the institute where they are living [8]; the experience of blind adults is studied through conducting semi-structured in-depth interviews and videotaping guided tours in their home environment [9,10].

These studies are complemented with the perspectives of a city guide, a university professor and two architects who lost their sight and continue their professional activities in this condition [11-15]. Their perspectives are studied based on analysis of their writings [16,17] and other documents, personal conversations, more formal audio-taped interviews, and video-taped lectures.

Another set of material is collected in the context of a workshop where people with different disabilities (motor, visual, hearing, intellectual) together with able-bodied participants visit a recently finished public building (a town hall) to assess its accessibility and usability [11,18]. The material is obtained through participatory observation of the visit and the collective discussions afterwards. The observations are recorded in field notes and photographs.

Similarly, material is collected during and about visits to public buildings in the company of persons living with different abilities or conditions (sensory, physical/motor, mental) [19-21]. Notes and photographs are made during participation in the building visits. These are complemented by meeting minutes, reports, formal interviews and e-mail communication with several stakeholders.

Finally, published autobiographies of people with a diagnosis on the autism spectrum—so-called *auti*-biographies—are used as a particular source to analyse how people living with this condition prioritise the physical environment, interpret it and deal with it [22]. For the analysis publications are selected that have been written by people with autism and about experiences of their own lives.

This observational, interview and written material is analysed to identify how the perspective of disabled people questions prevailing ways of understanding and designing space in architecture, as well as the implications of this questioning for how we, design researchers, regard architects' design process, its strengths and its weaknesses.

3. Understanding space

Analysis of the empirical material provides a nuanced insight in the perspective of people living with a disability. However, as we will demonstrate in this section, it also invites architects to reconsider prevailing ways of understanding space, in particular ways of understanding how space is defined. Boundaries in space that tend to be taken for granted are questioned from the perspective of disabled people; they are reshuffled, become blurred or are disregarded. On the other hand, their perspective also reveals spatial boundaries that are not generally considered as such.

3.1. Blurring boundaries in space

In his book *Architecture: Form, Space and Order*, Francis Ching clearly distinguishes between horizontal elements and vertical elements defining space [23]. The former include base planes and overhead planes, the latter both linear elements and vertical planes. In architectural design, the building elements that define space (floors, ceilings, walls) indeed are typically considered and conceived as separate elements; they are often made of different materials and constructed by different contractors.

People who are blind, however, seem to experience these different building elements as a whole. This became especially clear in the interviews with and guided tours by blind adults: "*Surprisingly people who are blind define ceilings as walls, which could suggest that they are experiencing the boundary of space more as a whole*" [9]. Moreover, people born blind seem to consider furniture as part of that same whole, suggesting that they do not distinguish between fixed building elements, such as a wall, and movable objects, like a sofa.

This distinction between fixed building elements and movable objects also becomes blurred in relation to dynamic touch.[i] Dynamic touch occurs when one uses a tool, *e.g.* a white cane, to touch with [24]. In the study with adults born blind, "*[d]ynamic touch is hardly observed during the video walks. This is not surprising, since tools are mostly used in an unsafe environment or for specific tasks rather than in familiar environments such as home*" [9]. This suggests that from the perspective of people born blind, movable objects like furniture serve not only in defining space, but also as tools through which building elements are sensed.

3.2. Revealing extra boundaries in space

On the other hand, the perspective of disability reveals boundaries in space that are not generally considered as such. For people who are blind, for instance, sound may create a clear boundary in space. An example of this can be found in the writings of John Hull, a professor who describes his experience of becoming blind [17]. Since he has lost his sight, he writes, he loves thunder because it puts a ceiling on his world and prevents him from wandering in infinity which is frightening and disorientating.

More in general, Hull compares the role of sound with what "*turning on the light*" is for people without visual impairment. Sounds can be used to make the environment "*audible*": "*the first thing I do is get out my little portable radio set, which I carry with me almost always. And the first object I come to, (...) I lay my little radio down and I turn it on. That is my way of turning on the light*" [17]. This also relates to his great liking for rain, which allows him to perceive different silent objects from a distance. He hears the rain against the windows, but also in the driveway, on the bushes, on the street. The rain causes on everything in the environment a slightly different sound [10].

In addition to sound, haptic qualities may create a spatial boundary. This is highlighted by Carlos Pereira, a Portuguese architect who lost his sight. A room that seems coherent from a visual perspective, he points out, may be experienced as multiple spaces if one focuses on the differences in temperature. In the absence of sight, the part of the room that is lit by direct sunlight is an entirely different space than the part in the shadow, because the warmth of the sun provides a completely different haptic experience [12] (Fig. 1). The difference in temperature introduces a haptic boundary that partitions the visually coherent room into two different spaces, thus underscoring the importance of temperature as a haptic quality [26].

Difference in temperature is found to reveal boundaries not only in space, but also between (groups of) building materials that tend to be considered as homogeneous. Stone is generally considered as a cold material—like ceramics and metal [27]. This contrasts sharply with the experience of David Mellaerts, a city guide who lost his sight. Mellaerts clearly distinguishes between stone that feels warm and stone that feels cold: "*Every type of stone has [...] its own warmth,*" he contends. For example, "*[T]he bluestone window sills feel considerably colder than the surrounding sand-lime bricks,"* whereas *"[f]errous sandstone feels [...] warmer than sand-lime bricks*" [16] (Fig. 2). Here the perspective of a blind person reveals an extra boundary which partitions the category of stone materials according to their temperature.

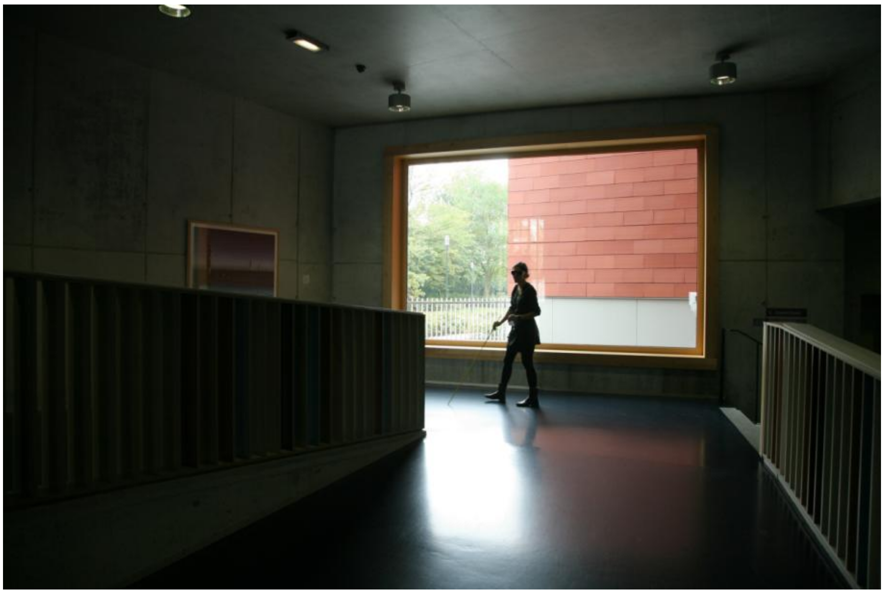

Figure 1. Part lit by direct sunlight and part in the shadow are two different spaces. © Rob Stevens.

3.3. Questioning, reshuffling and disregarding boundaries between body and world

Across the board, people rarely bother about the boundary between their body and the material environment; convinced that this boundary is clear, they hardly give it a moment's thought. Some people with a diagnosis on the autism spectrum, however, do linger over the boundary between their body and the material environment and even dare to **question** it. One *auti*-biographer, for instance, describes his fear of remaining seated on a chair for too long: *"At a certain moment, the interface of the chair is as warm as my body temperature, and at that moment I have lost the boundary between me and that chair"* [28]. In his experience, sitting on a chair for too long ends up blurring the difference between the chair and his body [22].

However, boundaries between body and material environment are challenged not only from the perspective of persons with autism. Worth mentioning in this respect is the workshop in which disabled and able-bodied people assess a building's accessibility and usability. Central to the workshop is the participants' 'doing' of the building, by re-enacting the day-to-day, real-world, real-life narratives of the building and its users. These narratives include typical sequences or quotidian episodes such as way finding around the building, getting in the building or taking an elevator, as well as site-specific sequences like looking for information, waiting for service/queuing, or taking place in a 'service cubicle' [18]. In this way, the material configuration or the architecture's identity is performed, while at the same time and in the same movement it is the architecture that performs the participants' movements and their disabilities [29]. By consequence, the workshop and its effects seem to **reshuffle** the boundaries between body and world, between "subject" and "object": *"Far from considering these two as ontologically separate or pre-given entities, Barad claims that "*[*a*] *posthumanist account calls into question the givenness of the differential categories of 'human' and 'nonhuman', examining practices through which these differential* *boundaries are stabilized and destabilized" (Barad, 2003, p.808). Both the making of subjects and objects is done in co-production, without separating one from the other*" [18].

Figure 2. "*Every type of stone has [...] its own warmth"*. © Peter-Willem Vermeersch.

In the examples above, the boundary between "subject" and "object" is questioned and reshuffled. Sometimes, however, the boundary between the category of "subjects" and that of "objects" may be entirely **disregard**ed. The accounts written by persons with a diagnosis on the autism spectrum suggest that, for them, there is no essential difference between (other people's) bodies and (material) objects. One *auti*-biographer describes that even human bodies, or empty faces, can be seen as physical entities in space [22]: *"Those [empty] faces were as lacking in content as furniture, and I thought that, just like furniture, they belonged in the rooms I saw them in."* Consequently, *"sitting on the lap of a stranger, on the lap of an empty face, hadn't been any more difficult than sitting on an armchair"* [30]. Other *auti*-biographers note the same essential similarity between people and objects: *"When I'm not concentrating on people, they just look like shapes, like furniture and trees are shapes*" [31].

In summary then, these examples illustrate that, in the experience of disabled people, boundaries between body and world, between "subject" and "object", may be questioned, reshuffled or even entirely disregarded.

4. Conceiving space – What architects design

So far, we have demonstrated how the perspective of disabled people invites architects to reconsider prevailing ways of understanding space, and in particular ways of understanding how space is defined. In this section, we will demonstrate what happens when designers—both professional and "everyday" designers [32]—accept this invitation, and consider disability not as a problem to be solved, but as an opportunity to expand their ways of conceiving and shaping space. Based on a set of examples, we show how the experience of disabled people may inspire designers to rethink space in several ways: by conceiving a new kind of spatial configuration, by using building materials in novel ways, or even by expanding the very notion of building materials.

4.1. Everyday Designers

According to Ron Wakkary, *"[a]n everyday designer has no formal design training yet through interaction with existing designs modifies or creatively extends designs into new uses*" [32]. In studying the spatial experience of people living with various abilities and conditions, we noticed that several of them do engage in modifying and/or creatively extending their home environment. Particularly interesting in the context of this paper, is that they start from their particular experience of space in doing so.

People who are blind, for instance, may deliberately introduce sounds in their environment to facilitate orientation [10]. Several blind adults participating in the interviews and guided tours, put small mats in places where they have to pay extra attention. These mats may signal a staircase or a small step, for instance. They are often placed at the start or end of a staircase, or a stair carpet is used. In addition to a haptic cue, mats provide an auditory cue when one steps on them: one's footsteps sound more dull and muffled [*ibid.*].

For a similar reason, one person who is blind introduced the sound of trees in his front garden: "*when we arrived here, we deliberately planted two trembling poplars at the extreme corners of the street side, that was with a view to coming home alone*" [10].

Yet, interventions in space may serve other purposes than orientation as well. When John Hull was refurbishing his house, he wanted a "*rain room*", where he would be able to listen to the rain. When he asked the carpenter for a roof covering that lets the sound of the rain through, the latter did not know what to answer. Nobody had asked him that question before. In search for an answer, the carpenter ended up putting several samples of roof coverings under the shower [17].

Simple as these three examples may be, together they illustrate how the perspective of disabled people (*c.q.* people who are blind) may lead to conceiving and defining space in novel ways. Being blind themselves, the everyday designers in these examples have a heightened awareness of the importance of hearing and touch in the experience of space, and integrate this awareness in how they modify and extend the environment they live in.

4.2. Professional Designers

Besides everyday designers, we also found professional designers who accepted the spatial experience of disabled people as an invitation to reconsider prevailing ways of conceiving space.

A first example we found in the work of the Belgian architecture firm Stéphane Beel Architects. The firm designed *Museum M*, a new museum site for the city of Leuven (Belgium), which opened in 2009. The main entrance of the museum is marked by a protected fronton with columns. In many museums, visitors have to ascend to enter—think about the British Museum, for instance. A striking characteristic of the main entrance of Museum M is the fact that visitors have to descend to enter the museum (Fig. 3). In the period of the construction of the British Museum, museums were a privilege for the bourgeoisie. By contrast, the descent before entering Museum M is supposed to symbolize its accessibility to all people.

Figure 3. Visitors descending to enter Museum M. © Caroline Van Doren.

This accessibility further takes shape in the spatial configuration of the entrance. Visitors can descent by the lazy stairs or the swinging ramp. Stéphane Beel paid special attention to the integration of both: stairs and a ramp cross each other (Fig. 3). He considered it very important that different visitors (for example a wheelchair user and an able-bodied person) do not have to separate, they can enter together [21]. According to the project architect, the design team did obey the rules for guaranteeing accessibility, but they dealt with them in an innovative way by crossing the ramp through the stairs. Judging from visits to Museum M in the company of disabled people, the implementation of the idea still shows room for improvement—visitors with a visual impairment complain about the fact that the handrail is interrupted and the staircase shows too little contrast—yet the idea as such is clearly appreciated [*ibid.*].

A second, more conceptual example, is a project by the Croatian architects Vinko Penezić and Kresimir Rogina. In 1990 the architects designed the futuristic project *Glass House 2001 for a Blind Man* [33]. With this conceptual design they wanted to highlight the discrepancy between architecture and the digitalized world, which in their opinion offers unexploited possibilities for creating audio-tactile experiences. In order to explore these possibilities, Penezić and Rogina juxtaposed the qualities of glass as a building material with the experience of blindness. Since the main features of glass—transparency and reflection—are meaningless for blind persons, the architects developed a system to transform sensations of light and shadows into the morphology of sound and touch. A simple container is built up of hollow, glass elements, combining the material's strengths (*e.g.* its workability) with its weaknesses (poor sound and thermal insulation) (Fig. 4). The glass elements are worked such that the surface gets a particular texture; inside these elements water and air is streaming at varying temperature and speed, controlled by microprocessor. In this way, existing technologies transform the weaknesses of glass into new, unknown possibilities that further add to the audio-tactile experience.

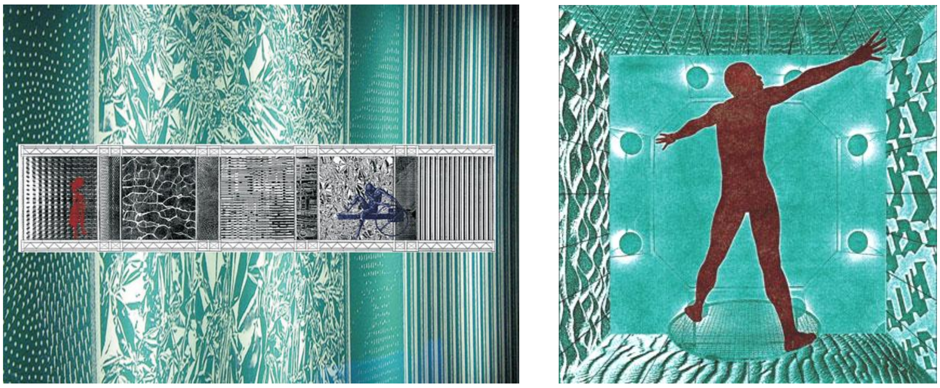

Figure 4. Glass House for a Blind Man 2001 © Penezić & Rogina

For the third example, we refer to the work of Carlos Pereira. After losing his sight, this architect designed a series of bathing facilities. Amongst these is a sea bathing facility at the coast in Lourinhã (Portugal), which aims to offer the exceptional multi-sensory experience of swimming in the sea to swimmers and waders of all ages and abilities (Fig. 5). In this project Pereira extends the range of materials used in designing built environments so as to include water and air. The sea bathing facility converts the concrete structure of redundant fisheries into basins for swimming and engaging with sea life. Receptacles for various marine species offer a collage of colours, textures and concavities within reach. In this project, "*the water that fills up the basins […] is as much part of the architecture and the experience as the concrete used to shape the basins*" [12]. From the architect's perspective, the experience of the space would considerably change if the water were omitted; by consequence *"the water becomes as much a building material as, say, the concrete"* [*ibid.*]. Similarly, Pereira describes how the placement of a wall on the beach can shape the wind, and change a person's experience of it: different orientations of the wall relative to the direction of the wind can change its effect from almost unnoticeable when aligned to very disruptive when transverse. For Pereira, both water and air are very special building 'materials' in that they allow a person to be *"involved in the material*" [*ibid.*].

Figure 5. Sea bathing facility, Lourinhã (Portugal) © Carlos Mourão Pereira.

What these three examples have in common is that the architects involved question the basic form and content of space from the perspective of disabled people. Attention for disability in architectural design typically leads to designing a space first and then adding on features to make it more accessible, *e.g.* adding a ramp next to a staircase, or Braille to elevator buttons. By contrast, the architects referred to in the examples above take the experience of disabled people as a starting point to conceive a new spatial configuration, exploit underused features of a building material, or even extend the notion of building material.

5. Conceiving space – How architects design

Accepting the invitation to understand and conceive space in novel ways by starting from the experience of disabled people has implications in terms of what is designed, but also in terms of how the design process unfolds. In this section, we therefore demonstrate how disability challenges and impacts the design process, and triggers the search for and use of new design procedures and tools. Such triggers are particularly evident when considering the perspective of people who are blind. Their outspoken attention to non-visual sensory qualities brings to light the limitations of architects'—and other designers'—visual ways of knowing and working [13].

5.1. Documenting the building site

A first aspect of the design process that is challenged from the perspective of disabled people is the documentation of the building site. Across the board, architects tend to take pictures of the building site in order to have references to work with during the design process. In the context of Pereira's way of designing, however, this approach turns out to show considerable limitations. Since Pereira has lost his sight, he contends, it is extremely important for him to visit the building site and to touch everything, to feel the place. In order to have references to work with after the visit, he asks his collaborators to make audio recordings of the site that he can listen to in his office. For sound, he points out, changes a lot: "*a market place at 4 pm is completely different from one at 3 pm*" [13].

After having visited the building site, the recordings play a determining role in the design process. Worth mentioning in this respect is Pereira's design of a river bathing facility in Schaffhousen (Switzerland) (Fig. 6). Originally, he had imagined locating the bathing facility very near to the falls. Yet, eventually, he decided to change the location. Listening to tapes recorded near and far from the water falls, he realized that in his first proposal, people would be unable to talk and listen: the sound of the falls would become noise when they are talking. Whence the decision to go a little further so that you can talk [13].

Figure 6. River bathing facility, Schaffhousen (Switzerland) © Carlos Mourão Pereira.

Besides sound, Pereira also uses touch to document the building site. When he needs to take along details of an existing building (*e.g.* door stills, the shape of a handrail, transitions between different building elements,), he takes "a sample of the building" by moulding with his fingers a lead wire over the building parts under consideration [15]. Under his fingers, the lead wire traces whatever shape that comes along, and translates the 3-D material form of the detail literally into a fullscale 2-D section. He then puts the moulded wire into a cardboard folder, allowing it to be transported without deformation. Back at the office, the lead wired shape can be either copied onto paper through drawing or digitalized, by putting it in the scanner. Once in the computer, Pereira's colleagues can transform and manipulate the shape, for instance by scaling or editing it, or superposing it onto other shapes.

Besides sound and touch, Pereira is looking for ways to register the smells of a building site as well, but so far has not found any [13].

5.2. Communicating design ideas

A second aspect of the design process that is being challenged from the perspective of disabled people is the way in which architects/designers communicate design ideas—both to oneself and to others [13]. In general, designers are known to use models and codes that rely heavily on graphic image [34]. In architecture and other design domains, drawings, diagrams and sketches are aids both to internal thinking and to communicating ideas and instructions to others. Numerous studies have investigated the role of sketching as design aid. Overall, the conclusion of these studies is that *"[t]he key 'tool' to assist design cognition remains the traditional sketch. It seems to support and facilitate the uncertain, ambiguous and exploratory nature of conceptual design activity*" [*ibid*.]. In the absence of sight, however, the key tool to assist design cognition—the traditional sketch—seems to lose its power: while making a sketch may still be possible to some extent, reading off information from it is certainly not [13].

After he lost his sight, Pereira thus had to look for alternative tools or procedures. What has become his most important way of communicating design ideas, he contends, is gesture: when wanting to describe something to a collaborator, he forms it with his hands. In order to address specific points of the design, the collaborator may take his hand and starts pointing on it and manipulating its shape. Although more appropriate for design features at scale 1:1, "the hand can become anything" at any scale, Pereira contends, ranging from the shape of a handrail to an entire construction site. Besides gesture, Pereira makes extensive use of physical scale models. Cardboard models, for instance, may be quite detailed or very abstract. For most complex forms, he uses models in clay (Fig. 7); for orthogonal forms Lego turns out to be excellent.

Figure 7. For complex forms Pereira uses models in clay © Carlos Mourão Pereira.

Christopher Downey, a Californian architect who lost his sight, had to look for alternatives to sketching as well [14]. In his case, these alternatives had to fit the day-to-day practice of the architecture firm he works with. The architects in this firm rely heavily on Building Information Modelling (BIM) based on an integrated CAD-model. Downey had to find a way to access this model, and to formulate and communicate his design ideas in response to it. Eventually, Downey ended up plotting drawings extracted from the model on an embossing printer (a type of matrix printer that prints Braille dots and patterns on a thick sheet of paper), which allows him to "read" them with his fingers and hands. He combines these plotted drawings with Wikki Stix, wax sticks he can cut, bend and stick to each other and to the paper (Fig. 8). In this way, he is able to test design ideas by shaping some sticks and temporarily fixing them onto the original drawing. After "reading" the result with his fingers and hands he can re-adjust the sticks and manipulate the "sketch" he just made, as if he were sketching on tracing paper laid over a drawing.

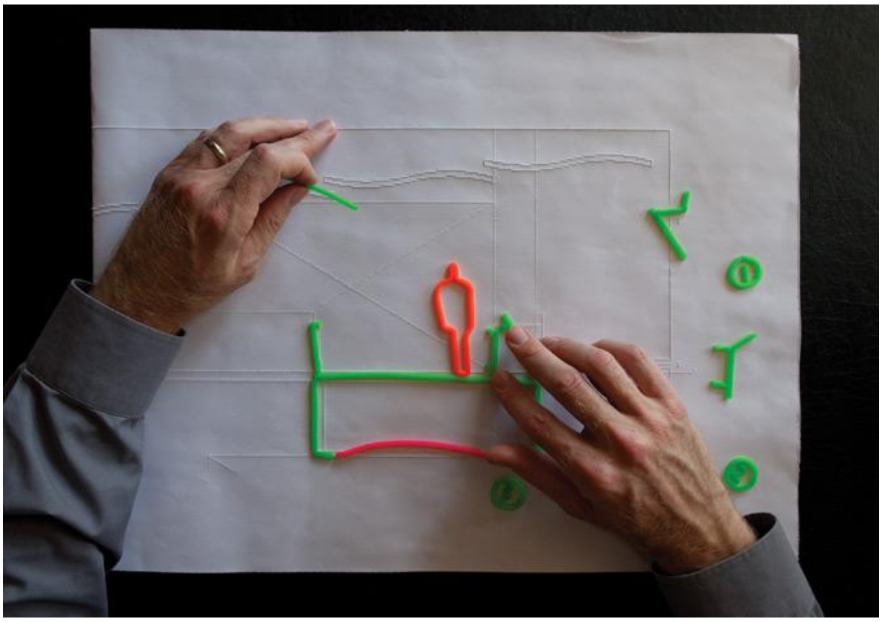

Figure 8. Using wax tools to "sketch" on embossed plans © Don Fogg.

5.3. Selecting building materials

A third aspect of the design process we would like to mention here, is the selection of building materials. In architecture, designers often evaluate and select materials for a building based on small-scale samples available from material manufacturers and suppliers.

We already referred to John Hull who wanted for his "rain room" a roof covering that lets the sound of the rain through and, to this end, made his carpenter put several samples of roof coverings under the shower.

A somewhat similar anecdote is mentioned by Downey [11, 14]. In the architecture firm he collaborates with, the interior designer used to work with material palettes to get an idea of the visual composition of materials in future spaces. At one meeting they discussed the difference in texture between two flooring materials, which were chosen by the interior designer to contrast each other. But this choice was mostly informed by visual features. In the discussion, however, Downey put the samples on the floor and tried to distinguish between the materials by moving his cane over them. While the textures of the flooring materials *looked* contrasting to the interior designer, they did not *feel* contrasting to Downey when using his cane.

5.4. Significance

In the examples above, we have shown how different aspects of architects' design process—documenting the building site, communicating design ideas, selecting building materials—are all challenged and impacted when bringing in the experience of disabled people (*c.q.* people who have lost their sight).

The fact that the designers involved in the examples above use other senses than vision (*c.q.* hearing and touch) to interact with the building site, with models, sketches and drawings, or with samples of building materials is significant for several reasons [13]. It reminds us, design researchers, that the essence of non-verbal media in design is their ability to "talk back" [35] and, at the same time, demonstrates that this "backtalk" [35] may occur through any of the senses. Moreover, the outspoken attention to sensory qualities in the work by Penezić and Rogina and by Pereira brings to light the limitations of media that provide only visual talkback, such as sketches and drawings, as design tools in architecture.

6. Discussion and conclusion

We started this paper by pointing out that, across the board, architects tend to associate disability with accessibility norms, which they experience as limiting their design freedom and creativity. By way of contrast, we have demonstrated the possibilities of approaching the relationship between architectural design and disability from a different angle. Drawing on a range of empirical material, we have shown how the experience and perspective of disabled people challenges the ways in which architects tend to understand and conceive space, and points to possibilities of extending these ways in the direction of more multisensory design approaches.

The experience and perspective of disabled people challenges prevailing ways of understanding space. Their outspoken attention for non-visual spatial aspects, such as sound or temperature, draws architects' attention to the fact that our experience of space is intrinsically multisensory in nature. This attention may lead to reshuffling, questioning or disregarding boundaries that are taken to define space, or may even reveal spatial boundaries that are not generally considered as such.

The experience and perspective of disabled people challenges prevailing ways of conceiving space in terms of *what* architects design. Their spatial experience may trigger architects to question the basic form and content of space, by designing a new spatial configuration, exploiting underused features of a building material, or extending the notion of building material.

The experience and perspective of disabled people challenges prevailing ways of conceiving space also in terms of *how* architects design. Their perspective sheds an entirely different light on design procedures and tools that architects—and design researchers—tend to take for granted: it brings the limitations of these procedures and tools to the surface, but also shows possible directions for expanding them.

If we consider the relationship between architectural design and disability in this way, what turns out to be limiting, then, is not so much disability, but rather architects' fixed ways of understanding and conceiving space, including the design procedures and tools that architects—and design researchers—tend to take for granted.

This raises fundamental questions about the way design research has been and is being produced, also in the context of this symposium on spatial cognition and architectural design. The outspoken attention for visual communication in the symposium's scientific agenda is but one example of the way in which the nature of architectural design is stabilized in definite models. In the past decades, considerable effort has been put into empirically nailing down how architects (and other designers) work and think. As a side effect, aspects that may escape easy measurement (*e.g.* the role of non-visual senses [8-10, 12-13]) or seem 'obvious' and uninteresting [11], received little attention and are largely absent in the prevailing notion of architectural design.

This is not to say that visual communication, or the role of sketching, is unimportant in architectural design. The point we want to make here is that taking for granted the outspoken attention for these aspects enables and constrains any research on architectural design: it sets limits to conditions of design research possibility, for instance in the context of developing the next-generation design tools. In view of this, we conclude this paper by inviting design researchers to conduct research that allows for other, alternative articulations of what design may or can be—be it by considering the perspective of disabled people, or by bringing in any other perspective for that matter.

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[i] In relation to the built environment, Jasmien Herssens argues, haptic perception involves active as well as dynamic and passive touch [9]. Whereas active touch [25] and dynamic touch [24] require movement from the body itself, passive touch [25] arises from movement in the environment.

Presentation to the Spatial Cognition for Architectural Design Conference 2011

Spatial Cognition and Architectural Design in 4D Immersive Virtual Reality: Testing Cognition with a Novel Audiovisual CAVE-CAD Tool

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1. INTRODUCTION

The development of new 3D visualization technologies and novel algorithms for calculating and dynamically displaying complex structures in large-scale immersive CAVE facilities provides a transformational opportunity to designers and architects, as well as cognitive scientists interested in understanding complex tasks involved in spatial cognition. Approaches commonly in use by architectural designers to render 3D structures include a variety of computer aided design (CAD) tools that simulate 3D objects on a flat 2D computer screen. Although such screen-based visualizations are referred to as 3D models, they must be interpreted by the human brain as a 3D object, and require the viewer to imagine the egocentric experience accurately. Whereas highly trained design professionals may have greater cognitive facility with this mental transformation, clients and users are often unable to create accurate mental representations from 2D plans and elevations or indeed from "3D walkthroughs" viewed on 2D desktop screens. For the cognitive scientist, the availability of more realistic representations that involve multiple coordinated sensory modalities offers the possibility of studying spatial cognition using more natural experimental conditions.

2. CURRENT AND FUTURE HUMAN SCALE VR FACILITIES AND THEIR APPLICATIONS

The implementation of large, human scale virtual reality (VR) facilities, such as the StarCAVE at UCSD's Calit2, has introduced a novel tool for displaying and testing the user’s experience and responses to life-sized design spaces. In the StarCAVE, architectural settings are back-projected on 360^{o} surround screens in a stereoscopic view that allows a single viewer or a group of up to 10 people to experience movement through the realistic, full-scale model of a building or built settings.[i] (**Figure 1**) Multiple projectors and computers drive and stitch together the stereo images that are viewed with passive polarized glasses. Moreover, the recently implemented capacity to add to the visual presentation of the design a realistic and accurate representation of the dynamic sound properties of the space has enhanced the uniqueness of these facilities for use in the creative aspects of the design process, as discussed in another section below. [ii]

Figure 1: View of the StarCAVE with the back panel opened to allow a group to experience a VR representation of a healthcare facility design.

While back-projection has some advantages and some limitations, the arrival of 3D television and large flat panels in the consumer market has enabled the virtual reality community to build novel devices at a small fraction of the cost of projector-based systems. These displays are also easier to install and maintain. The NexCAVE at Calit2 (**Figure 2**) is an example for how 3D TV displays can be mounted to form an immersive VR system. The screens may be installed in a 3x3 array, which is curved towards the user in both directions, so as to maximize the coverage of the user’s field of view. A 10th display is mounted below the center column to allow viewing the floor. The screens may be configured in larger arrays for enhanced peripheral views, larger content and CAVE like enclosure.

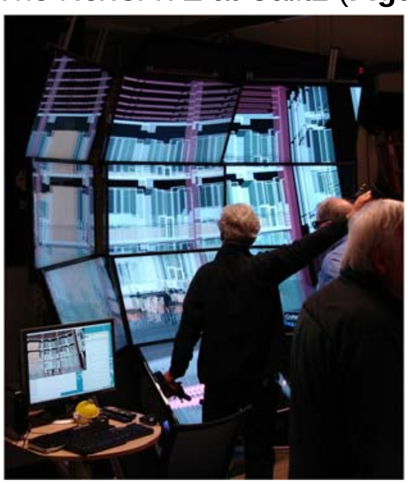

Figure 2: Next generation of flat panel 3D Immersive VR systems illustrated by the NexCAVE.

The availability of powerful consumer graphics cards has transformed VR visualization functions, enabling multiple displays to be driven by fewer computers, simplifying administration and maintenance, while reducing power consumption. The recent trend towards PC systems offer opportunities for Windows based systems rather than Linux operating systems which can be harder to administer. VR tracking systems adjust the images across the display screens, merging them into a single view of a 3D model. Hand-held input devices and infra-red head trackers with 3D interaction capabilities track the participant's location and point of view within the virtual world. Because of the availability of inexpensive high resolution cameras, optical tracking systems are now more affordable, and are in many ways superior to other tracking technologies (such as electro-magnetic, mechanical, or ultrasound based systems). [vii]

3. DEVELOPMENT OF A SOFTWARE DESIGN TOOL FOR THE IMMERSIVE VR ENVIRONMENT: CAVE-CAD™

A team of neuroscientists, clinicians, architects, designers, engineers, and visual computation research specialists created a novel software applicationcalled CAVE-CAD™ that offers a number of innovations with an intuitive user interface that allows users to experience full-scale design as they modify and move through 3D renderings. Innovations include the ability to render and change the auditory and visual environment in real-time, enabling rapid development and display of different design options.

Until recently, facilities such as the StarCAVE were only able to display architectural models developed using standard CAD software that could only be modified by changing the original files offline. The new version must then be re-imported before it can be displaying again in the CAVE, a laborious and time-consuming approach. Changes in design using this process may incur high costs and limit the design team's ability to provide a significant number of alternative design options given the timeline or budget of the architectural design process or experimental protocol.

Figure 3. Using CAVE-CAD ™ software architecture can be constructed around the viewer, immediately offering an experience of the design. Shown here are some of the tools (drop-down lists, palette cube) that have been implemented in the software.

To overcome this, we have developed software, called CAVE-CAD™ that allows the design process to be carried out entirely within the StarCAVE or one of the more recently implemented portable immersive CAVE facilities.[iii] CAVE-CAD™ possesses several unique features that are particularly useful to real-time immersive 3D design. For example, instead of multiple option menus, functions are accessed through smart 3D icons that move with the designer to provide easy access to design functions, finishes and modifiable building elements (**Figure 3**). With this system, architecture can be constructed around the viewer, immediately offering an experience of the design, with sightlines within the building and through openings to exterior spaces presented with geometric accuracy. Options for adding, for example, dynamic shadows (time of day, season) and different external settings (nature scenes, cityscapes), enhance the perceived design.

4. IMPLEMENTING THE AURALIZATION OF IMMERSIVE VIRTUAL ARCHITECTURE

The augmentation of VR visual display systems by an audio component increases the sense of immersion and perceptual realism by connecting the visual scene to a coherent spatial auditory dimension. Spatial audio perception can be provided either by signals through loudspeaker arrays that surround the viewer position, or by addressing the viewer's ears individually through headphones or controlled projection of sound beams.

Enhancement of the VR experience by the addition of sound also adds relevant qualitative information to the visual experience. Our SoniCAVE™ project seeks to establish a set of tools that complement visual architectural design with auditory features accessible directly through the immersive VR display technology. In the context of CaveCAD ™, SoniCAVE ™ provides instant auditory feedback for accurate architectural acoustic prediction. Unlike previous acoustical modeling packages, changes to model geometry as well as the reflective and transmissive properties of floors and walls are continuously mirrored in corresponding changes to the audio rendering, providing coordinated access to visual + auditory simulations of the designed structure (**Figure 4**).

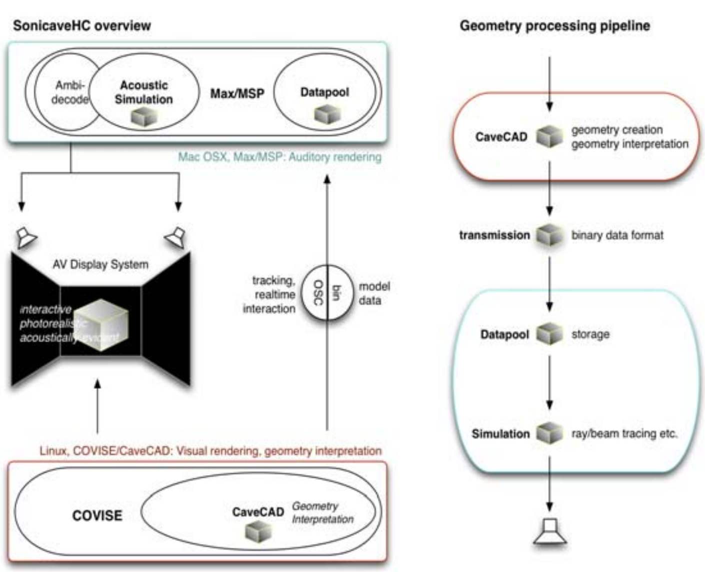

Figure 4: The SoniCAVE audio-visual system linked to CAVECAD visualization renders sound-scenes in real-time that reflect the sound profile of materials used.

Beside directionality and localization of virtual sound sources, the auralization of a 3D visual architectural model in real-time requires the development of a set of models each supporting a specific rendering strategy for the sound projection system used. The model includes several components, such as direct sound, specular and diffuse reflections, and transmitted as well as ambient sounds. Direct sound and specular reflections can be implemented with panning algorithms, such as VBAP or higher order Ambisonics, but the modeling of diffuse reflections and transmitted sound require a very direct connection between the display system layout and the sound rendering. The successful transfer of an ambient sound scene into the VR context includes the development of appropriate capturing and modeling techniques in which both the speaker layout used for sound reproduction, the microphone layout used for capturing, and the intermediate steps of processing and rendering, all need to be mutually compatible. The enhanced acoustical control adds a greater sense of realism to the display of architectural models and allows acoustic considerations to become an immediately relevant component to architectural design.

5. TRACKING GAZE AND ATTENTION: DEVELOPING AN EOG APPLICATION

The environment of the StarCAVE provides a controlled laboratory setting within which individual design features can be tested in realistic, complex virtual environments. In order to asses attention paid by subjects to visual cues and to help determine those that are most effective in navigating a built structure, we have developed the means to assay visual attention by computing 3D eye convergence using a wireless electroculography (EOG) system that is synchronized to the subjects view.[iv] Using the wireless 3D EOG system, along with additional instrumentation such as wearable EEG caps[v] and the head and movement tracking systems built into the StarCAVE, neurological and physiological responses of a freely moving human subject can be monitored in real time.

Compared to video-based eye tracking, EOG monitoring is functionally a much less complex tool. Whereas visual eye trackers must process and transmit video rate data (20Mbits/sec), EOG based trackers need only transmit low-bandwidth bio-potential signals (100kbits/sec) for processing. Physically, EOG recording can use relatively small (4-5 mm) electrodes that adhere readily to the skin around the eye, though we are currently developing dry non-contact electrodes for these purposes[xiv], and the electronic hardware can be light and easily portable. One major drawback with EOG based methods, however, is the lack of long-term accuracy due to electrode drift [xiv], necessitating our development of methodology for calibration before and during use.

In our current implementation, we use 8 adhesive electrodes placed around the eyes to record the potentials induced by the retinal dipole of each eye. Wires are held in place using the polarizing glasses used for #D visualization in the CAVE. A custom-designed wireless instrumentation system is used to amplify and transmit the EOG signals. Each channel is DC-coupled to a high-resolution 24-bit ADC to ensure accurate recording of low-frequency information in the EOG.

Signals are sampled at 500 Hz and transmitted via Bluetooth telemetry to a nearby laptop, which synchronizes stimuli and data from the CAVE. [iv]

This instrumentation allows for acquisition of eye position data simultaneously with brain EEG recordings and audiovisual stimuli, including the relative position of the viewer, which can then be analyzed by the research team to create a composite view of the subject's experience within the CAVE. Signals from the individual eyes encode azimuths and elevations, yielding information on depth, gaze and saccadic movements that can be correlated to attention and searching behaviors. Correlated with the EEG information, the underlying cognitive functions present during these behaviors may be assessed. This synchronized information is collected wirelessly, allowing the unfettered movement and more natural behaviors while performing navigation tasks within the virtual environment. These methodologies for improved calibration of EOG signals to visual targets and attention, virtual space wayfinding protocols, and dynamic multisensory environments are being implemented within the StarCAVE and other immersive environments to ascertain the effects on attention and cognition.

6. STUDYING COGNITION BY STUDYING BRAIN ACTIVITY IN THE VR ENVIRONMENT: AN APPLICATION TO WAYFINDING STUDIES BY MONITORING EEG IN REAL TIME

Immersive VR systems such as the StarCave provide controlled experimental environments in which a virtual building or an entire virtual urban city may be tested. Our initial studies enabled viewers to guide their own travel and visual experience with a remote wand as they moved through full-scale landscapes, townscapes or buildings. The first person perspective was found to offer greater engagement and more natural exploration of building models than do desktop navigation studies. Users reported that the sense of presence while navigating the environment, and in particular, the sense of being lost during wayfinding studies, were consistent with the actual experience of navigation.

The use of VR in combination with electroencephalographic (EEG) brain imaging allows for systematic investigation the brain dynamics underlying spatial cognition during movement. Synchronized with motion capture of the participants head movements and perceptual location of the subject in the VR CAVE model, EEG brain dynamics can be recorded with high temporal resolution and analyzed with respect to the first-person perspective of the subject’s view within the CAVE. This is in contrast to brain imaging methods that do not allow for movement, are too heavy to accurately follow the participant’s movements, or have insufficient temporal resolution to track the sub-second time course of brain activity accompanying cognitive processes.
Previously, brain imaging methods have used desktop-based VR studies with highly restrictive experimental protocols in which participants navigate in 2D virtual environments displayed on a flat computer screen. Subjects must sit still and restrict eye movements while navigating in order avoid interference with the

cortical brainwave data of interest from muscular potentials, or inaccuracies from sensors too heavy to follow participant movements (e.g., fMRI, MEG).[vi]

The absence of any natural movement, however poses a serious problem for the navigator. Idiothetic information that is needed to update egocentric and allocentric spatial representations is missing. In other words, an embodied process of spatial orientation in the natural world becomes dis-embodied in a desktop virtual world. [vii] A more natural spatial orientation approach in the immersive StarCave is based on participants' ability to freely move in the virtual environment including orienting movements of the head and the eyes during exploration. As a consequence, idiothetic information stemming from the vestibular as well as the proprioceptive systems provide the user with a wider range of sensory information approximating information processing during natural navigation. [viii] Riecke et al., (2010) suggest that the absence of translational body movements due to the restrictions of the physical space in VR environments such as the starCave might have little impact on results. [ix]
Advanced data driven analyses methods such as independent component analyses (ICA) have been shown in earlier experiments (Gramann et al., 2010; Gwin et al. 2010, 2011; Makeig et al., 2009) using mobile brain imaging methods (MoBI) developed at the Swartz Center for Computational Neuroscience, UCSD to successfully dissociate brain activity accompanying spatial cognitive process from non-brain related electrical activity (e.g., neck muscle and eye movement activity). [x,xi]

Our initial recordings using MoBI in the StarCave revealed a wide-spread cortical network to be involved in navigation from a first person perspective. The virtual reality experimental setting comprised completely ambiguous corridors with no visible spatial cues as well as hallways with a number of salient objects that could be used as landmarks to guide orientation within the same building. Brain dynamics revealed a wide-spread cortical network to be active during both ambiguous and non-ambiguous surroundings including occipital, occipito-temporal, parietal, and frontal brain regions. In particular, the parietal cortex, an area that subserves the integration of multisensory information embedded in distinct spatial reference frames, revealed differences between oriented and disoriented trials (**Figure 5**).

The differences were most pronounced for the lower alpha (8-10Hz) and the theta band (4-8 Hz). The desynchronization of alpha activity in or near the parietal cortex during orientation in ambiguous environments indexes increased activity of this cortical area underlying cognitive processing. As compared to orientation in unambiguous environments, in ambiguous environments participants have to search for any information that might possibly inform on their current location and orientation with respect to the overall structure of the environment. This increased demand for attention and integration of multisensory information received during orienting movements, i.e., vestibular and kinesthetic information, reflects the cognitive state of being disoriented in a featureless environment. [xii]

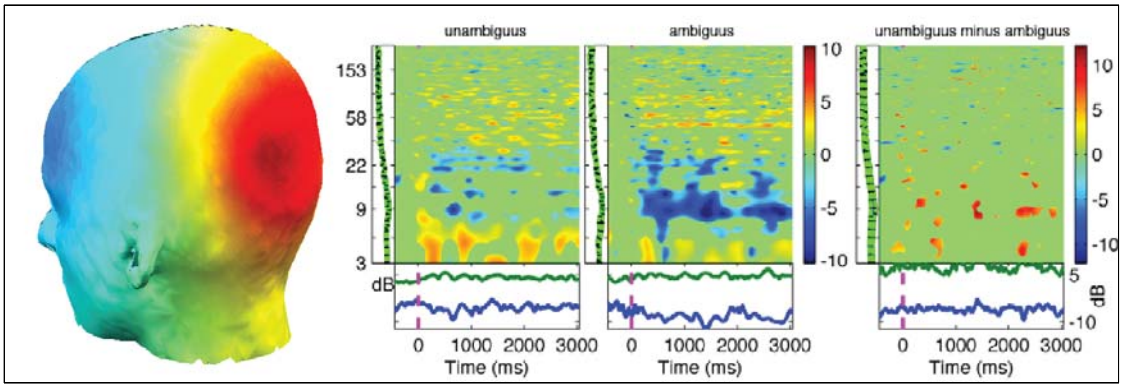

Figure 5: A 256 electrode array reveals different EEG frequency responses in unambiguous spaces with no visual cues compared to ambiguous virtual reality spaces devoid of wayfinding cues. [xii]

These first very promising results demonstrate the potential of combining the StarCAVE with neuroimaging methods such as MoBI to provide new insights into the neural foundation of spatial cognitive processing during active exploratory behavior. [vi]

7. APPLICATION TO HEALTHCARE FACILITY DESIGN

The impact of being lost in a healthcare setting may be of great consequence. In a 2004 study of a 300 bed hospital, it was revealed that staff spent 4500 hours a year helping patients and visitors find their way, associated with lost staff time equivalent to US$220,000 a year. [xiii] Serious adverse events may result from delay in the provision of care, increased stress levels, or unintended transmission of infection from lost patients.

Although a great deal is spent each year on wayfinding signage systems, many are of limited value. Individual features of design may be assessed in virtual settings to understand their specific influences on memory and wayfinding performance (**Figure 6**). The medical and psychological condition of users may affect the rate of learning, persistence of memory, and ability to understand wayfinding cues. In addition, navigation memory strategies are susceptible to stress and fatigue, and thus likely to influence visitors and staff as well as patients. A greater understanding of the cognitive processes used in memory formation, retrieval and successful navigation holds the potential to inform designers about the salient characteristics of environments that support effective spatial cognition.

Immersive virtual reality studies synchronized with cortical EEG recordings offer the opportunity to test healthcare wayfinding systems based on our knowledge of cognitive navigation strategies in both healthy and patient populations, with 3D EOG used to confirm visual attention to design cues proposed.

Figure 6: A first-person perspective in an immersive CAVE representation of patient rooms reveals sight-lines between clinical and patient avatars and provides a test environment for optimizing design features that may reduce serious adverse events. Two adjacent rooms are shown here from the point of view of an external nurses' station, allowing visual and auditory monitoring of both rooms.

8. CONCLUSIONS: NEW APPROACHES TO STUDY SPATIAL COGNITION IN ARCHITECTURAL DESIGN

A number of studies demonstrate enhancement of performance and reaction time when multiple sensory modalities are used. With the combination of CAVE-CAD™ and SoniCAVE™ as well as neurological and physiological monitoring described here (**Figure 7**), a more realistic range of audiovisual stimuli and architectural features will be under the control of the designer, who can test the response to alternatives and modifications in real time. The design team and their clients can thus request and immediately experience the consequences of design modifications. Further, researchers can rapidly create and test new designs and environments to reveal effective wayfinding cues and cognitive navigation strategies for built settings that range from small to large places. The creation of this virtual immersion design laboratory supports our ongoing studies to explore the strategies used in spatial cognition.

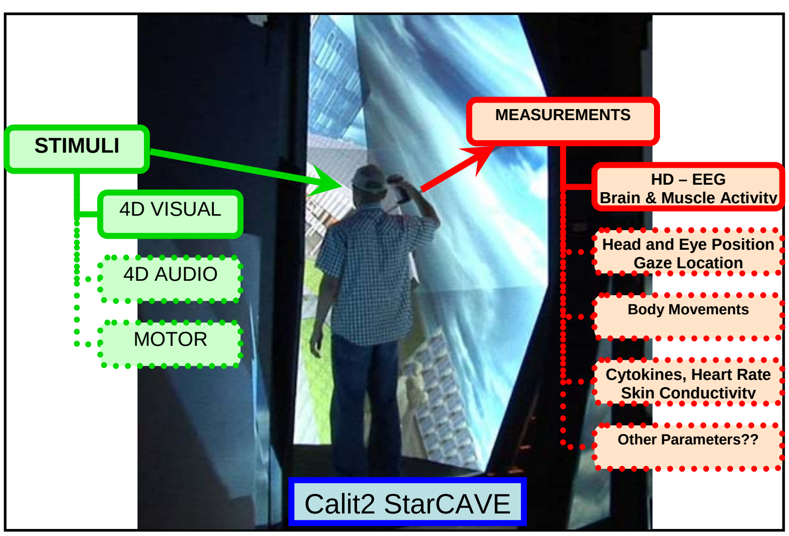

Figure 7. Summary of current and planned features of our approach to audiovisual VR instrumentation and human response monitoring for testing architectural designs. Dotted lines indicate features currently under implementation or development.

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Flat spaces and deep planes: evaluating the spatial potential of two-dimensional computationally generated visual stimuli

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Abstract. This paper discusses the critical, functional and conceptual implications of a method for evaluating the spatial potential of generative computational drawing as perceived by designers. The method involves the generation of sets of non-representational drawings with common algorithmic structures but different degrees of deviation from a legible order. These drawings are then interpreted by a number of designer-participants who are invited to sketch based on what they perceive. Rather than analyze the results of this experiment, we expose its implicit hypotheses and problematize its methodology. Though this process we provide frameworks for inquiry into the relationship of generative computation and the design process at a time when coding is increasingly pervasive in academia and practice.

Keywords. Generative computation, spatial potential, perception, language, abstraction, sketching, aesthetics

Introduction

Motivation and Disciplinary Observations

The pervasive presence of computers in academia and practice along with a growing technological literacy amongst designers, shifts "coding" from an experimental anomaly to realm of a commonplace practice, claiming a place in design processes and pedagogy.

Designers increasingly have direct access to computation. Application-neutral resources such as graphics libraries, scripting languages, open formats, and cross-platform programming languages are readily accessible. Architects can practically engage programming without a significant investment of money or time.

This pervasive presence of computational media corresponds to practical necessity. As architects take on new social, environmental and ethical burdens, the forces influencing design decisions become interrelated and interdependent. This chaos warrants a shift away from the use of standardized, tradition-biased tools and towards a constructed design process. An algorithmic approach to the generation, rather than the direct modeling, of form has led architects toward methodologies employed by artists for decades.

This act of appropriation is often, however, reduced to an instrumentalization of the models of generative art and their literate translation into generative models of architecture instead of seeking their inherent spatial potential. This invites a commonly shared skepticism on the impoverishing effects of computation on the design process. The act of the derivation of generative spatial models from generative art implies a design process of merely linguistic operation, based solely on cognitive operations while excluding its perceptual capacity. At the same time it is often the case that this translation sets its criteria for success at the level of a superficial, mere appearance mimesis of the "novel aesthetic qualities" of computational art (randomness, complexity, swarming, attracting/repulsing etc). These attitudes impede the designers from perceiving and operating on the inherent spatial potential of the representations that they generate. This causes an apparent schism with pre-computational conceptions of the design process, as a cyclically repeating sequence of thinking, making, and perceiving of drawings that suggest -without overtly defining- spatial implications. This operation of "flexibly seeing" or to "embedding" into a drawing or other artifact not one singular symbolic reading but a field of potential meaning, states, or conditions as well as the ability to strip away existing frames of reference and their associative bias while asserting others, from memory or other stimuli, keeps the process of design open and allows for the emergence of new schemes and ideas.

Furthermore, in education, computational values associated with coding align well with awareness that the role, definition, and expectations of a professional architect are moving targets. If the nature of practice in ten or even five years is unknown, what and how should we teach students in professional degree programs? The answer, for many educators, is a pedagogy of meta-critique: projects provide a scaffold of contradictions and ambiguities within which students construct, implement and evaluate strategies for design and study. Pre-made tools, in the form of software, for example, are rejected as inflexible, linear, bias-laden, and influenced too highly by soon-to-be outdated traditions. Even at beginning levels of design education, therefore, programming is becoming an essential medium.

"Computational aesthetics" as a line of inquiry is in some respects the "elephant in the room" of contemporary architectural trends and discourse. Ironically, a popular shift away from aesthetic values towards an exigency of rigorous efficiency has led to profound evolutions in aesthetic performance, especially with respect to the architectural surface. Coding is responsible for new common aesthetic phenomena distinct from the historic notions of the composed facade, the volumetric edge, and the signifying decoration. We believe an open question is: if architecture and the representational artifacts of an architectural design process are structurally influenced by computation, what are the aesthetic implications? And, can we associate a computational aesthetics with meaning and expressive capacity?

Objective

In this paper we aim to problematize the tension between generative computational processes and sketching in relation to spatial cognition and perception. We use as a point of reference the methodology and findings of a pilot non-technical experiment in which we engaged participants in actively interpreting computationally generated drawings containing a common geometry that, to a controlled and variable degree, follows or deviates from a gridded datum. Instead of an analysis of the results we mainly focus on a critical discussion of the design of the experiment itself. The purpose of this meta-discussion is to construct framework, which will contribute to the articulation of questions on the spatial potential of generative computation rather than provide answers or prescriptive operational methodologies for designers.

We first provide a brief description of the method and findings of the non-technical experiment, as well as of the context in which it was designed and executed. We then discuss the rationale behind the fundamental design decisions that we made in this experiment. This exposes a set of implicit hypotheses originating from different areas of research including aesthetic theory, artificial intelligence, brain and cognitive sciences and psychology, which open broader discussions on the tension between generative computation and sketching. Consecutively, we critically assess the methodology that we use by placing it in a historical perspective of similar studies evaluating computational aesthetics and comparing it with other widely used methods. Finally, based on the above observations, we propose drawing as a conceptual vehicle in order to assess / reveal the spatial potential of generative computation.

Aesthetics and Computation

Generative computation typically invites and often requires an external framework for evaluation and judgment. Without such a framework, nested iterations and versions can yield ever-expanding fields of possibilities and explorations. Similarly, quantity and flexibility of outcomes can render the designer oblivious to implications of low-level structural decisions. Whether to focus a cyclical process or to question early assumptions, a consideration of aesthetics provides can provide a needed foil.

Generative computation undoubtedly influences aesthetics. Mass customization leads to dynamic relationships between constituent parts as well as between parts and whole. The formal legibility tends to assume a fielded rather than figural topology. Visual conditions such as gradients, flows and networks–trademarks of generative computation that are nonetheless foreign to pre-computational architecture–become typical. These conditions may have inherent capacity for meaning and/or expression. Or, they may participate in a productive, cyclical design process in which aesthetic judgment is one factor, which influences structural decisions of the generating algorithms. Regardless, isolating and evaluating computational aesthetics has obvious merits in this context. The main pitfall of such evaluation is that the aesthetics is, partly by definition, difficult to quantify. In a related fine art discourse, John Dewey asserts that art can only be considered for it's "expressive" capacity rather than that which it "expresses," for even the notion of "representation" incorrectly assumes a similar perceptual experience from one viewer to another.

The prominence of generative computing in architecture now is analogous to the surge in computer art between 1965-71. As is often the case, architecture lags behind its allied disciplines. At issue for architects now is that the conception, design, construction and maintenance of architecture can rest entirely within the domain of computation, as was the case with computer art in the '60s, when it became rapidly possible, feasible, and practical to program and produce not only computational images, but complete computational works. As was the case with computer art, architecture as a discipline finds itself able to interpret the total implications of a computational process. But, again, inevitable pitfalls emerge: Even it is acknowledged that aesthetics are uniquely appreciated by humans, we are not necessarily the best judge of our own minds. It's also possible that aesthetic impact occurs more within the perceptual apparatus than our cognitive functions. Therefore it may be futile to, for example, as an artist (or architect, as the case may be) to "score" a work on an aesthetic scale.

1. Experiment

1.1. Context

The design, execution and findings of the experiment presented cannot be accurately discussed without a reference to the context in which it was conceived. The hypotheses which it is designed to test are generated at the intersection of two different lines of research which however both frame representation, perception and cognition as central areas of inquiry.

The experiment was developed as a pilot study within the context of the Human Intelligence Enterprise class at the MIT Department of Computer Science and Electrical Engineering (Winston, 2011), instructed by Patrick Henry Winston, Ford Professor of Artificial Intelligence. The class evolves around the computational understanding of human intelligence, through the analysis of seminal works focusing, amongst others on language, vision, story understanding and analogy stemming from artificial intelligence, neuroscience, developmental and cognitive psychology. Questions such as the role of visual characteristics of perceptual stimuli and verbalization in priming creative imagination posed in quest for ways to understand and emulate human intelligence, were crucial in the initial framing of our study.

These questions were informed by our personal research trajectories developed through our participation in the Design and Computation Group at the MIT Department of Architecture, which endeavor to better understanding of the design process, the role of sketching as a way in which designers operate on and with their imagination and the displacements / continuities that computation brings in this process.

1.2. Seeing-sketching Exercise

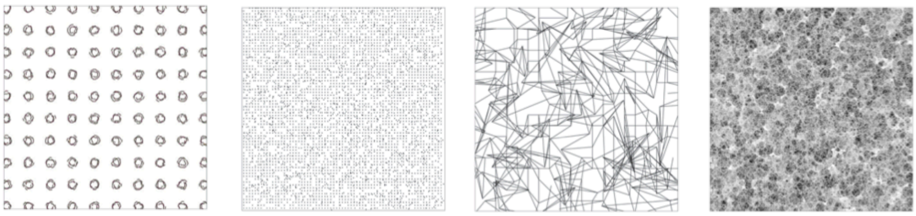
We designed and executed a pilot study, which involves creating and calibrating a suite of complexity-controlled drawings. We generated a matrix of thirty-six source images using four geometric sets, each with nine degrees of deviation from a regular geometric order. Deviation is achieved through the incorporation of random values. Each set is calibrated with the intent of producing an image at level nine–the most deviated–in which the underlying order is completely occluded by the weight and scale of the random values. It can be said, therefore, that the increasing visual presence of the random values increases the complexity of the resulting images. Unlike in Schmidhuber's "low-complexity" art (Schmidhuber, 1997) no new discernibly systematic, mathematic order is used describe any of the geometric deviation from our level zero onward. Any presumed "low-complexity" order is fabricated in the mind of the viewer.

After the generation of the cards we orchestrated blind design experiments in which the participants were prompted to look at a single image from the matrix and draw a sketch based on what they perceived. This process was repeated four times for each participant. For two of the four cards the participants were instructed to verbalize what they saw prior to sketching. All participants were students enrolled in the undergraduate Bachelor of Arts (with a major in architecture) degree, the professional Master of Architecture degree program, the Master of Science in Architecture Studies Degree program or the Ph.D. in Architecture Studies degree program.

Apart from the practical consideration of eliminating the influence of anxiety about drawing skills in the sketching part of the experiment, the decision to exclusively select architects as participants in the experiment was in line with our broader interest on what are the factors which influence what designers, trained as spatial and visual thinkers, "see" in computationally generated drawings.

1.3. Analysis of Results

The participant responses are organized according to their corresponding source card in, again, a 4x9 matrix. With the verbal descriptions we developed a set of quantitative parts of speech analysis and qualitative criteria for evaluating written content. The findings of this analysis, which are referenced in more detail in a paper pending publication, indicate a priming of analogical descriptions as well as verbal descriptions primarily perceiving action, state, motion or quality, in the intermediate levels of the scale.



Level 2
Broken circles. Circle is divided into small arches and they are shifted. They seem to have double layer of circle

Level 4
The mutation of hair follicles following experimental techniques in chemotherapy although the patient maintains density, the shifted scalp causes odd patches

Level 7
A car accident along a freeway with people yelling at each other and the mangled car in the lower left corner. There were a few kids involved but they don't appear to have suffered any injuries

Level 9
Foam, soap bubbles, density, porosity, swiss cheese, disintegrate, temporal, deep and shallow, sand, piles, mounds, dew drops, intersection, hierarchy, different size, same shape

Figure 1. *Examples of images generated as part of the pilot study from each of the four geometry groups at various levels with examples of corresponding verbal descriptions produced by participants*

The most suggestive results lie in the evaluation of the participants sketches, with or without prior verbalization. Within the context of our initial research the criteria, which we developed, were referred to as "originality criteria", denoting "how far" the participants were able to go from the information visual stimulus. This was evaluated based on a comparison of the participant's sketches with the initial image with which they were presented in order to detect one or more of the following operations:

- Transformed geometry: The participant's sketch was compared with the given image so as to identify transformations of topology, orientation or proportion. Anything beyond the replication of the initial image was considered as a belonging to this category.
- Transformed scale: This refers to transformations either to the size of the boundary of the source image or to the scaling of the elements which it contained.
- Indicated movement: In this category we evaluated whether the sketches presented spatial or temporal movement, shown either through symbols (arrows, dotted lines, motion "streaks", etc) or multiple states of a geometry in sequence
- 3-D: This category, which is in strong convergence with the hypothesis of this paper identifies if the sketch indicated depth though the employment of a projective heuristic (perspective, axonometric or isometric)
- Scene or setting (part of a story): The scene or setting criterion also touches upon issues of space, with more emphasis however to the signification rather than the geometric characteristics of space. This criterion examines if the drawing shows a staged arrangement of objects in space, the interaction of objects or a reference to a specific place
- Pictogram: This last category indicated whether the participant's sketch showed an icon, symbol or image of an object or person distinct from the geometry used to generate the source image.

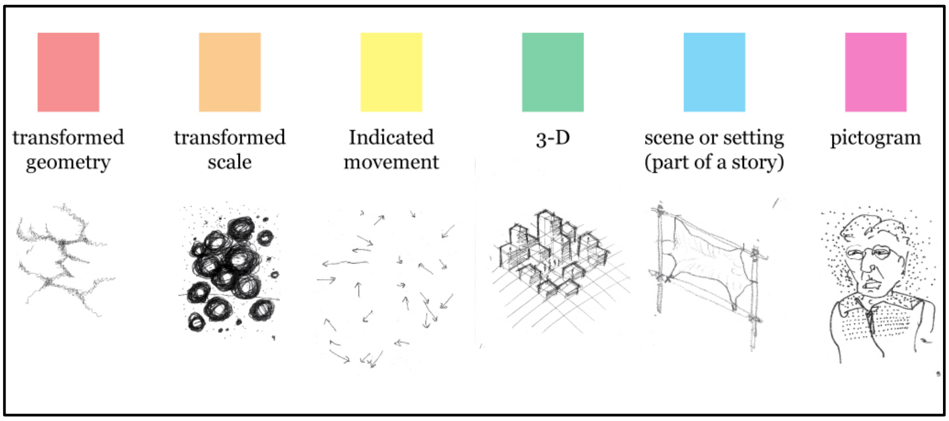


Figure 2. *The spatial qualities used to evaluate the sketches produced by study participants with examples of sketches that meet each criterion.*

These binary criteria were overlaid in the matrices of the participants' sketches. The results of this analysis indicated the existence of a trend for "higher originality" participant drawings at intermediate complexity levels. It also points towards the fact that verbalization prior to sketching primes novel interpretations of presented images and creates the ground for the emergence of space, movement and stories. However, we should stress that in order for this trend to be validated as a conclusion, the experiment would call for a larger sample and perhaps a different evaluation methodology including the review of the participants' sketches by individuals unbiased with the details of the experiment.

2. Initial Framing

A point of departure of this study was a framing of imagination and creativity as processes, which are not intrinsic or transcendental characteristics of the designer, but behaviors that emerge spontaneously through operations on the outside world. Within this context, much of the designer's training could be viewed as the development of tactics to evoke these operations. An example of these strategies is the increased ability of experienced designers versus novices to detect unintended features and to regroup parts of sketches, encouraging new interpretations (Gero et al. 2001).

Drawing from Marvin Minsky's suggestion that the production of novel ideas does not come from a distinctive form of thought, but is instead the ability to internalize external stimuli and recombine them in different ways moving beyond what they perceive. (Minsky, 1986) This understanding of creativity orients the investigation with design and the interaction of the subject/designer with objects and artifacts produced throughout this process.

Within the context of the Human Intelligence Enterprise, the pilot study was designed to trace the existence of trends in the way that the visual complexity of computationally generated drawings affected the responses of designers prompted to operate on them. Within the context of our experiment we framed visual complexity as a vehicle to approach the notion of ambiguity, which is commonly accepted to create the ground for constructive perception (Tversky, 2001). However this does not imply that the latter can be reduced to the former.

Furthermore, we introduced in the pilot study the parameter of verbalization prior to sketching. The purpose of this was first, to provide indices towards the role of language on operations that are considered to be non linguistic and second as a form of loose interview, allowing us to have more insights in the participants' reactions to the presented stimuli.

The experiment was designed as an exploratory approach to two hypotheses:

The first hypothesis was the existence of a "Goldilocks" principle for visual complexity. This was based on the fact that complexity operates in a spectrum from too little–barely noticeable– to too much–noisy and obfuscating. This hypothesis, which can almost be considered commonplace, was inspired by Winston's and Finlayson's study on analogical retrieval, where they illustrated the existence of a operable middle ground in the similarity of descriptions as priming analogies. Within the context of aesthetics there is a long tradition of similar hypotheses, from Fechner's principle of the aesthetic middle also known as Webber-Fechner law (Fechner, 1860) to Goel's studies in 1995 showing that the more ambiguous a visual stimulus is, the easier it is to reinterpret; however, after this ambiguity exceeds a certain threshold, the harder it is to assign any interpretation at all.

The second hypothesis was that linguistic activity is closely coupled with perception. Research in the domain of cognitive psychology indicates that language combines and uses information acquired by different encapsulated systems of representation regardless of their domain specific content. In this framework, language does not assign symbols to an already perceived reality but acts as a combinator, actively taking part in the formation of perception. A salient working example of such a direction are Elizabeth S. Spelke's and Linda Hermer-Vasquez' experiments on the relationship between spatial memory and language in the task of navigation, which demonstrate that language provides a domain-general medium for conjoining geometric and non-geometric information (Spelke et al., 1999).

The purpose of this paper is after viewing the experiment in its original context to abstract it and develop a critical discussion on the explicit and implicit assumptions that it makes on the role of perception and symbolic reasoning in way designers operate on visual stimuli. The fact that the images shown to the experiment participants were computationally generated, makes this study a fertile ground for the framing of questions on the role of generative computation in design processes.

3. Discussion: Methodological dissections

In this section we will abstract the experiment from its initial context and re-frame it along a tangential research hypothesis, investigating the spatial potential of generative computation. The way that the cards were generated and the incremental increase of their visual complexity, while preserving the same computational structure (code) raises two lines of thought which can inform our discussion on generative computation in architecture.

First, it exposes a tension between the underlying structure of the computational drawing and its mere appearance. What factors, qualities, or conditions become parameters in terms of the designers' response to this indirection and how these parameters can be isolated? Addressing this question offers a framework for approaching some of the main critiques on computational drawings, namely a rift between ontology and structure. To use an example from our experiment: this could be translated as an exploration of when the computational drawings' structure or entities starts being undecipherable or unimportant for the participants and the results that this has on their operation on the drawing. If we were to substitute the characterization of the experiments' spectrum as a transition from "low" and "high complexity" as a transition from concreteness to abstraction then at which point in the spectrum does space and external associations emerge, and how does this related with broader discussions on these two terms?

Second, it plugs into an ongoing and rather heated discussion which can be condensed to the dilemma of whether design creativity is primarily related to cognitive, symbolic operations (language, reasoning) or is a sensory process where "pre-cognitive" perceptual operations are heightened. This contrasting dipole is the basis of the assumption that computational drawing, as a predominantly linguistic activity, is a new paradigm, in rupture with the "traditional" ways in which design was done through processes of constant seeing and doing. Through our experiment we propose that such dualisms can be avoided by using recent findings from cognitive psychology to re-frame language as a process strongly coupled with perception and not as a merely symbolic act.

In the following sections we further problematize these two discussions using references from the field of computer art, aesthetic theory and cognitive psychology.

3.1. Abstraction vs. Concreteness

One of the earliest and most influential efforts to systematically explore the aesthetic potential of the computational medium was undertaken John Maeda's Aesthetics and Computation Group at the MIT Media Lab. Returning to the fundamentals of geometry, color, motion and interaction, Maeda's group provided the ground for an isolation of the aesthetic potential of generative computational art with emphasis on dynamic abstraction.

In his text entitled "Essay for Creative Code", Golan Levin, an Aesthetics and Computation Group alumnus, expands upon his excerpted remarks in Creative Code and attempts to define the essence of abstraction in computational art, drawing from a multiplicity of conceptions of what abstract entails. Levin defines "abstract" as any art whose subject matter primes the fundamentals of form rather than the form itself–process, structure, matter, iconic archetypes–while avoiding narratives and representations.

According to Levin, abstraction is the suppression of details so as to bring to the surface fundamental concepts or structures. Pattern, an open ended structure, is asserted as the "fundamental subject of abstract art". Abstraction is portrayed as a process in which the observer engages in an act of completion of a visual or perceptual structure. This process, is also referred to as "closure" (McCloud, 1993) making the user more aware of an internal mental structure though which the artistic content is perceived. This invites the notion that a work of art need not be spawned by an experience by the artist. Abstract art can be generated that invites "closure" and ensures an "experience" of some value on the part of the viewer.

The necessity of "closure" aligns with the hypothesis of an abstraction sweet spot, which maximizes mental motion and invites spontaneous operations on the visual stimulus in question. More interesting, however, is that it seems to prime the underlying structure of a computational drawing in relation to its visual appearance and to suggest that productive experience emerges from the bringing forth and completing this structure rather than for example engaging in free association or seeing things that have not true to the drawing's structure.

Levin's comment on "randomness" as a pitfall for abstraction reveals this approach: "Randomness finds an optimal employment below the threshold of perception, as noise in somatic textures, without which computational designs can often seem lifeless, overly-regular, and dull." However, his discussion of the need for "some greater expression", surpassing the mathematical raw materials of the generative computational drawing suggests that this structure cannot be reduced to a linguistic operation or to a mathematical algebra.

We read Levin's discourse as suggestive of a kind of structure perceived in computational drawings which is expressive of, but not reduced to, their linguistic computational structure. His critical approach de-emphasizes the verbal definition of the computational drawing–the code–while also rejecting a focus on its mere appearance. Instead, it offers the indirection between the two as the most fruitful field of inquiry and criticism.

This converges with one our suggested readings our pilot study, which emphasizes the role of intermediate complexity features, where the computational order was still decipherable but not directly legible in the drawing as the most productive area for the perception and sketching of space and motion.

3.2. Language vs. Perception

The discussion of the role of cognition and symbolic reasoning in human intelligence has been an object of controversy. In the field of design and computation there is widespread skepticism regarding whether drawing media that require the predetermination of topologies and structures impedes creative thinking by restricting the designer into a purely cognitive processes and impeding sensory participation with the design artifacts. One of the most well articulated responses on the intrusive nature of computers in the design process are Shape Grammars, which allow designers to embed emergent shapes and properties in computational drawings. George Stiny proposes this theory as an antidote to "The intrusions that limit novelty and impede inquiry because a well intentioned representation fails to anticipate something interesting, something unexpected" (Stiny, 1998)

In the field of Artificial Intelligence, a focus on the emulation of the human mind's "internal reasoner" and the understanding of senses and perception merely as Input/Output channels is criticized as the fundamental cause for the almost non-existent progress towards the visions of "strong" Artificial Intelligence. Researchers in the field increasingly assert that a large part of human reasoning takes place in precisely these perceptual channels and it many times happens on the fly, without requiring "internal processing"

Given the AI perspective, it is easy to misinterpret the incorporation of verbalization in our experimental methodology and most importantly the suggestion that verbalization primes productive imagination as an assertion of sketching or design as a primarily cognitive and symbolic process. However, this is not the case. Within the context of our study, and taking into consideration research conducted in the field of Artificial Intelligence and cognitive psychology, we treat language as part of the human perceptual apparatus, acting as a combinator of otherwise encapsulated perceptual streams such as color, spatial navigation etc in larger conceptual constructions.

This framing of language allows it to participate in constructive perception offering the ground for novelty and innovation.

4. Discourse on Method

After having articulated the internal tensions and implicit hypotheses underlying the design of the experiment we take a step back in order to critically discuss the fundamental assumptions, which underpin its methodology. In this section we will first place this experiment in a historical perspective of similar experiments developing statistical methodologies to explore aesthetics and human perception and briefly comment on this methodology in comparison to alternative methods. This first step will be used to convey the basic assumptions of different attitudes in researching human perception and does not have the ambition to provide a complete historical overview of the field. The main focus of our account will be placed in explanation of decision to use sketching as a way to test our hypotheses. This will lead to the conclusion of our discussion where we will use the observations that we have made so far as a way to argue against for a productive coexistence of computational drawing and sketching. This overcomes the commonly shared dualisms between computation and drawing and views them in a productive continuum.

The act of showing images to participants and extracting quantitative and qualitative analyses of their responses is an inherently statistical act. It assumes, first, that such “metrics” and “criteria” can be established, and second, that there is a level of objectivity in human perception resulting from a common structure of the human mind as it interacts with the attributes of objects. In his book “Architectural Principles in the Age of Humanism”, Wittkower articulates this tension between renaissance proportional systems linked to cosmological order and the late eighteenth century emergence of aesthetics and taste. Robert Vischer's Empathy theory (1873), for example can be interpreted as suggesting that aesthetic qualities such as beauty are a priori conditions of the subject and his judgment rather than innate qualities of an object.

This era coincides with the emergence of mathematics and measurement as the central mechanism for the acquisition of knowledge. (Kuhn, Hacking) Measurement allows for exchange and comparison. It renders distinct entities commensurable allowing the development of common discourses.

The combination of this paradigmatic shift towards subjective aesthetics along with a turn towards quantification, statistics and enumeration is apparent in Gustav Fechner's psychophysics. In an attempt to measure aesthetics, Fechner employs statistics to link input stimulus and sensation. His experiments result in Webber-Fechner law or “the principle of the aesthetic middle”: “In order that the intensity of sensation may increase in arithmetical progression, the stimulus must increase in geometric progression.” (Fechner, 1860) In other words, people “tolerate most often and for the longest time a certain medium degree of arousal which makes them neither over-stimulated not dissatisfied” (Hight, 2008). Taking this into consideration one can for example evaluate constitutive cultural constructs of architecture such as the golden section as average and not ideal. According to Jonathan Crary, Fechner’s work marked the emergence of a new type of subject–the “observer”–that was at once the target of increasing regulation and standardization and a sovereign authority (Crary, 1992). Aesthetics are seen subjective but nor individuated. Fechner's work initiates a tradition of physiological aesthetics, a measurement and quantification of the subject's sensoria, which can be critically revisited in the current context.

We offer that neurobiology poses a contrasting value system and corresponding methodology with research that seeks to shed light on intelligence by capturing and documenting brain states during various activities. Rather than take on the as-yet impossible task of building a model of the brain, external observations allow inference and speculation about our mental structures unencumbered by introspection or reciprocal self-observation.

5. Conclusion

We offer a methodology for studying the design process without ignoring a fundamental unknown about the nature of design–whether it is a perceptual or cognitive act: the interpretive sketching by architects as a means to evaluate trace artifacts of the design process. Of course, architects are trained to be productive sketchers–to generate ideas rapidly, to improvise with pencil and paper. Rather than distinguish between learned creative skills and the capacity for an artifact to illicit creative behavior, we address both as a coupled set. We return to the domain of the drawing, and away from a consideration of models, for the production of variable aesthetic conditions. The sketched response can thus be compared directly with the source material.

Drawn content and drawing as analysis isolate the spatial potential of the aesthetics unencumbered by overtly spatial conditions in a geometric model. Sketching with pencil and paper is still the best medium for he improvisational creation of drawings. It then becomes necessary to sketch an interpretation of other drawings, which consist lines shapes and tone created within 2-D space of the images (as opposed to three-dimensional geometry projected onto a two-dimensional surface). This invites a meaningful comparison between sketch and source material.

John Dewey claims that all art must be framed within the context of the human perception. "An experience," to Dewey, involves the fusion of the sensory stimuli affected by the art with the memories, past experiences, mental frameworks and structures of the individual. Dewey implies that human perception is both unknown and individual. Therefore, it is invalid to consider what, specifically, is being expressed–as though art could be truly "representational." Instead, Dewey proposes that art has a certain expressive capacity. Meaning should not be derived from the work itself but with respect to the perception of the work. (Dewey, 1958)

Drawings serve an explicit and measurable function in a cyclical design process. Historically, ideas were drawn to enable judgment by the designer. Within the same operational continuum, generated drawings can address the nature of human perception given our ability to see what we might not be able to think and to draw what we might not be able to see.

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Innovations in Architectural Education: Immersion in Neuro-Architecture

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Abstract
The emerging discipline of 'Neuro-Architecture' offers design students and professionals a new paradigm of design inquiry and practice. Using scientific methods to measure the brain, mind and body's responses while immersed in full-scale physical or virtual building mockups, a more realistic and ecologically relevant design inquiry process may test design hypotheses and validate architectural outcomes. The addition of wearable, and wireless sensors to track movement, visual attention, and concurrent electroencephalographic (EEG) brain responses may reveal the association between EOG, ECG, and EEG and specific design features. These objective and sub-conscious data, together with ethnographic observations and subjective survey data, may reveal the design *'as used'* rather than 'as built' and inform research-based design guidelines. Students that proceed through this 'inside-out' approach, clearly show development in skills that consider how the built form serves human function and experience *within* the design space.

Keywords. Architecture, education, neuro-architecture, neuroscience for architecture, CAVE, virtual reality, design thinking, design inquiry, evidence-based design, research-based design, spatial cognition, navigation, wayfinding, electroencephalography.

Introduction

It has been suggested that architecture is inhabited design.[i] As such, the experience of *immersion within design* defines an essential element of the human encounter with architecture. Studies from the disciplines of phenomenology environmental psychology have sought to understand the human encounter with architecture using anecdotal, experiential, and observational methods to explore and predict responses to design. Visual representations, using 2D pencil plans and elevations, small-scale models, or more recently, flat-screen digital models are used to test design hypotheses or as a proxy for full-scale design settings.

However, there is a great deal of skill and experience required to accurately imagine or emulate the experience of being immersed within a space. Further, there is a great deal more that can be revealed by studying the human response to design *beneath* the level of behavior. At the level of the *biological* response to design, a measure of sensorial, emotional and cognitive interactions with design may be now explored.

1. Neuro-Architecture

The emerging discipline of 'Neuro-Architecture' offers design students and professionals a new paradigm of design inquiry and practice. Using scientific methods to measure the brain, mind and body's responses while immersed in full-scale physical or virtual building mockups, a more realistic and ecologically relevant design inquiry process may be used to test design hypotheses and validate architectural outcomes. The addition of wearable, and wireless sensors may be used to track an individual's movement, where the viewer is looking, and their concurrent electroencephalographic (EEG) brainwave responses to reveal visual attention, fatigue, or stress in response to specific design features. These objective and sub-conscious data, together with ethnographic observations and subjective survey may reveal the design *'as used'* rather than 'as built'.

A new curriculum in immersive research-based design has been developed to apply a 'Neuro-Architectural' process to evaluate architecture. A lecture series in Neuroscience for Architecture introduces students to

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the brain systems that control sensory, motor, visceral, emotional, and cognitive functions. In addition, the scientific method and the means to access, analyze, and interpret bio-medical research are taught. With this skill set, students can critically evaluate 'evidence', and meaningfully translate research into design principles that may inform design for the continuum of human conditions. An in-depth course on 'Research in Design' extends disciplinary approaches to include methods from the humanities, arts, psychology, engineering and the medical sciences. The process yields traditional case studies, evidence-based design concepts, and rigorously studied research-based design guidelines to inform design. An 'Immersive Design' course brings all of these methods together, teaching students to transform 3D digital models into full-scale 4D interactive and immersive CAVE mockups that can be used to test specific design hypotheses. Students that proceed through this 'inside-out' approach, clearly show development in skills that consider how the built form serves human function and experience *within* the design space.

Figure 1. *Immersive Design Course: CAVE enables students to accurately visualize design elements from a first-person full-scale perspective.*

In contrast to real-world studies, often complicated by uncontrolled confounding factors, the immersive virtual reality CAVE environment provides a controlled laboratory in which long-standing architectural theories and design hypotheses can be explored. Students in architecture and researchers in computational visualization have together tested a number of concepts, and evidence-based design hypotheses. Interestingly, these cutting-edge methods are useful in aiding a broad range of design questions, from modern parametric concepts to classical concepts suggesting an innate predisposition to well-described ratios and orders in design.

2. Immersive Design Studies

For example, CAVE tests have explored in initial tests visual attention to golden ratios. Initial studies documented the well recognized sensation of 'compression' with low ceiling height, that revealed observable changes in alpha EEG waves in a subject exposed to ceiling height change in a virtual building mockup. Repeated studies would help to define the dimension of ceiling height modification associated with repeatable EEG stress changes, preferred views or ratios, and other principles that guide design. (BBC TV, Secret Life of Buildings, 2011)

The ability to accurately create the experience of design space is an important skill for both designers seeking to create successful wayfinding strategies, and for researchers investigating the mental processes and strategies used in spatial cognition. As visualization of first-person perspectives and sight-lines from 2D plans and elevations, or even from desktop '3D model walk-throughs' is difficult, studies used 4D fully

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immersive virtual CAVE mockups to provide a more realistic egocentric navigation experience that also included a greater richness of visual elements and immersive cues likely to be used by subjects in real environments. (Edelstein et al. 2008)

Hamilton (2011) created a full-scale virtual model of the Salk Institute to test preference for specific volumetric space geometries such as prospect and refuge, and isovist measurands used in Space Syntax (Peponis et al. 1998). In comparison with desktop walk-throughs, subjects were able to more naturally explore the vistas afforded by the design, using head movements and reorienting gestures to give visual attention to those design elements of interest. Analysis of user preference correlated survey results and movement paths with specific design measurands. To test the author's hypotheses about preference for layered depth complexity, the original stairwell design was modified to offer views to additional layers of depth, and found to yield greater preference scores than the original Kahn design.

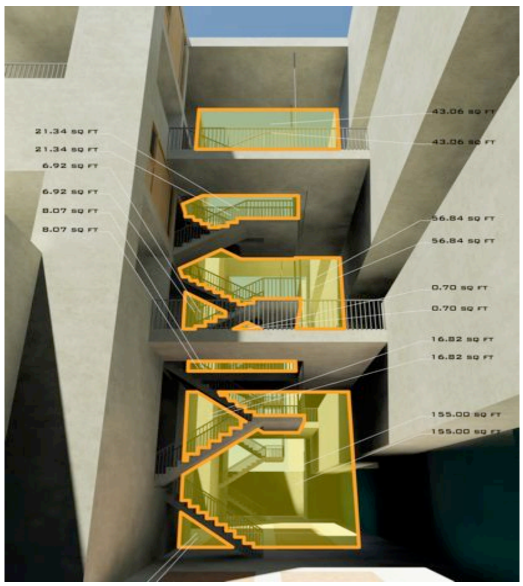

Figure 2. *Evaluation of volumes and depth layers in 4D immersive CAVE model of a modified Salk stairwell design.*
Credit: Tyler Hamilton, 2011.

It is integration of these advanced technological innovations that, perhaps counter-intuitively, allows for more realistic evaluation of architectural concepts, and more comprehensive assessment of human responses. This offers students, researchers and practitioners the means to re-examine long-held design principles and novel ideations before the first brick is laid.

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Evaluating Phynomenology by Spatial Cognition

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Abstract. This research has two study components. One is to explore whether the generation of phenomenology in architecture forms could be perceived by viewers through the construction of mental imagery in spatial cognition. The second component is to demonstrate the use of cognitive maps and spatial reasoning to find a location in a complex building group. The purposes are to develop a new method for evaluating the original design intentions after buildings are built.

Keywords. Phenomenology, Spatial cognition, Post-occupancy evaluation

Introduction

Traditional designs have concentrated on the stylistic expression of a building to match with a periodical style or regional style, in order to categorize a design as a part of a specific period in time or region in concern. After the beginning of the Modernist movement in the early twentieth century, designers possessed the freedom to express their own design character by applying their own design language through utilizing special design representations. There have thus been a large number of new forms created and new phenomena generated. However, no particular labels have been created to categorize the new design trends after the terms of post-modernism (1970s) and deconstructionism (1990s), and the methods developed to evaluate how the newly created environments benefit dwellers have been limited. In the twenty first century, notions of user-centered design emerge. Scholars in this new field expect that the spaces created in a design should provide appropriate environments for the users of the environments. Measurement tools used to evaluate the appropriateness of spaces are through post-occupancy evaluation.

In post-occupancy evaluation, mechanical, structural, and HVAC systems used in buildings are often the factors applied for evaluation. These systems physically exist in spaces that could be touched, visualized, and measured. However, there exist intangible elements of phenomena created by the material, color, spatial layout, and the correlation between buildings and their sites. These phenomena usually are perceived by users as patterns, which are not physically presented but are intermediary entities in essence [1]. However, these intangible elements have direct connection to human cognition that should be evaluated as well, as these phenomena have direct influence to the cognition after they are attended, recognized, and perceived.

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As a beginning project to lead this direction, this research intends to explore methods of evaluating the impact of phenomena, generated by design, to human cognition. As a pilot study, the concentrations are on how phenomena created by design do affect human cognition. The fundamental concept of this study is to apply spatial cognition as the study methods to accomplish the missions. It is expected that through this research, a method of evaluating the intangible data generated in buildings through designers' intentions will be explored and established for further studies.

1. Concept

The phenomena generated by architectural form have been discussed by scholars in the field of phenomenology. Phenomenology is a philosophical design current in contemporary architecture and a specific field of academic research, which is based on the experience of building materials and their sensory properties [2,3]. In general, phenomenology approaches design in a highly personal and inward looking; it favors clean and simple over complex. Impacts of phenomenology to architecture started in the 1970s with work by Norberg-Schulz [1] and later by Robert Venturi. Alvar Aalto, Charles Moore [4], Steven Holl [5,6,7,8], and Paul Andreu were the architects best known for applying the theory in their designs.

In the philosophy of science, phenomenology is used to illustrate a body of knowledge that relates empirical observations [9] of phenomena to each other without paying detailed attention to their fundamental significance. When it is used in psychology, it refers to subjective experiences [10], especially emotions of which the person is not fully aware. For instance, in relationships the problem at hand is often not based around what actually happened, but is based on the perceptions and feelings of each individual in the relationship [11]. In short, the phenomenal field of psychology focuses on "how one feels right now".

In general, phenomenology relates to events or every something that may be experienced. In architecture, building forms create an environment that has some phenomena associated and experienced by users or viewers through perception. From the design point of view, designers may apply their experience and feeling of materials, spaces, colors, texture, and proportion to create forms. From the resulting product point of view, the created form may have designated some specific portion or visually outstanding segment to be perceived. Thus, phenomena appear through consciously designed form and perceived through human cognition. Results of the perception can be represented as information resources which will generate certain knowledge to be applied for solving problems.

This research develops a case study to investigate into the impact of building form and its associate phenomena to human beings in an environment through the application of spatial cognition. Spatial cognition, in this study is defined as: "the ways human beings learn, understand, and navigate through the world using a mental representation of space, which could be the mental image or mental map used for reasoning through everyday activities." The conceptual framework of the study is to find out how the phenomenon of space translates into a mental image or map that dictates our cognition, and whether the mental image or mental map is more salient during this cognitive process.

2. Conceptual framework and research methods

2.1. Phenomena in space

Phenomena, as defined as any event that may be experienced in an environment, could be seen as certain kind of sensory information obtained from sound, view, touch, and smell. This study, at this stage, focuses on the experience perceived from spatial cognition through vision.

During the visual perception processes, the perceived information would be interpreted mentally with some reasoning to generate awareness of an object or circumstance. Results of such awareness obtained from visual perception could be classified into two major categories.

- Category one: The feeling and perception of the space created by the nature of the materials that are used to construct the space. The nature of the material, for instance, relates to the color and texture appeared on the surfaces of objects. These perceived data could be termed pixel information of mental imagery.
- Category two: The location and position of the viewer in the space, which are shaped by the viewer's consciousness. These data relate to the geographic information registered in a map format [12].

When viewers immerse themselves in the environments, they would start to perceive the spaces, and certain cognitive operations are utilized to create specific cognitive results during perception and knowledge development stages. Specifically, the fundamental cognitive operations required to process the perception and to create the pixel information of mental imagery and geographical information of mental map, are briefly explained in the following to serve as the hypotheses of this research.

2.2. Cognitive operations

For category one of mental imagery, after a scene in a space is perceived, viewers will generate a mental image of the space, process the image in the working memory, and selectively save it in memory. If there are special feelings about the space generated at the stage of perception, which may be caused, for instance, by the characteristics of materials or the proportion of the spaces; then interpretations of these feelings do occur and be associated with the mental image to form a dual-coding representation stored in the long-term memory [13]. Of course, other factors of the surrounding sound, movement, and smell would also modify and shape the interpretation of events. When viewers revisit the same space, they might scan through their memory to search for the stored mental representation of image and its associated interpretation first, do pattern matching between the external view and internal representation next. After the patterns are matched and the spaces are recognized, their associated data of learned interpretation and sometimes its related feeling do reappear. In this series of actions, mental image is the major representation used in the process.

For the second category of geographic information, which happens in navigating through the environment, a mental map as a representation is generated to strategically fulfill the navigation purposes. While navigating in space, viewers must apply mental visualization, rotation, orientation, classification, and whole-to-part relationships to find the related and correct data from their mental map to safely arrive at desired destinations. Visualization is the ability to construct, manipulate, and interpret images in the mind. Rotation is the cognitive ability to mentally rotate objects in space, and be able to maintain orientation and attributes during that spatial transition. Orientation is the ability to construct references among parts. Classification is the ability to comprehend relationships between objects and to develop meaningful groupings. Whole-to-part relationships are the capacity to construct complex objects into a whole and to deconstruct complex objects into parts. These cognitive mechanisms and cognitive representation used in spatial cognition at both categories are summarized in Table 1.

Table 1. Cognitive mechanisms applied and results generated in two categories.

Category	Cognitive mechanisms	Cognitive results
Spatial perception	Visualization Pattern recognition	Mental imagery
Spatial navigation	Visualization Rotation Orientation Classification Whole-to-part relationships	Mental maps

2.3. Experiments to verify the cognitive operations in the post-occupancy evaluation

A post-occupancy experiment is conducted to test: (1) these hypothesized mental activities in spatial cognition, and (2) the experience obtained that typically represents the phenomena reflected in architectural forms. The experiments, applying spatial cognition for post-occupancy evaluation, are currently in the preparation stage at this point of time. The tasks are to have subjects completed three cognitive tasks at the MOMA buildings in Beijing done by Steven Holl (2009). Steven Holl, a famous architect, has a number of publications explaining his applications of phenomenology in design [5,6,7,8]. His notions of porosity, chromatic space, fluid space, and anchoring among others have been applied in this MOMA complex.

In testing the notions expressed in designs, three experiments are designed to demonstrate whether viewers do perceive the intended phenomena in forms and how efficient it is to navigate through the fluid space, which are the bridge spaces (see the images in Figure 1).

- Experiment task 1:

  The first task is the study of mental image. Subject will be located in the exterior of the building to view the façade, generate a mental image representing the façade, and draw the mental image on paper with a label to describe the meaning of the image to finish this task. This image represents a reconstruction of the mental image after it is perceived. The label accompanies the drawing is the representation of viewers' interpretation of the image. This task will verify the viewers' perception of the visual patterns of porosity and image of sponge appeared on the façade that were intended by Steven Holl (see Figure 1).

  The second component of this experiment is to ask the subjects to view the bridge, develop a mental image to represent the view, and draw the mental image on paper together with a label of the image to finish this task. This component will verify Steven Holl’s intention of using the analogy of “dance” in this design (see Figures 1 and 2).

Figure 1. Images of exterior & bridge of MOMA in Beijing.

Figure 2. The painting of Dance by Henri Matisse in 1909.

- Experiment task 2:

The building complex has three levels of ground, intermediate, and top. The ground level has cinemas, shops, restaurants, and reflecting pools with many ways to move through. Steven Holl called this level the place of urban porosity that connects to all sides. The first task of this experiment is to interview subjects with questions on the orientation and whole-to-part relationship on this level.

The second task is to test the perception of the second level that mainly consists of roof gardens. The purposes are to test the level of comfort while expose to the gardens that do not anchor to the ground.

The third task is the evaluation of the top level, which has bridges connected all eight towers. According to the design, there are swimming pools, libraries, and reading rooms allocated along the bridges. It would be valuable to test the users’ level of comfort in the narrowed and semi enclosed public space perceived by Chinese culture.

- Experiment task 3: Subjects will be asked to navigate the complex from the starting point, which is the west middle of the ring to find the theater and community room on the lower levels. Simple maps of the entire system (the map shown in Figure 3 is a part of the system) will be provided. Yet, no explanation of the maps will be given to the subjects, who will be asked to read the maps and find the ways to get to the required destinations. After the subjects have found the destination, a simple sketch of the mental maps that they used for navigation is required to be drawn for completing the experiment. This task will test: (1) how dwellers use short cuts verses how strangers could explore spaces in a new environment, and (2) how easy the subjects could memorize the route they travelled and map the mental route to paper maps through reconstructing their mental maps.

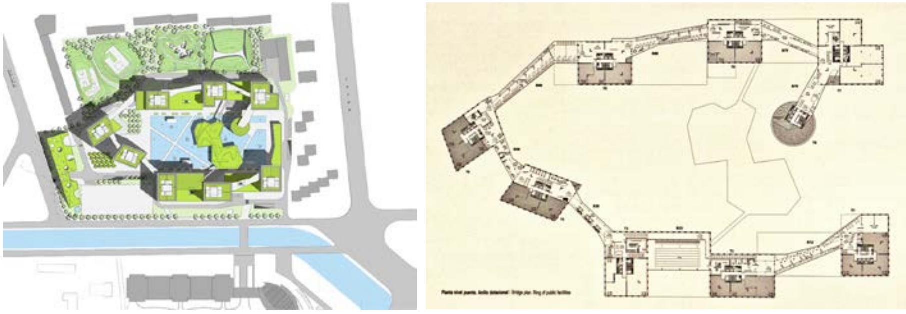

Figure 3. Site map of MOMA and floor plan of the bridge ring.

2.4. Subjects and experimental procedures

Subjects participate in this project will include two groups of resident and non-residents. Resident group will be the dwellers who live in this complex since its completion in 2009. The purposes of studying the cognitive performance from this group are to explore whether their cognition, shown through their mental image, has been modified or revised throughout these years living in the complex. If the perception has not been changed, then it could be concurred from this experiment that the first perception of the space dominates humans' cognition. Otherwise, what cause the changes and modifications of knowledge representation, which is the mental image in this case, could and should be explored.

The non-resident group will be the persons who have not visited this building complex before. These subjects are new to the complex and appropriate participants due to the fact that they will generate a first mental image from this first experience. The character of the generated images could be used to compare with the ones by resident group.

Within each group, three teams of elementary students (5^{th} grade at age of 10), college students (sophomore at age of 20), and senior citizens (65 years old) will be invited to participate. Each team, within the group, will have 10 participants. The purposes of having three different ages group are to compare the differences of cognitive performance between ages. It is assumed that different public spaces will generate different perceptions and experiences to different group of users which would affect groups' cognitive performance respectively.

Before the experiments start, the nature of the experiments will be explained to the participants, and short interviews after the experiment will be conducted as well. The entire experimental activities will be tape recorded for data analysis.

3. Expected outcome and discussions

The complicated series of experiments will take a fairly long period to complete. Expected outcomes of experiment 1 will have sketches of mental images drawn to represent the mental image generated internally and labels written to explain the interpretation of the phenomena they perceived. In task A of experiment 1, drawings and labels will determine if the intended design of porosity, as explained by Steven Holl, has accomplished its expected phenomenon to all subjects. The task B of experiment 1 would have similar results of producing a sketch and a label to express the perception of the bridges connecting eight residential units. According to Holl's explanations, the configuration of the bridge connection was inspired by the painting of "Dance" by Henri Matisse in 1909 (see Figure 3). It would be interest to find out whether the dance phenomena or something else would be perceived by all subjects in the six teams of two groups.

In experiment 2 of evaluating the use of spaces, the collected numerical data through answering questions will be analyzed by statistic analyses to verify the outcomes; particularly on the cognitive performance of orientation, comfort level of the roof garden, and users' perception on the use of public space.

In experiment 3 on testing spatial cognition on navigation in building complex, the bridge system is a complicated configuration located on the sixteenth and/or nineteenth floor; whereas the location of the theatre is on the first floor in the south middle part. It will take a special route to get there through the complex. As expected, three teams in the non-resident group will have different outcomes on: (1) the time to complete the navigation, (2) the number of times spent on rotating the given map to match with the mental rotation, (3) the landmarks selected as pivot point for reference, and (4) the number of times to find the reference points. Variables representing the cognitive factors in experiment 3 will be further extended for data analysis after the data is collected.

A paper map is a record of the physical location of buildings or artifacts. A cognitive map is a presentation of spatial relationships that enables the mind's eye to plan movements through the environment. The study aims to examine the cognitive maps constructed by each subject, as well as the spatial reasoning methods used by subjects to solve a complex path finding problem in this experiment.

4. Conclusions

The experiments developed at this point were conceived primarily as pivot studies for exploring spatial cognition in evaluating architectural form. MOMA is a successful project done by Steven Holl, who applied the notions obtained from his architectural training in US to designs in a foreign country. If the phenomena, that were intended to express through form, have well perceived by subjects or dwellers in that country, then the phenomenology is a universal one that passes the cultural boundary and which could be tested by the results obtained particularly from experiment 2.

For the experiment 3, if subjects can't find the destination in the group of buildings or in a complex effectively, then the dwellers in the complex either are not capable of performing their cognitive function (teenage kids and senior citizens), or the design fails to provide user friendly environments to the habitants.

Combining the results of three experiments, it might be possible to compare the information provided in the mental images and mental maps for understanding the activities involved while doing space recognition versus space navigation. Similar methods could be used in the urban scale, as explained by Hillier (1996) and Devlin (2001), to explore how spatial cognition could be used to explore the space syntax and to measure spatial configuration of urban space.

This research is a joint project between two institutions and this article serves as the major theory structure of the works to be completed in Beijing. Currently, a small pilot study on applying similar method to test mental images and maps through spatial cognition is under the planning stage at Wuhan University in China. Of course, the purposes are to evaluate the building phenomena created by design intentions after the buildings are occupied.

As a footnote, it is also hoped that after phenomenology perceived through vision is explored, other dimensions of phenomenology through perceptions of sound and touch could be further studied in the future.

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If *space was the machine…* Usability research for spatial design

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Abstract. This short position position paper draws a parallel between spatial cognition research and Human Computer Interaction, to identify the ways in which research on interaction between humans and machines can contribute to a more user centered spatial research and design. Second part of the paper introduces a dissertation project drawing on HCI tradition in identifying affordances that influence experience of movement in architectural settings.

Keywords. Participatory design, ethnographic research, usability, spatial design, HCI, user experience, wayfinding

1. If space was a machine, would it be a PC or a Mac?

What is spatial cognition? As Montello explains *spatial cognition concerns the study of knowledge and beliefs about spatial properties of objects and events in the world* [1: 14771]. So cognition is knowledge, or to be more precise, cognitive systems that we create *include sensation and perception, thinking, imagery, memory, learning, language, reasoning, and problemsolving* [ibid.].

Cognitive science has been influenced to large extent by emergence of computers and since the field's beginning it has been tightly paired with computer science. Neisser, for example in his *Cognitive Psychology* [2] used the metaphor of a computer to describe information processing of human cognitive system. But computers and other machines have also been prominent „actors" in cognitive science in other ways. Human Computer Interaction discipline from its beginning was applying cognitive approaches to study how people interact with machines, by both creating models for how humans process information and by translating them to design of machines and systems (think: a mental model of operating a telephone and a model that the design of such machine should follow to make it possible to make a call).

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What do machines have to do with spatial cognition? In 1923 Le Corbusier claimed that 'A house is a machine for living in…' [3] and although his theory has been refuted, some contemporary spatial scholars use a similar – yet distinctively different – metaphor of space as a machine (see for example [4]) to emphasize the co-mechanisms between people and their environment and in particular environmental structure.

This metaphor of space as a machine is in particular interesting in terms of looking at the field of Human–Machine and Human–Computer interaction (HCI), which over the past decades focused on user-centered design and usability. If HCI is looking at how we interact with machines, and if space was a machine (in a metaphoric sense) can this metaphor be taken further into studying and designing space as an interactive machine, learning from the HCI as a field that has been focused on usability and user-centered design for decades?

Cognitive science has in fact strongly informed the field of HCI. One of HCI gurus, just to give one example, Donald Norman, the author of *Psychology of Everyday things* [5] is a professor emeritus of Cognitive Science and a recent receiver of the Benjamin Franklin Medal in Computer and Cognitive Science and a former advisor to Apple Inc. His work has influenced the practice of usability studies and user-centered design and development of many commercial products and technologies, including some of the most successful Apple products.

But if cognitive science has informed the HCI and design of machines so much why hasn't the spatial cognition community been equally successful in producing applications for design of built environment [6]**.** In other words, why do we not have a Don Norman for architectural design?

Perhaps one of the possible explanations is the evident epistemological difference between the two broadly defined disciplines. Since its beginnings HCI has gone through a paradigm shift, from studying cognition to studying user-experience (see for example [7, 8] for more on the paradigm shift). As McCarthy and Wright point out in "Technology as Experience"; experience is an *irreducible totality of people acting, sensing, thinking, feeling, and making meaning in a setting, including their perception and sensation of their own actions* [9:54]. In that sense HCI understanding of its research interest departs from cognition– it is no longer *perception, thinking, language, reasoning,* nor *problemsolving*, but the totality of user experience. And experience is not only the research interest of HCI, it is also what HCI thrives to provide design recommendations for – not necessarily task solving (with calculator or spreadsheet) but doing "fun stuff" on your machine (think: some of the Apple "I am a PC, I am a Mac commercials").

Another important issue that HCI has embraced is the situatedness of actions [8]. It can be best portrayed by an example: using an ATM machine is one thing, but using an ATM machine while you have a line of people standing behind you is another thing. This situatedness is often difficult to test in a laboratory setting (and perhaps this is why it is not surprising to hear about Apple employees loosing the new models of Iphone in bars – this is where the actual, most valid testing takes place!).

2. Applying the HCI paradigm to research on- and design for- movement in built environment

The following sections will be a brief introduction into my dissertation project which, in some ways is an attempt to draw a parallel between the two fields of (computer) systems design and architectural design, brining user experience into the research on- and design for- movement in built environments.

Social science and environmental social science in particular has addressed the issue of human movement through the lenses of different disciplines – more often than not – cognitively oriented. Psychology has provided insights into the cognitive processes directing decisions made by people as they move through their environments [10, 11] how they are influenced by individual differences [12] and strategies that we employ in finding our way through environments [13, 14]. We now also know more about the development of spatial cognition [15] and route and spatial learning [9] as geographers and urban planners have examined how we construct and use mental maps [16, 17, 18]. Interestingly, most researchers with a cognitive orientation chose to focus on wayfinding rather than any other form of human movement.

Perhaps, this is not surprising given that wayfinding is a decision making process for choosing a spatial route. In fact, there is so much wayfinding research that it has become predominant in the discourse on movement in environmental psychology (a search in the "Journal of Environmental Psychology" shows, for example, 43 articles on wayfinding and only 7 on walking). In other words, if we were to the discussion from the first part of this paper, the research on movement in built environment has conceptualized movement mostly as a problem solving cognitive task and not a holistic experience of moving through a space. But, in the broader picture, it could be seen as a limitation as most of the movement that takes place in buildings is in fact not limited to finding one's way.

Therefore my dissertation project, aims at **identifying the environmental qualities that influence the everyday experience of movement in indoor architectural settings**. To do so, I have employed triangulated methods drawing on: the ethnographical tradition of studying experience, structural analysis of layouts analysis, and a participatory design approach. The study sites for this project included four distinctive office/institutional buildings, that differ in terms of spatial layout and architectural style (as they were designed and each built in a different decade). Three of the buildings have been used as office and teaching spaces for one of the departments at a university in Norway. The fourth building, which served as the study site for participatory design, was being designed at the time when this study started and data were collected.

The methodology used in this project builds both on methodologies often used in, though not exclusive to HCI, namely ethnographic methods and participatory design method. The qualitative data yield from of these methods contributed to a fuller understanding of users' needs, use patterns and requirements for the architectural program of a building. These methods have been paired with quantitative, structural analysis approach (space syntax analysis). Some initial examples of the qualitative data analysis and results will be presented at the symposium and juxtaposed with space syntax, and critically assessed in terms of the data they yield, and their contribution to answering the research question of this project.

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A Cognitive Approach for Spatial Design: Built Environments in Urban India

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Abstract: India is in a rapid phase of urbanization. Up till now, the urbanization process was mainly affecting megacities but now the small and medium cities are developing very fast. The built environments in these developing cities are emerging with varied spatial configurations. The non congruence between user preferences in terms of space proxemics and the spatial configuration is observed in most of these emerging built environments. User preferences in terms of space proxemics vary due to cultural differences. There is a lack of understanding of user preferences, while planning and designing the built environments. This has a lot of physical and social implications in the developing cities such as the environmental and socio-cultural conflicts. To understand the user preferences about the use of space in an urban environment, it is important to comprehend the relationship between a built environment and its users. The relationship or the interface between the user and the built environment can be understood by studying the spatial experience of the users. Spatial cognition is the central aspect of the continuum of spatial experience.

The first objective is to study the spatial configurations of the traditional built environments and the variations due to the varying user preferences in the different cultural settings. The second objective is to evolve the methodological framework to investigate the relationship between the spatial configuration and the spatial cognition to deduce user preferences about space proxemics in the contemporary context. For the first part of the study, organically evolved urban cores of the select Indian cities are analyzed.

The significance of the study in terms of the theoretical aspect is that it provides a support to establish the fact that there are culture specific user preferences about the space proxemics in the public domain. There is congruence between the user preferences and the spatial configuration of the traditional built environments, making them more humane. The spatial configurations in the contemporary built environments need to maintain a similar kind of congruence with these user preferences, so as to avoid the socially / environmentally conflicting situations in urban areas. Thus, in terms of the methodological viewpoint, the study tries to evolve a framework to understand the user preferences about the space proxemics in the public domain as cognitive constructs through the study of the spatial configuration and the cognition. It can be furthered in terms of the modeling of neighborhoods in these developing cities, appropriate to its cultural context.

The understanding about the man environment (built environment) interface will help to generate a spatial design approach to deal the built environments in the developing cities of India to make them humane and thus sustainable.

Keywords. Built environment, Spatial Cognition, Spatial Configuration, User preferences, Urban India

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1. Introduction:

India is in a rapid phase of urbanization. Up till now, the urbanization process was mainly affecting the megacities but now the small and medium cities are also developing very fast. The residential areas in these developing cities are emerging with the varied spatial configurations. A residential area with some homogeneity and contiguity is usually termed as neighborhood. The neighborhood has varied definitions and also has differential importance for different groups and populations depending on the culture, the context and the social system, etc. Yet, the simple and common characteristic of a neighborhood is that it is an area intermediate between the dwelling and the whole city, which is better known and with which one has more identification (however minimal) than the larger unknown area; it becomes a figure against the ground of the city. (Rapoport, 1982) Neighborhood leads to the formation of a "sense of belonging" and the definition of "my own area". Thus, though it is physical entity, primarily it is a cognitive construct.

1.1 Problem Identification:

In the emerging urban environments of the developing cities in India, the users' spatial behavior for the daily routine activities show that the use of the spaces and the facilities in the cities is done in fragmented manner. The required coherence, about the use of spaces in the neighborhood and then at the city level, seems to be getting lost. The non congruence between the user preferences in terms of the space proxemics and the spatial configuration is observed in most of these emerging neighborhoods. The User preferences in terms of the space proxemics vary due to the cultural differences. The Space proxemics is a term for the man's use of space as a specialized elaboration of the culture. (Hall, 1966) The urban environments and specifically the neighborhoods are usually planned according to the planning norms that evolved in India on the basis of the British planning legacies. There is a lack of understanding of the user preferences while planning and designing the neighborhoods. This has a lot of physical and social implications in the developing cities such as the environmental and the socio-cultural conflicts. This does not mean that these growing cities should not develop, but there is a need to understand the user preferences in terms of the cognitive constructs about their immediate surroundings, that is neighborhoods. Spatial design is a comparatively new discipline which is at the interface of the traditional design disciplines such as "design" (architecture) and "planning" (urban planning). It emphasizes on the working with people and space. The Spatial design approach, based on the understanding developed about the user preferences through cognitive studies, can help in this scenario. This will help to maintain the coherent harmonious link between a house, a neighborhood and a city instead of developing into a fragmented urbanity.

1.2 Built environments In India:

The three important determinants of the spatial configuration in a built environment are - firstly the natural setting in terms of topography, climate, secondly - the political and bureaucratic setup and thirdly, human response to these contextual aspects. Throughout the world, the natural settings remaining similar, the built environments differ - predominantly due to human preferences.

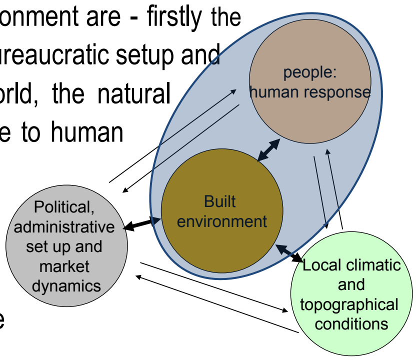


Fig 1: Determinants of built environment

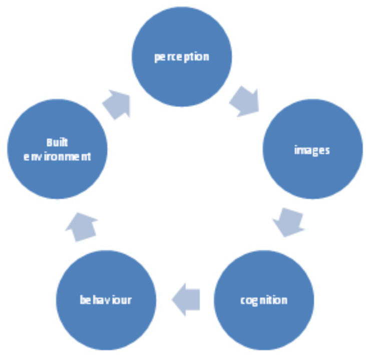
Built environments in developing Indian cities do not confine to the historic objects frozen and preserved in their own time and space. But just as cultural traditions they have transcended the time and space to remain alive and appropriate even in the present. (Desai, 2007) India has a history full of intense, political and cultural experiences. Therefore it has multiple and pluralistic manifestations resulting in multi layered built environments.

Fig 2 : Old city Nasik: Socially cohesive built environments in old parts of the Indian cities.

Most of the developing cities have urban cores as traditional settlements. These traditional built forms, though have developed at a particular point of time, they were left to evolve in physical pattern as the society evolved. Thus, till date, these built environments have been very much "living" and "thus "evolving". The existing spatial configurations in these built environments are a result of the process of natural selection of human preferences over a period of time. The traditionally evolved built environments appear chaotic and disorderly to urban planners and designers. However, if observed minutely, they present a very humane and harmonious experience. (Karimi, Kayvan, 1997) These built environments show a great compatibility between a physical form and its users. For users, if the spaces which they inhabit are compatible to their needs then they reinforce the positive elements of their culture that help to provide identity and strength. (Hall, 1966) Thus, such built environments are socially cohesive environments. The contemporary built environments though satisfy most of the physical parameters of "good environmental quality", they lack in terms of the congruence in terms of user preferences. There is a need to develop an approach to deal with the developing built environments in terms of giving a physical design direction to the urban growth, conservation and change with emphasis on human preferences. The built environment studies contributing to such positive theories, particularly about Indian scenario, are lacking. The point is that, at this juncture, there is a need to find out some possibilities of building an explicit framework about dealing with the emerging built environment with focus on human preferences, using the empirical studies done earlier.

2. Need of the study:

Neighbourhoods are a part of urban environments. The physical component of urban environment is 'built environment' which in turn is very much interrelated to social environment as well. Built environments basically mean everything that is humanely created, modified, arranged or maintained. Thus, collectively, the products and processes of human creation are called the built environment.(McClure, Bartuska, & Bartuska, 2007) It is as old as mankind, yet, "Built environment" as a concept is a relatively recent and very much an inclusive. We have been studying and analyzing built environments under the heads such as architecture, urban design, urban planning etc. Understanding "built environment" as an all inclusive concept makes a lot of difference as now the focus is on the interrelationships between its components and interrelationships between a man and an environment. To understand the user preferences about the use of space in an urban environment, it is important to comprehend the relationship between built environment and its users. The relationship or interface between a user and a built environment can be understood by studying spatial experience of the users. Human spatial experience can be broken down to various parts:



1. Existing reality around… built environment

2. Perception of the environment
3. Forming its images and schemata
4. Structuring of those images and schemata to form “spatial cognition”
5. Use of the built environment for daily routine…spatial behavior
6. Evaluation and evolution of built environment.

All these components of “human spatial experience” form a continuum. The breakage is for understanding the purpose. While using the built environments, human beings try to structure the information about it to make it manageable. This process of deciding about the behaviour, on the basis of defining what is done, when and how here differs from there in a built environment; is called “spatial cognition.”(Rapoport, 1977) Thus, spatial cognition is the central aspect of this continuum of spatial experience. The built environment is not directly responsible for the behaviour but the subjective structuring of it in terms of spatial cognition is responsible for the behaviour. It’s a mending mechanism between a man and his environment that governs human behaviour. The cognitive constructs are based on meanings, preferences and importance given to urban spaces and places, which are specific to a user group with a similar contextual, cultural background. Hence, to understand user preferences, it is necessary to study spatial cognition. Spatial cognition has two views. One view is related to psychological view and the other is anthropological. Psychological view is about the correctness of schemata developed which depends on environmental knowledge. It varies with individual as the environmental knowledge will vary from person to person due to age, sex, experience, exposure to environment and spatial aptitude. But the anthropological view is about the process of imposing order by the society at large by attaching importance and meaning, which can be termed as developing cognitive constructs.(Rapoport, 1977) Thus the anthropological view of cognition is required to be considered for research as it tries to understand cognitive constructs as user preferences about space proxemics which are specific to a society due to a common cultural background.

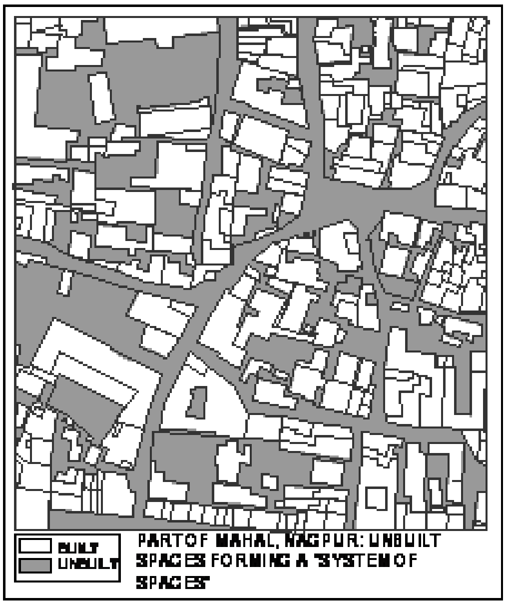


Fig 3 : Old Nagpur: built and un-built spaces

In a built environment, there are un-built spaces in terms of linear spaces (roads) and convex spaces (urban open spaces), which form a system of spaces. Set of relations between the number of spaces in a system of spaces; can be termed as configuration.(Hillier, 1996) Analysis till date suggests that far reaching practical implications on human spatial experience are not because of visual appearance but because of spatial configuration in terms of a system of spaces. Thus while studying user spatial experience; the built environments need to be studied in terms of its spatial configuration and cognition.

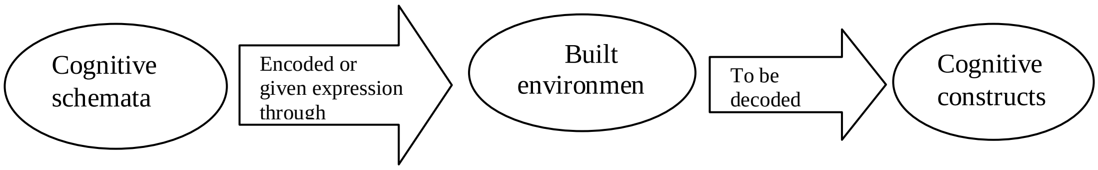
Therefore, there is a need to understand user preferences in terms of space proxemics, through the study of the relationship between spatial configuration of neighborhoods and spatial cognition of its users.

3. Research objectives:

The study is based on the assumption that the spatial configuration of built environments should be in congruence with user preferences in terms of space proxemics. And these preferences vary considerably due to cultural differences. Thus first, one needs to study spatial configurations of traditional built environments and the variations due to varying user preferences in Indian cultural settings. The second objective is to evolve methodological framework to investigate relationship between spatial configuration and spatial cognition to deduce user preferences about space proxemics in contemporary built environments.

4. Spatial configurations of traditional Indian built environments:

For the first part of the study, that deals with spatial configuration gets evolved over a period of time due to user preferences about space proxemics, organically evolved urban cores of select Indian cities are analyzed.



The values, beliefs and attitudes as a part of culture, act as filters to evolve cognitive schemata. Thus, the culture specific user preferences are a part of cognitive schemata. The cognitive schemata get embedded in built environment through its spatial configuration, evolved over a period of time. This schema can then be decoded in terms of cognitive constructs through the analysis of spatial configuration of built environment. Design itself is the physical expression and making visible of cognitive schemata.(Rapoport, 1977) Since the objective is to deduce cognitive constructs in terms of user preferences, responsible for spatial configurations specific in Indian context, it is important that we take samples of spatial configuration which are evolved over a period through the process of natural selection. Hence the spatial configurations of traditional urban cores of developing cities are considered for the study, and not the complete cities. India is a vast country with a lot of diversity. Urban cores of five developing cities in central India with similar topographic and climatic conditions are considered for the study.

4.1 Selected Samples:

The selected cities are Nagpur, Bhopal, Varanasi, Lucknow and Nasik whose urban cores are analysed (fig 4). All the cities are developing cities with population ranging within 1-2 million, as per 2001 census. The climatic conditions are also similar as tropical or subtropical climate with wet and dry or humid conditions. The elevation of these cities from mean sea level is varying between 300-500m above mean sea level. These cores are mostly the dense parts of the cities with densities within 500-700 persons/hectare and are at the geographical centre of the present cities with ring radial pattern of road network.

4.2 Procedure:

Space syntax methodology is a set of theories and techniques that analyze the topological relationships of settlement spaces (system of spaces). Plans are transformed to a dimension-less form of diagrams or graph representation for examining patterns of physical and visual linkages. It rests on the concept of “depth” in terms of “number of steps”. Metric distance and depth are two important factors in spatial cognition. But found that depth becomes more influential than metric distance as the spatial scale of cognition expands. (Long, Baran, & Moore, 2007) Thus the syntactic analysis based on the notion of the depth is considered for the undertaken study. The space syntax methods describe the topological connections of unit spaces through depth analysis typically using the graph theory. There are three different types of analysis and the most suitable for the settlement level analysis is the **axial-line analyses.** The space is represented by straight lines, so-called axial-lines. In brief, the space to be examined is modeled by the 'fewest and longest straight lines’ covering all convex spaces (Hillier & Hanson, 1984). The Axial-line modeling captures the basic features of continuous spaces such as the outdoor space between buildings in a city, a space that is a 'net' of long and intersecting 'street-spaces'. Therefore, axial-line modeling is often applied in the urban analyses.

The configuration of the selected samples is then analyzed using the space syntax methodology to deduce about spatial configuration. The “Axial map analysis” using Depthmap is carried out. Configuration parameter integration is considered. Integration of a space is by definition expressed by a value that indicates the degree to which that space is integrated or segregated from a system as a whole (global integration), or from a partial system consisting of spaces a few steps away (local integration). The placement of important urban landmarks and activity nodes is studied w.r.t. their integration in the overall system. This helps in understanding the preferences of users and the meanings associated with that as embedded cognitive constructs.

4.3 Findings and discussions:

Axial line analysis of the built environments in urban cores of the select Indian cities has highlighted the following facts about the spatial configuration of its built environment.(fig 4)

The global integration maps for traditional cores of Nagpur, Bhopal, Nasik, Lucknow and Varanasi are shown in figure 4. Apart from the numerical synthesis of syntactic parameters, which indicates a syntactic identity for the Indian traditional built environments, there are fine variations within the selected five. These variations point towards the varying human preferences for space proxemics due to the cultural differences. The cultural differences are mainly due to social norms rooted in the religion followed by majority of the population in the select five examples.

In case of Nagpur, the overall system of spaces is such that it forms a sort of orthogonal grid at the global level with better integration as it connects as well as segregates the local area with the rest of the urban system. The same orthogonal grid is not continued in the residential clusters. The subsystems formed within the system have truly organic pattern with higher mean depth and lower integration. This makes these areas less permeable, thus avoiding unnecessary through traffic. Such slightly segregated spaces from the global grid, yet having better integration at the local level are present inside the residential clusters. The internal organic and tree pattern of system encourages pedestrian movement. It helps in making a better use of these spaces by the residents for outdoor activities, social interactions and playing.

In case of Bhopal, there is a system of spaces with orthogonal grid in the centre which was a walled city. But the same orthogonal grid is not continued in the area surrounding the walled city. The subsystems formed outside the walled area are truly organic, making the outside walled area unintelligible and impermeable.

In Nasik, there is a system of spaces with deformed orthogonal grid. It is on the banks of river Godavari, which flows through the city. Yet, the spatial configuration has little orientation towards the river. In case of Varanasi, there is a system of spaces with deformed radial grid oriented towards the holy river Ganges. The river plays an important role in the socio cultural and religious activities of the city. The spatial configuration is quite indicative of that. The local parts are quite segregated and every part is finally oriented towards the river Ganges thus establishing continuous visual and physical linkages to the river. The overall system of spaces is highly segregated, making the city impermeable and inaccessible to strangers. The city was invaded a number of times by Islamic rulers during 9th and 10th century. It may be one of the reasons for immergence of such an unintelligible spatial configuration.

For Lucknow, the overall system of spaces is radiating from the political and religious core evolved on the banks of river Gomati. Unlike Varanasi, the local subsystems are not oriented towards the river. The global system is formed by two or three radiating highly integrated roads which easily connect the core with the rest of the system. But the same radial grid is not continued in the residential clusters which are organic. Public areas are distinctly separated from residential areas.

Thus the spatial configurations of the selected five examples show variations of user preferences about space proxemics. It is obvious that the norms about how the public and the residential domains are integrated or segregated are different for different cities. To further investigate about the human preferences about the culture specific space proxemics, the placement of important religious, the administrative or commercial urban activity nodes, in the overall spatial configuration are observed. The local integration syntactic maps are superimposed on the maps of urban cores where the important urban activity nodes are marked.(fig 4) It has highlighted that, in case of Nagpur, the activity node having local bazaar, religious activities and administrative activities are not located on highly integrated streets. They are located on the second order streets, in terms of their integration values. This makes these activities slightly segregated from the global system. Similar observations were found in case of Nasik, where important activity nodes such as temples are placed on the streets with second rankings in terms of the integration values. In case of Bhopal and Lucknow, the main urban elements and activity nodes are mostly the mosque and the bazaar street. These are placed on the streets with high integration level i.e. on global network. In case of these cities with dominating Muslim population, the important activity node which is a public domain, is segregated from the local network. For Varanasi, as the river is the most important focus of the urban life since ages. Hence here the observation is very peculiar. The important urban elements such as palaces, temples, cultural activity centers and bazaars are along the river, and segregated them from global network. This was because of the fact that the main accessibility then was through river. Except, for Bhopal and Lucknow, which has dominating Muslim population Nasik, Nagpur and Varanasi do not have important landmarks, activity nodes on highly integrated linkages but have urban elements on local networks. The analysis helps to understand the fact that important religious, administrative or commercial urban activity nodes evolve along movement patterns, depending upon the culture specific space proxemics about public spaces.

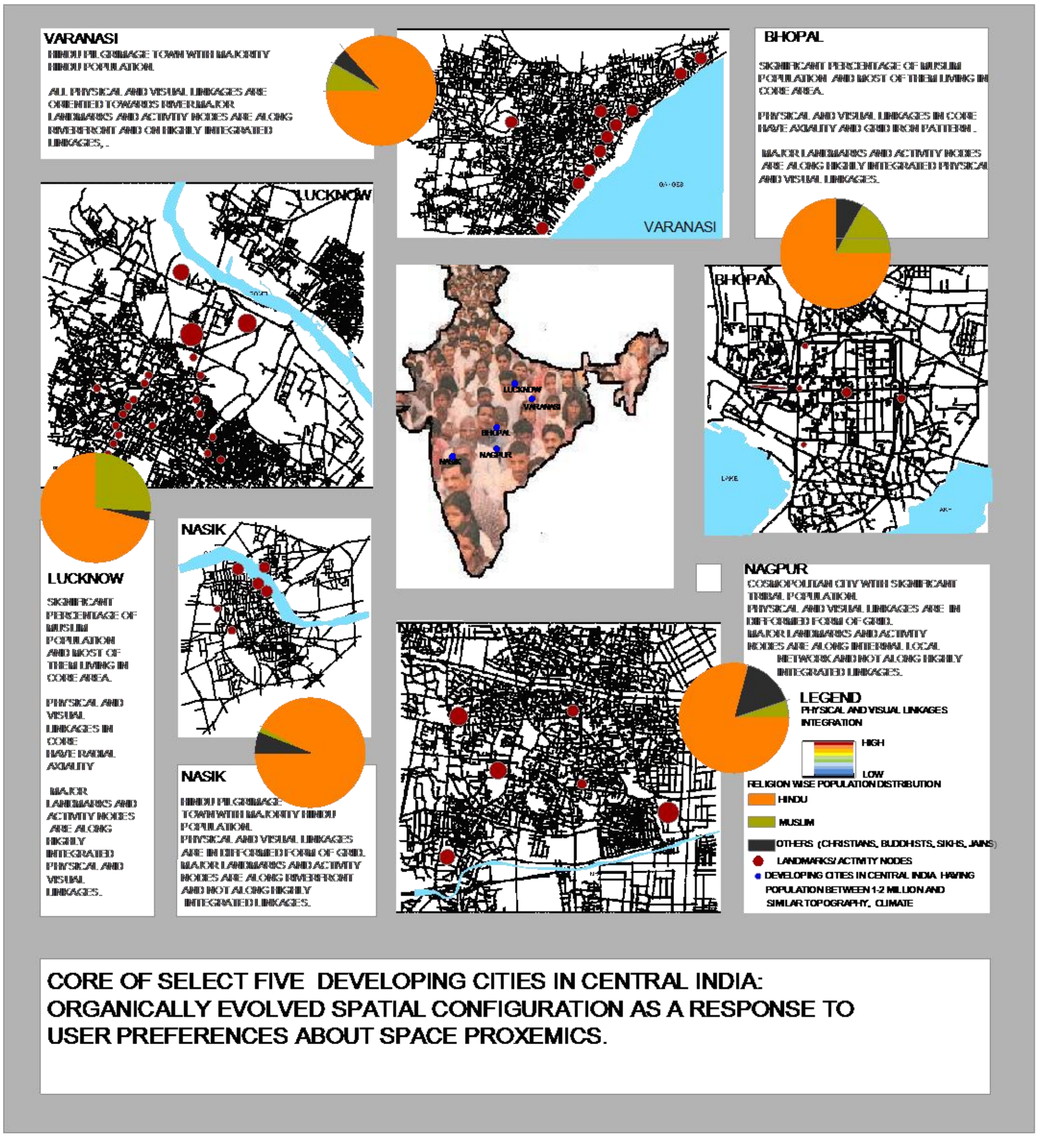


Fig. 4: Analysis of spatial configuration of urban cores

4.4 Outcomes of the syntactic analysis of select urban cores:

1. The cores of select Indian cities analyzed here have organic pattern. Though superficially, the organic patterns look similar, the analysis has highlighted that the configuration relationship between the spaces changes in these built environments. And certainly, there are differences in built environments due to differences in user preferences and embedded cognitive constructs of the society.

2. Depth minimizing form is far more intelligible than depth maximizing form (Hillier 2007). The traditional built environments have higher mean depths and subsequently less integration compared to modern environments with grid iron patterns. Yet, they seem to be much more socially cohesive and humane. For a given society, we need to understand the principles of depth gain based on the values / rules of human preferences.

3. Thus, while dealing with the built environments, there is a need to determine whether and how to minimize or maximize the depth gain. This understanding about spatial cognition may help to generate a humane approach to spatial design decision making of built environments in India**.**

5. Spatial Cognition: Methods and Problems

Based on the analysis of traditional built environments, it is clear that there is a need to understand user preferences before dealing with the spatial configurations of emerging built environments. For that there is a need to derive a framework to study relationship between spatial configuration and cognition of its users and to understand user preferences in the contemporary context.

Spatial cognition is reconstruction of space in thoughts. (Downs & Stea, 1974) For cognition, environmental information derived from cues in the form of observable physical aspects of an environment. It is then filtered in mind and crystallized as cognitive constructs. Thus, perception in terms of acquiring environmental cues is a process and cognitive map is the product of that process.(Downs & Stea, 1974) Filters are in terms of point of views/ preferences/ values which are culture specific, and are usually common for a given society. It is important to make explicit these values and filters through the understanding of spatial cognition. This in turn will help us to achieve congruence between the configuration that we facilitate through planning and design and users' behavior, in a built environment.

In general, the process of acquiring spatial knowledge is denoted as the cognitive mapping process. The product, the sum total of environmental information stored in memory is called cognitive map. Although not strictly cartographic, a cognitive map experientially contains some map like qualities. The development of cognitive map is mostly through direct communication with the physical environment except in some cases, where it is through indirect representations such as direction maps, pictures or moving images.

Environmental knowledge structure or cognitive map has places, spatial relations and travel plans (behavior decisions). The locations of places and spatial relations between them in terms of locational, relational, configurational leads to formation of cognitive map. Relational knowledge builds on locational knowledge and is about distances and directions. Configurational knowledge about an environment accumulates over a period due to locational and relational knowledge as the notions about proxemics get embedded into it. For us to understand, user preferences in terms of space proxemics, the configurational knowledge of cognitive map is most important.

There are various methods discussed and used by a number of researchers. Some of them are as follows: (Stokols & Altman, 1987)

- Asking subjects to Introspect by Binet in 1894
- Through maze learning by Tolman in 1932
- Sketch map advocated by Lynch in1960
- Sketch map procedures and some resulting topological clustering to classify / categories Appleyard 1969
- Use of toys and games with children by Blaut in 1970
- Interpoint subjective distance judgment by Briggs in 1972
- Recognition tests about city scenes by Milgram in 1972
- Combined scaling and category grouping methods to obtain judgments of interpoint proximities by Golledge and Spector in 1976
- Judging locations and objects by Farrah in 1977
- Estimations of length of streets and angles of intersections by Byrne in 1979
- Subjects to interact with a computer in order to develop configuration of places by Baird in 1979
- Photos of places and locations to be placed on map board by Rayner in 1980

The search for the most appropriate way to represent stored information in the form of a cognitive map is quite crucial. Developmental difficulties in spatial abilities and differences in verbal and drawing skills always interfere in externalizing internal spatial structure.(Stokols & Altman, 1987) Sketch map is the most used methods by researchers. Sketch map assumes that a person understood:

- The abstract representative notion of a map and its relation to the real world.
- Translating spatial information from large to small scales.

Spatial aptitude or expertise varies with profession. Common man, with average or no spatial aptitude, will have difficulty in using sketch map to externalize his cognitive constructs. In India, the appropriateness of sketch maps as a process to understand about cognition is questionable. In Indian context, it is observed that the cartographic understanding is very poor. People are not used to comprehending, using or drawing visual representations of built environments around, in the form of maps. Here, the following statement holds true. "We easily recognize configurations without conscious thought and just as easily use configurations in everyday life without thinking of them, but we do not know what we recognize and we are not conscious of what we use and how we use it."(Hillier, 1996).

6. Formulation of Methodology:

For studying the contemporary neighborhoods, they need to be investigated in terms of its spatial configuration and spatial cognition of its users, to deduce the pattern of user preferences in terms of space proxemics. For the research, the view of cognition considered is mostly about giving meaning to the world rather than knowing about it. For evolving methodology for such a study, the already mentioned user-built environment interface is referred to. The relationship or interface between user and built environment can be understood by studying spatial experience of users. Human spatial experience can be broken down to various parts including spatial cognition, behaviour and configuration. The spatial configuration of built environment is not directly responsible for the behaviour but its subjective structuring in terms of spatial cognition is responsible for the behaviour. Thus, other than cognition and configuration, another important component of man environment interface is human spatial behavior. The behavior is certainly guided by spatial configuration as movement is fundamental to behavior. But the preferences adopted for movement and spatial behavior are determined by proxemics. Proxemics refers to the study of man's transactions as he perceives and uses intimate, personal, social and public space in various settings while following out of awareness dictates of cultural paradigms. Thus, human behavior in space is overt manifestation of spatial cognition of environment. ((Markandey, 1997) Also argued by Downs and Stea(1974), human spatial behavior is dependent on the individual's cognitive map. A fundamental spatial concept for space proxemics is "spatial separation". The elemental term used to describe separation is distance.(Gärling & Evans, 1991) Thus subjective distance assessment is also an important aspect of understanding spatial cognition. Therefore, spatial behavior maps, structured interviews and subjective distance assessment, can become more valid methods for understanding cognitive constructs in Indian context. The analysis of spatial behavior maps can help us to identify the pattern of use of urban spaces, roads, facilities for daily routine activities. Thus the user preferences about the use of spaces can be understood as cognitive constructs.

Spatial configuration of a built environment can be studied and quantified using space syntax methodology. As mentioned earlier, it is based on topological concept of depth and does not consider metric distances. Configuration parameters such as connectivity, local and global integration, and interpretive parameters such as intelligibility and synergy are considered. Connectivity of an axial line measures the number of lines that directly intersect that given axial line. Thus connectivity of a space represented as an axial space, denotes the number of immediate neighborhoods of a space. Integration of a space is by definition expressed by a value that indicates the degree to which that space is integrated or segregated from a system as a whole (global integration), or from a partial system consisting of spaces a few steps away (local integration). The correlation between connectivity and global integration is an important indicator of how clear an urban system is for its users and is called as Intelligibility. The relationship between local integration R3 and global integration Rn, is called synergy. It indicates the relationship between parts of the spatial system to the whole system. These parameters can quantify the spatial configuration.

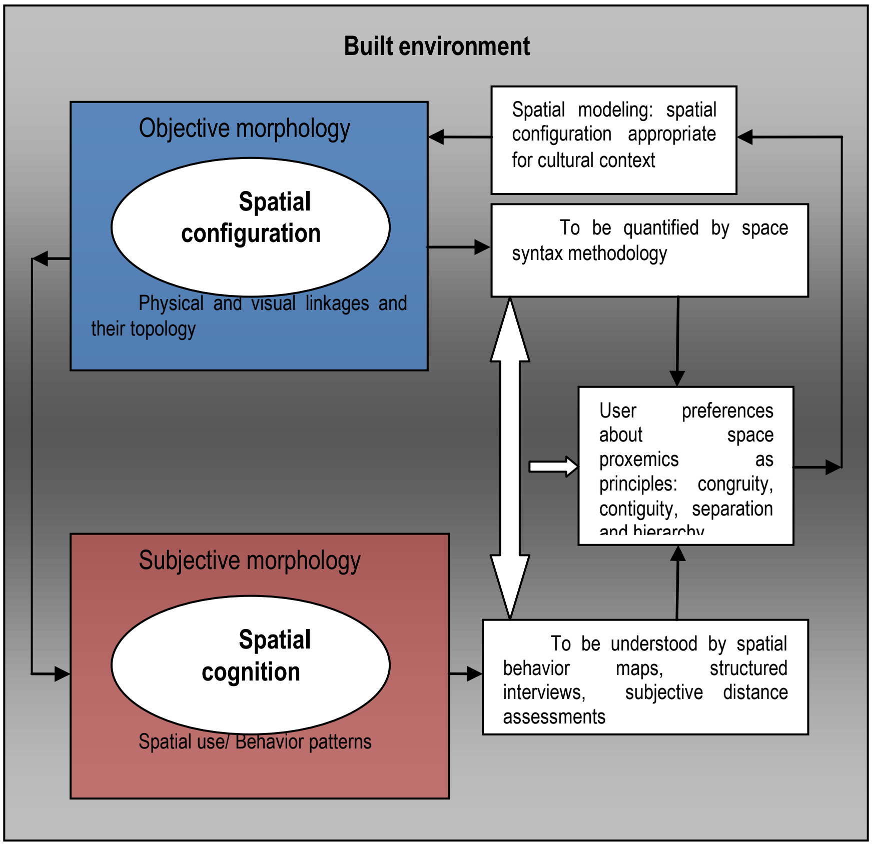


Fig. 5: Methodological framework

Any built environment has places and linkages within them. The places are defined by the concept of differences of dissimilarity. They are spaced by distances. Thus the relationship between configuration parameters and preferred destinations for daily routine activities can highlight the important principles of space proxemics for a given set of users. They are congruity (harmony and appropriateness), contiguity (continuity), separation (distance) and hierarchy. Thus the evolved methodological framework is shown in fig 5.

7. Concluding remarks:

The significance of the study in terms of theoretical aspect is that it provides support to establish that there are culture specific user preferences about space proxemics in public domain. There is congruence between user preferences and spatial configuration of built environments in traditional built environments, making them more humane. The spatial configurations in contemporary built environments need to maintain similar kind of congruence with these user preferences, so as to avoid social / environmental conflicting situations in urban areas. This does not imply that we should return to the past or cities should not grow into big urban spaces. But the lack of coherence in the emerging built environments with user preferences may face the risk of transforming a city from a locus of convergence into a focus of segregation, dismantling the favorable situation into gregarious urbanity. (Medeiros Valerio & Holanda Frederico, 2007) Thus, a methodology to understand about man environment interface through the study of spatial configuration and spatial cognition is worked out. It will help to generate a cognitive approach to deal built environments in urban India. It can be furthered in terms of modeling of neighborhoods in these developing cities, appropriate to its cultural context.

This understanding about man environment (built environment) interface will help to generate a spatial design approach to deal with the built environments in developing cities of India to make them humane and thus sustainable.

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Lines: Orderly and Messy

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Abstract

People arrange things in the world. Those organizations, dishes of various sizes and shapes piled up on shelves, windows aligned on buildings, buildings line up on streets, create regular patterns, patterns that contrast with the random patterns of nature. The patterns are good gestalts that the eye sees as vertical and horizontal lines, as boxes. Those lines and boxes can support abstract ideas, categories and hierarchies, repetitions and symmetries, one-to-one correspondences and orderings, embeddings and recursions. Early designs of these spaces are also formed of lines, but hesitant, messy ones. The ambiguity of these configurations of lines allows many interpretations, fostering the flexibility and creativity essential for design. Lines are what the hands draw, what the eyes see, and what diagrams the world.

Key Words: architecture, diagrams, visual communication, categories, abstraction

Lines: Orderly and Messy

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A number of years ago, in a talk to an interdisciplinary audience at Columbia, the architect Edwin Schlossberg made a startling claim: Architecture is information. No, I thought, architecture is concrete, literally: it's bricks and mortar. Information is abstract, in the mind or in the cloud. Architecture is the buildings that give shelter, the bridges that allow passage, the gardens that provide pleasure; some we admire for their elegance and beauty, some we decry. But the claim stayed with me, there must be a way it could be true. And here's how: engineering is the bricks and mortar, and architecture is design. Architecture is in the mind, and expressed on paper, actual or digital, or in models or words or gestures. Architecture is sometimes, but by no means always, and by no means necessarily, expressed in the world. Architecture communicates.

Architecture communicates in simple, direct ways. The human-sized vertical rectangle anchored to the ground with easy access allows entry. The smaller transparent rectangles not anchored to the ground, layered on the walls, allow light, air, visibility. The narrow long rectangles bordered by walls along the floor allow passage. Fundamentally, architecture communicates the structure of the designed object, and the structure, in turn, guides behavior. Where to enter, where to find stairs or elevators, which corridors lead somewhere, which are dead-ends. In the larger world, where to cross the street, where there is a bus stop, a freeway entrance. Architectural style communicates: this is a courthouse, this is a church, this is a discount store, this is an expensive neighborhood. Architecture can do these things subtly or blatantly, elegantly or crudely. These ways that architecture informs are obvious.

But architecture can communicate much more than style or function. Now it is my turn to make claims, perhaps more startling than Schlossberg's, and perhaps in his spirit: Architecture diagrams the world. Next: Architecture communicates abstractions. Here's what the world looks like, as created by nature.

Not perfectly random, but certainly helter-skelter. Now compare that to what the world looks like as created by design.

Quite different.

Orderly Lines

The architectured world is not random, it is orderly. The architectured world is not helter-skelter, it is patterned. The patterns repeat. The patterns create lines. The architectured world is created by purposeful actions, for other actions. Beginning with our hands, the lines formed by the shelves used to organize books, dishes, clothing. Next to our feet, the lines formed by the streets used to arrange houses, stores, and parks. The lines at cross-walks. The lines of bridges crossing rivers. The lines of the corridors connecting offices. Some of the lines are dotted, connected by the eye: the horizontal and vertical lines aligning windows on high-rises, the lines linking seats in auditoria, the lines connecting tables in restaurants. Not just lines, but horizontal and vertical ones, joined by right angles. Strong forces in the world support horizontal and vertical lines, the vertical force of gravity and the horizontal force of flat ground. Things oriented horizontally and vertically stay put; diagonal things, even slightly diagonal things like the many medieval towers in Italy that still keep falling, are unstable. The antithesis of lines at right angles: round. Round wheels readily roll, exactly because they are unstable.

Of course the lines of architectural design are not always straight, nor the angles always 90 degrees. The rows in auditoria are often curved, as are the streets in suburbia (not to mention the sculptural creations of Gehry and Haddad). Sometimes the lines even come back on themselves, creating circles, as in traffic circles or round tables and the chairs surrounding them But these are still lines, and the departures from parallel and perpendicular have orderly reasons, curved rows provide broader visibility of the stage, curved pathways create slower, more relaxed exploration with more views. The curved lines, just like the straight ones, reveal, indeed, diagram, the organization of the chairs and the houses. And by diagramming the organization, they diagram the concept underlying the organization. This is a much deeper sense of the claim that architecture is information.

The designed world diagrams itself. That diagram provides information about the conceptual organization of the world. Beginning again in arm's reach, and in the kitchen.

Notice that the dishes are not only lined up horizontally on shelves, they are also piled up vertically. They are grouped by form and use, which coincide: the plates together, the bowls together, the cups together, in separated piles. They are not only grouped, but sub-grouped, again by form and function. The neat horizontal lines and orderly vertical piles signal abstract information, specifically, categories, and categories and sub-categories, hierarchical organization. The architectural design provides the structure, vertical and horizontal hierarchical organization; the particular content provides the content. Now is a good time to note the architecture of the dishes; they are meant to be stacked in like piles.

Here's another example, illustrating the same principles:

Design informs many other abstract concepts. Look at this example:

The plates and bowls and cups are no longer in piles by kind. Rather, they are distributed so that each diner gets one of each. Here we have one-to-one correspondences, a concept crucial to counting, arithmetic, mathematics, logic. And business. Patterns are repeated, and they are balanced. Going larger:

Here again, one-to-one correspondences. We don’t know for sure, but we presume that each room has a balcony. We can see that each balcony has pillars, an arch, a railing, and decorative details, not only balanced, but arranged symmetrically. Symmetry, another concept basic to art and science, and of course to architecture and design. Not only symmetry, but also repetition, recursion, and embedding, hierarchies of patterns, more concepts that are core to abstract thought.

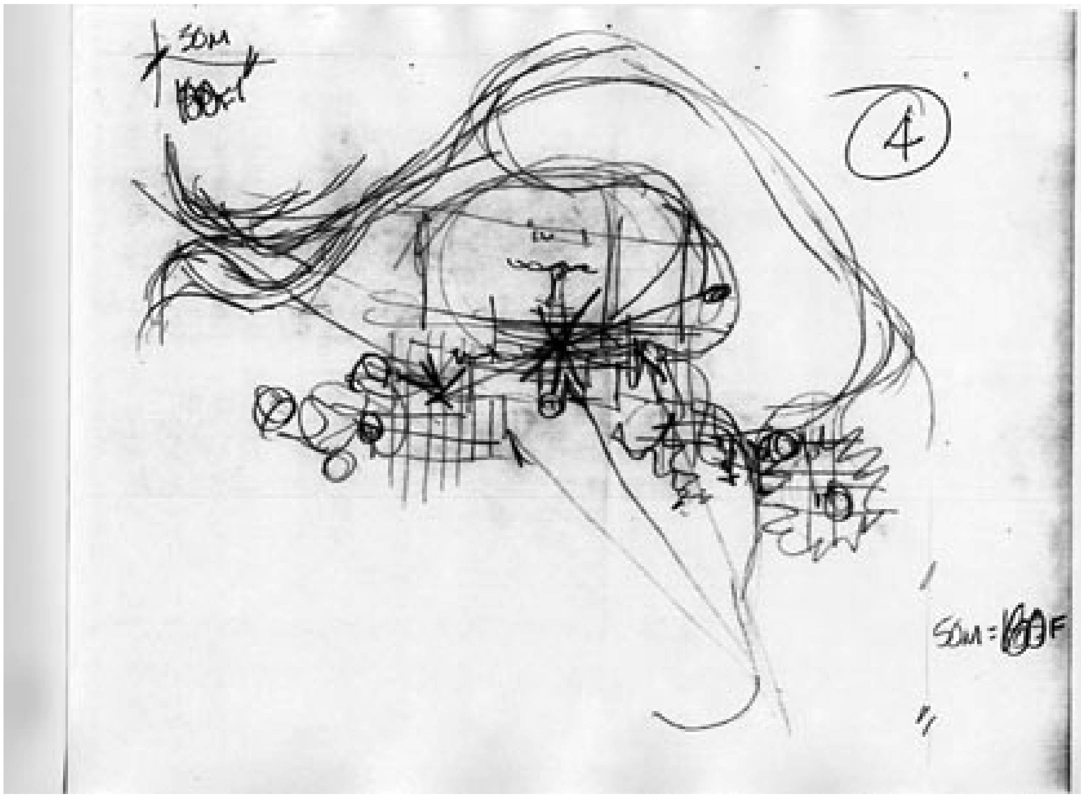
Here’s another example, one of many designs that show ordinal position, in this case, an assembly line.

Quite impressive, the range of abstract concepts architectural design captures and conveys. Categories, hierarchies, one-to-one correspondences, symmetry, repetition, embedding, recursion, ordinal relations, and of course, interval and ratio relations as well, for example, in the distances between city blocks. These spatial organizations represent abstractions, and those abstractions allow a deeper understanding of the world.

The diagrams created by designing the world can teach. They can teach the specific content, dishes, clothing, food come in categories and subcategories, cars are manufactured part by part in a meaningful order. They can also teach abstractions, that things in the world belong to categories and subcategories, that they can be distributed one-to-one, that the patterns of things can be ordered and repeated and embedded, wholly or by parts. The diagrams in the world can allow people, even very little ones, to make inferences from structure to content.

Messy Lines

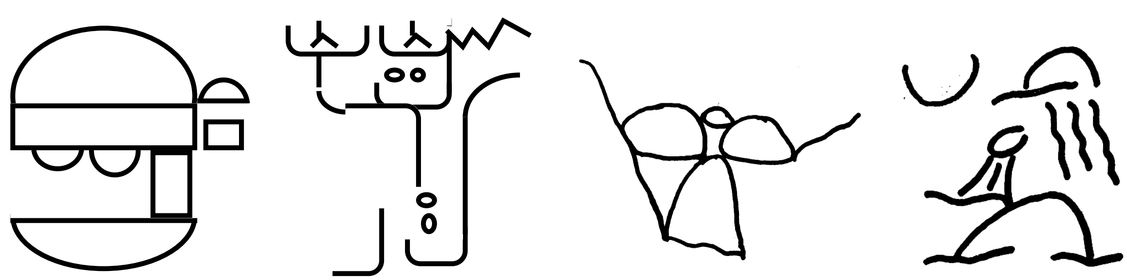
Now let’s turn from the neat and tidy designed world to the act of designing. It looks like this:



Nowhere is the organized rectified world. Instead, lines, lines that are tentative, messy, vague, uncertain. As is the design, at this point, the beginnings of a design of a museum by an experienced architect (Suwa and Tversky, 1996). Like the overview of Manhattan, this is an overview of set of buildings, yet it is looks more like the scattered leaves than the overview of Manhattan, where streets and buildings and the pattern they create are easy to recognize. These lines are not easy to interpret, or rather, they are consistent with myriad interpretations. And that is the point. The very ambiguity of the sketch allows interpretation and reinterpretation. Rather than freezing a design into a final form, the sketchiness of the drawing encourages thinking of many alternatives. Not only architects but artists and designers of both the concrete and the abstract rely on the tentativeness of sketches (e. g. Goldschmidt, 1994; Kantrowitz, in preparation; Schon, 1983). Sketches allow exploration of ideas and discovery of new ones.

How do people make new discoveries in ambiguous sketches? To learn more about the process, we video-taped experienced and novice architects as they designed a museum with certain constraints. Afterwards, we went through the video with them, video-taping these sessions, asking them why they drew every line that they drew, and then analyzed those protocols. Both novice and experienced architects reported making numerous discoveries in their own sketches, seeing aspects of the design that they had not intended at the time that they sketched. The new discoveries were productive, that is, they led to new design ideas (Suwa and Tversky, 1996; Suwa, Tversky, Gero, and Purcell, 2001). Although both novice and experienced architects made new discoveries in their own sketches, the novices made mostly perceptual discoveries whereas the experienced architects made functional as well as perceptual discoveries. Novice architects, like experienced ones, made inferences about size, shape, distance, and pattern. However, experienced architects were also able to make more inferences about change from their sketches, such as how the traffic would flow or how the light would change during the day and with the seasons. Experienced architects were able to "see" the consequences of their designs. How did the architects, especially the experienced ones, make new discoveries? They reported that they made discoveries in their sketches when they regrouped the elements of the sketches in their minds, when they mentally reorganized their sketches.

We decided to bring a model of that task into the laboratory, adapting a task developed by Howard-Jones (1998). In a variety of studies, we asked people, some designers, some ordinary people, to come up with repeated interpretations of these ambiguous sketches, presented one at a time (e. g., Suwa and Tversky, 2001; Suwa and Tversky, 2003; Tversky and Chou, 2010, in preparation; Tversky and Suwa, 2009; Tversky, Suwa, Agrawala, Heiser, Stolte, Hanrahan, Phan, Klingner, Daniel, Lee, and Haymaker, 2003).



Drawing 1 Drawing 2 Drawing 3 Drawing 4

Here are some of the things we've found. Experienced designers get more ideas from ambiguous sketches than novices. Experienced designers are also more resistance to fixation, they keep getting new ideas when novices have stopped. Skill and ability matter, both perceptual skill and conceptual skill. People who are better at finding simple figures in complex ones better at getting new ideas from sketches, probably because getting new ideas depends on mentally decomposing and reconfiguring ambiguous sketches. This is a perceptual skill measured by the Embedded Figures task (Gottschaldt, 1926) Those who are able to come up with remote associations are better at getting new ideas from sketches, as finding new interpretations depends not just on perceptual reorganization but also on the broad thinking needed to find interpretations. This is a conceptual skill measured by the Remote Associates Test (Mednick and Mednick, 1967; find a word connecting *thread, pine*, and *pain*). The two skills are independent, that is, uncorrelated, but both are needed for what we called *constructive perception* (Suwa and Tversky, 2003). Constructive perception means actively using perception in the service of some end. Because constructive perception entails decomposing and recomposing parts and wholes, arranging and rearranging them, finding new relationships, and taking new perspectives, all with interpretations, functions, or goals in mind, it would seem to be a general attitude for innovative thinking not just for design of tangible objects and buildings but for design in any domain.

There are other ways to encourage finding new interpretations of ambiguous figures. Rhythm matters. Random presentation of the different sketches yields more new interpretations than blocking them, the same sketch trial after trial (Tversky and Chou, 2010). The advantage of spaced presentation of the figures is probably both perceptual and conceptual. Perceptually, it should be easier to take a new perspective on a sketch when it hasn't been viewed for a while, especially when the sketch is ambiguous. Conceptually, it should be easier to think of a new domain of interpretations when the sketch hasn't been viewed for a while. Interestingly, each figure induced its own set of domains; there were almost no cases of transferring a domain of interpretations from one figure to another. Thus, the figures weren't completely ambiguous, they did suggest some domains and some examples within the domains more than others.

Hints matter, in subtle ways. New groups of participants were presented with the sketches in random order and asked to find a new interpretation each time they saw a sketch, as in the previous research. Some participants were given hints for finding new interpretations, either a perceptual hint or a conceptual hint or both. The perceptual hint suggested that mentally regrouping the elements would encourage new interpretations. The conceptual hint suggested that thinking of new domains of objects or scenes would encourage new interpretations. The two hints, then, correspond to the two components of constructive perception. The effects of the hints were intriguing (Tversky and Chou, in preparation). People tended to give groups of related interpretations, that is, interpretations from the same domain. For example, drawing 1 tended to elicit kitchen appliances and drawing 4 tended to elicit beach scenes. We counted both the total number of different ideas, whether or not they were in the same domain, and the number of different domains, irrespective of the number of ideas in each. For sheer number of ideas, hints elicited more interpretations than no hint, and the conceptual hint had a slight advantage. For number of domains, either hint elicited far more than no hint, but two hints were no better than no hint. This is probably because trying to use both hints was like trying to use everything, the default case of those not provided with hints. Together, the results suggest that hints serve to focus thought by giving thinkers a guide to searching for and constructing new ideas. There was some evidence that a top-down conceptual strategy is more effective than a bottom-up perceptual strategy, perhaps because the conceptual strategy provides a source for generating interpretations of figures that allow many interpretations.

Ambiguity doesn't necessarily coincide with messy lines. Giacometti's drawings come to mind; out of a jungle of line stubs seemingly going anywhere emerges a beautifully articulated face and body. Picasso's paintings of Dora Maar or Francoise Gilot illustrate the opposite; from clear clean lines drawn from several simultaneous perspectives emerge incoherent unstable images of faces. Both attract the eye, in the case of Giacometti, to discern the single intended image, in the case of Picasso, to consider a multitude.

Lines in the World, Lines in the Brain, Lines on the Page

Lines are what the hand draws and what the eye sees, a magical convergence. The world the retina captures is unformed sparkles of light of varying brightness and color. The brain connects the dots. Connected, dots form lines, lines that are straight that form horizons or paths or platforms or sides, lines that bend or curve or twist around that define figures, objects, buildings, backgrounds. Architects draw lines to design, first messy tentative lines that can be interpreted and reinterpreted, but ultimately clear forceful lines, lines that when instantiated in the world will organize the things in the world, lines that will form diagrams that will inform us how the world is organized and how to behave in it.

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Spatial cognition, memory organization and creativity in planning and architecture[1]

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Abstract. The significances and the roles of creativity and memories in spatial organizations are boosting the increasing attention of scholars and professionals. In cognition-oriented spatial studies, creativity is gradually considered as a normal character of an organization. This thesis is sustained by, e.g., the evidences on the role of memory in the most creative parts of the activity of architects, combined with exceptional association abilities representing the real bulk of creativity.
The paper discusses such issues, by analysing the case studies of single-agent and multi-agent spatial organizations under the level of spatial design. The paper explores possible modelling approaches and system architectures supporting cognition-oriented activities in spatial organizations.

Keywords: Spatial memory, Spatial creativity, Multi agent planning, Urban architecture, Spatial organizations.

Introduction

The comprehensive conceptualization of space representation and management often represents a critical step toward the building up of intelligent machines based of ontological space description. Also, space organization is an essential share of the spatial abilities of human agents, made up of intriguing sensorial and cognitive interplays. A deeper functional analysis of the intelligent abilities of human agents is worthwhile doing, so as to shed light on spatial features, and avoid accepting superficial explanations. As a matter of fact, human agents are able to first conceptualize spaces, then design and organize them for human organizations. For example, they can apply such features in architectural design, by making use of intriguing cognitive processes based on routinary as well as non-routinary approaches that need to be investigated [1]. Basically, this is another case in which the evolution of techniques and technology on automated reasoning and automated design agents, from origins to current high-level status, could not provide but flawed duplicates of human abilities [2].
When looking at the concept of creativity, we find it assumed as a complex non-routinary cognitive feature of human agents, that is, an intentional and intrinsically aware process used by agents' cognition to redefine in new ways her/his situations within the world. Although creativity does remain debated concept, some literature

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[1] The present study was carried out by authors as a joint research work. Nonetheless, D.Borri wrote chapters 1 and 2, D.Camarda wrote chapters 3 and 4.
[2] Corresponding Author

increasingly tends not to consider it as a prerogative of few special human agents. Rather, creativity is more and more seen as a particular portion of the normal cognitive patrimony of the human agent, apt to be used in specific circumstances [3][4].
The present research tries to add the space domain to other typical creativity domains examined in cognitive science. In particular, the concepts of space understanding and space organizing are scanned by making reference to creative (non-routinary) cognitive functions, beyond the routinary ones, in a modelling perspective. In this context, we have explored suggesting case-studies of interactive creative actions among civil architects, within a game-theory framing situation (space organization) [5].
Space knowledge, spatial action and organization of space contribute significantly to build the domain of civil architecture. Within such concurring participation, a critical role is played by disciplines as aesthetics and art, that are intertwined with the mechanisms of creativity. In particular, some studies deal with architectural creativity, as investigated through self-biographies by master architects. Basically they represent the architects' memories of designs, spaces, architectures, experienced along their life and reported as commented memos for new design activities. Such literature is able to suggest that space memory strongly and primarily affects work approaches and creativity [6]. Also, because architecture is made up of technology, too, then spatial memories are suitable to be scanned through the concept of technological memory. This is an emerging topic, that is increasingly considered as useful to conceptualize technological change in its interplay between tradition and innovation [7].
The experiments carried out are mainly interactions that simulate a cooperative activity. They are actually based on a chess-type interaction game among architectural-design agents, whose only goal is playing *per se*. Architects' graphic design moves on a paper sheet are recorded on a multimedia environment and then analyzed by researchers. Then ontologies and procedures are extracted and discussed from snapshots *à la* Veloso [8]. Analyses suggest that creativity is highly tributary to memories, coming from both expert, domain-specific knowledge and nonspecific knowledge [2]. Routinary moves (reactive-adaptive routines) seem to depend on the restrictions placed by other characters of the space that is being designed. On the contrary, non-routine (creative) moves are apparently depending on the memories and the abilities that the expert agent succeeds in activating during her/his designing tasks. Interestingly, the incoming of further agents in the interaction arena drives to the establishment of a coral dialectic with the two original agents, like in an orchestra concert. This circumstance is interestingly similar to the creative no-goal jazz session with suggested by Schon to explain cooperative planning actions [1].
The above description represents the basic framework of the present paper, which is structured as follows. After the present introduction, the next section deals with some preliminary problems in strategic planning, particularly addressing the active vs. reactive modes of planning. Section 2 analyses the intriguing interplays between memory end creativity in cooperative/competitive design plans by civil architects, using some suggesting case studies. Brief discussion and conclusions are carried out in section 3.

1. Cooperation, determinism, reactivity dilemmas in strategic planning

Today strategic planning is considered an appealing type of spatial planning, in that it allows more democratic as well as visionary, perspective features. Yet, tough difficulties emerge in both logical and computational terms when considering the multiagent aspects of spatial planning [9]. In particular, this difficulty poses a problem on the frequent process of synthesizing single individual choices from social choices. As Arrows puts down, such intriguing problem is rather irresolvable without relaxing the conventional rationality axioms [10].

However, although the operation of relaxing rational axioms is classically hard, new approaches seem to be promising. In particular, the last decades have given birth to new forms of interactive planning, involving even large numbers of agents in complex social and technical tasks. In such cases there is typically a tough dilemma between cooperation and non-cooperation or competition among agents, subdivided in a great range of possible fuzzy and at times undefined actions and conflicts, urging robust scientific reflections.

Both theoretical and historical models of spatial planning seem to show that an abstract-procedural-normative (APN) model of planning, born in systems theory and in cybernetics, has found few applications in spatial planning. This rational approach has been even hardly discussed and evaluated in domain literature. On the contrary, it is still prominent in optimization-based management science and computer science. APN model proves to be competitive when dealing with the optimization of an individual's perspective [11].

A further rational model of planning (practical-procedural-non-normative, PPNN), born in communicative and organizational theories and inspired by behavioural paradigms of social interaction , needs to be considered. Although largely used in spatial planning, it is rejected by formal optimization planning because the complexity of routines hampers the setting up of a functional and logical architecture. PPNN model has gradually grown from involving small to large group [12], toward a context more typical of comprehensive urban/regional planning. As it is based on agents' interactions, PPNN model shows a marked cooperative feature.

Yet, both APN and PPNN models make use of systems theory/analysis to provide own routines with a number of distinctive systemic prerogatives. On the one side, APN uses systemic processes to give rational direction in complex processes. On the other side, PPNN provides stronger resilience to systems based on manifold mechanisms and agents. Both fall short in situations of many variables and agents, as well as of semantic complexity, such as ambiguity and uncertainty. In fact, in these cases a proper explorative, creative and not procedural rationality is demanded. To this aim, hybrid approaches are more useful, able to put an APN procedure as individuals in PPNN procedures, or to insert a logical procedure based on a social responsibility of the individual agent in APN procedures [13].

When knowledge on an initial state is fully available, then a plan can be classically defined as "a sequence of actions that leads the agent from the initial situation to a goal state". Yet, if initial knowledge is incomplete (as normally occurring in spatial planning), then manifold action sequences can develop from different potential starting situations [14, pp. 241-242]. Today, conventional planning approaches diffusely considers such classical planning as not being quite useful in real-world situations. Conversely, it does remain valuable in many sectors, ranging from logistic to process planning and programming [15]. In addition, classical planning has been recently enhanced on its intelligence and operability, as in case-based planning [16], multi-agent planning [9], and non-STRIPS planning (the acronym stands for Stanford Research Institute Problem Solver [17][18]).

More specifically, generating a plan may involve basically two aims, i.e., the reaching of a goal or the reaction to an external occurrence. In general, a goal is a condition related to intermediate as well as final action states: yet, classic planning normally considers a goal as a condition put down on a final state, formally expressed as a “conjunction of clauses” [19, p.48][18][20].

Classic planning usually assumes that the initial, state as well as all the effects of actions, are known and that the world is substantially unchanging, close and static. It results that classic planning is inapplicable to such dynamic and unpredictable domains as social and environmental domains (but even to robotics or to the navigation of networks). Intelligent classic planning can be efficient (i.e., correctly functioning) but still ineffective if it falls short in reaching its goal [15, p.330].

Lets’ now look at the economic standpoint. The theory of rational choice assumes that in order to reach a goal, an agent needs to scrutinize and evaluate available alternative actions against possible outcomes and a related utility function. Practical situations are intractable by this theory because they result as very complex [21]. Planners that make use of abstractions, or hierarchies of tasks, or other heuristic-based mechanisms to scan and drive solutions through potentially infinite spaces are more able to deal with real-world problems [22].

HTN (Hierarchical Task Network) Planners, for example, use domain knowledge under the form of a scheme of task decomposition. In comparison to classic planners, HTNPs require large domain information, together with task sets and decompositions of tasks. The architecture of HTN plans allow getting around large regions of the space of searching, so restricting the exploration only to primitive actions that result from selected sequences of the decomposition of tasks. In the end, HTN planners use parsing algorithms to prune plans that are partially ordered basing on primitive actions.

There is a number of theoretical and practical experimentation that show the existence of metastrategies that can be applied in diverse domains, with little adaptation [22][23][24]. In our socioenvironmental domain, that is a real-world domain, planners search only on portions of alternative spaces of action, so avoiding an infinite domain. Particularly resource limitations (such as time) drive their exploration of action potentials of actions, often making use of an instinctive automatism that planners’ memory unconsciously selects among all possible automatisms for a given planner in a given plan. Such occurrences show that the searching space is not characterized by a feature of infinity –then resulting only an abstraction. Infinity does not exist in the restricted context of practical reality, and this is a stimulus toward theoretical reflections that address the modalities through which operational searching spaces are formed and become functional [23].

Now, if a given system is described a number of constraints and state features, it is interesting to reflect on the modalities of integrating the effects of an agent’s action in the world (action of the first order), with the impact of the system’s actions (of the second order) on the agent her/himself and her/his ability to perform that action. This involves reflecting on ‘structure’ problems [25], ‘ramification’ problems [26], and ‘qualification’ problems [27], that are largely debated but never actually solved problems [28]. When an action needs is represented by state constraints, a couple of aspects emerges as significant roles played. First, constraints encapsulate the relationship between existent objects and coherent states of the system. Second, they work as ramification as well as qualification constraints, and in this way they define intrinsically the indirect effects of actions, so constraining the implementation of further actions.

A convincing alternative to classical planning has been recently proposed in terms of reactive planning [29]. Basing on the stimulus-and-response principle, it has developed mainly in rapidly changing domains, and the so-called 'universal plan' is probably the most renowned case [30]. A universal plan is a function that implies levels of decisions at any step of a process, about the modalities of making the following step basing on the current state at the time of decision. This is different from generating a process of actions from an initial toward a final state, i.e., from the classical planning approach. Although universal plans would inherently involve exploring enormous spaces [31][32], general planning problems (with the exception of socio-environmental ones) show a degree of structuration apt to generate universal plans that are small and effective [30], even in an oversimplification (contested in literature) of the inherent polynomial hierarchy [33] [34].
With the aim of narrowing the concept and scope of universal plans, some scholars propose the limitation of universality by using few properties, such as plan solidity and in plan completeness [35]. Also, in order to enhance the operability performances of universal plans, probability features are explored. In fact, universal plans are connected with casual databases that allow a coherent redefinition of completeness so as to include the case. An example of such probabilistic and reactive universal planner is Stocplan [35]. However, the stratagem is not enough to relieve universal plans' inefficiency when facing general-plan problems, so basically narrowing their applicability to limited problem classes.
As a matter of facts, when comparing Stocplan with other classical planners in a number of testing domains (e.g., the traditional toy blocks world or other frameworks), there are not particular differences in results, so meaning that shortfalls still remain unaddressed [17][35]. When turning to socio-environmental plans, both classical and reactive planning approaches show even more criticalities and inefficient performances, so involving an enlargement of reflection categories, in order to achieve more substantial effectiveness.

2. Analyzing and modeling spatial creativity.

Creativity is commonly considered as an innate ability, by which actions of original creation give rise to brand new items and elements. On the other side, creativity can be also regarded as a process able to transform and recombine existing entities, toward different, novel configurations.
Architectural composition indicates that creativity is an original starting point for a process of transformation that follows a quasi-musical sequence. It is a peculiar attitude addressed at transforming the reality in an unconventional way, which is represented as a memory. This attitude is largely dependent on environments, architects, lifestyles. As a matter of facts, spatial creativity is a terrain on which it is hard to fix an objective, a referential framework for the interpretation of artistic and/or architectural creations. It drives to an intertwining of own memories, reminiscences with the resemblances of different artists and/or architects.
In particular, our exploration focuses on the singling out, manipulation and storing of memories in form of concrete images but also of spatial schemes and patterns, acting as spatial references for drawing on a blank space. This blank space is a paper sheet ready to be made 'dirty' by the agents' putting shapes, geometries or constraints, in a physical but also mental action, so as to develop the proper drawing effort.

In this context, the present chapter shows two design approaches, apparently very different from each other, involving multiple agents or a single agent in the carrying out of given design tasks. A brief discussion will follow to evaluate contextual results. All the experimental sessions are organized by (and some actually held in) the AAM art Gallery in Rome.

2.1. Duels vs. duets on a blank sheet

In the first experimentation, the layout situation is made up of two expert agents approaching the blank sheet together. Clearly, this is not a case of solving design problem: rather, it is just starting up and sharing a drawing game from scratch. In the entire series of meetings, the basic layout situation is made up of pencil duels/duets among architects. Because of this reason, the meeting series in the gallery is titled ‘Chess games’, emphasizing the seemingly ‘gaming’ process occurred in the drawing space, where master protagonists of contemporary architecture play together.
Such ‘chess games’ show intriguing and suggesting interaction dynamics. In particular, the mutual positions of objects and agents evolve according to agents’ cognitive actions developed in the spatial contexts. Such moves and cognitive actions drive to step-by-step, evolutionary results, coming out from the efforts on the drawing space.
The meetings set up in the gallery are all documented by multimedia files. They are carried out with a multi-agent layout, in which dr. Vincenzo d’Alba, a young Italian architect and design virtuoso, is present in all sessions. The objective of meetings is not to share a project, but rather an experience, a space of design, in order to organize and sign it, starting from scratch. Therefore, we can say that the layout shows up as being objective-oriented, rather than dialogue-oriented.
The resulted material is interesting, particularly with regard to some fundamental questions, such as the behaviour of an expert agent in a multiple-agent ‘paper space’. In figure 1 there is a visual excerpt of the first interaction carried out with Alvaro Siza.

Fig. 1 **– Agents interaction, their position at the table and the output drawing.**

When observing the expert agent, it is clear how spatial memories are connected to his own formative history. When reference memory is richer, then drawn images are more numerous and significant. But memories are stimulated also from the interaction: therefore, new images of old memories are created, as well as new memories can revive old images, following a permanent and repeated intersection of cognitions and actions.

Also, the process shows some evident themes and features of creativity. First, the role of the environment is critical and represented by context-based constraints on memories, as well as on novel associations of primitive forms or derived forms of geometry. It comes out also that creativity is not a rational process in a pure form, but it is strictly combined with the concept of intentionality in actions. The intention of drawing an image, perhaps aimed at an architectural creation, stimulates creativity and boosts the image drawing itself. From the cognitive point of view, the task of image drawing is similar to move a computer cursor in the brain, soliciting our attention focus: more than paper design, it is actually 'mental design' [36][37][38].

Mind images, objects that are in multiple places of memory, and that create the referential bulk of the expert agent, represent an actual database which is in permanent evolution. In it, diverse themes and memories that are distant in space and time become essential portions of its cognition structure [39]. Architect Zumthor puts down that the valuable moments of the inspiration of the expert agent come out from a patient work, following and developing an abrupt appearance of an internal image concerning the realization of a new design piece, by which the entire project structure changes and is reorganized in few seconds [6].

In figure 2 there is a synthetic table of the main process features of some of the most intriguing duet/duel sessions.

	agents	environment	table	sheet	agents' position	agents' working sequence	initial interaction behaviour	standard interaction behaviour	drawing space (% sheet)	sequence of agents' drawings	drawing consistency	game appearance	most committed agent
1	1 (Siza) 2 (D'Alba)	crowded, moder.noisy, music	round	large	side by side	2 → 1 → 1/2 → 2	attentive, ready	strongly proactive, reactive	100%	mostly continuative	mostly coherent	cooperative	2
2	1 (Purini) 2 (D'Alba) 3 (Ortiz) 4 (external) 5 (external)	crowded, noisy	rectangular	narrow, long	side by side	2 → 3 → 1 → 1/2 → 2 → 1 → 1/2 → 1/2/3 → 1/4 → 1 → 1/2 → 3 → 5 → 3	reluctant, unactive	weakly proactive	70%	mostly discontinuative (time overlaps or gaps)	partially coherent	(partially) cooperative	3
3	1 (Canella) 2 (D'Alba) 3 (Semerani)	silent	round	narrow, long	around the table	2 → 3 → 2 → 1 → 1/2 → 1/2/3 → 1/2 → 2 → 1 → 3 → 1 → 2	attentive, ready	proactive, reflexive, weakly reactive	80%	mostly continuative	partially coherent	cooperative	1
4	1 (Aymonino) 2 (D'Alba)	silent	rectangular	large (n.4 paired sheets)	facing	1 → 1/2 → 2 → 1/2	indifferent	nearly null	90%	(separately) continuative	Incoherent (2 drawings)	non-cooperative	1

Fig. 2 **– Raw comparison of the main process features in different interaction sessions.**

A quick analysis shows that the interactions appear as cooperative games, even with different relevance. Yet, this is not an exclusive peculiarity, since at least session n.4 shows a completely uncooperative approach. In this case, the behaviour of agents with each other starts with indifference and leads to a rather null interaction. As a whole, cooperation seems to be most fruitfully oriented to consistent and consequent drawings when cooperation is well ensured. It is interesting to note that the high number of agents involved is not an obvious guarantee either for cooperation and proactive behaviour, or for consistent drawings. Session n.1 confirms this occurrence with only 2 agents.

In general, that session is thoroughly very instructive. By examining video clips, we realize that first expert's work develops in an intricate and intriguing interweaving with her/his memory and with the memory of the second expert. Architects look mutually at their drawing advancements and complete the creative spatial work when one of them stops. Then they resume and organize their process again. It seems evident how cooperation revives autochthonous memories and stimulates new elaborations and associations, in an evolutionarily creative path.

2.2. Solo performances

Chess games were designed with the purpose of creating a framework where to share form and architectural creativity, a design space to be organized through a multi-agent approach, starting from a provocative initial point in game mode.

Now we try to investigate issues with a more direct single-agent approach. We refer to the methodological framework proposed by Buchanan at the end of the 1980s for the elicitation of expert knowledge in the field of artificial intelligence through 'sharing observation' [1][40]. It is a silent observation, a light interference by the knowledge engineer, toward the expert involved in the execution of the analysed task. The architect was observed while working alone this time, facing a blank sheet of paper, with a design theme that is unknown until the beginning of the experimental design.

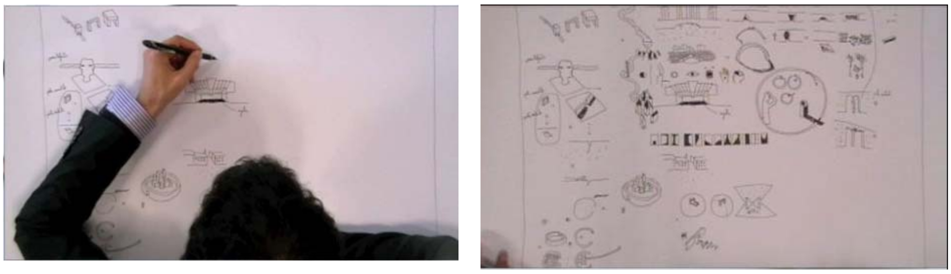

Fig. 3 **– First meeting drawing**

The purpose of the experiment is to try to understand what are the geometries and the reference memories of a project work. The theme that has been put forward to the architect is the design of an urban door. The sequence of sessions observed was reported on video clips and can be listed as follows:

1. First extemporary drawings
2. Development of what had been drawn in the previous meeting, toward the definition of the leading project idea
3. The leading project idea comes to maturity and reaches a detailed definition with own themes, materials, languages, shapes
4. The designer looks at the city and the environment surrounding the door
5. The designer shows possible types of urban doors among with to choose
6. Conclusion and definition of the door

Between those drawing meetings, interval interviews are carried out, where the designer deals with his signs, explains the reasons behind his choices, describes the mental path underlying the unraveling of materials and drawing objects.

The process design of the architect has been analysed through five main categories, i.e., size, form, geometry, the value of memory, logical groups. This allowed us to observe that the approach to the project, to the paper space, to the time taken to draw the various elements has gradually changed, evolving towards greater sizes of elements, as well as towards different times engaged in same areas of the sheet.

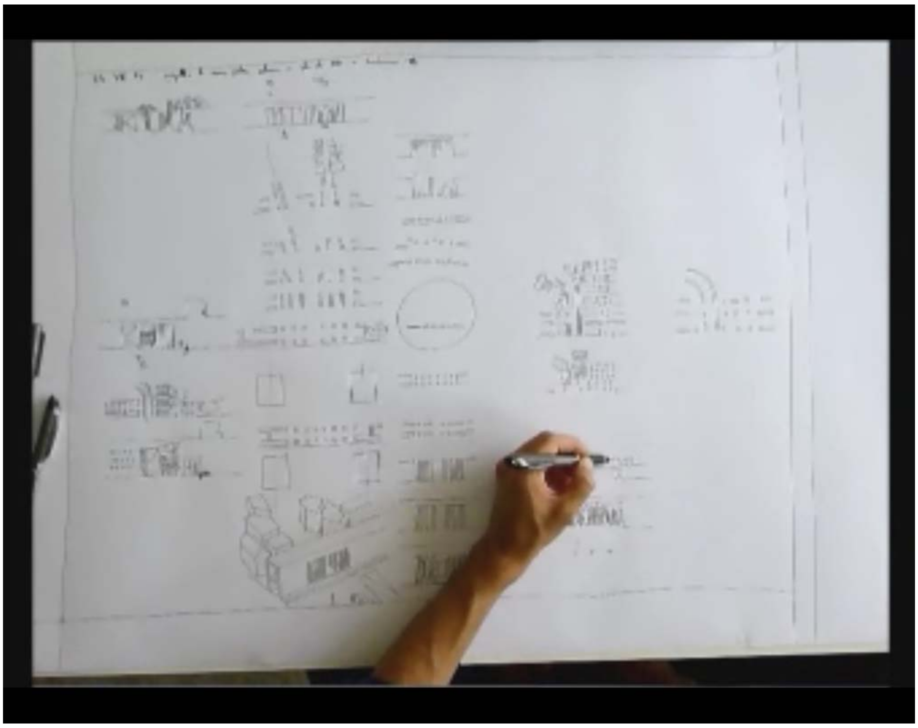

Fig. 4 **– The final door drawing**

In the end, an abacus of forms and related reference memories has been set up, so as to locate each form in its conceptual development path. By dividing the work into logical groups, functional classes have been encoded toward the construction of an ontology of the design elements in designing an urban, as activated for the urban background memory of the architect.

The objective is building a tool that can help the architect have his bunch of memories constantly accumulated and constantly renewed and extended, so as to make them always available. Through an ontology-based tool, an interactive abacus would be always open for possible amplification of the inductive abilities of the architect in his creative work.

1. Discussion and conclusion.

In the work by M.J. Schoppers, the concept of reactive plan is given a first dignity of operational activity in human agents [30]. Further, in the work by Herbert Simon, a form of reactive planning with no goals is conceived, embedding the possibility of a series of actions aimed at responding coherently to external stimuli. He highlights the case of chess games as a paradigmatic example of such cognitive and operational process [41, p.147]. As a matter of facts, chess game is also cited as being an instructive case of competitive game among agents in game-theory terms [5, p.31].

When looking at the drawings built by architects in our experimentations, their action resembles a proper competitive-game session, with the same chess-game setting à la Simon. Yet drawings are traditionally considered, similarly to many architectural works, as an actual product, i.e., resulting from a process toward a physically recognizable end. In this sense, the extent to which a drawing built by competing architects represents a no-goal plan may well appear questionable, so needing further investigation.

Contrary to Simon’s positions, and more typically, plans appear as goal-oriented processes. Either in the classical cybernetic position or in more complex socially contextualized situations, a sequence of actions toward a recognizable end is largely evident in planning undertakings [42]. Generally we expect architectural drawings to match such layout in most cases. Particularly self-evident appears to be the case of a single designer supporting her professional architectural activity. Yet such commonsense situations may hide activities consciously or unconsciously not oriented toward a predetermined, consistent final artwork. In that case, the extent to which an architect’s drawing represents a goal-oriented plan appears questionable, so deserving further exploration.

The experimentations accounted for in this paper have been set up with such intriguing organizational framework in mind. Even if the main research questions addressed are substantially different, the model of the game layout is considered and dealt with in parallel with critical interest.

Today most of cognitive science scholars converge on conceiving creativity an ordinary specific cognition function. It is patrimony of all living agents, casually or intentionally activated in certain situations, challenging the old conception of creativity as exceptional endowment of talented cognitive agents [3][4][43]. But the idea remains of a largely unexplored set of cognitive mechanisms and abilities, hardly repeatable by computer programs. That occurs because of the evident human (biotic) features of divergence from routine reasoning and calculus, use of intuition and other intriguing biotic generic cognitive behaviours (introducing analogies, abstractions, relations, boundaries, equalities, consistencies, and beauties into the expert and domain-dependent reasoning) [2].

In this framework, we have assumed that the creativity studied in the domain of space organizing can be modelled by addressing both routine and non-routine (creative) cognitive functions. The experimentation carried out above has provided interesting results in that context.

In space organizing, creativity makes memories raise from cognitive databases and stimulate new elaborations and associations, toward the final artwork. Also, activities are often boosted in case of cooperative multi-agent tasks, even if creativity is not always separable and recognizable as a single-agent feature. Nevertheless, there is not an automatic correlation between the number of agents involved and the support to memory elicitation.

However, showing how memories are a critical reference for project activities is functional in a creative perspective to produce a tool that is constant an "expansion" of personal memory. This could be further extendable with time, and elements of the architect’s its history and education would be always visible and available, instead of being given up by limited availability of memory allocations.

Creativity has emerged as a rather ordinary activity of cooperative and non-cooperative agents, whose main ability is to operate intentional associations on knowledge bases. In this sense, it seems to confirm some basic assumptions of our work. Because of such findings, the quest for models of architectural composition can be a reasonable target to be aimed at, in order to support and enhance planning and architectural creative efforts.

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Spatial Cognition Research as Evidence–Base for Architectural Design(ing)

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Abstract. Systematic application of research to architectural design is necessary, but often quite difficult. Besides the obvious educational and outlook differences between designers and researchers, the format of research publications hinders designer's comprehension and use. Also, the all-inclusive nature of architectural design limits detailed study of each and individual research project. This paper begins with a presentation of an experiment that was conducted to investigate how architects interacted with and used research derived evidence in design tasks. Using five lessons that were learned from this endeavor, it moves on to comment on how Spatial Cognition literature could be made more accessible to the architectural profession. To this end an emphasis is made between the two extremes of 'more-detailed-less-generalizable' and 'less-detailed-more-generalizable' information. Architecturally relevant information is visually dominant and resides at a certain point between these two extremes. Also, for a receptive designer audience, strategic alliances should be made with 'research-focused designers'.

Keywords. evidence-based design, architectural education, research, environmental elements and properties, health-care facilities

Introduction

Scientific research and architectural design do not overlap neatly. While architectural designing is mostly synthesis, research is analysis. While designing is an intuitive process, research deals with empirical data. Essentially architectural design is inclusive, while research is exclusive. Research is underpinned by a scientific method, while most architects favor art. Hypothesis and research methods are very specific, architectural concepts are vaguely defined. Small differences matter in research; they are less meaningful in design. Researchers try to control for extraneous variables, architects have to embrace them all, and design for many conditions. Research is a neat bundle but architects deal with 'messy vitality' (Venturi 1966). Finally while research ends with specific conclusions, architectural design brings forth one version of many possibilities. In this way, architectural design is more like a 'beautiful' hypothesis in three dimensions, obviously a very elaborate and most often an expensive one[1].

Various attempts have been made to bridge the gap between research and design. The role of such organizations as Environmental Design Research Association (EDRA, established 1968), International Association for People-Environment Studies (IAPS established 1981), People and Physical Environment Research (PAPER established 1980), Man-Environment Research Association (MERA founded in 1982), immediately come to mind. These are groups of 'research-focused designers' i.e. designers who care about research and look for ways of integrating research in their designs. We might contrast this with 'design-focused researchers' who focus on ways of improving and assisting design endeavors. Cognitive scientists, computer researchers, and perhaps the now dormant 'design methods' group fall in this category. In general, there is a clear line between these two groups who have very specific research agendas. The former are mostly 'designers' interested in research and its use, while the latter are mostly 'researchers' interested in assisting designers.

The most recent and sustained endeavor in the US to encourage the integration of research in designing, is the Center for Health Design (CHD, www.healthdesign.org) and their push towards what they call 'Evidence-based Design (EBD)'. This is the process of contentious, explicit, and judicious use of current best evidence from research and practice in making critical decisions, together with an informed client, about the design of each individual and unique project. It is an ambitious idea, and perhaps learning from the experiences of 'research focused designer' organizations mentioned before, CHD has already started making strategic alliances with practicing architects/firms, owner organizations of health-care buildings, and health-care equipment manufacturers. The activities of CHD are gradually gaining momentum, and is no doubt being aided by the new challenges posed (especially in the US) by health-care legislation, changes in remuneration procedures, federal laws, and of course, evidence-based medicine. The combined effect of all of them is gradually pushing the health-care facilities design industry to be more responsible in relating architectural designs to institutional goals and objectives, and in this process, 'evidence' or research is becoming more and more prominent. However, although health-care has taken the lead at this moment, there is no reason why this process cannot be easily applied to other kinds of architectural projects. Indeed (Hamilton and Watkins 2009) makes a point that it does.

The difficulty of adopting EBD lies perhaps not in the process itself, nor in the building types, but rather, in changing the perspectives that many architects develop, and undoubtedly the formative stages are in their education. Professional architectural education in the US is accredited by the National Architectural Accreditation Board (NAAB), and to date more than 100 schools are accredited. As part of this process,

[1] Many architects consider the final design proposal as the end of the process. Others undertake post occupancy evaluations to learn from them. However, evidence-based designers, (described later in this paper) consider design as a hypothesis to be tested later using appropriate research methods.

schools are required to address as many as 32 criteria that are considered relevant for successful practice. Each criterion again has to be met at either 'understanding' or 'ability' level as specified by NAAB[2]. Among the criteria listed, only three, i.e. less than 1% seems to be of direct relevance to our concern here. They are 'applied research' (understanding), investigative skills (ability), and human behavior (understanding). Granted that NAAB criteria are effectively the 'least common denominator' in the standards of professional education, and universities have a higher goal of providing education of value, one can easily argue that training for architectural practice is focused more toward the 'intuitive' side of architecture, and less towards research, or even research-based design.

One group of professional architects who value scientific research and try to use it are those who practice EBD. Regarding this group, Kirk Hamilton (2004) have suggested that they operate at four levels of practice. Level one designers stay current with literature in the field, follow the evolving (environmental) research related to the physical settings, interpret the meaning of evidence as it relates to specific projects, make judgments about the best design for specific circumstances, use design concepts based on bench mark reviews of other projects, and produce work that advances the state of the art by developing tangible examples of improved design (see figure # 1). Level two practitioners do all of the above and also hypothesize and measure design effects; level three practitioners report the results in an unbiased manner, and level four practitioners publish their findings in 'peer-reviewed' scientific journals. While an implied intention of EBD (and CHD) is encouraging more and more level four practitioners, in reality level one is the biggest group. In a recent survey of 40 top health-care design firms in the US, a full 92% of the respondents reported that they engage in some form of evidence-based design (Cama 2009). However, as many as 75% of them also reported that they only interpret scientific evidence found in peer reviewed journals and use it in making design decisions. This means that a avst majority of EBD practitioners are at level 1, and to assist this large group, one has to reflect on the translation of evidence or research to appropriate design moves. The first factor in this endeavor is the identification of 'architecturally relevant' evidence/research. This suggests on one hand, to the process of finding appropriate research and its comprehension, evaluation, and translation; and on the other, to the presentation of research for architectural consumption.

1. Study to examine the 'sharp-end' of evidence-based hospital design

To understand this situation in a bit more formal manner, a study was undertaken to examine the process of evidence-based design, especially from the point of view of the 'change-agent', the architects, who are at the 'sharp-end' of implementing the evidence-based design process (Haq and Pati 2010). In this study, a graduate level architecture design class, called a studio, was used as a surrogate environment to examine how designers interacted with, and used research based evidence. Twelve

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[2] Ability is proficiency in using specific information to accomplish a task, correctly selecting the appropriate information, and accurately applying it to the solution of a specific problem, while also distinguishing the effects of its implementation. Understanding is the capacity to classify, compare, summarize, explain and/or interpret information. (http://www.naab.org/accreditation/2010_Procedures.aspx, accessed 31st Oct 2011)

enrolled students were all working towards their professional architectural degree and were within a year of graduation. Since the difference of these students with young architects in professional design firms were only a year or so, the students were considered representatives of the young professional group. The studio class included a nursing professor and a health-care researcher, in addition to the main studio professor.

1.1. Method

The overall studio-class was divided into three phases: knowing a hospital, knowing the evidence, and integrating them into architectural design proposals. In the first phase, students were guided through ethnographic studies of all departments of general acute care hospitals, taken to visit two large general hospitals, and were provided lectures about the functions and design of hospital buildings, including workflow processes, space needs, equipment specifications, and viewpoints of various stake-holders. The students also independently investigated concepts, spaces, and technology; and were asked to study four program areas of a hospital and their relationship to the larger hospital in greater detail.

The second phase was more related to our concern here. At this time the students were introduced to three main categories of literature – scientific research publications, industry and trade magazines, and recently published books that focused on bridging evidence and design (for example Malkin 2008). Many web-based resources of reputable institutes and organizations were also included in this list. Finally, the students worked in groups to develop detailed design proposals to fit the program for a 200-bed acute care hospital in three different pre-selected sites. At the end of the semester they were administered a questionnaire to capture their perceptions and assessments regarding their collation, assessment, appreciation, and specially application of evidence (research) in their design processes. A detailed analysis of the process, the designs produced, and survey data indicated four issues related to designer-evidence interaction, and these are relevant for our interest here.

1.1.1. Inter-relationship of evidence to one another, and to physical settings

The first challenge was to comprehend how evidence was relevant to design and how they could be meaningfully organized. The class quickly realized that there was only a handful of global issues (patient-safety, patient well-being, care-giver well-being, system efficiency, and so on). The challenge of articulating subsequent layers were two-fold. First, higher order issues do not have a 1:1 'nested' relationship to sub-issues. For instance, exterior views could be associated with relieving patient stress, reduce acute staff stress, increase staff alertness, etc. and they all address different outcomes. Crowding could be related to patient stress as well as medication errors, and perhaps other higher order issues of interest. Second, physical settings and related issues bear a many-to-many relationship. In other words, a type of setting (such as an inpatient unit) could be associated with more than one issue. For instance, stress is a factor in in-patient setting, as well as in imaging, emergency, critical care and so on. Articulating issues and sub-issues and relating them to physical settings in a comprehensive and meaningful format quickly became formidable to the participants. They abandoned the task and resorted to creating single page reports of key evidence and their translations into design. In total, the class created 232 reports which were obviously non-hierarchical (or non-nested). These later became data for analysis.

The difficulty of collecting and organizing the available evidence for reference in a meaningful way is also reflected in the survey responses of the students. They rated the evidence collection task at 53%, i.e. halfway between ‘very easy’ and ‘very hard’, despite the fact that the students were assisted in finding relevant articles, and were even supplied with literature from which to extract the evidence from.

1.1.2. Phase-complemented evidence

The facility procurement process has a number of phases through which a project is envisioned, programmed, preliminary ideas are sketched out, design is developed, construction documents are produced, building is constructed and so on. Obviously, different groups of experts play different roles in these stages. In general four facility procurement phases are related to design: conceptual design, schematic design, design development, and construction documentation. In each of these, certain evidence may have greater or lesser relevance. Thus one that is highly relevant in the visioning or the programming phase may not be so important in a subsequent design phase. For example, the decision to incorporate single rooms with views in a hospital is usually decided early on, with optimization being of concern during subsequent design phases. On the other hand, the role of color and its effects is considered at a very late stage of design, and perhaps by an entirely different group of designers.

Filtering evidence relevant to a specific facility procurement stage can be difficult. In the survey response the students noted that only 20% of the evidence examined was informative at the schematic phase. This is of significance, especially when we realize that the schematic phase is the most crucial part where major concepts and architectural ideas are formulated and do not change substantially in later phases. Judging by the results of this small study, research investment contributes to only about 20% of design decision making; a number that should be of concern to researchers.

1.1.3. Evidence vis a vis context and precedence

Precedent analysis is ubiquitous in architectural design. Even the NAAB student performance criteria list ‘use of precedents’ at an ‘ability’ level, in addition to ‘investigative skills’. To take advantage of this designer skill not only should research be presented as related to specific environmental elements, it should also be coupled with information about how it might fit into different contexts, and instances of its use in previous examples, i.e. precedents, if available. In short, how was the particular issue dealt with by previous architects? What were the physical conditions? What was the impact of design interventions? And so on. Since precedent analysis of evidence is not available in scientific research publications, our students appeared to have gravitated towards trade journals for this purpose. Although they have reported that they found more evidence (54%) in peer reviewed journals as compared to trade publications (46%, see figure 2), an examination of 232 single page reports that documented how evidence was translated into design showed that 60% of the evidence was extracted from industry sources, while only 23% was taken from scientific journals, and the remaining

17% from experience, anecdotes and interviews (see figure 3). This indicates a key challenge that designers face. While they perceive to find more evidence from scientific publications, they have difficulty in transcribing them to design moves, and so fall back on publications that may not be 'scientific' enough, but nevertheless has images and context, and in this way provide precedence.

1.1.4. Vocabulary

The students' greater comfort with industry and trade publications may be understood by the stark differences in vocabulary between designers and researchers. Knowledge representation through drawings and diagrams as they appear in professional journals, books and trade sources was more conductive to design learning as was seen in our experiment. It seemed that the students approached different sources selectively: scientific publications for evidence, and non-scientific sources for precedence. Recent books that attempt to provide more visual information was very helpful. For example, Malkin's book (2008) has a chapter on patient units that is presented in both words and diagrams. This serves as a possible direction for information representation. Designers think, analyze and synthesize evidence visually (Sanoff 1991). This is an important consideration and seems to be a prerequisite for greater and more appropriate use of scientific research in design.

1.2. Lessons learned from the studio experience

From the small study described above we see that a focus on environmental factors (elements) is an important concern for architects. Additionally, we note that:

1. Visual and/or diagrammatic representation of research results is significantly better than textual representation. This suggests two things: identification of environmental elements and description of the properties of those elements. Environmental elements have to be specified in a manner in which they can be sketched, diagrammed, or photographed (i.e. visualized). Additionally, their properties have to be matched to both their physical features and design outcomes.
2. Textual descriptions in a flat hierarchical format as found in most scientific publications may not be intuitive to designers, and may even hinder extraction of relevant information in a timely and cost efficient manner.
3. The relationship between higher and lower order issues needs to be clarified and explained. In other words, the relationship of outcomes not only to physical factors, but also to one another has to be clarified.
4. The relationship between research findings and its applicability to specific physical situations should be stated in the form of a 'precedent', a research method that is well known to architects.
5. Facility procurement-phase complemented evidence filtering system should be an essential component of research presentation. This will make the search and retrieval processes provide the 'right information at the right time', and will allow a better adoption of research results.

We will now turn our attention to Spatial Cognition and consider its research findings with special emphasis on the five points mentioned above. At the outset, we declare that it is not our intention to provide a comprehensive review, but to highlight what we consider to be important characteristics of research information that is valuable to architects.

2. Spatial Cognition research for architectural design(ing)

We begin with the distinction between the profession and the discipline of architecture. Although this division is subtle, the previous study may have identified a gap between them. Additionally, the discipline of architecture is enriched by contributions from other disciplines and because of this too, the question of translation for the profession (designers) become paramount. The discipline is broad based and its research includes many spheres, or, it learns from research in many disciplines. Schwarz (2011) has identified seven such spheres, namely: environmental research, cultural research, social research, technological research, design research, organizational research, and educational research. Although cognition research is not listed here, he does bring it forward as a valid response to criticisms of environment-behavior studies, which were broadly based on social research. Cognition studies have addressed the criticism that a study of human external behavior, without understanding the cognitive processes involved, is simply treating the built environment as an incidental stimulus array, rather than a meaningful environment for the immersed person. Whether or not cognition is a separate research domain within architecture is irrelevant for this paper, but we do want to acknowledge, at the outset, that it has been beneficial to both ‘research-focused designers’ and ‘design-focused researchers’.

One might speculate that the requirement for a bridge between today’s cognition researchers and architects is a relatively late phenomenon, but in its inception spatial cognition was integral to architecture. This was of course rooted in the pioneering work of Kevin Lynch. This Frank Lloyd Wright trained architecturally savvy MIT professor of planning perhaps did not consider himself a cognitive researcher, yet his book, ‘The Image of the City’, (1960) remains a classic in both disciplines of spatial cognition and architecture. The notion that certain physical elements of a city make up an individual’s ‘generalized mental picture’ of the exterior physical world, that it is a product of both immediate sensation and memory, and that it guides behavior (especially wayfinding), comes from Lynch; and these are also the founding concepts of the later field called ‘Spatial Cognition’ (Gifford 2002).

2.1. Two models in Spatial Cognition

Spatial cognition has had other influences too, and over the years has been enriched by interdisciplinary contributions. Therefore, it is not unexpected to find two dominant models in it. One is a human model that investigates internal processes such as action plans, strategies, cognitive information (cognitive maps) and so on, including their formation and development across the life span, interpersonal variances, cultural effects and such (see table # 1). The other model, more relevant to architecture, is the environmental model. This seeks to identify physical elements and properties that have cognitive significance. It seems that the environmental model of Spatial Cognition is specifically based on Kevin Lynch (1960), who proposed that a generalized mental picture (or a 'cognitive map') depends on an environmental property called 'legibility', i.e. the ease with which parts are recognized and organized into a coherent pattern. Lynch also identified five physical elements that are significant in this process; i.e., nodes, paths, landmarks, edges and districts. An important aspect to note is that Lynch's descriptions of these elements (and his sketches) are not very detailed. He seemed to understand that as descriptions get more detailed; they become less generalizable, and therefore less useful to designers, for whom innovation is crucial. Researchers of course favor more detailed (and therefore less generalizable) information, and hundreds of subsequent studies have sought to find exact descriptions of the proposed five elements (see Appleyard, (1969) among others). It may not be unfair to state that the subsequent studies have not featured quite as favorably in architectural curricula or literature.

2.2. Unit elements of the environment

Perhaps the most relevant aspect of Lynch's contribution in regards to architectural design is the distinction that emerged between environmental elements and properties (table #1). Not only that, his book is infused with sketches and diagrams which assist visualization of those elements. In other words, Lynch spoke the architect's language. It is therefore of no surprise to see the influence of Kevin Lynch in architecture and urban design, where even today, more than fifty years later, published books in the subject do not, and most likely cannot, omit references to his contributions. See for example Carmona, Tiesdell et al. (2003), LeGates and Stout (2007) etc.

The distinction between environmental elements and environmental properties is an important one, and is perhaps at the crux of the relationship between spatial cognition and architectural design. Is this distinction explicitly made by scholars in Spatial Cognition? Perhaps not. Encyclopedia definition states, "Spatial Cognition concerns the study of knowledge and beliefs about *spatial properties of objects and events* in the world" (Montello 2001, authors italics). It then goes on to provide examples of these properties and relate it to the second model of spatial cognition, human aspects. Identification of environmental aspects whose properties are being studied do not seem to be well addressed.

This I believe is an important concern because a quick literature survey to isolate the environmental elements used or identified by Spatial Cognition researchers yielded a very limited set (see table # 2). Most importantly, the five elements discussed by Kevin Lynch seem to be the 'paradigm' on which subsequent researchers have sought to identify environmental elements. Noteworthy is that the notion of 'edges' became less relevant, and the notion of 'districts' and 'nodes' were integrated into concepts of 'domains' or 'places'. In other words, cultural values were being associated with physical descriptions. Later, in a discussion of micro-genesis, Montello (1998) summed up these efforts into a triad of environmental elements: landmarks, routes and layouts; and this he suggested had been the 'dominant framework' for quite some time. To this list, Weisman (1981), a professor of Architecture who studied wayfinding, added ‘signage’.

2.3. Properties of physical elements

Environmental elements gain cognitive presence because of certain ‘memorable’ characteristics. As mentioned before, a majority of cognition research has sought to identify and verify these properties for cognitive presence, and in this way has established the elements themselves. Properties are understood either as residing within an element itself, or in its relationship with others. For example ‘vivid color’ may be a property of a wall, which makes it memorable and act as a landmark. A higher order property is the relationships between elements. They have been variously described as ‘choices’ (Norberg-Schulz 1971), ‘visibility’ (Braaksma and Cook 1980), ‘visual access’ (Weisman 1981), ‘connectivity’ (Hillier and Hanson 1984), ‘integration’ (Hillier and Hanson 1984) etc. Properties of physical elements understood by looking at relationships to others bring forth the notion of configuration (Siegel and White 1975; Weisman 1981; Hillier and Hanson 1984).

The next development along these lines is predictable; aspects of relationships i.e. what is being related and the nature of these relationships are investigated. Thus we see the use of various computerized tools to map the relationships between elements, mainly focusing on topological and metric relationships, and experiments to investigate the cognitive correlates of these environmental properties (Haq 1999; Kim and Penn 2004). How useful are these for architecture? That will be discussed next.

3. Implications of cognition research mapped to the studio experience

At this point we return to the lessons learned from the studio experiment reported earlier and use them to contextualize the relevance of spatial cognition research on architectural designing.

1. We have noticed that visual and diagrammatic representation is appreciated by architects. It is far easier to diagram environmental elements, than their properties. This is perhaps the most important reason for the predominance of Kevin Lynch’s five elements. While his five environmental elements are well explained, they were also profusely illustrated. In general, cognition researchers are less focused on environmental variables and usually do not discuss architectural relevance. As we develop more and more sophisticated visualization techniques and computerized tools, we might begin to think of transforming or extending existing research to visuals and diagrams. This does not imply that research is simplified or ‘dumbed down’. Rather, it is the findings in visual form that provides the architect a very quick summary of research and allows him/her to think about its significance to the task at hand. In this regard, Space Syntax computer program generated map output, which clearly shows the distribution of values in a plan layout is noteworthy.
2. Research publications are not the forte of architectural professionals, to whom the results are useful, but only for one aspect of the numerous overlapping

issues that they deal with at any given moment. Researchers usually worry about external validity; architects are concerned with architectural validity. It would be a good idea to make arrangements so that as results get validated with more and more research, their architectural implications are published in a separate format.

3. The relationship between higher and lower order issues need to be explicitly explained. These may appear in different publications, and perhaps addressed by different researchers at different times. Nevertheless, a compilation, comparison, and publication of these interrelationships is important. These should also include notes regarding conflicting information. In spatial cognition literature, one important development could be clarifying the relationships between environmental elements and their many properties.
4. As more and more cognitive research is applied to design, they must be recorded as precedents for later designers. Some concepts have been in use for quite some time, especially in urban design and wayfinding design. Recently, findings from Space Syntax research has been used to comment on existing building layouts (Brosamle, Mavridou et al. 2011) and buildings elements (Brösamle, Mavridou et al. 2009), at least theoretically. A good strategy would be to use architecturally significant buildings for these academic endeavors, as was recently attempted by Carlson, Holscher et al. (2010). Additionally, interpretations from Post Occupancy Evaluations might also be helpful in making the link between research findings and design applicability.
5. Facility procurement phase complemented filtering system for cognition research may not be too difficult. While at the predesign stage concepts of environmental elements may be useful; in later design stages (where optimization becomes important), their properties and effects could be studied. For example, at the pre-design phase the concept of landmarks could be introduced, and as the design progresses, more and more properties could be studied as it relates to the problem at hand.

4. Final comments

We began by stating clear differences between research and design. While researchers are considered experts in their own domain, designers have to rely on many kinds of information, while their own expertise is the ability to quickly understand research results, manage diverse and often conflicting materials, think of applicability to the specific problem at hand, and then move on to consider other evidence. Architects are also visual thinkers and visual problem solvers. Among them, those who are research-focused designers are more willing to consider research in their design processes. Finally architecture is about designing a new condition that satisfies many criteria, and doing it in an aesthetically pleasing manner. To help in this gargantuan task, the more specific research results are with respect to architectural applicability, the better it is. If presented visually, it becomes easier to comprehend and use. Finally, research derived ideas need to be neither too general, not too specific. The former presents difficulty of physical definition while the latter reduces the ability for novelty. In other words, if too general, then it will not be very applicable, if too specific, then it cannot be used to make a new design condition.

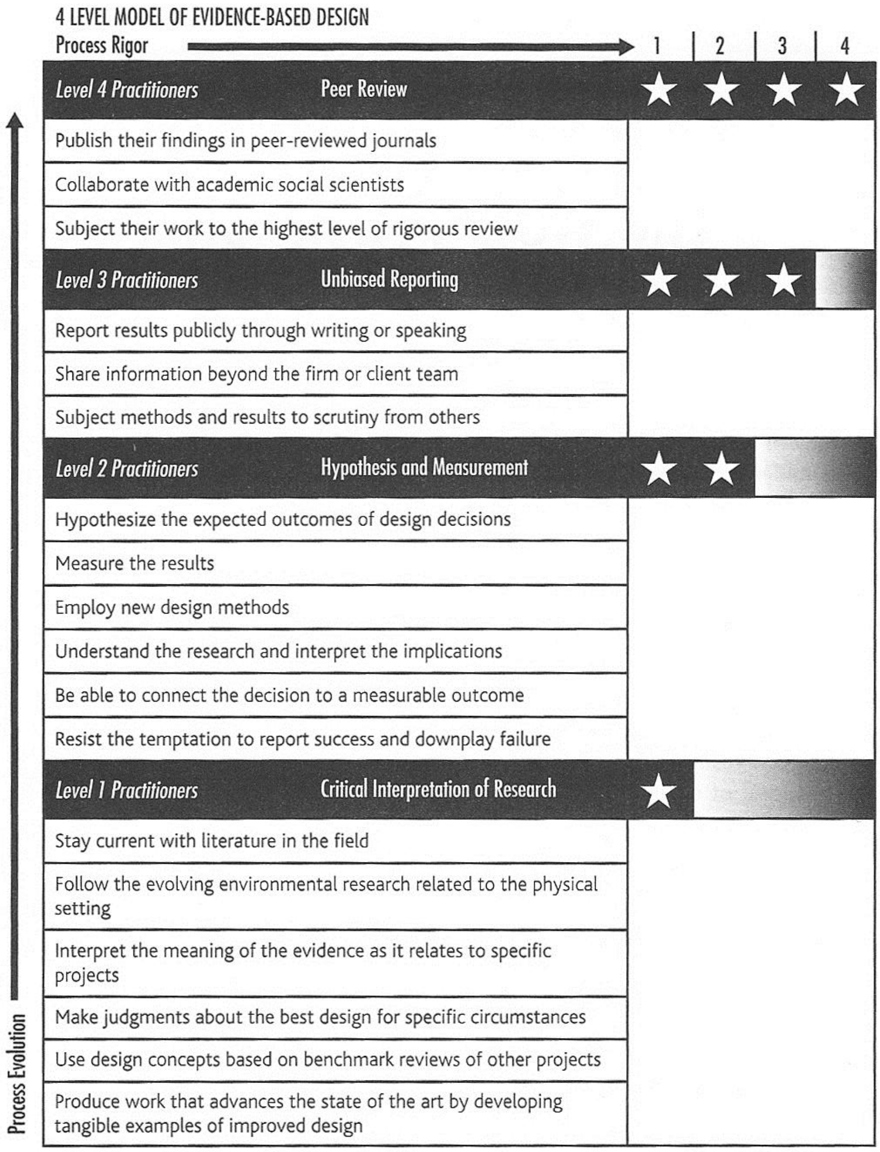

Figure 1. Four levels of Evidence-based practice

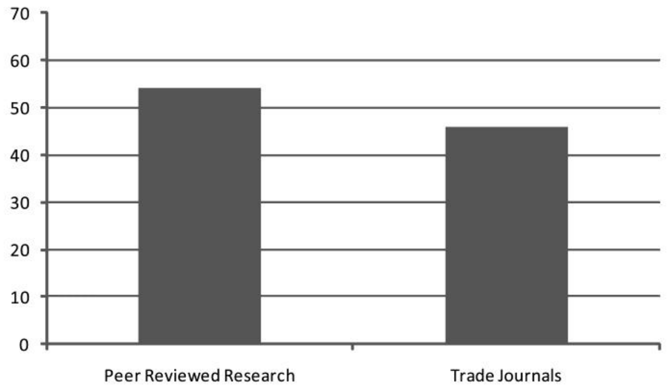

Figure 2. Sources of evidence collected by survey participants

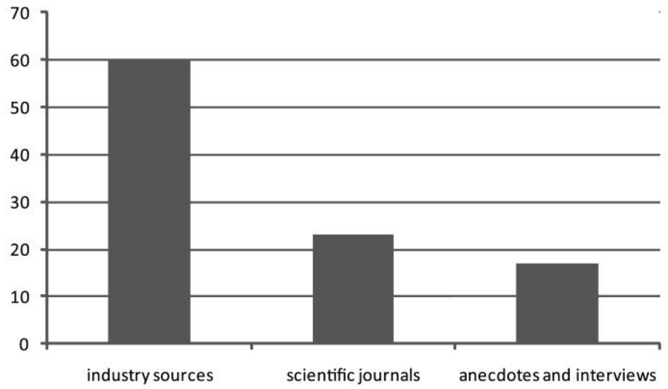

Figure 3. Sources of evidence used in architectural design

Table 1. Two models of Spatial Cognition

Environmental Model		**Human Model**
Environmental Elements	**Environmental Properties**	
Landmarks	Complexity	Cognitive map
Routes	Coherence	Strategies
Layout	Mystery	Action plan
Signage	Legibility	Social knowledge
	Gestalt	Schema
	Differentiation	Micro-genetic development
	Visual access	Development across the life span
	Visibility	
	Location	
	Size	
	Distance	
	Direction	
	Separation and Connection	
	Shape	
	Pattern	
	Continuation	
etc	etc	etc

Table: 2. Various environmental elements and properties that were found to be influential in cognition research.

Yr	Author	Environmental Elements					Environmental Properties
		Lines	Points	Areas	Elements	Edges	
60	Lynch	Paths	Nodes	Districts	landmarks	Edges	
69	Stea	Paths	Points			Boundaries and Barriers	
69	Appleyard	Paths	Nodes & Points	Districts	landmarks	Edges	
70	Best						Choices in a route
71	Norberg-Schulz	Paths	Places	Domains			
75	Siegel and White	Routes	Nodes				Configuration
76	Tobler						Configuration
78	Kuipers	Paths	Places				Relative Locations
78	Kuipers						Topological relations
78	Golledge		Anchor points				
80	Braaksma						Visibility between destinations (Visibility graph)
80	Evans						Color differentiation
81	Weisman				Signs		Visual access Architectural differentiation Plan configuration
83	Heft						Transitions between vistas
84	Garling et.al.		Places				Spatial relations between places.
86	Garling et.al.						Degree of visual differentiation Degree of visual access Complexity of layout
89	Leiser et.al						Node-link network
89	Rovine and Weisman				landmarks		
90	Peponis et.al						Syntax Integration
91	O’Neill						Inter-Connection Density
95	Evans et. al.				landmarks		Pathway Configuration
95	Gopal						Configuration (Neural Network Model)
99	Haq	Lines	Nodes				Integration-3 Connectivity
01	Haq	Lines	Nodes				Integration-3 Connectivity
01	Kim	Lines					Integration-3

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Sketch Understanding for Learning Engineering Design

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Abstract. Sketching is commonly used during design. We are exploring the hypothesis that qualitative reasoning, especially qualitative spatial reasoning, and teleology suffice for providing useful feedback to students learning to use sketching in engineering design.

Keywords. Qualitative Spatial Reasoning, Artificial Intelligence, Sketch Understanding, Engineering Design, Education

Introduction

In engineering, designs are often communicated using a combination of sketches and language, especially during conceptual design. Sketches by their nature are imprecise: Quantitative analysis and traditional simulation are inappropriate given the low precision of hand-drawn parts. Yet people routinely think through a design via reasoning about sketches, and use sketches to explain a design to others. Our hypothesis is that methods of qualitative, causal reasoning developed by the qualitative reasoning community capture this human ability. By combining qualitative models, especially qualitative models of space and shape, with teleology and visual reasoning, we are creating software, the CogSketch *Design Coach*, which can understand human explanations of designs. The program is motivated by our work with the Engineering Design and Communication course[1] (EDC) at Northwestern University. EDC is the introductory course for freshman in engineering majors. Instructors in EDC find that students have trouble learning to communicate with sketches, a key skill for engineering disciplines. Given the complexity and wide scope of engineering design sketches, creating a Design Coach which could let students practice explaining their designs and give feedback on said explanations is a challenging AI problem. We chose to focus on mechanical designs because, after reviewing a corpus of past EDC projects, it was clear that mechanisms were a significant, non-trivial part of the design space [1].

1. CogSketch

The Design Coach is built on CogSketch[2], the Qualitative Reasoning Group's sketch understanding system [2]. It is used for both cognitive science research on spatial

[1] http://www.segal.northwestern.edu/undergraduate/edc/
[2] http://www.qrg.northwestern.edu/software/cogsketch/index.html

reasoning and representations and as a platform for intelligent educational software. While the user draws, CogSketch dynamically constructs and maintains visual and spatial representations of their sketch. CogSketch contains a large-scale knowledge base[3] with over 58,000 concepts and a flexible reasoning engine that combines visual, spatial, analogical, and logical reasoning in a unified way. Unlike most sketch understanding systems, which focus on recognition, CogSketch provides simple ways for users to segment their digital ink into *glyphs* and identify them in terms of concepts from the knowledge base. This enables CogSketch to operate over a much broader range of domains, without recognition errors. CogSketch uses models of visual and spatial processing to identify relationships between glyphs (e.g. “above”, “inside”) and to break up glyphs into pieces (e.g. identify the surfaces of an object). By labeling what they draw with concepts that have mechanical implications (e.g. rigid object, spring), knowledge about the physical world in the form of qualitative mechanics [3, 4] can be used to reason about forces and possible motions. This enables the Design Coach to reason about designs in a human-like way.

In addition to drawing parts, CogSketch also provides graphical ways of depicting relationships (as used in concept maps) and common annotations (e.g. sizes, force arrows). An additional language-like interface is used to enable students to describe aspects of their design that are not easily captured in sketches, e.g. the fact that the force exerted by a spring is greater than that of friction. CogSketch supports *comic graphs*, a generalization of comic strips that enables depiction of multiple states of behavior, including transitions between them, e.g. oscillations.

Given a student explanation, the Design Coach uses its qualitative understanding of the student’s design, grounded in its visual and causal analysis of the student’s sketches and language-like descriptions, to look for gaps and contradictions in their explanations. When found, the relevant parts of the design are highlighted as feedback.

To date our experiments have been mostly formative, improving the interface and the system’s reasoning to cover a broad range of relevant designs. This year we are starting in-class experiments, and we will continue to evolve the system with the goal of helping students learn to communicate via sketching. One important open problem is quantifying progress: Most measures to date are informal. We are working closely with EDC instructors on this as well, looking for reliable ways to measure improvement.

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Wayfinding in the Seattle Central Public Libary

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Abstract. Why do people get lost in buildings? Research has suggested that there are at least three factors that contribute to navigation difficulties: the spatial structure of the building, the cognitive maps that users construct as they navigate, and the strategies and spatial abilities of the building users. In this presentation we presented an integrated framework that represents these factors and their interfaces (Carlson, et al., 2010). We discussed each component and the processes that operate at the interfaces of these components, focusing on correspondence, compatibility and coherence. We then discuss a case study of wayfinding in the Seattle Central Public Libray. We discuss features of the Seattle Central Library that make wayfinding challenging, and describe an experimental study that was held in the library in November, 2011. In this study, participants were asked to navigate to 4 target locations, performing tasks that would normally occur in a library (such as finding a particular book). Confederates followed each participant and tracked their route using a customized application that ran on an iPad. After the wayfinding task, participants completed a battery of spatial tests. The analyses focused on categorizing performance in each of the 4 wayfinding tasks as a function of building features, information within the cognitive maps of navigators, and individual differences in spatial abilities and strategies. The key conclusion is that the participants could not be uniformly categorized as good or bad navigators; rather wayfinding performance depended critically on the interplay between the building, the cognitive map and strategy and spatial ability.

Keywords. Wayfinding in buildings; Seattle Central Public Library; spatial ability; individual differences; cognitive maps; spatial cognition

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TYPOLOGICAL AND PARAMETRIC DESCRIPTION

Spatial Cognition for Architectural Design Symposium: Pre-symposium **draft**

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When we describe buildings our interest alternates between their broad similarities or differences and their distinctive characteristics. At one end of the spectrum we have *classes* or *types*; at the other end we have *individuals*. Type is understood less in terms of literal resemblance and more in terms of underlying organizing principle. Individuals are described *parametrically*, according to the extent in which particular characteristics or properties of interest are present. The interaction between our understanding of type and our appreciation of the distinctive characteristics of individuals is fundamental to the design imagination. I have argued elsewhere that the relationship between an individual and a type moves in two directions (Peponis 2005): Usual design activity and creativity can be understood as the adaptation and development of an appropriate underlying type to the specific circumstances of a commission (site, program, budget, and client), an application of principles to a case. Fundamental creativity resides in the positing of a particular design as an instance of a new class yet to be explored; the individual building is taken, usually retrospectively, to exemplify a new way of approaching design rather than merely as a solution to a particular design problem. Be this as it may, I suggest that two questions of interest to the symposium of Spatial Cognition for Architectural Design can be stated as follows: how and when does parametric description promote a deeper understanding of the interplay between type and individual in architectural design and in architectural knowledge?

Much of my work has been associated with "space syntax". The term "space syntax" was coined in 1976 (Hillier, Leaman, Stansall and Bedford, 1976). It originally denoted the rules of arrangement that can account for the generation of complex patterns of built space and in terms of which we can identify and make sense of the significant similarities and differences in the way in which space is organized socially. As witnessed by seven international symposia on space syntax so far, the first held in 1997, the references of the expression "space syntax" have evolved. "Space syntax" has come to be associated with a family of computational methods for the analysis of the layouts of buildings and cities. These contribute parametric descriptions of spatial variables to studies of the social, cultural, organizational and cognitive functions of built space. They provide a foundation for understanding how space is occupied and how human behaviors acquire emerging spatial patterns. The underlying idea is that the spatial relationships at the core of syntactic descriptions are entailed with fundamental generic functions of buildings.

The architectural competition that has been organized in association with this symposium directed attention to two such generic functions: first, the creation of an environment that is intelligible to transient users (visiting academics at a major University) with no prior familiarity with the setting and no established routines of space use; and second, the support of serendipitous interactions and intellectual exchanges in the service of cross-disciplinary research and scholarship. The space syntax community has, at various times, made contributions to our understanding of intelligibility and serendipity as generic functions of spatial organization.

Taking intelligibility first, and citing only examples of research findings with which I am more intimately acquainted: People who explore a building or seek specific but not familiar destinations in it, are drawn to the circulation lines which are fewer direction turns away, on average, from all possible destinations (Peponis, Zimring, Choi, 1990), or have more destinations within a 2 turns range (Haq, 2003). Similarly, in museums, circulation lines which are fewer turns away from all exhibition spaces draw more visitors to them, even though visitors are more likely to return to circulation lines which intersect a greater number of other circulation lines (Choi, 1999).

Looking at serendipitous interaction next, there is case-study evidence that in work environments designed to support knowledge work, interaction networks and layouts are correlated: individuals who have interactions with a greater number of other individuals, who act as channels of communication between other people, or who need shorter communication chains to access anyone they choose, are likely to be located in spaces from which all other spaces are accessible with fewer direction turns (Peponis et al, 2007). There is also evidence that faculty whose offices are located on corridors that have more direct connections to the rest of the building are more likely to co-author papers with other faculty, and that pairs of faculty that can get to each other's office with fewer direction turns are more likely to be co-authors (Wineman, Kabo and Davis, 2009).

The work cited leads to the hypothesis that one particular parameter, syntactic integration, underlies both cognitive and social functions of buildings. Integration is a normalized and relativized measure of the connection of each line of movement within a building to all others (or to all others within a specified range) measured in terms of direction changes (Hillier and Hanson, 1984). Thus, integration and the underlying representations of spatial layouts which support its computation are of obvious interest to disciplines of spatial cognition, social networks, or organizational studies. Space syntax, as a program of research, helps describe and control the spatial variables involved with the cognitive and organizational functions of buildings. This is what it brings to the interdisciplinary table.

I want, however, to ask a question that should ideally be redundant: how relevant are findings such as the above to the discipline of architecture, and in what ways? The thirty-two submissions to the aforementioned competition demonstrate that designers went for syntactically integrated layouts in typologically distinct ways. A quarter of the schemes place the program around a main hall or atrium; more than a quarter place the program in a fundamentally linear building with a clear interior or exterior spine; a fifth of the schemes arrange the program around one or more courtyards; one scheme arranges the program in wings converging towards a main node; two schemes arrange the program around a circulation grid; and five schemes combine these principles, with a clear tendency to have wings converging to a central node. I would suggest that the typology is not only distinct but also predictable. These are some of the main ways in which buildings can maintain their legibility in principle, while growing large. Slab, courtyard, cross, spine, open plan and great hall are familiar types. With adaptations, they have been so recognized since the early morphological studies of circulation in buildings (Tabor, 1975; Willoughby, 1975).

What would space syntax, in the sense of parametric descriptions of generic spatial relationships, contribute to our understanding of the typological or generative choices that guide design? Given known types it is of course possible to compare them parametrically, to figure out, for example, how straightness of connection is balanced against length of journey. Parametric analysis, however, does not lead, by itself, to an identification of types or generative principles.

Much, but not all, of the application of space syntax in design is aimed at refining designs *after* the generative ideas have been formulated, or after typological choices have been made - space syntax has been useful in formulating design intent in cases where the site and the spatial structure of the context are important programmatic considerations. Accordingly, one could work to elaborate each of the submissions to the competition. With sufficient dedication to the task, one would even progress beyond the suggestion of small adjustments. In some cases, it is possible to identify fundamental design decisions that might have to be revised in order to arrive at a design that would even better support intelligibility and serendipity. Design, however, is a two level cognitive process, of commitment to typology or generative principles and of elaboration within the discipline of a type or of particular generators. Parametric analysis is better suited to the second level than to the first. This limitation does not merely reflect the fact that parametric analysis lends itself to adjustment more easily that it lends itself to the identification of strategic design alternatives. More deeply, unless the generator of a design is stated in language, diagrams, models, or some other notation, one does not know towards what ends parametric analysis should be directed. Making generators and typological choices explicit directs parametric analysis to clear ends much as parametric analysis elaborates and grounds abstract generative and typological principles into a fully materialized concrete design.

The creative tension between interest in generative principles and interest in parametric description of generic relationships is fundamental (Hillier and Hanson, 1984). The promise of a theory of elementary generators is to provide support for our sense of typological variety and to guide our classification of forms by type. Its cost is that it can imprison us within a rigid framework and blind us to new possibilities. The promise of a theory of generic relationships is that it can account for the way in which space functions socially even where we otherwise attest to fundamental typological variation. Its deficit is the risk of less discriminating power with regard to design intentionality.

With the hindsight of more than twenty-five years of collective research efforts, I would suggest that we have allowed the balance between typological and parametric descriptions, between the generative and the generic, to get out of focus. One consequence is that while the community of researchers associated with "space syntax" is mostly hosted in Schools of Architecture, the documented impact of "space syntax" on architectural design and pedagogy has not been in proportion to the effort, the great success of Space Syntax Ltd notwithstanding. Another consequence, more relevant to our symposium, is that, with some notable exceptions (Bafna, 2001, 2003, 2005), we have not bridged between the syntactic analysis of the designed object, and the cognitive activity that produces it.

I have some remarks to make as to how we might revisit the question of generators, within the field of space syntax. The two central ideas are "boundary" and "interface". As fundamental acts of demarcation, separation and conditional reconnection through their openings, boundaries are at the foundation of the human organization of space. In space syntax boundaries have been studied primarily as devices that define, mediate or control human relationships. Boundaries, however, also have visual presence; they work as part of the visual form of architecture. While this has been recognized in some space syntax literature (Peponis et al, 1998; Peponis and Bellal, 2011; Psarra, 1997; Psarra 2001), it has not usually been at the center of attention. Of particular relevance, in my view, is the fact that the visual continuity of boundaries can transcend the patters of functional subdivision of space in ways that suggest higher orders of perceptual and cognitive integration. This is of particular relevance in cases where secondary functional differentiation is desirable within the scope of an otherwise unified spatial domain. Many schemes submitted in the competition illustrate this in disposing informal lounges, meeting rooms, and seating areas within a domain which is visually unified by virtue of the disposition of primary datum boundaries, opaque or transparent.

One of the fundamental contributions of Hillier and Hanson (1984) is to show that the disposition of boundaries is always associated with the organization of interfaces between the inhabitants of a building (for example men and women, faculty and students) or between inhabitants and visitors (for example hosts and the guests in a house, the management and the patrons in a hotel, or the curators and the public in a museum). Interfaces are sometimes reduced to a specific boundary/opening at a specific location, as for example when a traveller crosses the line between the secured and unsecured area of an airport. More often, however, interfaces are organized across locations distributed over the building as a whole. The interface between faculty and students in universities, for example, permeates the zoning of circulation; the grouping of offices and their relationship to corridors and foyers; the disposition of labs, seminar rooms and lecture halls; the distribution of lounges, common rooms and amenities; the placement of library resources. Thus, in space syntax, an interface is not merely a point of contact between different domains. It often is a reconciliation of different organizing principles (for example the part of a house devoted to receiving visitors is often organized as a matrix of interconnected spaces, while the part of a house restricted to inhabitants is often organized as a set of branching domains). It is also a relationship between behaviors (for example movement and viewing in a museum; working alone at a desk and collaborating with others in an office). The idea can be extended to include a variety of other kinds of relationships: These can include the relationship between physical scales or organization (specific seating clusters, reading alcoves or other areas within an otherwise unified library; specific balconies or terraces within an otherwise unified theater foyer); the distribution of perceptual qualities over the premises (focal and ambient light in a restaurant or a museum); or even the organization of time (the relationships of convergence and divergence of paths taken and locations visited daily with paths taken and locations visited at less regular intervals within any complex building).

Those of us working in "space syntax" should bring boundary and interface at the center of attention and seek the appropriate notations that will allow us to identify or specify generative or typological principles of organization. For example, the creation of a well-integrated circulation spine is not sufficient for making a layout intelligible when significant accommodation is many direction turns or many boundaries removed from it. Hence the principle of the "shallow integration core": all significant accommodation should be one or two "steps" way from the spine (whether "step" refers to direction change or to intervening boundary). A shallow core, while contributing to an intelligible building, will not in itself support serendipity if it is entirely devoted to circulation only. Hence the principle of the "invested integration" core: integrated circulation spaces should encompass or be directly associated with appropriate primary functions, whether display and information resources, lounges or meeting areas, or perching stations. We hypothesize that the reason why the shallow and invested core encourages serendipity is that it allows interactions to occur as a by-product of movement being channeled past appropriate portions of the program. Thus, the shallow and invested integration core is a key typological ingredient of the generative use of space (Hillier, Hanson and Peponis, 1984; Hillier and Penn, 1991).

The task ahead is to state explicitly other generative principles such as the above so as to provide a richer repertoire of "syntactic typologies"; and then to use the findings of architectural or interdisciplinary research in order to explore how far each generative principle can be usefully probed, tuned, extended or transformed. The properly architectural contribution of space syntax depends upon our ability to map evolving design solution-fields in the light of our studies of generic relationships and functions.

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Contributions of Visual and Attentional Systems To Our Understanding of the Relationship Between Spatial Networks and Human Wayfinding

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Abstract. Predicting human movement through the built environment has always been a challenge to architects and of interest to researchers, but until recently the two fields have largely developed independently. With the development of increasingly more sophisticated modeling approaches within the field of architecture, researchers and their research will be essential to developing better predictions of what human movement and behaviour will look like without actually requiring the space to be built. Here, and in the context of the Space Syntax technique, we present two investigations of how navigation performance, behaviour, and psychophysiology are directly influenced by changes in the layout of an environment. We present initial evidence for the role of both local visual information (i.e., intersections) and global topological cues (i.e., syntax) in the navigational process and provide some evidence for the role of attention and arousal in this process. Together, the results suggest that a more complex spatial cognitive system underlies human movement and places emphasis on modeling techniques to account for these factors in order to develop more accurate predictions and more functional spaces.

Keywords. wayfinding, configuration, spatial networks, Space Syntax, virtual reality, psychophysiology, environmental psychology.

Introduction

The ancient Roman architect Vitruvius argued that good architecture should strive to satisfy three principles: firmnitas, venustas, and utilitas. While modern architecture has largely mastered the production of lasting architectural forms (firmnitas) which are artfully designed to convey beauty (venustas), we have had more difficulty producing equally functional forms (utilitas). This is especially true in the design of larger spaces where it can be harder to anticipate how people may use a space once it is built.

Indeed, it is this question the goal of understanding how spaces can be designed to achieve a desired function, in this case the function of shaping movement, that is of interest not only to the field of architecture, but also is of equal interest to researchers interested in understanding how environmental factors can shape emotions, cognitive states, and behaviour. In achieving this goal, a great deal of mutual interest

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exists, despite the potential outcomes of each of these two groups varying quite markedly. It is in the synergy of the work of both these groups that progress can be made in achieving Vitruvius' fundamental principle of *utilitas*.

Perhaps the most fruitful area of interest towards this topic is in the prediction of human movement using specific modeling techniques. This is best exemplified by the work of the Metabolist movement in Japan during the late 1950s and early 1960s. It is at this time that Tokyo experienced dramatic growth which had caused the city to develop into a piecemeal, disorganized, and chaotic urban system [1]. It is at this time that a small group of architects proposed that urban systems be examined in the broader context of biological systems. Pertinent to this paper, the Metabolists spoke of predicting human movement between neighbourhoods by examining the flowof water in the natural world -- the patterns of rivers and streams serving as templates for designing spaces that achieve the goal of allowing people to travel intelligently between spaces [2]. In doing so, the Metabolist movement was able to dramatically change how architecture at the time thought about and designed (and re-designed) as Tokyo continued to expand with fairly pronounced success.

This example, of using biological or natural systems in the design process, is where our interest lies and will be the topic of this paper. While a great many different types of modeling techniques are available to the modern architect and capable of producing predictions about human movement with relatively high degree of accuracy, these techniques are far from perfect. By examining how people behave within cities and examining the potential reasons for this behaviour, we can better refine these models, produce effective designs, and further refine our increasingly sophisticated understanding of human spatial cognition. Within this paper, we present two experimental investigations of the relationship between physical spaces and resultant behaviour using the Space Syntax modeling technique with the hopes that the findings will inspire interest in and lead to new ideas about the factors that may influence human movement through urban spaces.

1. Background

In order to present these studies in the correct context, we will begin by briefly examining what the behavioural sciences have learned to-date about human spatial cognition.

The first demonstration of a relationship between the physical elements of an environment and the ability of individual people to orient within the environment is most often credited to the work of Kevin Lynch [3]. Lynch demonstrated that humans may represent their surrounding spaces in terms of five distinct and basic elements: paths, edges, nodes, landmarks, and districts. Paths are lines which describe how users travel around the cities, like roads and railways. In contrast, edges are lines which prevent such travel, such as walls and fences. Nodes represent areas of particular interest, like intersections. These should not be confused with landmarks, which are objects that users can draw on as points of reference. Lastly, districts are a way to describe large sections of a city which have a unifying characteristic, examples of which would be neighbourhoods or boroughs. Cities and places in which there was an optimal distribution of each of the five elements appeared to be easier for people to develop an understanding of the overall layout of the environment. Lynch termed such environments as being *legible* spaces.

Later, Lynch noted that the element of paths was most impactful on the legibility of a city above that of the four other elements [4]. From his studies, it appeared that the way in which people are able to move through an environment -- the placement of paths -- could have radical consequences on how people learn about the space around them.

Subsequently, the importance of paths in shaping human spatial memory and perception was confirmed in the study of sketch maps produced by residents of cities. De Jonge [5] showed that residents of cities with linear, parallel, or perpendicular street patterns were able to produce more complete and accurate sketch maps of their environments. Accordingly, these findings placed further emphasis on the role of movement and paths, especially systematically arranged paths, and served to reinforce the idea that minutiae found in the design of a space can have profound implications for how individuals learn and experience their environments. However, the reason for these differences was not immediately evident.

Further research into sketch maps would show that elements were often not represented accurately in Euclidean space, but instead tended to distort the distance between each element while preserving the accuracy of the relations between elements [6]. Each landmark and element was found to be positioned by drawing it relative to the other landmarks already positioned on the sketch map Thus, it was argued, human wayfinding must be reliant primarily on topological descriptions of paths and landmarks rather than Euclidean descriptions of space.

Given this body of evidence, and our experience as agents that navigate the world with relative ease, it is perhaps unsurprising to expect that the influence of the layout of a space extended beyond influencing how we learn and mentally represent spaces. However, research would go on to show that the configuration of an environment alone could, indeed, shape human movement and cognition. In one of the earliest studies bridging the gap between these two areas, Weisman [7] evaluated human wayfinding in ten university buildings. He found that the simplicity of a floor plan of each building, as rated by one hundred independent judges, was a strong predictor of self-reported wayfinding performance. Assessed another way, with the average number of topological connections at each intersection or choice point being measured in a layout, it was found that increased complexity was related to a decrease in wayfinding performance and reduction in the accuracy of reproduced sketch maps [8].

Consistently, both lines of behavioural research investigating spatial memory and wayfinding behaviour suggest the importance of design and configuration on human movement and behaviour. It is clear that one of the most important factors in influencing behaviour is the layout of paths and streets and their systematicity between each other when reduced to topological descriptions of space. These two factors, together, appear to optimize human movement and the ease with which a person is able to learn an environment.

Within the field of architecture, these ideas are represented in what is most popularly known as the space syntax movement [9]. While, the goals of space syntax started out very differently than those of research in spatial cognition, the conclusions drawn from these two approaches are sometimes strikingly similar. The primary measure of space syntax, an axial map, represents spaces through a finite number of linear paths, minimizing turns between each space in the environment. It is through this process that Euclidean descriptions of the environment are discarded or degraded in favour of network-based relational descriptions of space.

Of particular promise is the examination of the local and global structure of the axial map using these network measures in the examination of human behaviour. Two measures of particular interest in this regard are integration and connectivity. While, connectivity represents the number of discrete connections that an individual paths intersects with and is thus considered a measure of local network properties, integration represents a more complicated comparison between each path and their relationship within the overall space. The most common formulation of integration consists of calculating the average number of connections between axial lines necessary to reach every other path in the environment. The measures of connectivity and integration together are intended to quantify space in a consistent and meaningful way. But, these two measures have also been found to be able to account for a significant proportion of aggregate human movement [10]. The most common form of evidence for this relationship was the correlation between specific characteristics of these axial maps, such as integration or connectivity, and traffic count data. Within the architectural field, the argument raised to explain this association between human movement and network properties emphasizes the role of configuration in constraining the way a person experiences a space, encouraging or impeding behaviour and movement. However, researchers have sought to further investigate this question by examining individual wayfinding performance using a variety of techniques. These studies of individual behavaviour have often demonstrated a continued and consistent relationship between human wayfinding and the topological descriptions of space syntax [11]. As such, this research is supportive of the view that human spatial cognition is primarily influenced by topological description of space, especially in the area of how spaces relate and link to one another.

The research described herein seeks to further examine and discuss the relationship between configurational properties of the environment and wayfinding behaviour with the goal of refining our understanding of the underlying spatial cognitive processes responsible for human wayfinding behaviour. While the experiments discussed in this paper are not intended to stand on their own, they are of significant interest to both researchers and practitioners interested in the link between design and movement. This paper discusses two studies directly investigating human wayfinding behaviour as it relates to topological measures (in our case, the measure of intelligibility, the correlation between connectivity and integration). The first study attempts to determine the relationship between global relational measures, local configurations, and human wayfinding. The second study investigates the role of attentional effortful processing in the perception of purely configurational cues afforded by an environment in an attempt to further refine our understanding of how architectural forms are perceived by users.

2. The Role of Local Visual Space

Despite the body of evidence suggesting a role of topological and relationship descriptions of space in the wayfinding process, we cannot rule out the potential role of specific information gathered in the local visual environment. This idea is based upon the marked overlap between axial lines and fields-of-view due to the nature of axial maps.

Research has established that early navigation in an unfamiliar building is best predicted by the local measure of connectivity [12]. In contrast, after a participant became familiar with their surroundings, integration became a better predictor of wayfinding behaviour. Furthermore, Haq [13], in a study of wayfinding in three urban hospitals, showed that axial lines instead of segmented lines had more predictive power in assessing the distribution of people within the hospitals. Together, these results provide evidence for the position that specific spatial properties associated with unsegmented axial lines are good predictors of individual human wayfinding behaviour. As such, it is deemed necessary for axial lines to, in some degree, represent lines-of-sight rather than a pure metric of spatial network properties alone.

Conroy and Bafna [14] suggest a framework to account for this overlap between fields-of-view (as measured by isovists) and axial lines. In their framework, an isovist consists of a two-dimensional field of view afforded by a specific location. In contrast, an axial map is defined as the fewest and longest lines sufficient to pass through all the component spaces of a specific environment. As an infinite number of axial lines extending from a single position will cover the surrounding space in a similar way as an isovist, the two measures can be considered related to each other to some degree. It is this commonality that we consider further evidence for the position that the local visual space may play a role in configurationally-driven wayfinding behaviour.

Several investigations of wayfinding behaviour in virtual environments by Ruth Conroy Dalton provide more direct evidence of an interplay between isovist space and human wayfinding behaviour. More specifically, that people choose routes that maximize the volume of isovists and minimize angular velocity, taking paths that approximate long axial lines [15]. As such, it seems possible that incidental manipulations of local visual space, embodied and influenced by the manipulation of more global measures, may be responsible for some or all of the effect attributed to global spatial syntax measures.

Inspired by this question, an experiment was devised to compare the influence of local and distant visual features on navigation choices. This experiment compared the wayfinding behaviour of university students in two virtual environments: one environment with a high level of spatial intelligibility and one with a decreased spatial intelligibility. To assess whether local visual features are responsible for some or all of the effect of global topological factors on navigation, half the participants navigated with their vision restricted to the span of an average intersection.

2.1 Methodology

The methodology for this research followed two stages. First, two environments were constructed, one with relatively high concordance between connectivity and integration and a second, modified form, of this environment that reduced this correlation by shifting around edges and nodes. In the second stage, undergraduate students were immersed in one of these two virtual environments and asked to perform two tasks: find a landmark within the environment and then find their way back to the start position from that landmark. The path each participant followed was recorded and examined. However, of key importance, half the participants performed both tasks while immersed in digital fog. This fog restricted vision to only the size of a local intersection, preventing the direct perception of more distant visuospatial features and instead only affording access to the local visual space. Examples of the two conditions are shown in Figure 1. The configuration of both environments and a typical participant path are shown in Figure 2.

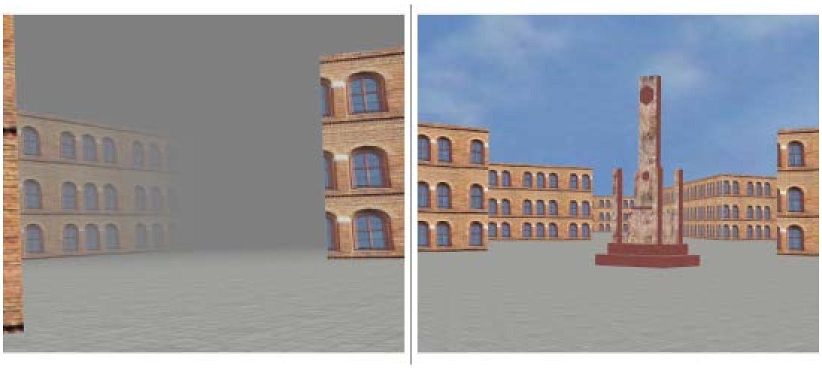

Figure 1. Examples of the two experimental conditions. On the right is an example of the restricted vision condition with fog obscuring features beyond the intersection itself. On the left is an example of the unrestricted visual condition with the goal landmark located directly in front of the participant.

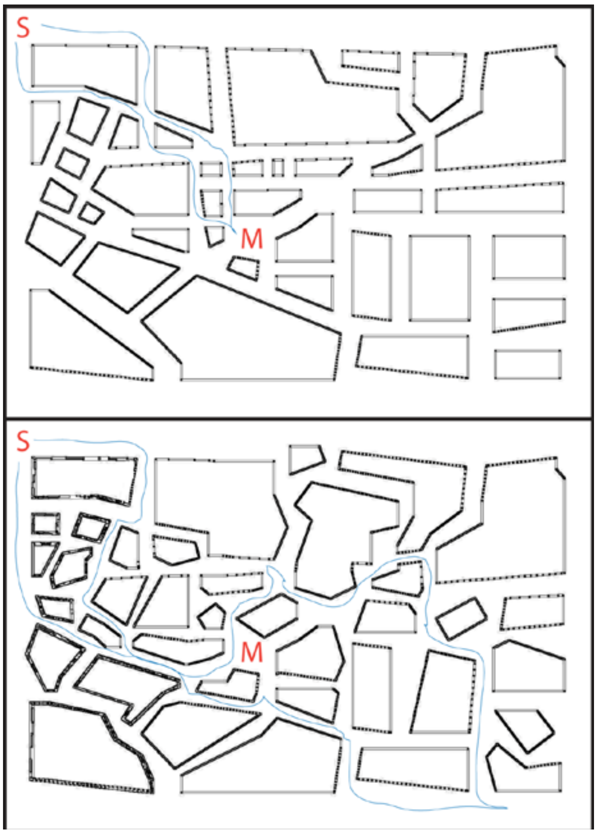

Figure 2. Overhead plan views of both virtual environments. The top panel shows the high intelligibility environment. The bottom panel shows the low intelligibility environment. 'S' indicates the start position for the wayfinding task. 'M' represents the position of the goal landmark. The blue lines show typical paths followed by a participant in each environment. Scale is 1200m x 800m.

2.2 Results

The path each participant traveled was examined across the entire navigation task. The results can be seen in Figure 3 for both the intelligibility and the restricted visual conditions in terms of the length of observed paths.

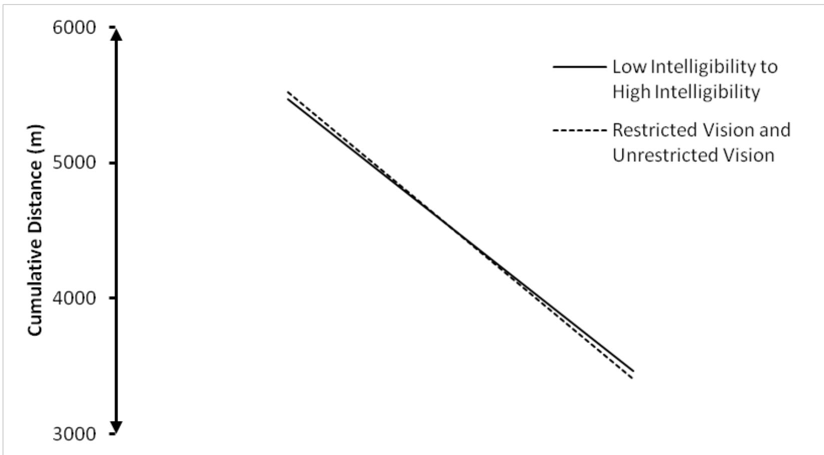

Figure 3. Path distance data was a function of both experimental conditions.

As one would expect based on the large body of existing research surrounding the influence of intelligibility on navigation, participants were found to follow significantly longer paths in completing both tasks when immersed in the low intelligibility environment than the participants did when immersed in the high intelligibility environment. However, as is evident, the visual restriction manipulation produced a near identical influence on the distance which participants navigated. In fact, this relationship was observed to be additive, where restricting vision in a low intelligibility environment produced the longest paths while unrestricted vision in the high intelligibility environment resulted in the shortest paths. Regression analysis was performed to determine whether the two manipulations interacted additively. It was found that restricting vision accounted for approximately 15% of the variance in the path distance measure. In contrast, the intelligibility manipulation accounted for approximately 17% of the variance in path distance. Together, both measures were able to account for 32% of all variance in the length with which each participant took to complete both tasks.

This high degree of concordance between the visual and intelligibility manipulations is perhaps unexpected. On the face of it, this appears to suggest that both global spatial measures and local configurational space (i.e., intersections) are capable of influencing route choices made through a novel environment. However, the fact that the two properties appear to be apparently independent, influencing movement in similar ways but remaining separable, should not be understated.

This is perhaps most interesting given the proposal that space syntax is based on the principle of *direct perception* proposed by Gibson [16]. It has been argued that space syntax accurately accounts for movement due to pedestrians evaluating the visual properties around them, making path choices based on which route offers the greatest visual affordance [17]. This is in contrast to more intuitive models which would argue that a person navigates simply by taking the optimum or most direct path to their goal.

The current results appear to confirm this hypothesis that affordances are driving path choice and not the motivation to optimize route choices. The strongest evidence for this position comes from the examination of the additive influence of both the manipulated factors. When both syntactic and local visual information is available to a navigator, their paths are optimal in length. However, when one of the two factors is not available, or worse, both factors are diminished, route choices become much less predictable and less optimal, varying from the paths predicted by traditional syntax analysis.

However, perhaps even more importantly, the results also show that this is not the only thing driving navigation performance through a novel space. The results clearly also show that the local visual space is of importance, even in impoverished or new environments where salient landmarks and other environmental attractors are not obvious or present, affording more information above and beyond that of such topological measures as connectivity and integration that may be perceived by examining more distant visual features.

While we are at the cusp of understanding the relationship between these two factors, the results appear to paint a more complex picture of predicting human movement beyond simply account for the topological structure of a space at the global level. Further, they suggest that improved predictions may arise from a more complex evaluation of *both* the local and the global space as they pertain to shaping movement.

3. Visual Attention in the Wayfinding Process

Given the results of the previous study it seemed prudent to investigate the role of attention and arousal in the perception of salient spatial information. Should effortful processing of environmental stimuli be necessary to perceive salient syntactic and spatial factors, it would be expected that fluctuations in this processing would result in some level of deviation from predicted paths. This has particular relevance in spaces where navigators are expected to be distracted or stressed, such as hospitals or congested cities, where demands created by the spaces could have a profound influence on behaviour, should they be observed.

However, despite the importance of this question in the production of more accurate design and modeling, remarkably few studies have investigated this research question. In an observational study of pedestrian movement through the city centers of Edinburgh and York, pedestrians were classified as unencumbered, carrying a small bag, carrying multiple bags, or escorting a small child, and movement speed was noted [18]. The authors argued that this classification not only accounted for physical effort but also for attentional effort required to navigate the city under each constraint. It was found that participant movement speed decreased as a function of the subjective encumbrance of their categorization. While, far from conclusive, this result does provide potential evidence for the need to navigate slower through an urban environment when one is forced to focus their attention on more than one task at a time.

The field of psychology is rich in studies of how performing one or more tasks at a time can influence behaviour. Research has shown that once an individual is required to perform more than one task, the performance on the second task can interfere with performance on the primary task in systematic ways. Within the field there are three main types of models designed to account for decreased performance when multi-tasking: capacity sharing models, bottleneck models, and cross-talk models [19].

Capacity-sharing models [20] argued that a person has a finite amount of processing capability that is shared in parallel amongst the task that person is required to perform at any given time. The more tasks a person performs, the less they can dedicate to any one task leading to a decrease in performance consistent with re-allocation of attentional resources. In contrast, bottleneck models [19] argued that certain tasks require the dedication of finite resources. Hence, only a single task can be processed at a time. Finally, cross-talk models [21] assert that performing multiple tasks produces interference as a result of the content of the information being processed, not the way that the processing occurs (as with both other types of models). Regardless of models, what is clear is that the performance of specific types of tasks concurrently produces marked changes in observable and measurable behaviours.

Of particular interest to us is the regulation of internal physiological states when performing wayfinding due to the relative ease of measurement and the relative ease of identification of task interference in those measures. We can take advantage of the fact that the autonomic nervous system is primarily responsible in monitoring and reacting to internal states through reciprocal connections with the central nervous system. The autonomic nervous system consists of a sympathetic (colliqually, related to the fight-or-flight response) and parasympathetic (i.e., rest and digest) nervous systems. Together, these two branches of the autonomic nervous system are capable of producing independent, coactive, or reciprocal physiological activity in the body, creating changes in physiological state in response to specific cortical activity [22]. As such, changes in the attentional load with which a person is experiencing would be expected to result in changes in specific physiological markers. For the present study, we were interested in two measures of cognitive state: eye blink rate and galvanic skin response.

3.1 Blink-Rate as a measure of cognitive load

Prior research has demonstrated a link between the rate at which a person blinks their eyes and the cognitive load that person is under. In general, the higher the cognitive load a person is under, the higher the blink rate that is observed [23]. This lead to the term *endogenous eyeblink* due to these eye blinks being triggered by internal cortical events rather than identifiable external events. In recent years, a consistent link has been demonstrated between the level at which a person is attending to a task and the rate at which they blink their eyes. In a series of experiments, Sandra Marshall demonstrated that if a person is engaged in a task instead of relaxed, distracted instead of focused, and alert instead of fatigued, their eye blink rate was found consistently to be elevated [24]. Furthermore, this blink behaviour has been found to follow periods of sustained information processing rather than distributed throughout the process [25]. Due to the relative flexibility of this method and relative ease of recording, this method is considered the primary measure of cognitive state for the present study.

3.2 Galvanic skin response as a measure of cognitive load

Galvanic skin response has been the subject of study for decades. Changes in nervous system activity related to specific cortical events has been found to result in changes in the conductance level of the skin induced by minute changes sweat level on the fingers and palms [26]. While the response can be dissociated into generalized increases in arousal or specific responses to stimuli, changes on a second-per-second basis in the galvanic skin response have been found to be related to cognitive load both behaviourally [27] and physiologically using event-related electroencephalography [28]. Specifically, across a period of time, the skin conductance level has been found to increase as a function of cognitive load. As such, tasks which are more demanding across a period of time are associated with an increase in the number of peaks in the skin conductance level (measured here as average frequency at a given point in time), showing a higher frequency per unit of time. As galvanic skin response is a latent measure, delayed by the speed of sweat excretion (amongst other factors), this is considered a convergent measure of cognitive state, rather than a primary measure in the present study.

3.3 Methodology

The present study took advantage of the potential of both blink rate and galvanic skin response in demonstrating the level of attention directed at any given point in time throughout a wayfinding task performed in virtual reality. To assess the degree to which an intelligibility demands attentional resources participants were asked to navigate in two environments consistent of high and low intelligibility. Both environments were adapted from Hillier's prototypical environments designed to represent intelligible spaces [10]. Both environments consisted of identical buildings, but in the second environment buildings were shifted in such a way that intelligibility was distinctly reduced. In each environments, participants were asked to navigate from the edge to a landmark located within the environment (located in the 'central square' of each environment) and then return to the start position. As such, we were able to assess the influence of syntactic information on both exploration and wayfinding behaviour.

3.4 Results

In order to accurately assess whether attentional resources are demanded in the perception and use of synctactic information in the wayfinding process, paths, velocity, and psychophysiological data were examined in using four different approaches. First, the data was compared across all navigation, as well as in their component segments: exploration and navigation. Second, the psychophysiological measures were mapped onto space in an effort to examine whether specific levels or combinations of connectivity or integration demand attentional resources.

Overall, intelligibility was found to significantly affect navigation performance. A mean distance of 1948m was observed in the high intelligibility environment as compared to 3042m in the low intelligibility environment. Similarly, a decrease in path velocity was observed for participants, with participants traveling an average of 1.81 m/s in the high intelligibility environment versus 1.35 in the low intelligibility environment. In the psychophysiological data, significant increases in blink rate and galvanic skin response frequency were observed between the two levels of intelligibility. The high intelligibility environment was found to be associated with lower blink rate, 12.15 blinks per minute as compared to 16.31 in the low intelligibility environment, and more variable galvanic skin response, 0.134 Hz versus 0.142. This pattern of results appears to suggest that low intelligibility environments not only result in increased necessity to stop (as embodied by a drop in velocity), but also increases in cognitive load as measured by the two psychophysiological responses.

This pattern of results was also observed in the analysis of the wayfinding component of the navigation task. Specifically, we observed a decrease in the path distance that participants required to return to the start position, with an average of 1144m in the high intelligibility environment as compared to 1894m in the low intelligibility environment. Likewise, velocity was found to be slower in the low intelligibility environment with an average of 0.78 m/s being covered in the low intelligibility environment versus 1.13 m/s in the high intelligibility environment. The low intelligibility environment was also found to be associated with a significantly higher blink rate, 18.27 blinks per minute as compared to 9.73 in the low intelligibility environment, and more variable galvanic skin response, 0.159 Hz as compared to 0.132 Hz. As above, we argue that this pattern of results supports the argument that attentional resources are being demanded when the relationship between connectivity and integration is weak or difficult to perceive.

In contrast to the outward segment, the exploration phase of the experiment did not produce similar results. While, distance and velocity were significantly different between the two environments, with an average of 704m being covered in the high intelligibility environment before finding the landmark and an average of 1148m being covered in the low intelligibility environment and an average velocity of 1.42 m/s being observed in the high intelligibility environment versus 1.10 m/s in the low intelligibility environment. No significant differences were observed in either the blink rate measure of the galvanic skin response measure suggesting that initial exploration does not suffer from an increased processing demand, despite producing marked differences in path choice and stop behaviour.

Surprisingly, the results appear to support the position that wayfinding through environments with decreased intelligibility demand more attentional resources than wayfinding through environments with more systematic intelligibility. This is supported by an increase in stopping behaviour, blink rate, and galvanic skin response throughout the wayfinding task, as well as overall in the comparison of both environments. However, to further investigate the relationship between the syntactic variables in the built environment and resulting psychophysiological reactions, the participant data was mapped onto the space in the following way. Each environment was segmented into discrete convex spaces producing 138 discrete areas per environment. Next, axial lines were computed allowing the average connectivity and integration-3 values to be computed for each area. Radius-3 integration was selected as it has been found to be the best predictor of human wayfinding performance [13]. This followed the logic that if an axial line passed through an area, it would be included in the average for that area. The resulting map thus consisted of the component intelligibility values mapped as spaces rather than lines allowing direct comparison with the navigation data collected during the task. Correlational analysis was then performed on the resulting data allowing us to assess whether the perception of specific levels of integration-3 and connectivity was associated with systematic changes in average physiological response experienced by participants. The pattern of the association between radius-3 integration and blink rate for the high intelligibility and low intelligibility data can be seen in Figure 3. Results for the high intelligibility environment indicated significant significant a correlation of 0.38 was found between integration-3 and proportion of observed blinks within the area. Likewise, galvanic skin response was found to correlate significantly with integration-3 values for each area and resultant skin response level on the order of 0.30. This pattern of results was also observed with connectivity values, showing significant correlations of 0.36 and 0.27 between connectivity and blink rate and connectivity and galvanic skin response, respectively. Interestingly, this pattern of results was not observed for the low intelligibility environment with correlations between the two values showing markedly decreased magnitude. However, this is considered to be the result of a ceiling effect induced by the constraints of low intelligibility environment and thus we argues this does not contradict the above findings, but instead provide further support for them. This idea is further supported by significant overall correlations between integration and the factors of interest when collapsing across both environments (r = 0.40 between integration-3 and blink rate, r = 0.149 between integration-3 and galvanic skin response. The overall distribution of blinks can be seen in Figure 4.

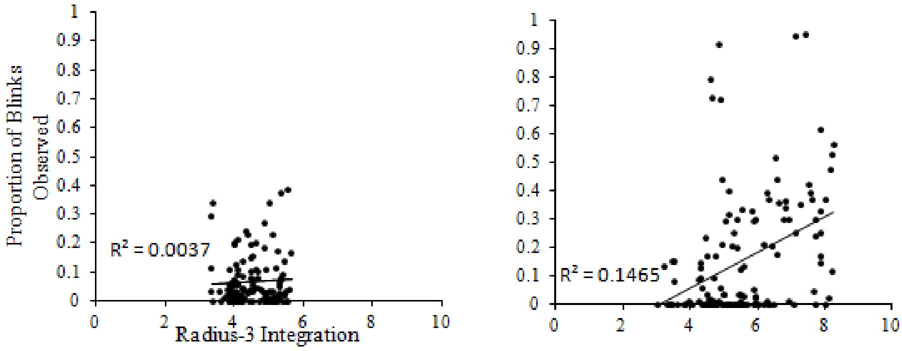

Figure 3. Scatterplot of the proportion of blink to non-blink behaviour in the low (left) and high (right) intelligibility environments. Linear trend lines have been plotted on both graphs.

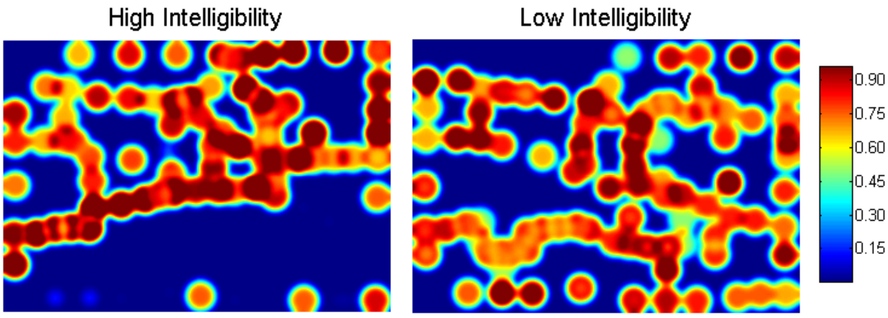

Figure 4. Heat maps of the distribution of blink rate as it relates to intelligibility of the environment. Mean blink rate for each area was calculated from the proportion of eye blinks observed within each discrete area of the environment.

Taken as a whole, the results of this study appear to suggest a consistent relationship between the attentional demands of wayfinding in low intelligibility environments. Overall, it was found that an increase in cognitive load was observed as a result of decreased intelligibility. Furthermore, as the values of integration and connectivity increase, a corresponding increase in blink rate and galvanic skin response was observed. These findings are not only informative, but represent our first attempts at better understanding the process underlying the role of intelligibility in normal human navigation. Taken together, these findings provide ample support for the arguments raised by Penn [11] regarding the perception of syntactic factors during navigation as an exosomatic process. Specifically, the idea that poorly structured environments can disable or reduce the ability for an individual to function and navigate effectively as compared to well design environments with consistent structural configuration. However, given that these results represent the first attempt at investigating this process, it remains to be seen is how this increased cognitive load resulting from poor design and configuration can relate to individual variations in these psychophiological factors can account for systematic or random variation from paths predicted by space syntax.

4. Conclusions

The results discussed within this paper have two-fold significance. First, they advance our understanding of the relationship between human movement and urban design. Of particular note is the evidence for the role of intersections and other local visual information in this process. While, further research will be necessary to elucidate the precise relationship between space syntax, the local visual space, and resulting human behaviour in greater detail, it is worth noting that understanding how space syntax and other spatial properties can influence behaviour is not as simple as accounting for the network properties of a space alone. Accordingly, the degree of association between global network values and human wayfinding flow, estimated to be as high as 60 to 80% [11], may be conflated between the factors of local and global space. In better understanding this relationship and the strength of the association it would therefore be possible to increase the predictive value of models derived from space syntax or other network-based measures by accounting for an even larger amount of the variance in human wayfinding behaviour.

While speculative, these results argue for increased rigor in the design of environment used in wayfinding research and potentially in real-world spaces. Increased attention will need to be directed at either intentionally manipulating or controlling the shape of local visual spaces, such as intersections, while adjusting global configuration and design.

Second, we identified a relationship between the intelligibility of an environment, the levels of connectivity and integration, and resulting changes in cognitive load. These results appear to suggest that certain levels of either parameter are more difficult to discern and thus demand greater attentional resources. These results have potential consequences in the understanding of the role of distraction in wayfinding through novel environments where configurational cues are largely the only source of useful spatial information. It remains possible that wayfinders who are asked or required to perform more than one task during the wayfinding process may be unable to perceive configurational information as accurately, resulting in derivations from predicted paths. While still in the early stages of research, this question remains an open and important one in further developing our understanding of how we remain oriented and become disoriented in familiar and unfamiliar environments. This idea is facilitated by the data presented herein suggesting that additional attentional demands are placed on a person as they navigate through an environment or an area with reduced intelligibility and could, perhaps, result in disorienting a person should those demands be too high.

While these studies provide some compelling evidence that the design of an environment, both locally and globally, can have a profound influence on the movement and behaviour that may be observed within them, but they also leave much to be done. Both experiments represent initial steps at investigating human movement behaviour in urban spaces as an result of an interplay between visual and attentional systems rather than some automatic or, relatively, simplistic process driven by a desire to maximize the amount one can see at a given time. Additional factors such as the role of landmarks, the presence of other people in the navigation space, and distinct neighbourhoods will need to be investigated to better understand the phenomena observed in the present studies as well as to understand how these factors can be implemented in modeling approaches such as Space Syntax.

Despite developing an increasingly more sophisticated ability to predict behaviour beyond the theories of the Metabolists, environmental modeling approaches can continue to profit from a synthesis with scientific research on navigation and behaviour. By better understanding our behaviour, psychology, and psychophysiology is influenced by a space, we will be able to produce more accurate predictions about human movement and come closer to truly mastering the art of architecture that Vitruvius defined for us centuries ago.

5. Acknowledgements

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Filling in along the way: Spatial inferences in building navigation

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As one travels through a building we glimpse only a fraction of the surfaces that define the entire space, yet from the accumulated glimpses we develop a sense of the space. Notably, the areas we have not seen are not treated as holes in this space, rather we can infer much of the unseen space from what we have seen. The combination of seen spaces and inferred spaces allows a building user to move through a building on familiar and novel routes.

One could imagine that many sources of information might be used to guide wayfinding through a building including signs to destinations, turn-by-turn instructions, as well as expectations about how buildings might be generally designed. Here we set aside what an individual users brings to the building to consider a bottom up approach, how does the structure of the building allow inferences about unobserved parts of a building?

Here we consider how work on the problem of object completion (e.g., Kellman & Shipley, 1991) where the hidden surfaces of objects are filled in based on the visible parts of the object might be applied to the analogous problem in building navigation.

The user may use the general properties of surfaces, their tendency to be smooth, to fill in parts of a building that have not been seen. In the first few moments in the building filling-in is simply extending surfaces beyond what can be seen to allow the best guess about which directions offer further progress into the building. In objects this extrapolation is linear, thus in a building surfaces will likely be inferred to continue along a straight trajectory. After wandering around in the building connections among experienced pieces of the building may be inferred – the experienced surfaces may be linked with smooth surfaces to begin to develop a map of the interconnections. This linkage will occur only under restricted geometrical conditions thus avoiding too many unlikely connections. Only when a smooth monotonic curve can connect two surfaces will they be seen to be connected. Finally as local regions in a building become well represented any statistical regularities may be used to anticipate other unexplored regions that appear similar when first approached.

Kellman, P. J. & Shipley, T. F. (1991). A theory of visual interpolation in object perception. *Cognitive Psychology*, 23, 141-221.

Designing Coarse to Fine

How can we anchor vague concepts in physical domains?

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Preface The notion of concept grounding assumes that the physical truth of the real world serves as the reference for the meaning of human concepts. This assumption is based on the idea that our concepts can be related to the physical world through perception with high precision. But do our concepts really come to existence through precise perception? Are our concepts not vague and imprecise initially and become increasingly more precise through gradual refinement? Don't concepts also come into existence through imagination? Mental images may be similar to physical images in some respects, but there also are important differences. If so, what does this imply for concept grounding?

This contribution is motivated by the observation that designers typically start their design process by noting overarching coarse relationships without first specifying details of entities that are related to one another; the details will be filled in later by successive refinement which may lead to a revision of the original coarse relations.

Coarse to fine is not yet very well understood in terms of knowledge representation. This is partly due to the fact that knowledge representation systems frequently assume or require consistent information in their representation structures. Consistent information can be achieved more easily 'bottom-up' – from the detail to the complex structure – as inconsistencies may be noted right away. But the human world of ideas and concepts is full of inconsistencies that our mind seems to have no problem to represent. Put differently, we probably should speak of inconsistencies that our mind is not capable of detecting or of resolving.

Nevertheless, for knowledge structures to be useful for reasoning and problem solving, at least a limited plausibility among the relations is required. I propose that plausibility – and even consistency – may be achieved on a coarse level without having a solution on how to structure this level in terms of details. Visual Perception may serve as a model of how this could work: if we perceive complex structures from a distance, we are not able to recognize the constituents of these structures in detail, neither the entities nor their relations; and still we are able to conceptualize the coarse structure. When we are getting closer, more knowledge about details may force us to revise our representation of the coarse structure. These changes may be moderate; they usually don't require a complete revision.

The relative strong stability of perceptual representations is due to spatial constraints in spatial environments and in perceptual systems. These constraints can be exploited by a representation and reasoning approach that I call *Spatial Computing'*. Spatial computing aims at using spatial and temporal constraints directly rather than modeling their effects in an abstract formal system.

In the following I include the draft of a paper on spatial computing which is currently under review. I will be glad to receive feedback regarding the content of that paper.

Spatial Computing

Towards designing a right-brain type architecture

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Abstract At the Advanced Study Institute on Cognitive and Linguistic Aspects of Geographic Space in Las Navas del Marqués in July 1990, I presented a paper on *Qualitative Spatial Reasoning*. In this paper, I suggested that spatial inference engines might provide the basis for rather general cognitive capabilities inside and outside the spatial domain. In the present chapter, I will follow up on this perspective and I will illustrate in which ways research in spatial cognition has progressed towards understanding spatial reasoning and spatial computing in a more literal sense. The chapter presents a progression of approaches to spatial reasoning from purely descriptive to increasingly spatially structured. It demonstrates how spatial structures are capable of replacing expensive computational processes. It discusses how these approaches could be developed and implemented in a way that may help us to better understand spatial abilities that are frequently attributed to the right-brain hemisphere in humans. The chapter concludes by suggesting that a suitable combination of abstract declarative representations and concrete spatio-temporal representations may be most effective for problem solving.

Spatial Problems.

Let us consider examples of some common spatial problems we may be confronted with:

1. Given the triangle ABC with the coordinates $A = (1, 3)$, $B = (9, 2)$, $C = (6, 8)$; is $P = (8, 4)$ inside or outside the triangle ABC?
2. (How) can I get the piano into my living room?
3. How do I get from here to John's place?
4. Which is closer: from here to John or to Mary?
5. Is the tree (walkway, driveway) on my property or on your property?

4

6.

Problem 1 is a classic high school geometry problem which can be solved abstractly with linear equations; the correct algebraic solution will locate *P* on the line *BC*; numeric solutions may place *P* inside or outside the triangle, depending on the number format and algorithm chosen; approximations to precise numeric values may cause slight deviations from the correct result. Problem 2 is a form of the classic *Piano Mover's Problem* in mathematics (Schwartz and Sharir 1983); although this problem can be represented geometrically, in practice it is rarely approached mathematically in the abstract representation domain but by trial and error in the physical problem domain.

Problem 3 cannot very well be presented in geometric terms; a graph structure that depicts the location 'here', John's place, and a traversable connection between them is more appropriate and often times preferable to a solution in the physical domain, particularly if John's place is far away. Problem 4 typically does not require the mathematically correct solution – which may take a long time to determine; a quickly provided estimate tends to be more helpful, in practice.

Problem 5 is another example where a formal approach may not be very helpful; but whereas in the Piano Mover's Problem the base information may be available in form of the piano's geometric dimensions, in the present example, we may have a legal document which specifies property boundaries in terms of geographic coordinates and a piece of property whose precise coordinates may be difficult to determine and therefore not known. Problem 6 also is related to the Piano Mover's Problem, but it is not specified in terms of numbers or language; it is a truly spatial problem presented physically to small children who will try to fit the small colored objects into the openings of the wooden cube and thus learn about spatial features like size and shape through physical processes by trial and error.

The examples illustrate that spatial problems may come in terms of numbers, language, or spatial configurations. Likewise, the solutions to spatial problems may be required in terms of numbers, language, or spatial configurations. The solution may or may not be needed in the same modality as the problem statement. The correct solution may not always be the best solution as quickly available suboptimal solutions may be more useful in certain situations. In other words: we may need to transform problems and solutions between different modalities and the generation of the problem solution may take place in a variety of modalities (cp. Sloman 1985).

This observation raises the issue whether we need to transform spatial problems into geometric formalisms to enable computational solutions by means of sequential interpretation of classic computer languages; or whether we can find ways to process entire spatial configurations directly, as humans seem able to do (Shepard and Metzler 1971). I will dub the classic computer science approach as *left-brain computing,* as information processing in the left hemisphere of the brain is considered language-like sequential; I will dub the approach of processing entire spatial configuration as *right-brain computing,* as the right hemisphere of the brain is largely considered responsible for spatial knowledge processing in humans (Fischbach 1992).

In this chapter, I will first review progress in qualitative temporal and spatial reasoning; I will then discuss the notion of *conceptual neighborhood* and how we can exploit it for spatial computing; I will introduce tools for processing qualitative spatial relations; next I will address the transition from spatial relations to spatial configurations; finally I will demonstrate and analyze the notion of *spatial computing* as contrasted to *propositional computing*.

Qualitative Temporal and Spatial Reasoning.

The starting point for much of the research in qualitative temporal and spatial relations in the past twenty years was the paper *Maintaining knowledge about temporal intervals* by James Allen (1983) (Fig. 1), although the underlying insights had been published previously (Nicod 1924; Hamblin 1972).

Relation	Symbol		Pictorial Example
before – after	<	>	
equal	=		
meets – met by	m	mi	
overlaps – overlapped by	o	oi	
during – contains	d	di	
starts – started by	s	si	
finishes – finished by	f	fi	

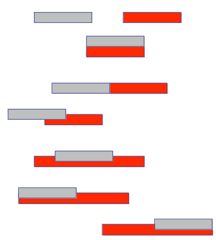


Fig. 1. The thirteen jointly exhaustive and mutually exclusive qualitative relations between two temporal intervals.

The intriguing result of this research was that thirteen 'qualitative' relations could describe temporal relations between events uniquely and exhaustively. There was an expectation that the idea of qualitative relations could be extended to spatial objects that share the extendedness property of temporal intervals. Initially, researchers had in mind a single spatial calculus that would compute all-embracing spatial relations between objects based on information about spatial relations between other objects. However, it became apparent soon that it would be more effective to develop specialized calculi that deal with individual aspects of space rather than a comprehensive spatial calculus that would integrate multiple aspects of space in a single formalism. For example, Allen's interval calculus (Fig. 2) could be easily adapted to 1-dimensional directed space (Freksa 1991) or to three spatial dimensions individually (Guesgen 1989).

B r2 C / A r1 B	<	>	d	di	o	oi	m	mi	s	si	f	fi
"before" <	<	no info	< o m d s	<	<	< o m d s	<	< o m d s	<	<	< o m d s	<
"after" >	no info	>	> oi mi d f	>	> oi mi d f	>	> oi mi d f	>	> oi mi d f	>	>	>
"during" d	<	>	d	no info	< o m d s	> oi mi d f	<	>	d	> oi mi d f	d	< o m d s
"contains" di	< o m di fi	> oi di mi si	o oi dur con =	di	o di fi	oi di si	o di fi	oi di si	di fi o	di	di si oi	di
"overlaps" o	<	> oi di mi si	o d s	< o m di fi	< o m	o oi dur con =	<	oi di si	o	di fi o	d s o	< o m
"over-lapped-by" oi	< o m di fi	>	oi d f	> oi mi di si	o oi dur con =	> oi mi	o di fi	>	oi d f	oi > mi	oi	oi di si

Fig. 2. A part of the composition table for the qualitative temporal relations (without the 'equals' relation) from Allen (1983). In most cases, more than one relation may result from a composition. "no info" means that all 13 relations may result from a composition.

Conceptual Neighborhood.

An important feature of physical time and space is that gradual changes result in small qualitative changes between the point relations involved. For example, in the transition from the *before* relation to the *meets* relation, only one of the four point relations between beginnings and endings of the two intervals changes: the relation between the ending of the first interval and the beginning of the second interval changes from *smaller than* to *equals*. Accordingly, perception and cognition of spatio-temporal configurations that result from small physical changes are closely related.

Furthermore, events in close temporal vicinity are related more easily to one another than events in different epochs. Similarly, nearby spatial locations are more easily related to one another than locations far apart – this insight is captured in the *First law of geography:* "Everything is related to everything else, but near things are more related than distant things” (Tobler 1971). The role of nearness extends from temporal and spatial neighborhood to the more abstract level of relations: certain relations are closer to one another than others; in fact, some relations are distinguished only by a single detail; these relations are called *conceptual neighbors* (Fig. 3).

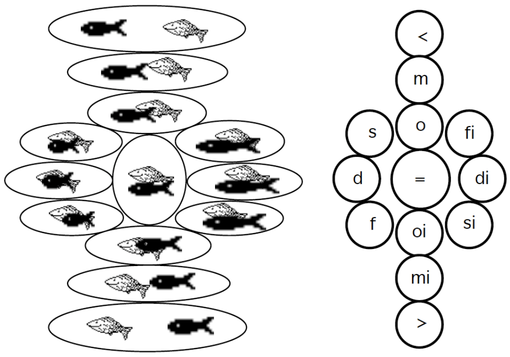


Fig. 3. (From Freksa 1991): Thirteen qualitative relations for one-dimensional directed space. The example compares the position of fishes in the horizontal dimension. The 13 relations are arranged by *conceptual neighborhood*.

The notion of *conceptual neighborhood* is closely connected to the notion of *spatial neighborhood:* Spatial neighbors can be defined as two locations, which are distinguished by a single detail, e.g. whose distance in the location graph is one (Fig. 4).

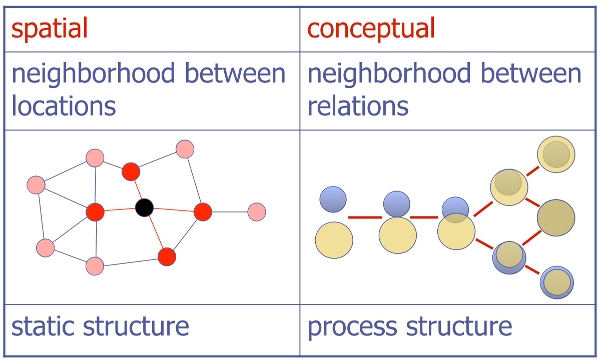


Fig. 4. Spatial and conceptual neighborhood: In the graph depicting spatial locations (left) nodes that are a single edge apart represent spatial neighbors. In the graph depicting spatial relations (right) relations that are a single qualitative criterion apart represent conceptual neighbors.

Structuring temporal and spatial relations by conceptual neighborhood enables numerous features for representing spatial knowledge and for spatial reasoning:

- Sets of neighboring relations can be lumped together to form *conceptual neighborhoods* and to define *coarse relations* (Freksa 1992a, b)*;*
- Conceptual neighborhoods define hierarchies for representing incomplete knowledge;
- Qualitative reasoning based on conceptual neighborhood allows for efficient non-disjunctive reasoning;
- Neighborhood-based incomplete knowledge can be easily augmented as additional knowledge is gained during successive reasoning;
- Coarse relations based on conceptual neighborhoods frequently exhibit a natural correspondence to everyday human concepts;
- Spatial and temporal inferences in qualitative reasoning typically result in conclusions that form conceptual neighborhoods;
- Reasoning that can be carried out on the basis of conceptual neighborhoods can reduce computation from exponential to polynomial complexity [Nebel & Bürckert];
- Conceptual neighborhoods can be formed on various levels of granularity.

Neighborhood-based reasoning.

One important feature of conceptual neighborhood-based abstraction is that *incomplete knowledge* can be conceptualized and represented as *coarse knowledge* (Fig. 5). By abstracting from missing or unnecessary details, reasoning can be carried out efficiently, avoiding computationally and conceptually problematic properties of disjunctive knowledge processing.

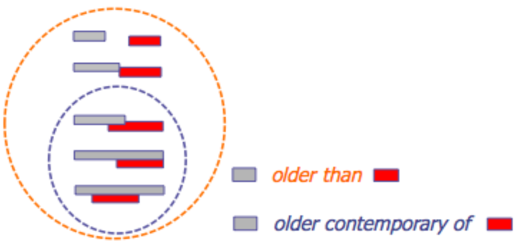


Fig. 5. Coarse temporal relations forming an abstraction hierarchy. The relation 'older contemporary of' corresponds to the conceptual neighborhood of the finer relations 'overlaps', 'finished by', and 'contains'. The even coarser relation 'older than' corresponds to a larger conceptual neighborhood that additionally includes the fine relations 'before' and 'meets'.

Coarse reasoning does not imply that inferences yield coarse knowledge only; conjunctions of partially overlapping coarse inferences based on imprecise or incomplete knowledge fragments from different sources result in precise or *fine* conclusions if the premises are appropriately chosen. With this property, the approach is suitable to model synergy of multimodal coarse knowledge sources that result in precise knowledge.

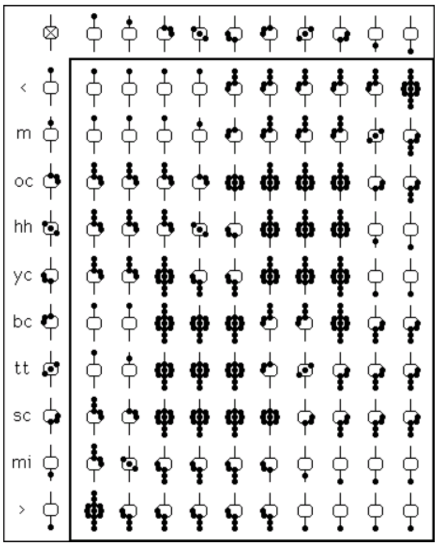


Fig. 6. Conceptual neighborhood-based composition table for coarse reasoning. Each black dot corresponds to a fine relation; conceptually neighboring relations form lumps of dots that correspond to coarse relations. In the table, conceptually neighboring columns and conceptually neighboring rows have been combined. For elaborate explanation see (Freksa 1992).

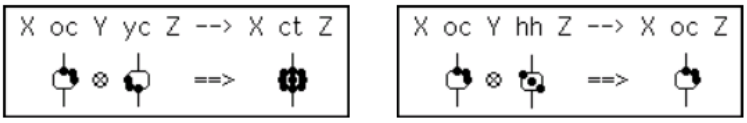


Fig. 7. Inference based on coarse relations. The figure depicts two instances of the composition relation (denoted by ⊗).

A multitude of specialized calculi and SparQ.

A considerable variety of spatial calculi have been developed over the past twenty years; these can be classified as

- Measurement calculi, e.g. Δ-Calculus (Zimmermann 1995))

- Topological calculi, e.g. 4-intersection calculus, 9-intersection calculus, RCC-5, RCC-8 (Egenhofer and Franzosa, 1991; Randell, Cohn et al.);
- Orientation calculi, e.g. point / line-based: DCC, FlipFlop, QTC, dipole or extended objects (Freksa 1992b; Ligozat 1993; Van de Weghe et al. 2005; Moratz et al. 2000);
- Position calculi, e.g. Ternary point configuration calculus (TPCC – Moratz et al. 2003).

To simplify the use of qualitative spatial calculi for specific reasoning tasks, various tools have been developed. The toolbox SparQ[1] [Wallgruen et al. 2007] integrates numerous calculi for qualitative spatial reasoning and allows for adding arbitrary binary or ternary calculi through the specification of their base relations and their operations in list notation or through algebraic specification in metric space. SparQ employs functional list notation and allows for easy interfacing with other software through command lines or TCP/IP request. SparQ has a modular architecture and can easily extended by new modules (Fig. 7).

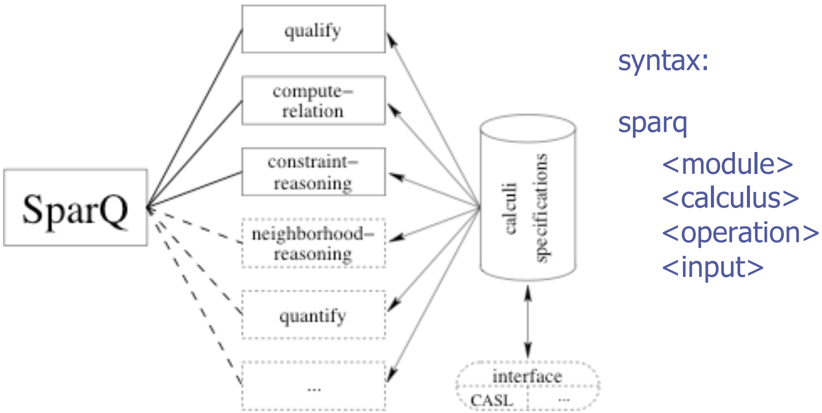


Fig. 7. Modular SparQ architecture. Operations in different qualitative reasoning calculi can be evoked through standardized commands.

SparQ performs a number of operations that are helpful for dealing with spatial calculi:

- Qualify: quantitatively described configurations are translated into qualitative relations;
- Compute-relation: this operation generates a qualitative inference for a given calculus based on the premise relations and the calculus specification;
- Constraint-reasoning allows for the specification of an inference strategy on a given spatial configuration and returns scenarios that are consistent

[1] www.sfbtr8.spatial-cognition.de/project/r3/sparq/

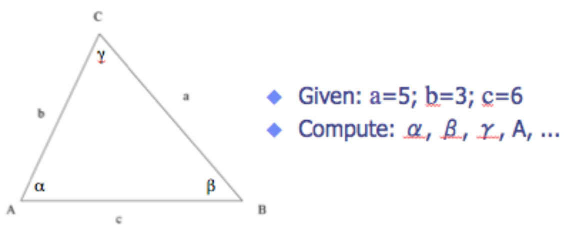
with the configuration; if the description of the scenario is inconsistent, SparQ informs about the inconsistency;

- Neighborhood-reasoning enables conceptually graceful constraint relaxation and yields semantically meaningful neighboring inferences;
- Quantify: this transformation is still in an experimental stage; the goal is to generate prototypical 'general' pictorial instances of abstract qualitative descriptions.

Although it is helpful to have a variety of calculi available in uniform specification and interface languages, there is still an issue about which calculus to use to solve a given task. Thus, there is a challenge to understand and describe spatial calculi on the meta-level in such a way that we can specify the given spatial configurations and the desired task solution in such a way that the available calculi can be automatically configured to solve the task.

From Spatial Relations to Spatial Configurations.

Quantitative computation of spatial configurations by means of Euclidean geometry is well understood. For example, in planar geometry, we can compute all angles, heights, and the area of arbitrary triangles, if the lengths of the edges of the triangles are given by means of the formulae depicted in Fig. 8.



$$\alpha = \arccos\left(\frac{b^2+c^2-a^2}{2bc}\right)$$
$$\beta = \arccos\left(\frac{a^2+c^2-b^2}{2ac}\right)$$
$$\gamma = \arccos\left(\frac{a^2+b^2-c^2}{2ab}\right)$$

$$A = \frac{1}{2}ah_a = \frac{1}{2}bh_b = \frac{1}{2}ch_c,$$
$$h_a = c \cdot \sin\beta = b \cdot \sin\gamma$$
$$h_b = a \cdot \sin\gamma = c \cdot \sin\alpha$$
$$h_c = b \cdot \sin\alpha = a \cdot \sin\beta$$

Fig. 8. Formal abstraction of geometric relations in the Euclidean plane.

These formulae are valid for planar spatial configurations independently of position, orientation, scale, or other influences. The reason for this is that in comparison to many other domains, spatial relations in the physical environment conform to strict internal laws that are not affected by contextual influences from other modalities. In other words: only few constraints need to be specified and all spatial relations are determined.

The principle is well known from constructive geometry. For example, on a flat sheet of paper, we can construct exactly two triangles from the specification of three edges, provided the specified lengths conform to the triangle inequality. In this construction, compass and ruler are capable of qualitative representation and they exhibit certain abstraction capabilities: the compass represents a length equal to some given length and can apply this length abstracting from location and orientation. Similarly, the ruler represents a distance and can apply it to any pair of points, independently of orientation and location (within practical bounds).

Preserving Spatio-Temporal Structure.

Although the formal abstraction shown in Fig. 8 is capable of generating arbitrary spatial relations through abstract computation, the abstraction mechanism does not preserve spatial structure in the way neighborhood-based representations preserve the domain structure. Structure-preserving representations have the advantage that essentially the same operations can be applied to the representation as to the represented domain. For example, on a geographic map we can navigate much like in the geographic environment with the advantage that we much more easily can maintain an overview and that we do not need to cover large distances.

As a consequence, structure-preserving representations are advantageous at least for those situations in which humans use the representations; this is the case for assistance systems, for example, where spatial and temporal representations are employed as human / machine interfaces. Humans can carry out zooming operations by moving towards or away from the representation medium; at the same time they can perform refining and coarsening operations; they can perform perspective transformations by looking at the medium from different perspectives; they can aggregate and partition spatial regions by making use of the natural neighborhood structures; they can move across the medium much like in the represented domain and they can experience spatial and conceptual transitions while doing so; structure-preserving media also may support shape transformation operations in similar ways as in the represented domain.

Are there further reasons for exploring structure-preserving representations besides the convenience for human users? I believe so. The operations described in the previous paragraph are important operations not only to be carried out by humans, but for spatial and temporal structures, in general; thus, structure-preserving representations also may be advantageous for machine processing. We will come back to this consideration in the next section.

Structure-preserving representations exploit structural correspondences between the representation medium and the represented domain. Geometric / diagrammatic constructions on a piece of paper may serve as structure-preserving representations of space, since flat paper provides the universal spatial structure that guarantees the correctness of trigonometric relations in a planar domain. Fig. 9 depicts universal correspondences between geometric functions in plane spatial structures.

Computation by diagrammatic construction is a form of *analogical reasoning* [c.f. Gentner 1983]: the basis for establishing analogies is given through the universal spatial interdependencies that justify the comparison between the source domain and the target domain; the analogies usually concern the abstraction from specific values in the domain. Nevertheless, geometric constructions are sequential constructions that are most easily described by classical algorithms and procedures.

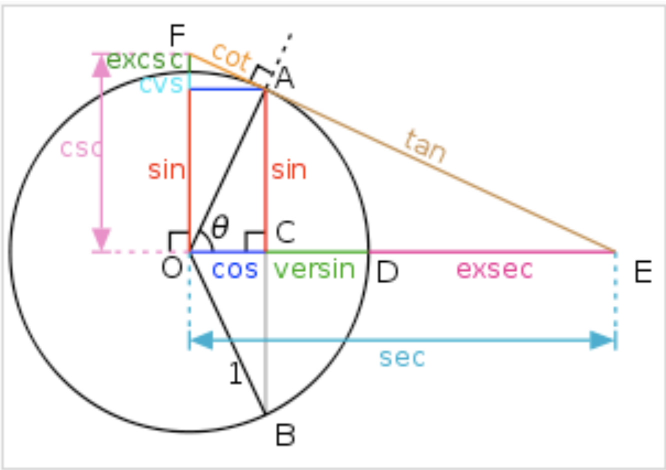


Fig. 9. Spatial construction of geometric functions. The graph depicts interdependencies of geometric relations. All trigonometric functions of an angle Θ can be constructed geometrically in terms of a unit circle centered at O.

Space as Computer.

In his book *Rechnender Raum* (Computing Cosmos / Calculating Space) (Zuse 1969), the computer pioneer Konrad Zuse discussed the issue of structure correspondence between computational representations and the physical domain. He addressed the issue on the micro-level of discrete vs. continuous structures, maintaining that discrete representations only approximate continuous structures and mimic random deviations rather than replicating the physical laws of quantum mechanics.

We want to discuss the idea of structure correspondence on the macro-level of spatial configurations and carry the notion of diagrammatic construction one step further, in this section. Suppose we apply three line segments to a flat surface as shown in Figure 7:

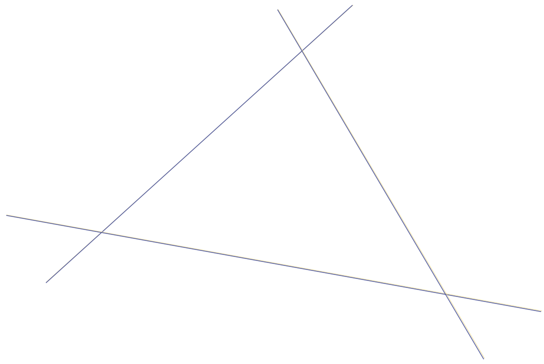


Fig. 7. Three line segments are applied to a spatially structured domain. Numerous specific entities and relations are established through the interaction of these lines and the constraints of the domain: nine new line segments, twelve angles, a triangle, its area, etc.

What do we see in this figure? We can easily identify nine additional line segments of specific lengths, three line intersections at specific locations, twelve specific pairwise identical angles, one triangle with a specific area, and numerous relations between those entities.

Where did all these entities and relations come from as we only placed three simple straight lines onto the surface? One way to answer this question is: The flat surface *computed* these entities and relations according to the laws of geometry. This would be the type of answer we would give if we would give a computer the line equations and the procedures to generate the mentioned entities and relations. What is the difference between the computer approach and the flat paper approach?

The computer algorithm encodes knowledge about the spatial structure of the surface that enables its interpreter to reconstruct in a sequential procedure step-by-step certain abstractions of its spatial structure that are constrained by abstract representations of the lines and their relationships. On the other hand, the flat surface itself and its spatial structure relate directly and instantly to the lines and generate the entities and relations without computational procedure by means of the inherent structural properties. If we are interested in the new entities and their relationships, we merely need to read them off the surface.

The different approaches to generating spatial inferences are shown in Figure 8.

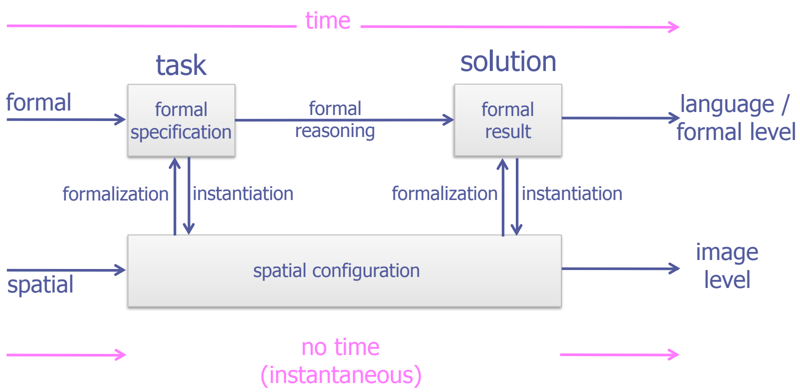


Fig. 8. Two approaches to generating spatial entities and relations: in the upper part of the figure, a classical sequential computational approach transforms a formal specification of a spatial configuration by means of formal reasoning into a result in terms of a formal language. In the bottom part of the figure the configuration is applied directly to a spatial structure; the spatial structure manifests additional entities and relations that can be read off by perceptual processes. Transformations between the intrinsically spatial structures and their formalizations are possible at various stages.

The formal procedural approach to computing spatial relations is shown in the upper part of the figure; the approach that applies spatial structures directly and instantaneously is shown in the bottom part of the figure. The intrinsically spatial and the formal representation can be transformed into one another; this allows applying (intrinsically) spatial computation to formal specifications and formal procedural approaches to intrinsically spatial representations; similarly, the results of either approach can be exhibited either in a formal or in a spatial representation.

Basic Entities of Cognitive Processing.

In geometry, the spatial world can be described in terms of infinitesimally small points; lines are viewed as infinite sets of points that conform to certain constraints, etc. In contrast, in cognition, basic entities usually are not infinitesimally small points; instead, they may be entire physical objects like books or chairs. The basic entities carry meaning related to their use and function and we perceive and conceptualize them in their entirety even if certain details are not accessible to our perception. It is known that we can apply simple mental operations, e.g. mental rotation, to simple spatial objects at once.

The cognitive apparatus appears to be flexible as to which level in a huge hierarchy of part-whole relations to select as ‘basic level’ [cp. Rosch, 1978]; the cognitive apparatus also appears to be able to focus either on the relation between an object and a configuration of objects, or, alternatively, on the relation between an object an its parts. Both transitions involve cognitive effort, while the mere consideration of the basic level appears almost effortless.

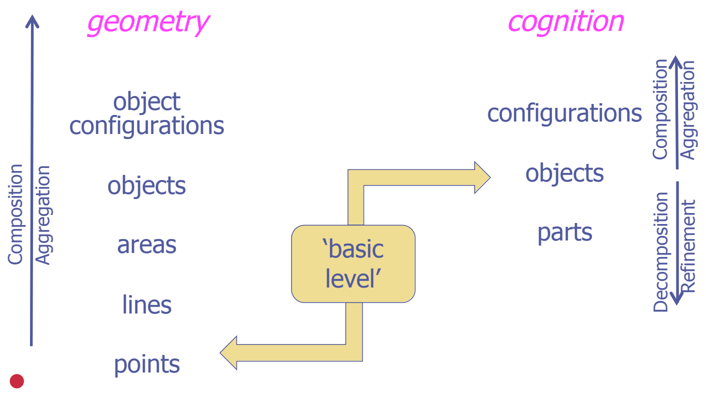


Fig. 9. Two ways to conceptualize physical objects. In geometry (left side), we build arbitrarily complex structures from atomic point entities. In cognition, the basic entities are complex, meaningful entities; through cognitive effort, basic entities can be decomposed into more elementary entities or aggregated into more complex configurations.

Concrete versus Abstract Computation.

The approach presented in this paper follows up on the considerations presented at the Las Navas Advanced Study Institute on *Cognitive and Linguistic Aspects of Geographic Space* twenty years ago (Freksa 1991): abstractions are extremely useful for computation and for understanding general principles; however, it may be highly advantageous to maintain essential structural properties, rather than abstracting from them and recreating them by formal reconstruction (cp. Fig. 10). Abstraction is an excellent preparation for reasoning *about* certain features and structures and to generalize; but using features and structures does not require abstraction (cp. Furbach et al. 1985).

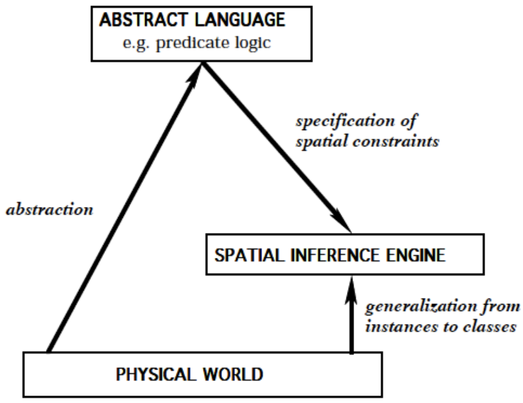


Fig. 10. Spatial inference engines can be constructed by constraining very abstract formalization languages or by generalizing over the physical world. (from Freksa, 1991).

Conclusions and Outlook.

Let me come back to the spatial problems that I used in the beginning of the chapter to introduce various perspectives on spatial challenges. A main message of this exercise is that spatial problems consist of more than solving equations. First of all, a spatial problem needs to be perceived as one. Second, it needs to be represented as one. Here we have lots of options, as there are many ways to conceive of space and of representing space. For example, space may be conceived of as empty space "what is there if nothing is there" or the space spanned by physical objects. Space can be described in terms of a multitude of reference systems as becomes evident if we look at the multitude of spatial representation systems and calculi we can develop. All these representations have benefits and disadvantages, depending on the problems we want to tackle or the situations we want to describe.

Nevertheless, spatial structures – and to a somewhat lesser extent – temporal structures appear to play special roles in everyday actions and problem solving. Many other dimensions seem to dominate our lives: monetary values, quality assessments, efficiency criteria, social structures, etc. – but do they play comparable roles with respect to cognitive representation and processing? I do not think so. I propose that this has to do with the fact, that internal representations may be a-modal, but they cannot be "a-structural". In other words: Cognitive representations and processes depend on a spatio-temporal substrate; without such a substrate, they cannot exist. But they may not depend on a specific spatio-temporal substrate: a multitude of structures may do the job – in some cases better, in some cases worse. Different abstractions from physical space may be advantageous in different situations.

Space and time provide fundamental structures for many tasks cognitive agents must perform and for many aspects of the world that they can reason about. Maintaining these structures as a foundation simplifies many cognitive tasks tremendously, including perceiving, memorizing, retrieving, reasoning, and acting. This is well known from everyday experiences as using geographic maps for wayfinding. For other domains it is helpful to create spatially structured foundations to support and simplify orientation; for example, spatial structure is the basis for diagrams that help us reason about many domains.

A conceptually simple implementation of a truly spatial computer could be a robot system that manipulates physical objects in a spatial domain and perceives and represents these objects, the configurations constructed from these objects, and the parts of the objects as well as their relations from various orientations and perspectives. A more sophisticated approach would involve the construction of a (visuo-?) spatial working memory whose basic entities are entire objects, rather than their constituents. Spatial operations like translation, rotation, and distortion would globally modify configurations. Perception operators extract qualitative spatial relations from these representations. The development of this implementation can be guided by our knowledge about working memory capabilities and limitations as well as by our knowledge about spatial representations in the human brain.

A final Note.

Although we talk about spatial cognition, spatial reasoning, and spatial computing, we frequently fail to characterize the type of solution to spatial problems that we want to achieve. However, our repertoire of approaches yields results on different levels of sophistication: some approaches yield solutions to spatial problems, others yield some sort of explanations along with the solutions, like 'this is the only solution' or 'this is one of possibly several solutions' or 'these are all solutions.

Why is sophistication an issue? For highly abstract, formal approaches, the quality of a solution is not obvious. Formal proofs and / or explanations are required to characterize the type of solution. In the more concrete, spatially structured solutions, the solutions are more easily perceptible, more obvious – proofs may not be required; on the other hand: can we be *sure,* that we found the best solutions, the only solution, all solutions? This is an old debate that reminds of the discussion on the validity of constructive geometry to find solutions or to prove their correctness.

Apparently, there are different domains in which we can ground our knowledge: perceptual experience about spatial and temporal environments and formal logics that does not require empirical justification. Both domains are important for human experience and human reasoning. It does not make much sense to say one is superior over the other; they are two rather different realms. They become particularly powerful when they are engaged jointly: one to carry out spatio-temporal actions and the other to reason about them and to explain what's going on in an overarching theory.

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Visibility-based Floor Plan Design – The Automatic Generation of Floor Plans based on Isovist Properties

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Abstract. *This article addresses the computer-based generation of spatial configurations. It examines how visibility properties can be integrated into the generation of layouts. For this purpose two different experimental approaches are presented. Both approaches are discussed with respect to their potential for the future development of automated floor plan generation based on the experiential qualities of space.*

Keywords. Generative Design Methods, Spatial Configuration, Isovists, Evolutionary Algorithms

Introduction

In the following article, we have drawn on an idea put forward by Benedikt [1] to generate spatial configurations on the basis of visual fields. Benedikt formulates this concept as follows: *"One might well ask: when is it possible, given one or more isovist fields (...) to (re)generate E [the spatial configuration] as a whole? (...) a direction seems clear: to design environments not by the initial specification of real surfaces but by specification of the desired (potential) experience in space (...)."* (Benedikt [1], p.63)

A spatial configuration describes an environment structured by limiting surfaces in which humans move or reside. The development of methods for the automatic generation of spatial configurations, and building floor plans in particular, is an important application area of artificial intelligence in architecture. Among the criteria commonly used for the automatic generation of floor plans are the size of rooms, their orientation with respect to sunlight and their adjacency to other rooms. Examples of their use can be found in Arvin and House [2], Elezkourtai [3], Li et al [4], Michaelik et al [5], Medjdoub and Yannou, [6], König and Schneider [7].

In the methods developed so far, comparatively little attention has been given to criteria that relate to the experience of space. Such criteria include, for example, the visual relationship between spaces or their character (open-closed, orderly-chaotic) and play a crucial role in the usability and quality of buildings. To integrate such criteria into generative methods, one needs to be able to describe them in quantitative terms. At the present time there is no definitive method for comprehensively and unambiguously quantifying the experience of spaces, however, a few methods have been developed

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that can be used to quantify some experiential aspects. Of these we will examine visual field analysis in the following section. Approaches that incorporate such analysis in the generation process are presented in the third section.

1. Quantifying the visual properties of space using isovists & isovist fields

People experience space through their senses, and the sense of vision in particular. These properties of spatial configuration, experienced by the sense of vision, are referred to as visual properties and are mainly influenced by two factors: the surface characteristics (materials, textures and colour) and the arrangement and size of the boundaries. Boundaries such as walls and ceilings regulate movement patterns (Hillier [8]) and define what you see or don't see from a specific point of view.

One method for measuring visual properties associated with a particular arrangement of boundaries is to use fields of view (isovists). An isovist (also known as a viewshed) relates to the part of an environment that can be seen from a single observation point [1]. Isovists are an *"intuitively attractive way of thinking about a spatial environment, because they provide a description of the space 'from inside', from the point of view of individuals, as they perceive it, interact with it, and move through it." (Turner et al [17], p. 103).*

To calculate an isovist, a certain part (the region *D*) of the theoretically infinite, Euclidean space E^3 is chosen (see Figure 1, left). Inside *D* there are boundaries: objects or surfaces that limit our ability to see unhindered. The sum of these boundaries constitutes an environment *E* (see Figure 1, middle) which can be equated with the term "spatial configuration" defined in the introduction. An isovist *Vx* describes the area within D, which can be seen from a particular viewpoint *x*. This area is always a single polygon without holes. The perimeter ∂V (in the following refered to as *P*) of *Vx* can be divided into three distinct components: (1) *Sx*: the field of view bounded by surfaces within E (2) *Rx*: the edge of the field of view not bounded by physical surfaces and (3) ∂ *Dx*: the field of view where it meets the borders of *D* (see Fig 1, right).

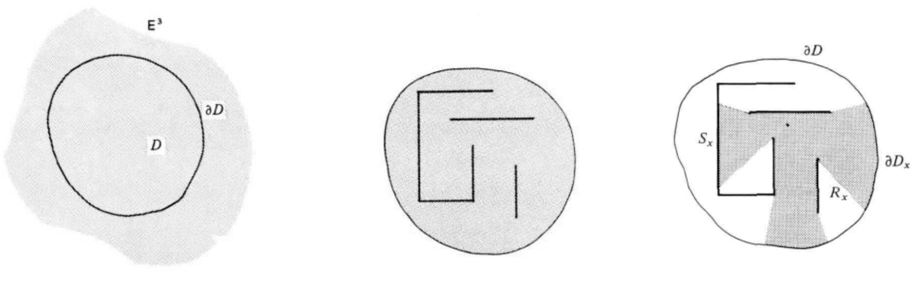


Figure 1. Left: a region *D* in Euclidician space E^3; centre: a spatial configuration (Environment) *E* within *D*; right: an isovist *Vx* and its perimeter ∂V which can be divided into 3 components: Sx (bounded by physical boundaries), *Rx* (not bounded by physical boundaries) and ∂Dx (bounded by the limits of *D*) Source: Benedikt [1].

Isovists can be calculated in different ways. Benedikt describes a calculation method based on rays which scan the environment for intersections. The Isovist *Vx* is specified as a set of lines, which are defined by the viewpoint and their intersection with the closest boundaries. Based on these endpoints, the length of the lines and the previously mentioned different components (*Sx, Rx, Dx*), various parameters are derivable that can be used to describe a field of view. These include the *area*, which describes how much can be seen from a particular point of view, the *perimeter*, which in relation to the area gives a measure of the *compactness* of the visual field, *occlusivity* that counts the sum of the length of open edges (not touched by physical boundaries), and *MinRadial* and *MaxRadial* which describe the shortest and longest distance from *x* to *E*. A detailed description of the formulas for calculating these parameters is not part of this paper, but a very good and concise summary of this can be found in Conroy [9].

The analysis of a single isovist provides information about a spatial configuration from one viewpoint. To evaluate an entire spatial configuration it is necessary to look at a configuration from more than just one viewpoint. To this end Benedikt proposes the creation of Isovist fields. The computer-aided calculation of Isovist fields is described by Batty [10]. A regular grid is generated for a certain *D*. For each point in this grid an isovist is calculated. The properties of these multiple isovists can then be represented by means of false colours. Dark points refer to low, light points refer to high values (see Figure 2).

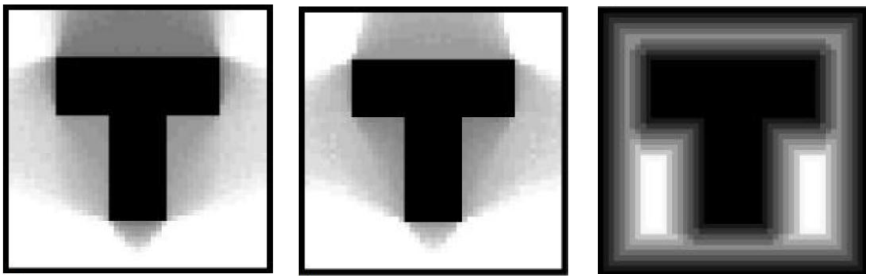


Figure 2. Isovist fields for a T-shape, left: the area; centre: the perimeter; right: MinRadial; Source: Batty (2001)

By using isovist fields it is possible to extract certain patterns or extreme values of the configuration as a whole. This makes it possible to easily find the locations within a floor plan that are most visible.

The experiential and behavioural dimensions of isovist properties are not yet fully understood (Franz [11]), but in empirical studies various correlations between those properties and the actually perceived spatial experience have been found. Franz and Wiener [12] showed, using VR experiments, that area, compactness and occlusivity correlate highly with how test persons rated the perceived beauty, complexity and spaciousness of a configuration. Furthermore, they showed that the subjects were able to find points in a configuration with the largest and smallest field of view. Conroy [9] and Wiener et al [13] found that isovists capture information that is relevant to wayfinding behaviour, especially when it comes to deciding where to go next. Stamps [14] deals with the description of enclosure by means of isovists. He notes that occlusivity alone is not sufficient to describe enclosure, since the distance of the viewpoint to the surrounding walls plays an equally important role.

Let us now come back the question raised at the beginning of the article: if we assume that it is possible to make statements about the experiential qualities of a configuration, it should in turn be possible to derive a configuration for an intended spatial experience. This question is examined in the next section using two experimental approaches for the generation of floor plans.

2. Generating floor plans based on isovist properties

For the generation of floor plans, we use an optimization method based on evolutionary algorithms (EA), which are well suited to our purposes due to their flexibility. To arrive at a solution with certain properties, no a-priori patterns for guiding the search process are necessary (Rechenberg [15]). The parameters that span the search-space are varied according to a certain stochastic process.

The two essential components of a generative system based on EA are the generative mechanism (GM) and the evaluation mechanism (EM). The GM serves to generate variants. This mechanism is based on a model that represents the particular problem in an appropriate manner. In our case, this model must be able to generate geometric representations of two-dimensional floor plans. Ideally, one would use a model from which any geometric layout variant can be generated but, due to the immense number of possible solutions, this would increase the computing time to an impractical level. Rules must, therefore, be defined that both permit a wide range of potential solutions and keep the search space as small as possible.

The EM of an EA is used to evaluate the variants produced by the GM. The way these variants are evaluated is described by a so-called fitness function. This function defines the qualities that the desired solution should have. In the context of this article, these qualities are described by means of minimizing or maximizing certain isovist properties. In the following section, two experimental approaches for generating floor plans using selected isovist properties are examined. The first incorporates visibility-optimization into an existing approach for the generation of floor plans. The second approach is an attempt to derive a configuration directly from the isovist properties.

2.1. Optimisation based on the properties of isovist fields

The approach presented in this section is a two-tiered approach based on an existing algorithm for creating rectangular floor plan layouts (see [3] and [7]). In a first step, the configurations with basic features are created. In the second step, these configurations are optimized with respect to visibility properties.

The first step consists of the positioning and dimensioning of rectangles within a given rectangle. The criteria applied aim to achieve a dense packing of the rectangles while maintaining desired neighbourhood relations (see figure 3). The underlying principles for solving this optimization problem, as well as details about EA will not be examined here and are described in detail in [7].

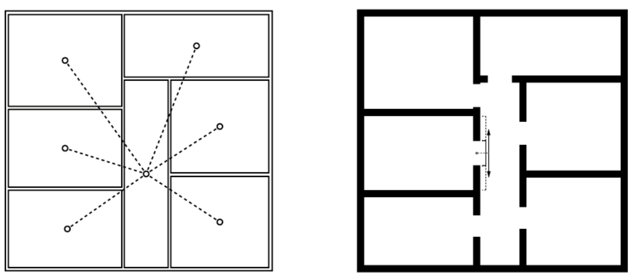


Figure 3: Left: typical result of the algorithm with a star-shaped topology Right: representation of the floorplan, whereby the position of the doors is variable to a certain extend.

The floor plans produced by this algorithm exhibit a dense and non-overlapping arrangement of rectangles within a rectangular container. Rooms that should be adjacent are arranged so that they border one another along a certain minimum length. Connections between rooms, such as doors or openings, can be created along this joint border. The generated floor plans are then used as a basis for further optimization using a fitness function for maximizing the average value for the area of the isovist field (mean isovist area: mIA). The function for an individual *I* can be represented formally as follows:

$$f_{(I)} = \left| \mathrm{mIA} - tA \right| \; ; \qquad \mathrm{mIA} = \frac{\sum_{i=1}^{n} Av_i}{n}$$

whereby *i* is the index of a cell in the isovist-field and *tA* is the target value for *mIA*.

Variants for the optimization process (GM) are created by changing the position of the doors. The geometric arrangement of rectangles is not changed, so that the criteria used for the first step remain fulfilled. The results of the optimization process are shown in figure 4. In the top row the original plans are shown, in the bottom row the configurations after isovist field optimization.

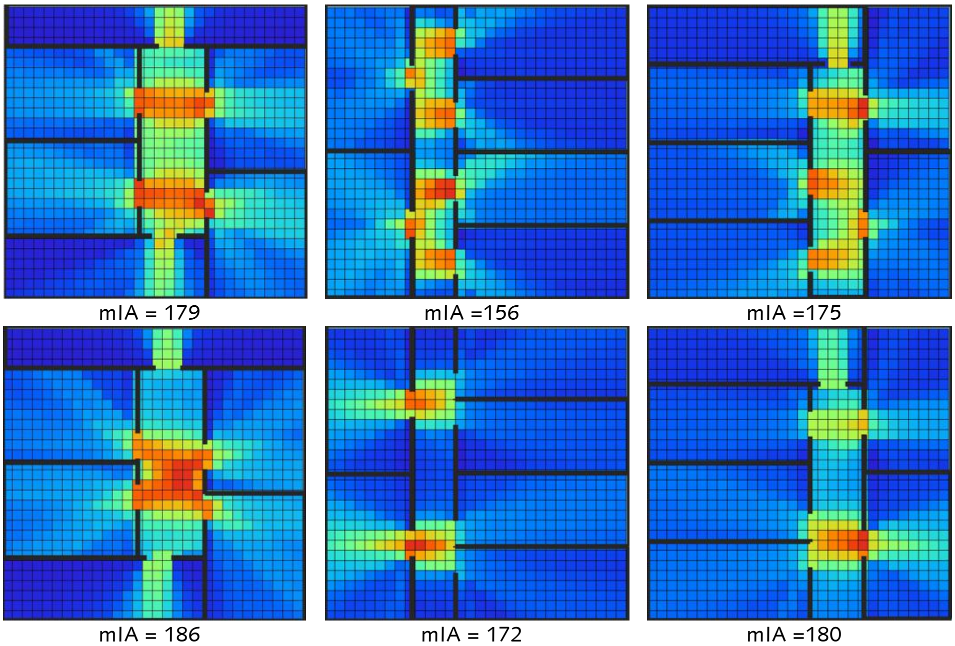


Figure 4: 4 different floor plans consisting of 7 rooms and a star-shaped topology before visibility optimization (top row) and after (bottom row). tA was set to 200, to maximize the mean isovist area of the isovist field of the configuration.

2.2. Generating Configurations on basis of single Isovists

The second approach presented here uses a simpler model for the generation of configurations as the first approach does. The model consists of a regular grid, in which horizontal and vertical lines can be “switched on and off” (see fig. 5).

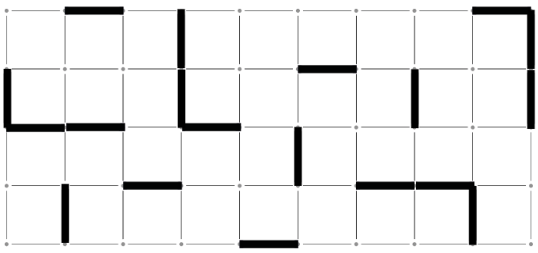
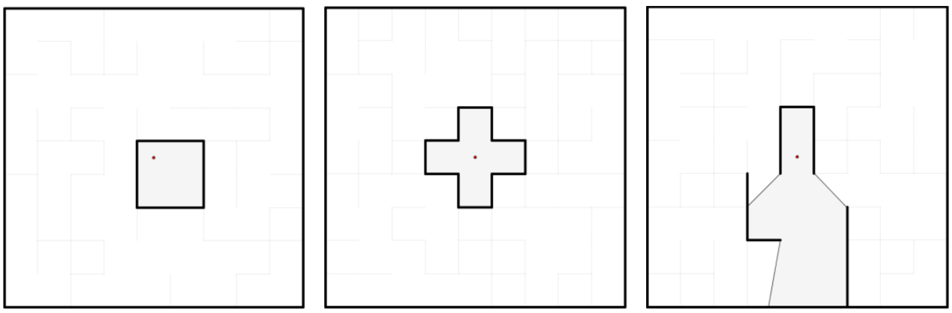


Figure 5: The generative mechanism uses a grid with horizontal and vertical lines (a similar approach is used in Krämer & Kunze [16])

The EM evaluates the resulting configuration from a single viewpoint. This view point is fixed and must be defined before the optimization process. The fitness criteria are area, perimeter and occlusivity. It is intended to define the shape and size of the rooms by these criteria. By mutation or recombination, horizontal or vertical lines of the individuals are switched on and off until a satisfactory solution is found. The target-function for optimizing the configuration is to minimize the deviation from the target values for Area (*tA*), perimeter (*tP*) and occlusivity (*tQ*) of the viewpoint. The deviations are normalized in the fitness function and can be weighted individually.

$$f_{1(I)} = |A_{Ix} - tA| \cdot wA \; + \; |P_{Ix} - tP| \cdot wP \; + \; |Q_{Ix} - tQ| \cdot wQ$$

wA, *wP* and *wQ* relate to the weights for summing the deviations from the target values in the fitness of an individual. In Figure 6 exemplarily solutions for different target values and weights are shown.



tA = 200 (A ~ 180)	tA = 200 (A ~ 224)	tA = 500 (A ~ 504)
tP = 50 (P ~ 53)	tP = 80 (P ~ 79)	tP = 100 (P ~ 114)
wQ = 0	wQ = 0	wQ = 0

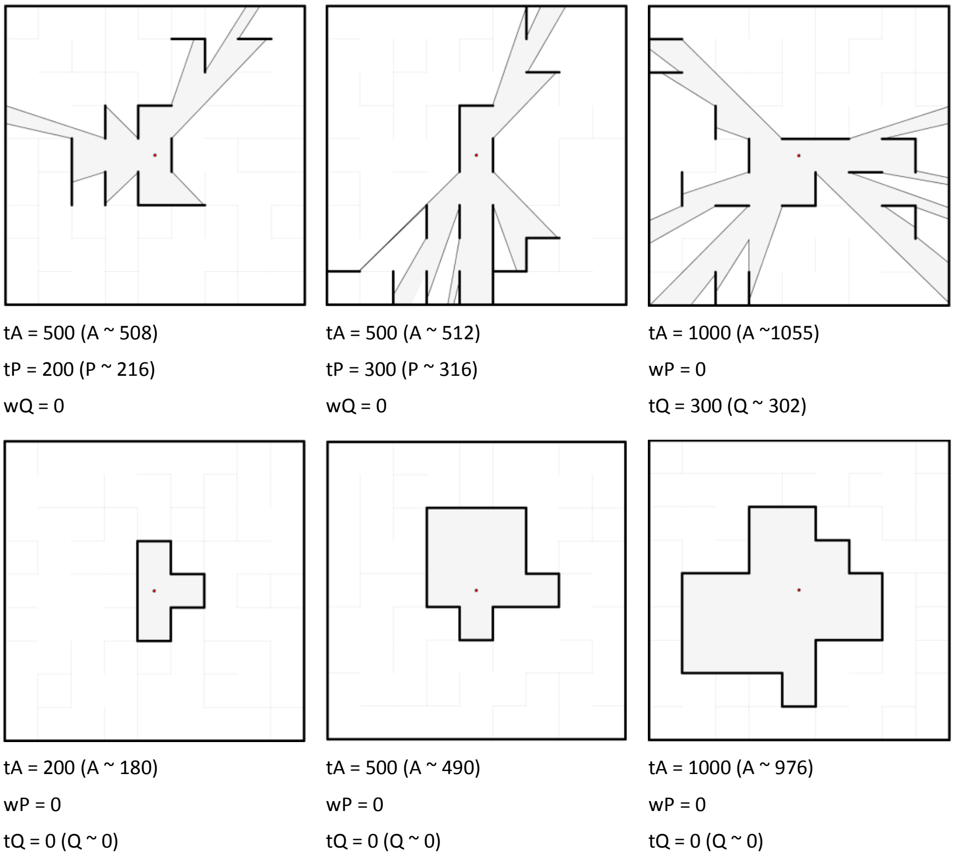
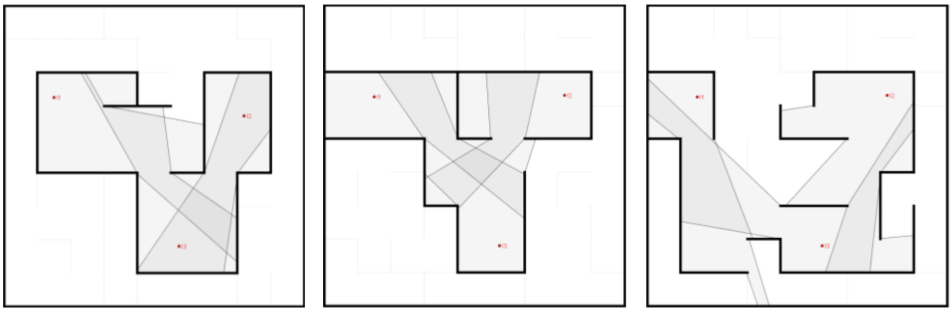


Figure 6. 9 Variants of configurations from a single viewpoint with different target criteria

To define relationships between different areas of a floor plan, it is necessary, to not only define the properties of one isovist, but to also define the relationships between different viewpoints. For this purpose we have extended the system with a further fitness criterion: the area of overlap of multiple isovists. The aim of this extension is to check whether topological relationships (accessibility) can be produced by a purposeful overlapping of isovists. If the isovists of two viewpoints overlap, both points are either directly visible, or mutually visible after moving in direction of the overlapping area (visual step depth <=1). If the isovists do not overlap the viewpoints are only mutually visible after moving 2 times in another direction (visual step depth = 2).

$$f_{2(I)} = f_{1(I)} + \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} \left| Ovlp(Ai, Aj) - tOvlp(i, j) \right|$$

Ovlp denotes the area of overlap between two Isovists. *tOvlp(i, j)* relates to the target value for the area of overlap between two isovists V_i and V_j. In a test scenario we have defined the position of three viewpoints 1, 2 and 3. From these viewpoints, the corresponding isovists V_1, V_2 and V_3 are generated. The target value for the area of overlap of V_1 and V_3, as well as V_2 and V_3 is 300. Between V_1 and V_2 there should be no overlap at all (*tOvlp*(1,2) = 0). Figure 7 shows three exemplary results of the experiment. The target values for area and perimeter were set to 600 (*tA*) and 100 (*tP*). These values make sure to generate rooms with a limited complexity, as shown in figure 6 (first row, third image).



Ovlp(1,2) = 0
Ovlp(1,3) = 318
Ovlp(2,3) = 388

Ovlp(1,2) = 0
Ovlp(1,3) = 332
Ovlp(2,3) = 324

Ovlp(1,2) = 0
Ovlp(1,3) = 338
Ovlp(2,3) = 291

Figure 7. 3 variants for configurations from 3 viewpoints *P1*(top left), *P2* (top right), *P3* (bottom center), whereby the isovists of *P1* and *P2* shall not overlap.

It is worth noting that currently the algorithm is not optimized. Because of conflicting target values the results are often not optimal. According to the above stated question concerning the creation of topological relationships it can be seen in the examples that the resulting “rooms” are not completely closed. So it is possible, that isovist areas which should not overlap (V_1 and V_2) are still accessible to each other. Ensuring topological relationships of rooms can’t only be described by the overlap of isovists.

3. Discussion

Two approaches have been presented, which use visibility-properties as shape-influencing criteria in the automated generation of configurations. Despite the fundamental differences between the two approaches their advantages and disadvantages can be discussed. The first approach optimizes the visibility properties using a two-stage process in the second stage and treated them so hard compared to the secondary criteria. The second approach can be described as "generation from the inside out", as the arrangement of the walls is based primarily on the properties of fields of view.

The first approach is effective for generating conventional floor plans (cellular layout with door openings) because in the generation mechanism basic assumptions are made about the relationship between form and function (one room is a rectangular element, spaces may not overlap, related areas must touch each other). Out of this results a disadvantage with regard to the integration of visibility-properties. Because of the defined assumptions there is only little scope for shaping the configuration through isovist-properties. To influence isovist-properties, only the position of the doors can be changed. This problem is not at least due to the two stages of the process. An integration of visibility-properties in the first stage of generation, however, remains

difficult, because in order to evaluate a solution with regard to these properties, first of all a consistent plan must be present. This is only available after the first stage, because it does not make sense to calculate isovists for overlapping rectangles without doors.
In the second approach isovists have a more direct influence on the arrangement of the walls, because the method for the generation of variants works with only a few basic assumptions. The arrangement of the horizontal and vertical lines is created solely by optimizing the isovist-properties. However, the solution space in this approach is severely limited by the simple model for the generation of variants. The line-grid offers very little scope for fine tuning isovist-properties. Either there is a line or not, it is not possible to vary the lengths of lines, for example, to set specifically dimensioned openings. Additionally it can be noted that between the defined points of view, areas emerge without a clear (functional) assignment.
Regarding the evaluation mechanism, the two approaches differ by the type of using isovists for the evaluation of the configurations. In the first approach, due to the use of isovist-fields, the configuration is evaluated globally using average values. This allows a characterization of the plan as a "whole". The disadvantage here is that an average value of the whole configuration (in our case isovist area) only offers little statements about local spatial qualities. The second approach uses locally defined positions to evaluate a solution. On the one hand this can be regarded as an advantage because it allows one to specifically locate visibility properties. On the other hand, it can be seen as a disadvantage, since the placement of these positions to a high degree determines the achievable results.

4. Conclusion & Outlook

The generation of spatial configurations based on visibility characteristics for us represents an interesting approach for the future development of automated layout design, since here space (more precisely, the graphical representation of space) is generated, starting from its experiential qualities. The two approaches presented in this article, however, represent only first idea sketches how to handle this task.
The presented methods can be further developed on two levels. At the level of the GM, the model for the generation of variants needs to be able to produce a greater variety of different geometric configurations. Here it needs to be noted that in every model, the GM is based on, assumptions are made about how space is represented geometrically. The more assumptions exist in such a model (eg, a room has the shape of a rectangle), the fewer the possibilities are to create the shape of space by the visibility-properties. To derive spatial configurations as directly as possibly from the visibility properties, it is important to use a model for the generation that operates with as few as possible assumptions regarding the shape of spaces. In this sense the model of the second approach seems to be more appropriate, than the one of the first approach. However, it is unfortunate that the second model (line-grid) does not allow any fine tuning of the geometry. This is disadvantageous, since even small geometrical changes can have large effects on the properties of an isovist.
At the level of the evaluation mechanism it is obvious, that the evaluation criteria used are not sufficient enough to comprehensively describe a spatial configuration. The major deficit is in our view, the exclusive use of either local or global visibility properties. Because humans never exclusively perceive space by movement or from a single location, the spatial experience can’t be reduced to neither global nor local

properties. For the EM, we see a promising potential in combining local and global properties. An interesting avenue for further research we see in the usage of "Place Graphs", as proposed by Wiener & Franz [13]. There, the values of the min-radials of the isovist-field are examined on high points and ridges in order to extrapolate the centers of rooms and their connections to each other from a 2-dimensional plan. As additional evaluation criteria it is worthwhile to continue to work with the relationships between different viewpoints. These can at best be analyzed in the form of a graph of mutually visible points (see Turner et al [17]. From this so-called visibility graph, measures, such as integration, clustering coefficient, control and controllability can be derived. A first promising approach to incorporate the integration value in a generative system can be found in [16].

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Architectural Gestures

Conserving Traces of Design Processes

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Abstract. Human wayfinding is a recurring topic in the spatial cognition research community and there exists a considerable number of studies addressing the topic. Nevertheless, results have only occasionally informed architectural design effectively. We present a series of case-based design sessions which explicitly emphasized human navigation and wayfinding. A set of graphical techniques is centered around a transcription/coding methodology for capturing spatial aspects of gestures and sketching on the one hand, and verbal aspects of accompanying speech on the other hand. Spatial aspects of gestures and drawing acts remain in the spatial realm and are thus exploitable for efficient human visual processing. In reference to the biological concept, an image derived from such a graphical analysis process could be refered to as *praeparatum*. The concept expresses the ability of the method to handle complexity without strong theoretical abstractions. At the same time *praeparatum* hints at its potential for scientific exploitation.

Keywords. Architectural Design, Design Cognition, Gesture, Scientific Imagery, Visualization, Praeparatum/Präparat, Expertise

Introduction

Human wayfinding is a recurring topic in the spatial cognition research community and there exists a considerable number of studies addressing the topic. Nevertheless, results have only occasionally informed architectural design effectively: When it comes to practical application, wayfinding research is often in the position to ask architects and planners for collaboration, but is seldom asked by them to support their projects. The question arises why this situation persisted over several decades of research activity.

Some researchers touch wayfinding issues in architectural design: [16] for example identifies factors of architectural legibility, [3] give a prescriptive model for systematic wayfinding design. Architectural design processes have been studied intensively in the Design Cognition community. [1,11]

We present a series of case-based design sessions which explicitly emphasized human navigation and wayfinding. Frequent gesture and drawing activity of our informers required a multi-modal approach for adequately analyzing verbal and spatial qualities of the recorded design sessions.

Design Cognition subsumes a variety of research activities focusing on general or common characteristics of design. The underlying theme builds on (supposed) universal properties underlying all design activity, irrespective of the design domain, "whether it deals with the design of a new oil refinery, the construction of a cathedral, or the writing of Dante's *Devine Comedy*."[1] [10] The previous summary is certainly a strong idealisation, nevertheless it will help to point out the contrasting scientific origins of the present work. The initial, primary objective was to identify and model architectural design knowledge relevant for designing navigable buildings. It was not primarily the intention to inform design or design research on universal characteristics of design. Instead, the presented research is originally dedicated to the wayfinding researcher to understand more of the characteristics and origins of complicated, and easy-to-use buildings. The approach is motivated from an the point of view of an 'outsider' who attempts to get an understanding (and eventually model) a specific, unfamiliar domain.

It is thus not surprising to find our preceding studies [5,6,7] methodologically rooted in knowledge-engineering and expertise modeling frameworks. [9] Although coming with methodological variations from study to study the overarching methodological paradigm can be characterized as case-based expert interviews. Early studies set out with open, only weakly structured interviews, in order to identify relevant concepts and terminology. Follow-up studies employed standardised example cases and active design tasks for investigating the active use of wayfinding specific architectural knowledge in an ecologically valid setting.

Along the way, research methods were confronted with a number of characteristics in the architectural design domain: Initial interviews and corresponding language-based analyses revealed some quantitative evidence for specific aspects: For example, with respect to *user-centered* vs. *building-centered* utterances, *reflection about the design process* itself, as well as whether a passage has an *episodic character*, [7] analyze patterns of co-occurrence in order to reveal differences in perspective depending on the user-specifity of the task currently performed by the expert.

Yet, spoken language is often *informal* and employs *idiosyncratic terminology*. Large proportions of design activity seem to rely on implicit or procedural knowledge and are hard to explicate in natural language. Instead, they manifest primarily in practices and intuitions of our informers. [2] While these properties of expert knowledge are well-described in expertise modeling literature [9], an other fact was especially forming for the subsequent methodological development: Informers frequently produced sketches and employed gestures in order to explicate spatial aspects of their ideas.

The complexity and (partial) informality of spatial content in architectural design activity turned out to be a challenge for traditional, mainly proposition-oriented knowledge modeling approaches. Knowledge elicitation techniques based on language alone, categorizations, card sorting etc. might be suitable for some aspects, but require a discrete a-priori structuring of the domain, e.g. coding schemes, concepts. Yet, the inevitabe abstractions and simplifications rendered these techniques non-credible with respect to their potential to earnestly capture the essence of design activity. To a large proportion, design activity handles complex non-propositional content; abstraction should only be one part of the methods that reasearchers apply to handle it.

Knowledge for design

The intention to avoid premature abstraction in the recording process lead us to a continuous refinement of interview recording techniques. The methodology to be presented here allows to conserve the traces of (cognitive) design processes for future exploitation,

[1] Emphasis in original

which in turn can handle it a-posteriori. Conservation alone is necessary but not sufficient for an effective scientific exploitation. As a second component, there is a need for efficiently accessing the material, again without having to over-reduce the complexity inherent in design activity.

Borrowed from medical or biological professional practices, *praeparatum*[2] is a concept that condenses a number of desired properties: First, it refrains from abstracting individual cases and condensing their properties into generalized representations such as categories or theories. Instead, the properties of an individual are preserved in their full complexity. The individual case is prepared such as to make it explorable under many different aspects potentially relevant in the future. Essentially, the decision of investigative aspects is delayed, while the complexity is made accessible for future aspectualisations. Besides the intention to preserve crucial properties to the maximum possible extend, a second purpose of the preparation process is to emphasize relevant aspects selectively, for example by coloring or selective preservation.

It was argued during the symposion (Ömer Akin; John Peponis) that re-iteration and delay are important components of a successful design process, and further, that scientific evidence could serve as material to be brought into the process in order to transform the state of design affairs. In the same session, the idea of a visual dictionary as a potential format for communicating scientific research results was brought up (Theodora Vardouli). Considering the idea of (inspirational) material in the design process, especially in the light of design as essentially multi-aspectual activity, visual or graphic representations clearly serve the purpose much better than databases or research papers.

In this vein, we present a set of preparation techniques for high fidelity transcriptions of gesture and drawing activity in design. Obviously, it is not the scientific research results themselves that will be dominant in the presented material but rather the reasoning and concetualizations of our architectural design experts. Yet, the technique can be seen as a first step towards a more integrative way of knowledge organisation. Spatial aspects of gestures and drawing acts remain in the spatial realm and are presented graphically. At the same time, accompanying (verbal) speech is visually integrated with the corresponding graphical (re-)presentation; thus exploiting it for human visual processing.

It could be argued that a praeparatum does not perfectly fulfill the criteria of a representation. Without going into the (many possible) philosophical debates on the issue of representation, we would like to make the one argument that it is general practice in architecture to use existing buildings as example cases for future projects. Following the argumentation of [12], architectural practice has the specific capability of finding integrated solutions for complex and ill-defined requirements: It does so relying on a large body of cultural knowledge, represented in the body of existing architectural projects and design experience.

Method

As already mentioned in the introduction, the common methodology of a series of preceding studies [5,6,7] can be subsumed as structured, case-based interviews or design sessions. In the preceeding studies, design tasks had pilot character and served mostly as a trigger for discussion, in order to identify key terminology and essential design con-

[2] german *Präparat* / english *to prepare*

cepts. Here, by contrast, design tasks were tuned to capture active design reasoning practice and are thus based on standardized materials and procedure. There is a considerable refinement with respect to the gesture annotation: In earlier studies, spatial elements were recorded without differentiating the type of gesture used to point it out. The present dataset captures start and stop timing of each gesture act and marks it accordingly in the transcript text. On the spatial side, positions and movement trajectories of fingers and hands are vectorised and overlayed with the standardized materials that served as example cases in the session. As discussed before, it was important to us to have recording and annotation techniques refrain from high level categorisations (and interpretations) but preserve the spatial characteristics and corresponding ambiguities and underspecifications that may be present in the gesture.

Materials and Procedure

Example cases were all presented based on standardized materials, that is plan views of buildings or building sites.

The first two tasks asked informers to complete an incomplete design solution such that a suitable navigation system would be achieved. Thus, the respective plans in the case materials where schematized so as to ommit aspects to be added by the informer in the design session. The second pair of tasks considerably differed from the two first, more canonic design taks: Participants were shown a fully specified plan of an existing building and then where then asked to *anticipate* the navigation behaviour of a person not knowing the building before. Informers were asked to anticipate possible navigation errors, cognitive difficulties, and particularly difficult areas or features of the building. For each of the eight participants the same sequence of navigation targets was to be anticipated. In Case 3, a multi-level departmental university building, participants had to imagine a user trying to find an office room somewhere in the third floor. In Case 4, the Guenne conference centre investigated by [13] served as a scenario. Imagined wayfinding here included a sequence of three search tasks. An important property of this class of tasks is that participants have to anticipate the situation of an individual user with a specific task immersed in the building.

We have argued earlier, that this type of inference is not particularly well supported by plan representations. [6] Our findings in [5] suggest that for experienced architects it is well possible to anticipate the situation of a user in a particular building location, based on an external plan representation alone. Yet, the same study finds this anticipation activity to be limited to a selection of single point locations, suggesting the task to be relatively demanding. It is an open point whether this cognitive demand of such anticipation tasks hints at a perspective shift in the sense of a mental visualization of the users' scenic impression. An alternative interpretation could argue that other demanding processes are involved in the anticipation, such as anticipating the user's available and required information for solving a wayfinding task. Theoretically, it is possible to anticipate visibility relations based on plan view alone without any visualisation of the user's viewpoint or perspective. If this were not the case, two-dimensional approaches such as Visibility Graph Analysis [15] and other space syntax methods [4] would have to be considered of limited value with respect to the visibility situation in a spatial arrangement. To conclude the last arguent, it is plausible to assume that architects visually imagine an immersed user's perspective but this is not necessary for the anticipation of visibility

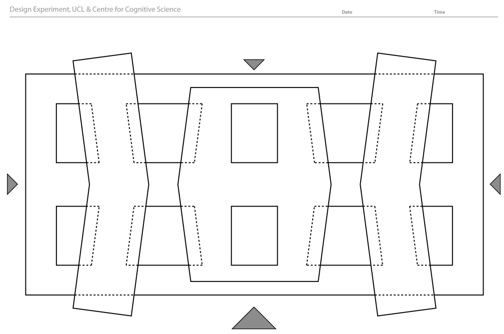

Figure 1. Material for design case 1. Original in A3 format, landscape orientation.

situations in spatial configurations. An article by Tenbrink, Brösamle and Hölscher in the present SCAD 2011 proceedings investigates the perspective issue from a linguistic point of view.

Example Case 1. Overall, there where four different example cases, each for a different task. Since the present paper only presents material from the first task only case 1 will be presented in detail. Figure 1 shows the structure of a hospital building. The building is organized along a lower part grid structure combined with an upper part consisting of three separate blocks on top of the grid. The blocks are only connected via the lower part. The grid structure creates ten open courtyards; eight are partly overhung by the blocks on top; two are within the central block. The overall structure is completely symmetric except for one of the entrances considered as the main entry, indicated by the larger of the four triangles.

Gesture and Drawing Annotation

According to [14], several concepts and terminology can be employed as a methodological foundation: *Gesture phrase* refers to any episode of gesticulation, when at least some part of the body is moving for the purpose of making gestures. Each phrase may contain several actual gestures or *gesture strokes*. The stroke is the constitutional part of a gesture – there is no gesture without a stroke, and what intuitively is considerded as a gesture tends to coincide with the gesture stroke. [14] The stroke is probably best described as the phase of maximal tension or the phase of information delivery, with most characteristic hand movement/shape considering the overall communicative act. Besides, McNeill describes *preparation*, *retraction*, and *hold* phases, which are however not of central interest here.

Transcript. As a first step, the audio stream of the interview sessions was transcribed, without considering the video stream at all.

Phrases and Strokes. The second coding step marks gesture phrases, that is phases where there is gesticulation recogniseable in the view of the camera. Phrases fall into two categories:

(a) Strokes that clearly relate to the plan of the current example case

(b) Mere gesticulation “somewhere in the air” without a clear relation to the plan

Phrases of the second category are annotated in the video, but will not be analysed any further for this paper. Hands starting to gesticulate and returning back to rest after gesticulation are the constitutional criterion for start and end of a Phrase. According to McNeill, nested gesture phrases are possible, especially if some feature or component of an enclosing gesture phrase is maintained while a subordinate phrase can be embedded. Often the enclosing phrase defines a reference frame which is re-used after the embedded phrase has ended. [14] For the sake of simplicity, the present work does not consider nested phrases, mainly because gestures outside the plan reference frame are not considered anyway. If the gesticulating hand leaves the video field of view the phrase is marked as terminating, however with an additional mark indicating a “technical” end; similarly for the beginning. For stroke annotation, phrases are re-visited in order to mark strokes of the first category (a).

For video annotation it is necessary to play the video at different speeds and to mark start and stop timestamps in reasonable precision in the video stream. Here, the commercial video cutting software Premiere was used, which supported fast video playback even with large media files. Timestamps could be marked by a granularity of 25 frames (video images) per second.

Trajectories. The annotated video as produced by the preceeding coding steps serves as the source for determining the trajectories of each gesture stroke: Location and movement of hands and/or individual fingers, pens, hand edges etc. have to be represented as vector graphics. Without going into too much detail here, it can be said that there is roughly a distinction between

(A) single finger/pen strokes (just using the pen as a pointing device)
(B) drawing strokes that actually leave traces on the paper
(C) multi-finger gestures where not the overall hand shape is most telling but individual finger positions or movements
(D) hand gestures where the overall shape of the hand is most important

These can again be different for each hand, that is, a right hand index finger moving can easily be combined with a grasming left hand shape in a fixed position.

Fingers, movement patterns and the integration in the transcript. When trajectories, strokes and phrases are available, this information has to be mapped on the transcript text. Watching the video again, for each phrase and each stroke the according position in the transcript text has to be determined at sufficient precision levels. McNeill suggests to slow down video speed in order to properly determine the sylable where the gesture actually is taking place. [14] Alternatively, playing the audio to or from a fixed position can help determine whether a sertain sound (letter/phoneme) is actually before or after that position. The latter requires the video software to play sounds precisely enough while at the same time reacting instantly to the inputs of the user/coder.

Together with the positions of phrases and strokes, additional data can and has to be stored. At minimum, the timestamp information is recommendable for easily tracking back to the actual video source. Additional codes for hand shapes, finger information, movement patterns[3] is provided for each trajectory element in the gesture.

[3] such as oscillating, repeated or hold etc.

Data integration. An integrated software solution providing all these functionalities (real time video playback, timebased annotation, text based annotation, spatial annotation in graphical material, relation between all these components) was not available at the time the project started. All components coming from different coding phases and relying on different pieces of software have to be integrated in a final automatic processing step. At the time of writing, the software we developed for that purpose was still in a premature beta state so that on the technical side we have to refer to future publications of documentation and manuals.

The software reads annotated transcripts and matches them against timestamp information exported from the video annotation. An integrated XML based format saves text, different types of intervals (such as speakers, phrases, strokes, subsections etc.), timestamps, finger codes, as well as meta information like interview session, informer aliases and so on. Trajectory information is available as SVG files from the coding process anyway. Based on this integrated XML and SVG dataset, an integrated spatial/verbal diagrammatic representation is generated as human readable PDF files.

Obviously, an (additional) interactive mode would be desirable. A predecessor version of the software was based on Inkscape[4] plugins and was used for the analyses of earlier interview studies. [8] Since the present version requires more complex graphics output we had to consider an interactive version as not feasible due to the expected development effort. More importantly, the static PDF transcripts effectively serve the purpose of reference, verification and presentation .

Gesture and Drawing Transcripts

The PDF files provide a compact human-readable external representation, which at the same time supports direct access with respect to temporal and spatial characteristics of the gesture data. (Fig 2) Fifteen or twenty minutes of focused design work are thus compressed into approximately 50 pages of PDF. Flipping through the (electronic) pages, a human viewer can visualy scan this amount of data for gesture types, locations or high level patterns in less than two minutes. It is important to note that this process is ad hoc, meaning that the material needs no further tuning with regard of the respective analytic purpose.

Preliminary and explorative use of the compact PDF format in a research context suggests that the format is suitable for several research purposes: Just as text transcripts are a fundamental step in audio-based verbal analysis, the presented method provides a full-fledged transcript equivalent in the domain of gesture and drawing activity (when two-dimensional reference material is available). Based on the transcript, decisions, considered information, discursive structures, location-centred analyses and the like can be performed, without having to re-analyse the videos again.

Präparate / Preparation

Obviously, the transcripts are an invaluable step for preserving and analyzing design activity. The present paper mostly leaves aside the analytic potential of the method, but focuses on the advantages coming along with the visual and spatial properties of the

[4] An open source vector graphics software, which uses SVG as main file format. It is particularly suitable for the task as scripting extensions can be easily integrated (http://www.inkscape.org/; URL checked 1 Jan 2010).

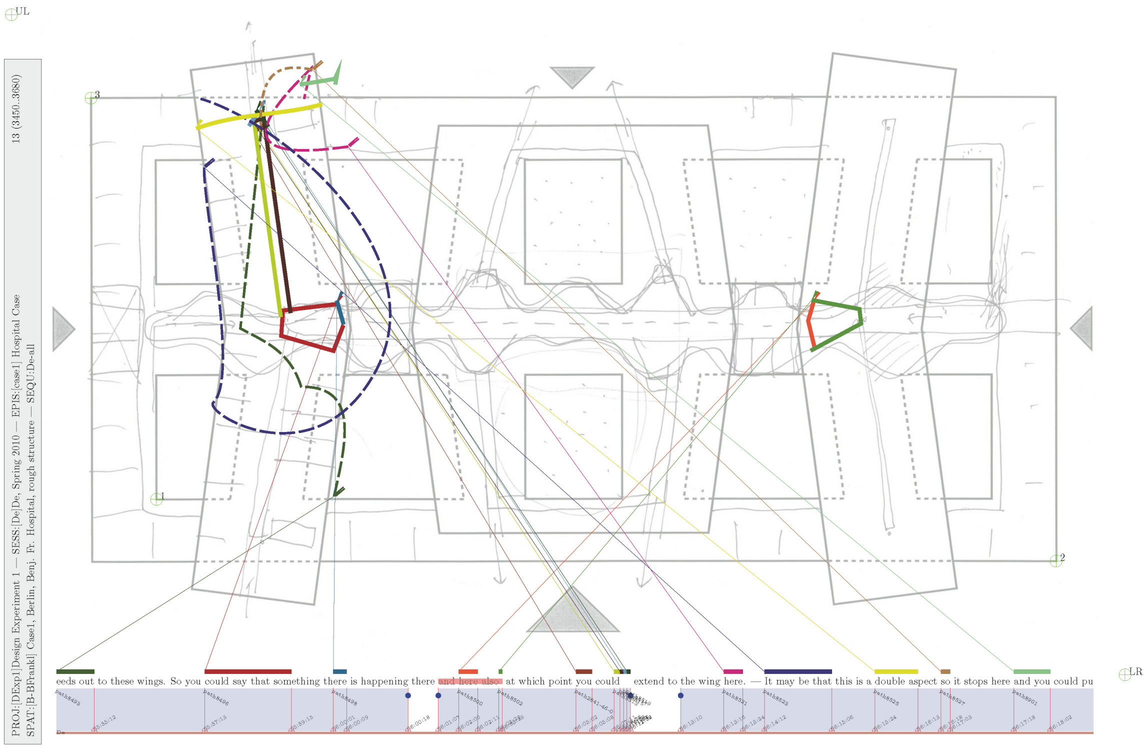

Figure 2. One example page of a raw transcript.

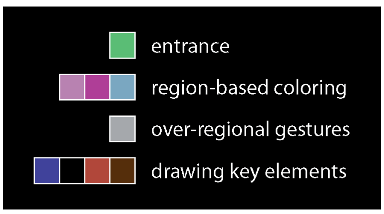

Figure 3. Figure caption.

material. Beyond reading it as a transcript, the PDF output may serve as raw material for extracting and imaging certain aspects of a design episode. A biological or medical praeparatum may be understood similar to a scientific image in the sense that it handles a large amount of complex data by exploiting it for human vision.

Similar to a biological preparation process or other scientific visualisation, color advances from a superficial, arbitrary attribute to a central information-carying component. Color palettes of the raw output had to be sophisticated during software development so as to provide a maximum of distinguishability and recognizability. In the raw stage, colors have no semantics beyond distinguishing subsequent gestures. (Fig 2)

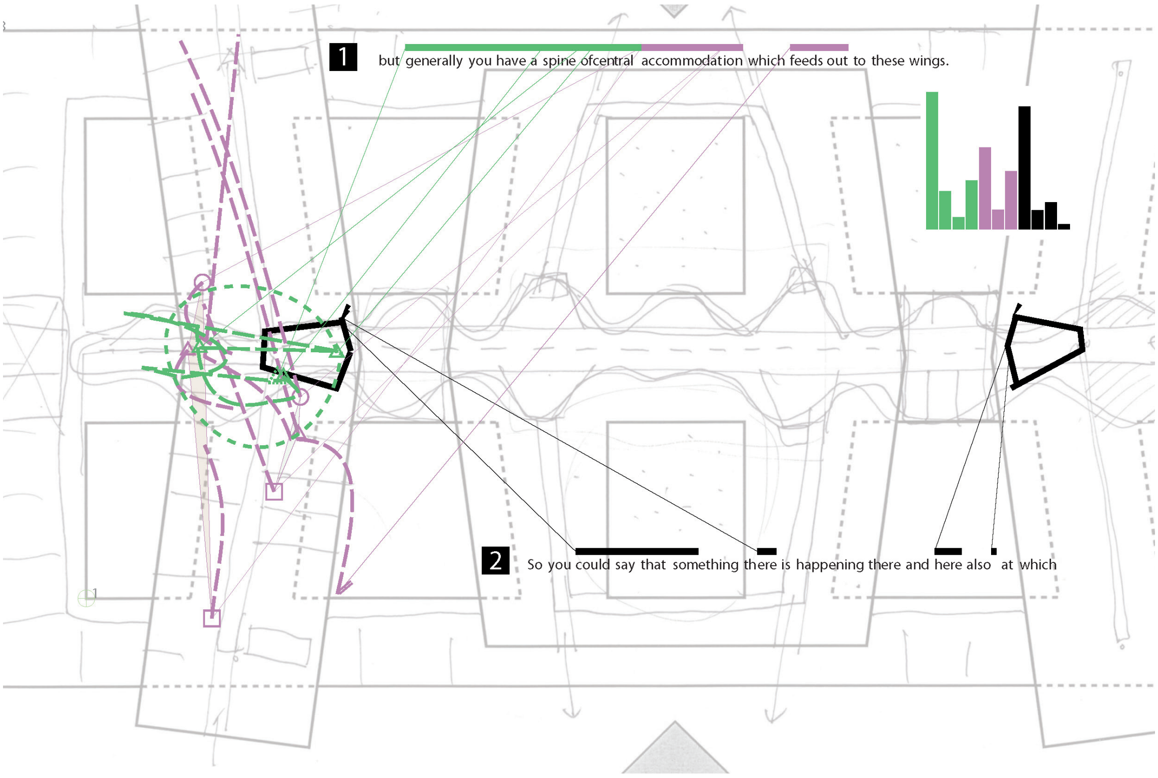

Figure 4. Example 1.

A purposeful re-coloring of the raw material emphasizes or 'prepares' certain aspects in the raw material – for the purpose of demonstration or for providing a particular piece of evidence. Again, color carries the information, which trajectories and other graphical elements belong to the same gesture stroke. Selecting objects of the same color, gestures can be re-grouped into meaningful sets of gestures. Assigning colors to these groups highlights the intented aspects. An important side effect of the grouping by color is that color patterns established in the spatial domain project back onto the text such that spatial movement patterns in the design activity are visible in the sequential pattern of colors.

Traces of Design Activity

This section attempts to give a first impression of the techniques currently under development. Three episodes from three different informers in the course of design task 1 serve as examples, here. All informers have had time to familiarize themselves with the building structure in the example case. Their task was then to "outline a proposal for a circulation system", especially having regard to "the vertical circulation, the transition between the lower part and the upper part". All informers extensively analyzed the example case in order to then develop a solution based on their analysis. Each chosen example episode covers a point where the respective informer makes a forming commitment with respect to the spatial arrangement of the vertical circulation. Typically, this is reflected in the first drawing activity in the area of the main axis in the lower part grid structure.

The focus clearly lies on the overall spatial arrangement rather than on a detailed gesture analysis. For that reason, only the most important elements of the graphical language of the gesture transcripts will be outlined: Gesture strokes are marked as colored bars ontop of the transcript text. The text passage of each stroke is connected with the corresponding stroke trajectory[5] via a straight hair line. Finger movement trajectories in gestures are represented by thin, dashed lines; drawing strokes are drawn as thick and un-interrupted lines. Icons at the beginning of each trajectory indicate hand shapes and finger codes.

Ontop of that the preparation modified/added several things to the raw PDF transcripts: Colors are modified so as to separate gestures based on their spatial location and extension into different areas. Drawing strokes are further distinguished from gestures by assigning dark colors to the former and light colors to the latter. (Fig 3) Line numbers are shown in white on black and were also added by hand. Finally, colored bars ordered in sequential order summarize phases of gesture activity as they derive from the region-based coloring. It is important to note that the color of the gestures was solely defined based on their spatial characteristics. So, the sequential color pattern reflects the spatial dynamics in temporal order.

The following four plates 4, 5, 6, 7 are a first demonstration of the new preparation technique. The first example is based on relatively little material, yet tracking a spatial dynamics in three phases:

1. Green shows gesture activity in a relatively focused location in the plan, where the lower levels' grid-like structure intersects with one of the higher level blocks sitting ontop. Obviously, the area is highly relevant for the design of a multi-level circulation.
2. Lilac highlights the gestures going beyond that part. Sequentially, these gestures precede (!) and accompany the phrase "feeds out to these wings".
3. The black polygones are *drawn* in the third phase and will later become sort of a crystallisation nucleus of the overall circulation outline.

In a similar – maybe less condensed – fashion the two other examples also begin with localist and central areas in order to proceed into more peripheral areas. An overall characteristics is that a first gesture-predominated phase preceeds a second drawing-phase.

In the second example (Fig 5) the informer developed the circulation system beginning from the main entrance (green). The most central core is placed relatively early (black). From there the circulation system develops along key access routes and connections, which is reflected in over-regional gesture activity (grey). As in the previous case, some gestures anticipate the location of the main cores in the blocks (light blue). This gives a hint how spatial dynamics of visit and re-visit patterns can be identified using coloration techniques. In the final phase of the episode, cores and finally the escape stairs are placed in the blocks. (light brown, dark brown).

[5]or hand shape outline (A dash-dotted thick line indicates the edges of whole hand gestures, for example in Figure 5.)

The Figures 6 and 7 show the third and most extensive example. Again, the entrance area and the central block gain most attention in the beginning. Later-on the entrance plays a subordinate role while the central area generally remains important (Fig 6, green, purple, green, light blue). Up to this point, there is no drawing activity. Then the informer marks the area of the central core by drawing a hatched rectangle. An 8-shape indicates the movement opportunities in the central block (black). The most central stairs is placed next (dark blue). Gesture activity still remains in that central part before it feeds out along the main axis (here, drawing and gestures are in light brown). Again, the access cores of the blocks are placed towards the end of the episode, followed by one final step marking the peripheral circulation (dark brown). This last example demonstrates that even a larger amount of overlayed gesture data can be colored appropriately for making it (roughly) comprehensive, even in a static visualization.

Summary

The presented approach can be characterized as a graphical technique for integrating and analyzing multi-modal design protocol data. It is centered around a transcription/coding methodology for capturing spatial aspects of gestures and sketching on the one hand, and verbal aspects of accompanying speech on the other hand. The main advantage of the technique is its great flexibility with respect to future investigations. By vectorizing gestures spatially, the coding process avoids strong theory-driven abstractions or categorizations so that the manifoldness and complexity of the original design session remain in the data.

For purposes of analysis and presentation, the graphical material of the raw transcripts can be *prepared* so as to emphasize relevant properties under investigation. The centrality of the concept *praeparatum* in the presented method reflects the attempt to preserve design in its full complexity without reducing it in theory-driven abstractions. At the same time, praeparatum also refers to the potential for scientific exploitation. In that sense, the technique could be a binding component between the ambiguities in the graphical aspects in the domain of architecture and the requirements for precision and replicability in the scientific realm.

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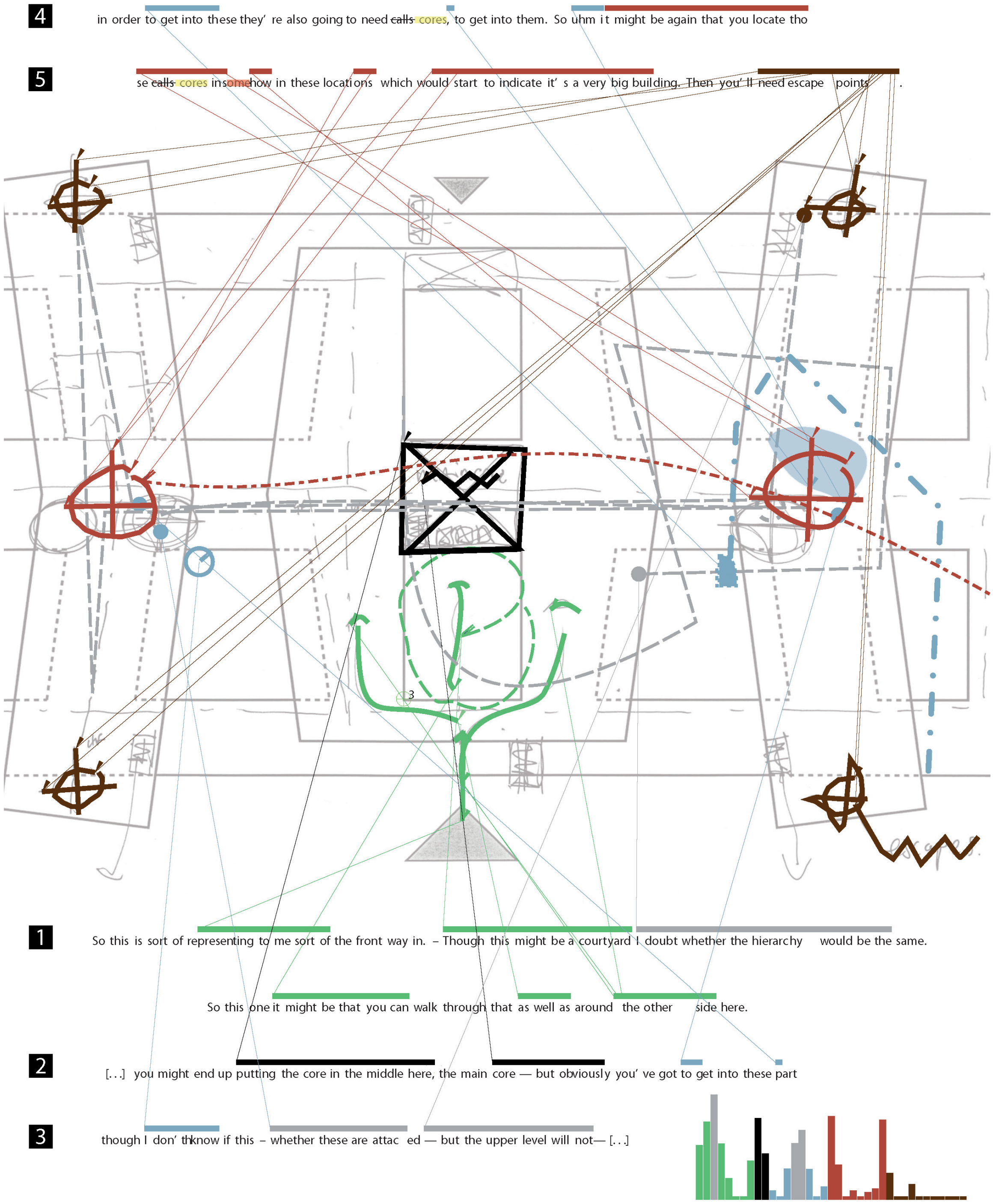

Figure 5. Example 2. Please note that the lower text blocks precede the upper ones. The thick dash-dotted line indicates the outline of a flat hand.

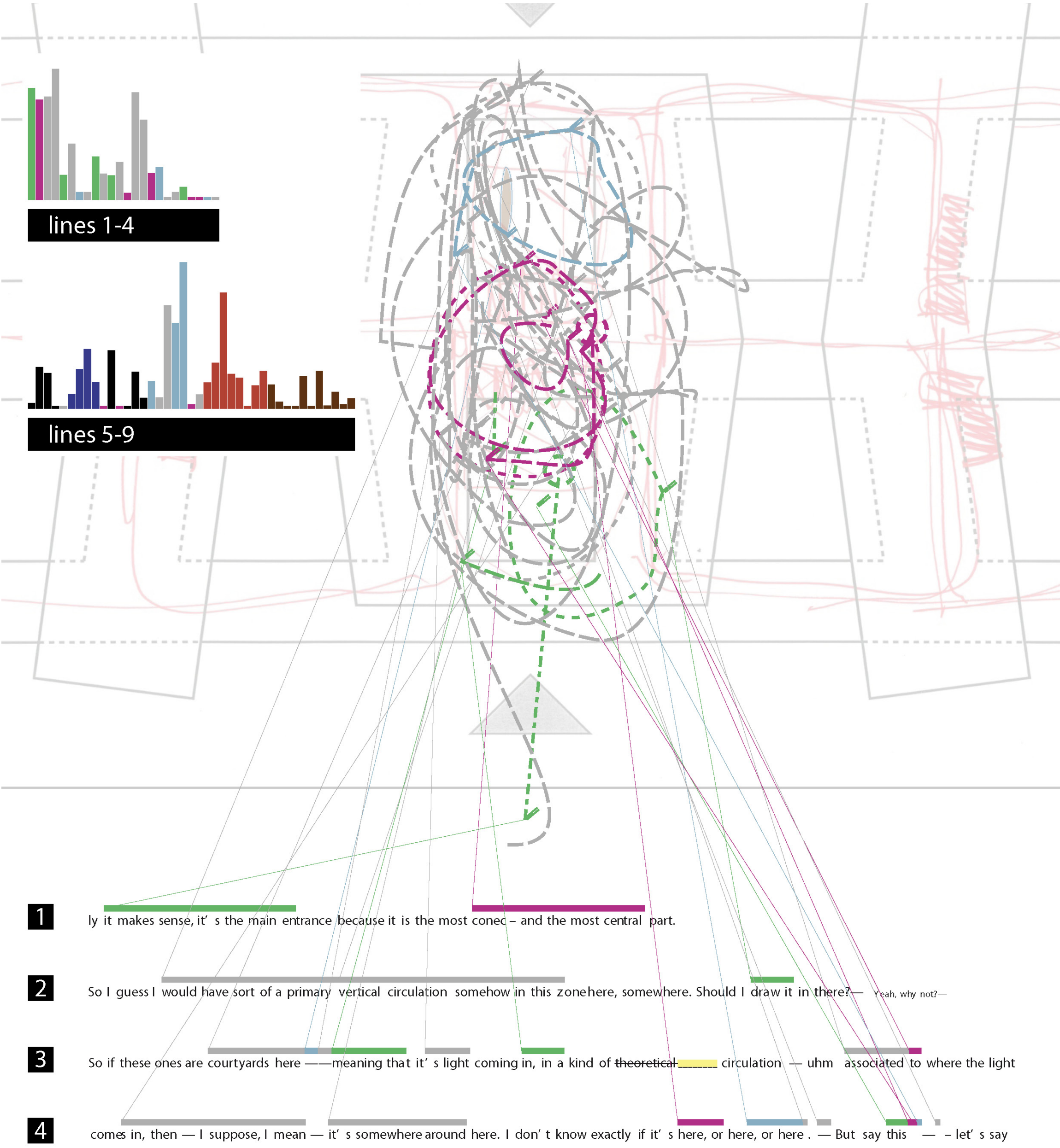

Figure 6. Part one of Example 3.

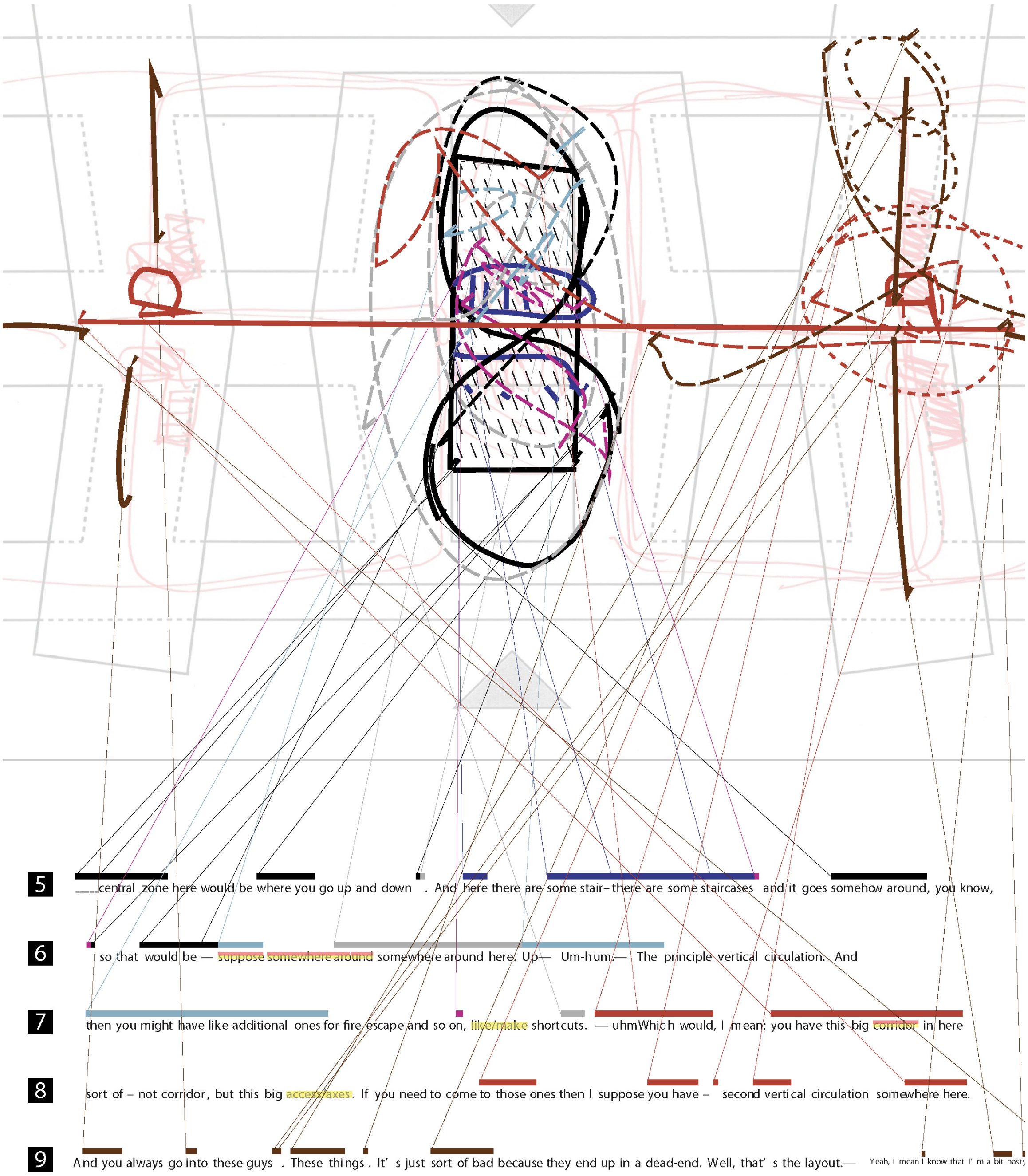

Figure 7. Part two of Example 3. Gestures in the main axes and the peripheral blocks are also colored like their neighboured drawing strokes (light/dark brown).

Flexibility of perspectives in architects' thinking

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Abstract. In this short contribution, we address the extent to which architects confronted with different kinds of conceptual tasks adopt different kinds of perspectives about spatial design, and focus in particular on the ways in which these perspectives are represented in language. Our data source is a set of interviews conducted with architects, covering a range of tasks that induce perspective taking to various degrees and that are closely related to the architects' typical design procedures. The architects' language reflects at least three systematically different conceptual perspectives, namely a) the current view of the configuration, i.e., the spatial prerequisites at hand as a building plan or concrete situation; b) the architect's design perspective in which a change to the current status is envisioned; and c) the users' navigation perspective encompassing the perception of the finished building.

Keywords. Architectural design, concepts, task relevance, perspective taking, linguistic representation

Introduction

Architectural design encompasses a broad diversity of tasks, ranging from material considerations via function, aesthetics, and creativity to intelligibility by the users of the architectural product. In the case of a complex building, the challenge lies in conceptualizing not only the prerequisites of the spatial situation and the expectations for the functionality of the building, but also the future users' perception of the complete configuration along with issues of intelligibility and navigability (Peponis, Zimring, & Choi, 1990; Bertel, Vrachliotis, & Freksa, 2007). Considering the latter point, complex public buildings such as airports, hospitals, malls, or university campuses often lead to fundamental wayfinding problems if they are visited irregularly (Gärling, Lindberg, & Mäntylä, 1983; Carlson et al., 2010). Since spatial knowledge cannot be accumulated sufficiently during a one-time visit, the building users need to derive the information required to reach their goal from the environment or rely on generic wayfinding strategies (Hölscher et al., 2006; Tenbrink, Bergmann, & Konieczny, 2011). Apart from signs and other explicit information aids, the building architecture itself may provide clues for users to derive suitable inferences about the goal's location (Frankenstein et al., 2010). Architects might take such systematic user expectations into account (Brösamle & Hölscher, 2007). The question asked in this short paper concerns the extent to which architects are ready to adopt different kinds of

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perspectives, such as the future users', in relation to architectural design processes, and how these perspectives may be represented in language. We present a qualitative analysis of unconstrained language data collected in a natural dialogue setting, highlighting how perspective taking manifests itself in the discussion of various architectural design aspects.

1. Perspectives and Tasks

Our current exploration is based on a set of case-based design sessions collected by the second author, which complements and extends previous interviews with architectural experts published by Brösamle & Hölscher (2007, 2008a,b). The case based design sessions cover a variety of discussion topics in order to investigate architects' thoughts about wayfinding oriented design. The current set of sessions addresses active design reasoning practice in the context of wayfinding-centred design requirements. Design tasks differ with respect to the degree of user/navigation-centredness in the requirements. For details on the procedure as well as a brief review of preceding studies on perspective in user anticipation tasks, please refer to the chapter by Brösamle and Hölscher in the present SCAD 2011 proceedings.

Our present focus solely concerns the flexibility of perspectives adopted based on the tasks given to the experts. Our notion of perspective for current purposes is based on conceptual rather than (primarily) visual distinctions, as represented in language (cf. Schober, 1998). The idea is that the same visual scene, namely a building plan shown to the architects, can be conceptualized in more than one way, depending on the current task at hand. This may for example involve anticipating or conceptualizing a different *visual* perspective on the scene, such as the future building user's perception. In the following we will work out in more detail which kinds of perspectives may have been triggered in the case of our interviews, and then address the ways in which these postulated different concepts may be represented in language.

As part of the design sessions, three types of tasks (or phases) can be distinguished as follows.

I. Investigation task

The interviewer presented a (schematized) plan outlining a basic building structure, and asked the expert to comment on what they saw: "What are you looking at? What gets your attention? What is particularly interesting about that?"

II. Design task

The interviewer pointed out (or reiterated, in case the architect had already noted this) that the plan did not contain a circulation system, and asked the expert to propose one: "I would like to ask you to outline a proposal for a circulation system for this type of structure – not every detail but roughly the overall structure and especially the vertical circulation, the transition between the lower part and the upper part of this structure."

III. User anticipation task

The interviewer presented new, fully specified building plans, and raised attention to possible wayfinding issues: "Imagine a person who does not know the building coming in here and then trying to find the way up to this third floor. Let’s say it’s an office of a person to meet on the third floor. Now the question is what will this person do or what might be the problems that this person could face when going to the third floor."

The interviewed architects generally took great pains to answer the questions in the way intended; their answers were extremely elaborate and detailed, and they were accompanied by much drawing and sketching on the paper in each of the three tasks. Clearly, the tasks as formulated by the interviewer triggered thoughts, ideas and associations of design experiences that they were ready to communicate.

The situation remained constant throughout the three tasks; interviewer and expert jointly looked at the building plans and imagined the situation described in the task. Therefore, the actual visual perspective on the scene never changed. However, the tasks were intended to highlight different aspects of architectural design, and may therefore have triggered different ways of thinking about the presented scenario. While the interview sessions were not originally designed to elicit specific conceptual perspectives (or types of linguistic structures), the following perspectives can be identified in the verbal protocols: a focus on the existing basic *building* structure in Task I (Investigation); a focus on a *design* change in the structure in Task II (Design); and a focus on the *user* in Task III (User anticipation). The linguistic analysis in the following section will address the extent to which such conceptual perspective changes affected the representation in language.

2. Linguistic representations of perspectives

As just mentioned, the three different types of tasks may have drawn attention to three different kinds of conceptual focus or perspective. Nevertheless speakers were entirely free to shift between different perspectives while discussing a particular task given to them. In fact, perspective shifting can be seen as a necessary and central cognitive step to accomplish the tasks in the first place. In the following, we will use the labels BUILDING, DESIGN, and USER perspective, respectively, to indicate the perspective that we consider as centrally relevant for each of the three tasks given to the experts. We will start by outlining the linguistic repertory to express perspectives found (post-hoc) in the linguistic data, and then briefly discuss shifts between perspectives as indicated by linguistic constructions.

2.1. Repertory of expressions for perspectives according to tasks

Our language data revealed that the three perspectives, reflecting the different ways of thinking about the scenario presented to the experts, were linguistically represented in different ways. In particular, each perspective could be expressed using each of the three grammatical cases: first person *I* or *we*, a variant containing the generic second person form, *you,* and third person (usually singular) *a person, they, he, she,* or *it.* How these were used differs for each of the three perspectives. Here are structural features as well as examples from our data for each of these.

I. BUILDING perspective

a) **First person.** In the context of the investigation task, when considering the observable structural features of the building, the first person form was

typically used to express the viewers' current perceptual limitation of the situation.
Examples:
We can't see what's beyond.
I don't know how wide these are.
I wonder what's going on in it.
I mean, I don't know what the scale of the drawing is but I suppose ...

b) **Second person.** The second person construed the viewer as a metaphorical owner, i.e., the perceiver of the scene.
Examples:
So you've got these at higher level, O2 and then you've got this at level O1.
Do you have rooms for patients towards the internal corridors?
If you've got rooms on this side ...
Then you have these sort of towers ...

c) **Third person.** The third person form represented the existence, properties, and relations of locations and objects in the building plan, often mitigated by hedges and verbs such as *seem* to express a degree of uncertainty in the perception of the scene.
Examples:
Maybe it's some kind of lecture hall or something.
It has a big entry.
It seems a bit – it seems to have general circulation areas.
There seems to be four entries on either end of the building. This seems to be a major public entry.

In brief, the architects reacted to the investigation task regularly by describing either *what **I** (the perceiver) can see, what **you** already have there,* or *what **the scene** seems like*.

II. DESIGN perspective

a) **First person.** The design task regularly triggered representations of the architect's thoughts and suggestions, deictically referring to the speaker as designer.
Examples:
I'd keep it fairly classical.
So I think I'll establish some sort of connection.
I'm gonna make this whole a stair.

b) **Second person.** Responses to the design task also contained references to a generic designer who could initiate changes, or a metaphorical owner in a hypothetical (changed) situation.
Examples:
In a hospital you might need more so you might want to have one there and one there depending on how big the whole thing is.
You'd probably have a core here.
You might end up putting the core in the middle here.
You might put a stair round the back of it.

c) **Third person.** Ideas about possible changes were furthermore formulated in an impersonal way by neutral constructions, references to the envisioned state of the building, or the passive voice.
Examples:
It might make sense kind of placing them here.
Because the building is so symmetric it should really have a kind of mirrored levels of access in both sides.
There would have to be some kind of entry reception.
Everything is distributed leaving the external perimeter free to have natural light for lots of rooms.

In brief, the architects reacted to the design task by describing either *how **I** could change the spatial situation, what **you** could do*, or *what **it** could be like*.

III. USER perspective

a) **First person.** Asked to anticipate user behavior, the experts sometimes described what they would perceive and do in the wayfinding situation suggested by the interviewer. This was rare in the interviews (in this category, unlike all others, examples were hard to find; however, no systematic quantitative analysis was conducted at this stage).
Examples:
There's a staircase obviously right in front of me.
I naturally would walk to the third floor.

a) **Second person.** A generic user, represented neutrally as *you* (with a possible conceptual trace of imagining the addressee personally in the conceived situation), could regularly be described as moving through and perceiving the scene.
Examples:
You need to get through.
How does it look when you come into here as the entry situation?
Or maybe you can actually come in and you've got a courtyard above you and you've got a huge entrance hall.
If you are meeting someone on the third floor that's not the staircase for you.
You're going to lift here and then again you've got a choice of directions. You don't know which way.

b) **Third person.** The user anticipation task also triggered descriptions of an unknown user, referred to as *person* or *they* whose thoughts, perceptions, and behavior were anticipated.
Examples:
The person will try to find a different staircase in order to go up.
They would climb the stairs to use the stairs and go up there.
This probably takes them all the way up to the third floor.
It could also be that they use some wrong stairs because …

In brief, the architects reacted to the user anticipation task by describing either *what **I*** or *what **you** would do to find your way around*, or *what **the person / they** would do.*

As seen in these examples, all three grammatical forms were used for all three tasks, with different functions. When the architects used the first person form *I*, they described either their current view on the building plan (BUILDING perspective), the changes they would themselves make (DESIGN perspective), or their own imagined navigation through the scene (USER perspective). When they used the second person form *you*, they very rarely addressed the interviewer (although this could also happen, as in *do you want me to draw on this?*). Rather, they employed the generic *you* to express metaphorical ownership or perception of the situation (BUILDING perspective), or to point to a generic designer (not necessarily themselves) who could initiate changes or metaphorically own (perceive) the envisioned situation (DESIGN perspective). Adopting the USER perspective the generic second person form referred to the hypothetical user (possibly the addressee) navigating through the building. When the experts employed the third form, they described the currently visible sketched building (BUILDING perspective) or its future form (DESIGN perspective), or the behavior and thoughts of a building visitor (USER perspective). Thus, the same linguistic forms could be used for each perspective, but the textual and conceptual context reveals the function of each form in each case in different ways.

2.2. Shifts between perspectives within a task

While the previous section outlined typical perspectives adopted in the different tasks given to the architects in the interviews, the architects were free to shift between perspectives within a task. This happened frequently, as in the following example:

> *Well anyway, so you want it close to the entry. [DESIGN]*
> *You've got a corridor here [BUILDING]*
> ***so** I might put it next to the core. [DESIGN]*
> *But then you cannot – maybe next to every core [?]*
> ***so that** you can always – don't know – so that you can always find it. [USER]*

Here the architect starts out by using the second person form of the DESIGN perspective (*you want*), followed by the second person form of the BUILDING perspective (*you've got*). Within the same sentence, connected by the causal (purpose) conjunction *so*, there is a shift back to the DESIGN perspective, this time in the first person form (*I might*). After some false starts and incomplete clauses using the second person form (which are not sufficiently developed to be associated with a perspective), the architect ends up using the USER perspective in its second person form (*you can find*), introduced by another causal (purpose) conjunction, *so that.* The emerging pattern is a shift from a design goal to an assessment of the starting situation of the object at hand, which causes a suggestion for design change, which again opens up possibilities for building users.

In the next example, the speaker shifts back and forth between DESIGN and USER perspectives:

But still I want to keep the central space [DESIGN]
***so that** you can basically see all the cores and everything around. [USER]*
Then you – from the mezzanine level – [?]
so you can also have retail around it but you still want to keep away from this, from the core. [DESIGN]
***Then** you see all the four cores [USER]*
and they have to have signs [DESIGN]
***in order to** tell you which one goes to which. [USER]*

This architect considers the aims of design (first person DESIGN perspective: *I want*) in order to (conjunction: *so that*) enable the user to have a free view on the staircases (second person USER perspective: *you can*). Then there's a shift back to the DESIGN perspective, this time in its second person form (*you can*, *you want*). After shifting back to the second person USER perspective (*you see*), introduced by the causally used marker *then*, a further design idea is inserted (*they have to have*) that causes an effect on the USER (*tell you*). As before, a causal marker indicates the shift from DESIGN to USER perspective (*in order to*).

Our final example illustrates shifting back and forth between BUILDING and USER perspectives:

if you come from there [USER]
because they don't seem to have entries. It seems to be the only one or maybe this is a disabled entry. I don't know. [BUILDING]
Or you could come from here [USER]
if that's a connection. It only seems to be a connection on the first floor. So I think this is the entry. [BUILDING]
So you come in and you see this stair and that goes to nowhere. So that's the first problem. So you don't – you probably go to – you want to go here. [USER]

This architect considers how the user might move through the environment by looking at and assessing the state of the building at hand. After considering a possible movement in the second person form of the USER perspective (*you come*), the speaker shifts to the third person BUILDING perspective (*they don't; it seems*) to provide a reason for the current conceptualization (indicated by *because*). Likewise, when an alternative movement is considered by again using the second person form of the USER perspective (*you could come*), there is an immediate shift back to the BUILDING perspective (*that is; it seems; this is*). Finally, the architect shifts back to USER (*you come, you see, you don't, you go, you want*) in assessing the user's potential problems in the spatial situation indicated by the building at hand.

As these examples illustrate, there are a number of recurring phenomena. For example, causal connectors such as *so that, if, in order to, because, then* are frequently used to indicate shifts between perspectives. Furthermore, the shifts between perspectives are clearly motivated by the challenges and purposes of the current task. For instance, envisioned changes to the current situation may systematically involve looking at the same scene in two different ways – assessing the current situation and developing a hypothetical scene in contrast to it. A future user's perspective can be conceptualized either on the basis of the current situation, or on the basis of the envisioned situation following the envisioned design process. The relevant conceptual basis is reflected in the language used by the architects in each case.

3. Discussion and conclusion

Our linguistic analysis suggests that the three tasks given to the architects in the case-based design sessions triggered different perspectives on the same spatial scene. In particular:

- The investigation task suggested inspecting the building plan as such, in the way it was presented to the architect at the current place and time; all that was asked for was the architect's spontaneous perception of the scene. In response, the architects described what they saw or what a generic person metaphorically owned (using the expression *you have*), or what the scene seemed like.
- The design task required the architect to conceptualize changes of this same scene that were not directly represented in the currently visible building plan. Perceptually, those changes could only be indicated by sketched drawings on the paper or gestures; nevertheless, the actual reconstruction suggested by the task of including a circulation system remained in the dialogue partners' minds. Using language, the architects described how they, or a generic person (*you*) could change the spatial situation, or what the situation could be like.
- The user anticipation task suggested imagining the finished building in a real world environment, along with an actual visitor to the building with an actual task in mind. This situation was completely at odds with the currently perceived scene and presupposed a conceptual transfer of an elaborate kind. The movement of the imagined building visitor could be indicated by dynamic strokes on the paper or gestures suggesting the navigation process through the real world represented currently only as a schematic 2D building plan. In language, the architects described what they, or a generic person (*you* or *they*) would do to find their way around in such a situation.

Although the different perspectives could be associated clearly with the three tasks given to the architects, they also frequently switched back and forth between perspectives in order to address the tasks, as shown by a close look at the linguistic representations. In other words, the architects *reframed* or *reconceptualized* the currently perceived scene flexibly according to the requirements of the tasks. This linguistically reflected conceptual flexibility in humans is well-known from other domains. Abundant evidence across scenarios indicates how speakers shift conceptualizations and perspective according to task and purpose (e.g., Nuyts & Pederson, 1997; Schober, 1998; Fauconnier & Turner, 2002). For the domain of architecture in particular, the current analysis represents a first step towards capturing the precise ways in which such a reconceptualization might occur, how it is linguistically reflected, and the extent to which shifts in perspective may be related to shifts in the train of thought. Ultimately, such an analysis may lead to an identification of the different kinds of perspectives and reconceptualizations that are at stake at particular stages within the overall architectural design process. Furthermore, identifying underlying perspectives in language may support the identification of the communicative purpose of particular gestures associated with the architects' speech. Without these, the case-based design sessions cannot be properly understood with respect to the conceptual depth of the architects' contributions (see Brösamle & Hölscher, this volume).

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Two grammar applications

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Abstract. The possibility of using graph grammars for architectural design is examined. First they are related to shape grammars by introducing the implementations of a specific shape grammar, the Palladian grammar, and a parametric shape grammar editor in U_{13}. Both of these applications use a graph grammar package as computational engine.

Keywords. Shape, graph, grammar, tutorial

Introduction

Shape grammar computer implementations have not been particularly successful in the past. Apart from the issue of finding algorithms that will support emergent shapes and parametric rules simultaneously, it is also an issue of handing edit capabilities over to the user. It is somewhat easier to write an implementation for a specific grammar, but these cannot necessarily be generalized for arbitrary grammars.

The last decades have witnessed an increasing interest in the topic, be it because the field is pushing to expand its reach, or because computational circumstances have improved. Starting from a report written by Gips [1], over a summary of the field by Chau et al. [2], up to some more recent implementations by Duarte et al. [3], Ertelt and Shea [4], Hoisl and Shea [5], Jowers and Earl [6], Jowers et al. [7] and Tresak et al. [8].

Most previous implementations work with the algorithms devised by Krishnamurti [9]. They are based on the maximal lines concept [10] and support emergent subshapes. However they lack the ability to model parametric rules, notable exceptions are Fleming [11] and the work by McCormack and Cagan [12][13].

Two projects that try to improve upon the situation are presented here. The first is an implementation of a specific grammar [14], the Palladian grammar by Stiny and Mitchell [15]. It does not support the editing of rules by itself, but the approach is sufficiently general so that it could be used for other grammars. The second is a shape grammar library named GRAPE [16] that supports both emergence and parametric rules. Currently it supports grammars in U_{13} x V_{02} and interfaces to several environments, including a web application, have been written.

Both projects are based on the GrGen.NET graph grammar library and hence map the shape grammars into graph grammars. Graphs and graph grammars are well known as tools to explore abstract systems of objects and their relations. In architecture these are often interpreted to be programmatic functions and their interrelations or, more concrete, spaces and their adjacencies [17]. These projects attempt to show that shape

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bound considerations can also be addressed using graphs if they are modelled appropriately and a graph to shape mapping can be established.

1. Palladian transformations

Palladian Villas have consistently been used to introduce new ideas for shape grammars; here too they serve as proof of concept. The rules taken from Stiny and Mitchell [15] are transcribed into their graph equivalent. The graph grammar is executed and the result is transformed into a plan by an interpreter module.

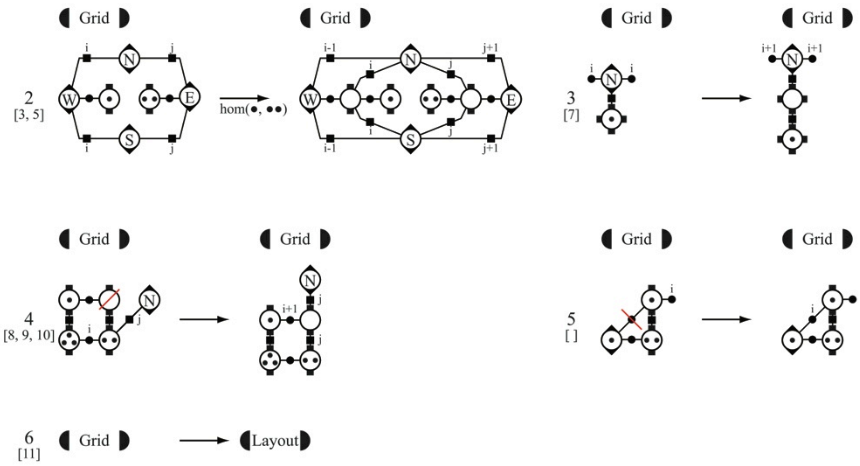

Figure 1. The rules used to grow the initial grid. Original rule numbers are shown in square brackets.

The implementation was to create a prototypical workflow to be used for other grammar implementations as well. Furthermore the logic was to be embedded into an existing CAD environment in order to reduce the necessary work of designing an interface and enabling the user to modify the results in a familiar environment.

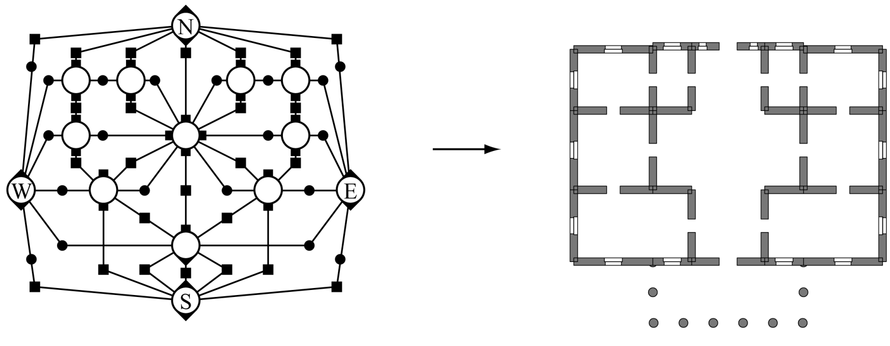

Figure 2. The graph derivation of the Villa Malcontenta and its shape interpretation.

The graph grammar was modelled in *GrGen.NET*, this graph rewriting system allows the graph model and the rules to be described in tailor-made modelling languages and to compile the grammar into more efficient .NET assemblies. These assemblies can then be included in any programming project that supports .NET. There are numerous CAD packages which support plug-ins developed in this manner; this project is implemented as Add-In for *Autodesk Revit*.

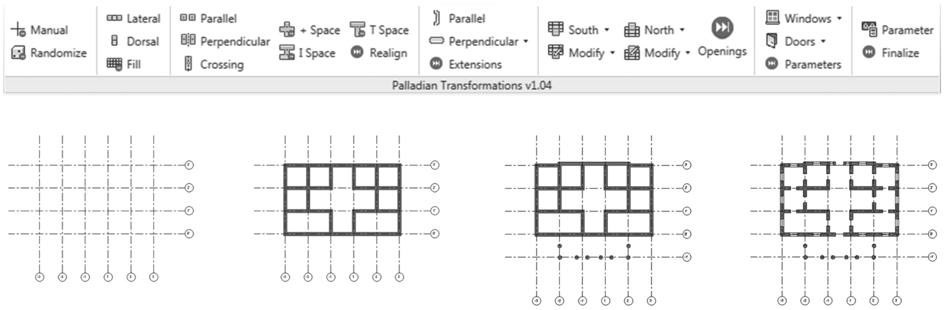

Figure 3. A montage showing the ribbon of the Autodesk Revit Add-In and several steps of a derivation.

2. GRAPE

To arrive at a general shape grammar interpreter a suitable graph model had to be chosen. Support for emergent subshapes and parametric rules were the primary requirements. For emergent subshape recognition the graph had to model maximal lines rather than line segments, a boundary element graph was chosen (**Figure 4**).

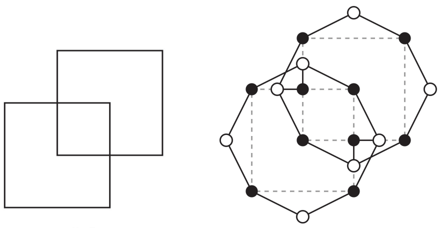

Figure 4. A shape exhibiting an emergent subshape and its graph representation.

Searching for topologies first, and then restricting them to specific shapes enables support for parametric rules. This has the additional advantage that the search will return all subgraph isomorphisms, which interpreted as subshape isomorphisms, allow to take the symmetry group of the shape and the entire rule into consideration.

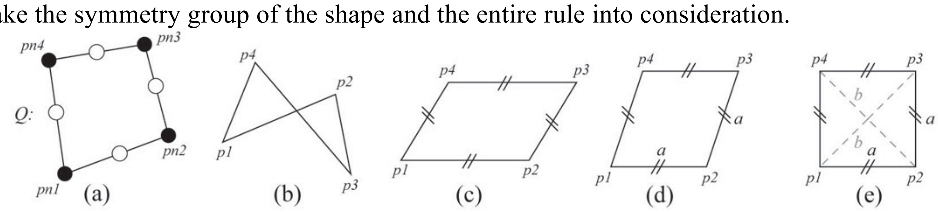

Figure 5. A graph representing a quadrilateral topology (a) and several possible shape matches (b-e).

The shape grammar library does allow editing functionality to be implemented; the extent of these is dependent on the specific implementation environment. In general there are two ways of defining rules. Either on the graph level as graph grammar rules, while this may be less user friendly it does exhibit the greatest amount of flexibility and clarity. The other possibility is to model the rules as shape grammar rules and then translate them into graph grammar rules. Writing the editor and defining the visual conventions for this approach is somewhat more involved, though of course accessibility to users is greatly increased.

Figure 6 shows some results taken from the web implementation. Several example rules are implemented, amongst them a subset of the Palladian grammar and several rules to test emergence and the parametric capabilities.

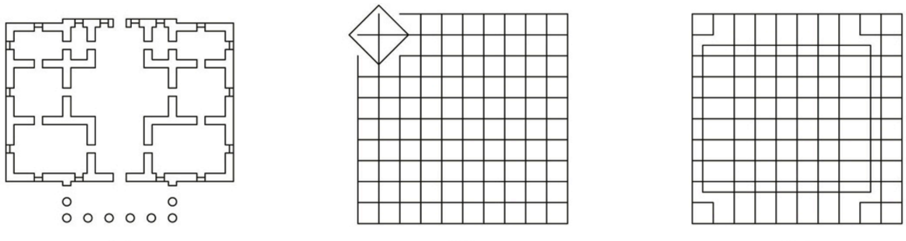

Figure 6. The generated plan of the Villa Malcontenta (a). In a 10x10 square grid 385 squares (b) and 3025 rectangles (c) are found to rotate.

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**Understanding People, Spaces and Cognition:
The intersection of Architecture and Cognitive and Computational Sciences**

Panel Session of SCAD 2011, New York

Science and Design

Eve Edelstein
November 17, 2011

The Context of Inquiry

"A good environment is a human right."
Dr. Schackenberg

Thus inspired, an interdisciplinary team of designers and scientists gathered to explore the means to restore and enhance the health of the earth and the built environment. The compelling need to focus on design as a human right issue formed the focus of proceedings at the DFG, where a special symposium convened to consider the many issues associated with the international peace and security missions of the DFG and NSF.

With synergy between diplomacy and science, collaborative meetings sponsored by the German Research Foundation, DFG, GCRI and National Science Foundation considered how architects and building users think, and also how designers work. The German Center of Research and Innovation called for an initiative to consider how science and design can sustain and enhance the human condition by considering what architecture itself can accomplish. Together, specialists from multiple universities and institutions explored how a worldwide initiative may strengthen collaboration, harness trans-disciplinary approaches and advance technological strategies to create and better serve built environments.

The Framework for Inquiry

*Indeed, the cognitive sciences provide an interdisciplinary framework
that includes computation, behavioral and scientific methods to inform a user-centered approach.*
Christoph Hoelsher

It is not surprising, given historical divisions between disciplines and limitations of technology, that there has been a lack of communication across the breadth of disciplines that explore the interaction of people and places. Now however, technology has eroded the barriers, enabling collaboration between disciplines that measure the mind, those that measure the brain, those that measure behavior, and those that measure specific features of the environment that we inhabit.

*"Architecture may be at risk of failing if it avoids the contribution of multiple disciplines
including the sciences, technology, psychology, art and marketing."
Malfunction follows lack of information."*
Mehul Bhatt

The impact of specific features and parameters of the architectural environment may be measured via carefully controlled experiments in both built and virtual design spaces, and using both relative and relevant scales, so that we may relate the physics of a space to the perception and experience of the built form.

At the level of neuroscientific study, an extensive body of literature, scientific methods and advanced technologies await application. Study of the mind and brain that explores the impact of the sensorium on cognition incorporates a broad spectrum of disciplinary thinking. Using both historic and emerging techniques, a greater understanding of the complexity of the human-architectural interactions may be revealed.

For example, wearable wireless brainwave and cardiac sensors, along with environmental and behavioral tracking systems integrated with immersive 4D virtual reality environments allow us to experience design concepts before the first brick is laid. In measuring the qualitative and quantitative affordances a building provides its users, we must consider all dimensions of a built setting, including how the space is used across the 4th dimension of time.

In order to expand our understanding of the relationship between design, space and cognition, it is necessary to form a bridge across multiple disciplines that allows for deeper inquiry into the art and science of design from the perspective of brain, body, behavior and the biosphere.

Human centered research must consider the effect and affect of design,
evaluating buildings or spaces 'as used', and not simply the form 'as built'.
Eve Edelstein

Thus, the light, sound, or texture of the materials that form and define a space may be logged and related to specific cognitive and behavioral responses as a user travels through the space. In this way, the stress of being lost, relief on arrival at intelligible space, or delight upon understanding of the logic of a design may be related to measurable architectural elements and events.

The shape of empty spaces underlines this point. Open space may be measured in the human terms of its allowance for activity, movement and connection.

Indeed, empty space may the strongest stimulus to inform function,
action and interaction – the basis for spatial cognition.
Eva-Maria Streier

Understanding Design

A tension may arise between architecture and behavior if the architect uses an 'expert' approach that is not informed by the 'lay' users' needs or perception. If the client or owner, rather than the user, guides all design decisions, the focus on user function may negate the focus on experience. This intersection of understanding between the user and architect is often determined by how well the architect, with advanced abstract thinking and detailed knowledge of building systems and details, is able to convey design logic to the users and owners. Cognitive science and computational analysis including immersive interactive virtual reality along with impressionistic studies together offer to inform design.

The Impact of Technology

It could be said that today, given the computational architecture, material and construction methods available today, that we design complex shapes simply because we can.

The shape of buildings reflect the technologies of the times,
and life is organized within such shapes.
Gabi Goldschmidt

If we consider history as a teacher, we see that technology transforms design. However, architecture responds to other forces, such as style, and including stylistic responses to technology. There will be an evolution in the response to emerging and evolving technologies.

The intersection of buildings and technology is reflected in historical shifts in methods
and building systems that result in social and cultural change.
Omer Akin

What technology do we need to help us in design, building, construction and maintenance of our built settings. We will abandon neither the pencil nor the computer. However, we must begin to incorporate the unspoken and unseen component of cognition. The brain that lies beneath. Otherwise we are ignoring technologies and techniques that can inform our mission.

Now, we may incorporate humanistic studies, using individualized technologies to drive design that serves the *human* interaction with buildings. Networked microsensors may inform us of the building's performance in location and feature specific domains. At the same time, human biosensors may synchronously relate specific environmental and built conditions with human responses, in order to inform design that meets needs and achieves objectives.

Real-time iterative computational programs that allow us to rapidly prototype and test the conformance of design to standards can provide instantaneous information that should be used to iteratively, showing how design changes human performance, and how design *should* change.

Omer Akin proposes
"Design in the future will evolve to consider individual and interaction over process and tools.
Working designs over documentation; Customer collaboration over contract;
Responding to change over following a plan."

Today, emerging modeling software and virtual reality visualizations allow for immediate and rapid prototyping that enables real-time exploration of how people experience spaces. In addition to the response to visual design, we explore the sensorium of design, and include in the digital design process, the rich human experience of all senses including sound, touch, and those modified by movement. Can we make touching architecture as satisfying as touching a book, or perhaps, as exciting as immersing oneself in a virtual design that reveals a thought – without a single brick laid? George Stiny defines rules that our minds see within patterns, yet these rules enhance rather than limit creativity. Let science and technology serve to reveal our cognition, our understanding, and our senses, measure them, and be used to support the design process.

Technology may thus release us to spend more time planning for the human response, rather than planning for change orders.
Eve Edelstein

We must demonstrate integrity in our design actions if we are to maintain credibility, and not allow the re-emergence of supremacy of technology to overtake the integrity of design for culture. And when we create architecture, that is when we create spaces for people, we must take care to measure the interaction between the human and the building, if we are to validate such claims.

To maintain the integrity of design, architects must be measured by their claims about the impact of design.
Wilfried Wang

Beyond quantification of design function, one must seek to measure the quality of design. The fields of the science of architecture and the fields that describe human function must not neglect the hard question. The question of how people respond to place. Owners and clients should similarly be informed of design intent that serves the basic human need of a good environment, at the level of the ecosystem and at the level of each building. Our organizational and institution and economic pressures must respond with integrity to human pressures as well. Good building is a human right. So too, good cities are a right. Technologies that are intimately connected to our understanding of human rights, in this time, and in this cultural place should drive architecture.

It may be said that the purpose of architecture, and of this conference is to explore how a good environment may become a human right.

Dr. Schackenberg

Discussion Group No. 1

Notes compiled by Eve Edelstein

Participants:

- **Ming Zhang**: **architect, practice, urban, transport, urban regional planning, land use urban form**
- **Vinayak Akin: Architecture, urban planning, urban infrastructure, education**
- **Aga Skorupka: Environmental psych, program, urban projects, public space, work environments, human factors, post**
- **Sven Bertel: Computer science, knowledge representation, artificial intelligence, cognitive models, human machine interaction, human factors, usability, early phase of design, eye tracking to inform**
- **Minqian Huang: Digital media, human computer interaction, analysis of architecture and design, easy user interface, practicality of system**
- **Gabi Goldschmidt: Architect, international, design, practice, design load, teaching and academia, design and visual thinking, pedagogy, why do some learn faster, not knowledge dissemination, but skill and thinking**
- **John Wetzel: Computer science, engineering design education, Cog-sketch, sketching**
- **Eve Edelstein: Anthropology, architecture, neuroscience, pre-design, programming , planning, health, virtual reality, EEG**

What do architects want to be told - or not - by an intelligent design system

- What tools are needed at different stages of design?

- Early conceptual vs later part of process
    - Abstraction without form
    - Organizing principles
    - Scale, massing and site
    - The experience of the space from the start

What I want to know

- Gabi Goldschmidt:
- Performalism
    - Impose envelope to evaluate key issues on a crude massing
    - The return of information related to imposed requirements
- Embodiment
    - Properties of a form
- Rationale
    - Support computationally
- Capturing style
    - Analysis of schematic style rules – computational generation of options
        - Analogy to endnotes: APA to MLA

- Ming Zhang:
    - Evidence-based tools early in the design process

        - Sequential process – requires different tools for different stages – that helps architects to create and innovate – and express and evaluate
            - Rendering at later / end stage
            - Early – talking to client, public, etc.
            - Bring evidence in earlier stages of design
            - Keep creativity in scope of architect

- Vinayak Adane
    - Difficulty in filtering subjective element in design teaching
        - Formalized meter for teaching design to be more responsive and understand elements of successful design
            - Eg. Alto or FLWright sensitive to experience
            - What is behind successful built spaces
            - Insight into human life – the way people life
        - Social-Cultural issues
            - Greater and better understanding
            - Crystallized approach to capture living systems and include in instructional settings

Aga Skorupka

- Politic
    - How we express behavioral / social knowledge for design communication
        - Representing findings in easily accessible mode
        - Info graphics
    - Political issue re. wasn't architect who wanted requirement, but a requirement that user centered approach (client or owner)
        - Communicate with design process not just the architect
        - Educate the architect and client and politic that drives design

Gabi Goldschmidt

- Can design features / principles be captured in computational system that generates an architect mode of thinking or components of design?
- Utilize a range of directions/issues that prioritize design initiative and priorities

Vinayak Adane

- Do we need to change the formal method of design thinking?
    - Cog science
    - Tools
    - Economics
    - Politics
    - Business
    - Practice

How can tools shorten the learning process?

- Can tools change mentor model
    - Reduce the time to go from inexperienced to experienced to master architect
- Learning to mentally image in 3D
    - With accuracy at early stage

        - As drawn vs. as built
        - At accurate scale

- John Wetzel
    - How can AI solve the problems we talked about
    - Generate styles from existing architecture
    - Cognitive model of how moments of insight happen

- Sven Bertel
    - Which representation in an architectural design process that
        - How do we partition and create ontologies of components of a sketch to match AI components
        - Mapping process to support when needed and not needed
    - Information design for specific purposes
        - How a support tool could convey a certain idea and prioritizing aspects of design in dynamic way without disrupting process.

- Conflict between professional architecture and internal system
    - Platform to improve design
    - Experience of practice –
        - How can this be conveyed
        - Can it be incorporated in a system
        -

Weird (but not) Wild Idea
- Ming Zhang:
    - Measure how architects think when they think?
    - The moment when an insight occurs!
    - Map the intermediate process of design
        - Not necessarily the final rendering

Eve Edelstein
- Passion
    - To understand the moment of creativity
- Practical
    - We have a common goal – to improve design
    - How do we make a common process?

What do you want to go home with
What do you want in 5 years
- Next steps
- Book Mehul Tim Christoph
- Event at Calit2
- Christian Freksa

Group 2 Discussion and Collaborative Research Topics
Compiled by Barbara Tversky

In the background was a free discussion, reigned in at points by questions: how can we (cognitive psychologist, computer scientist, designers) help each other? What research would bridge our fields? Specifically to the architects, what research from us would help you?

Free discussion

Nature of the design process. Typically begins top-down with an overall concept or metaphor for a building; for example, Louis Kahn thought about the library he designed as a violin. This approach contrasts with a bottom-up thinking about the specific uses/functions of the building.

Education of architects inspired by starchitects rather than by Starbucks designers; most architects design parts of large buildings or the next Starbucks branch, not iconic buildings.

What designers need:

Tools. Better, more user-friendly computer tools, especially predictive ones, like space syntax, that is, tools that bridge form or structure to use or function. Given the structure of a building or a room or an urban area, how will people behave, how will the space be used, how will people feel? (Similarly, how will the space behave? But this is an engineering problem). Building such tools would require greater knowledge of human behavior and improved models of human behavior, requiring three-way collaborations of architects, computer scientists, and psychologists.

Rules of Thumb/Terms of Reference. Because computerized tools cannot yet completely predict human behavior or building uses, designers want general heuristics or rules of thumb for human behavior, such as “Wayfinding relies on clear landmarks and paths. Landmarks signal points of action, typically turns, and paths are the routes people travel along.” A short list of rules of thumb would be useful to designers to keep in mind as they work and useful for instructors in teaching. Similarly, in designing, architects use paradigmatic or prototypic examples, iconic buildings, typical buildings, public spaces, cities, rooms, and the like. These examples are a) familiar to other designers; b) summarize and epitomize an interrelated set of physical, structural, behavioral, social, and emotional features. “Piazza” communicates a medium-sized public open outdoor space that is typically surrounded by familiar popular landmarks such as a cathedral/temple or municipal building or market, a place where people gather and meet. Other examples would be Bilbao or pub or Apple Store or Walmart.

Compiling a set of rules of thumb and paradigmatic examples would require collaboration of architects and psychologists. Both the methodologies and the results would be of interest to psychologists as the results, rules of thumb and paradigmatic examples, are representative and interesting cases of knowledge structures and reasoning from them. The results would be of interest to architects as they would be directly useful in design. The methods and the results would also be interest to computer scientists, who could develop programs for understanding and generating them.

How do different kinds of spaces affect behavior and feelings? Both the previous projects will address this.

Design Process. Research that characterizes the design process, especially research using the new tools. How are they used in practice at different phases of design? Research directed at understanding the social aspects of the design process; design is always a team effort.

Tools. How do the various kinds of tools, language, sketch, various computer tools, and models, affect design thinking? How can the tools be designed to allow designers to better visualize and imagine the buildings and spaces they are designing as well as they behaviors and reactions of users?

SCAD 2011 Group Discussion

group 3

Saturday 11.19.11

Compiled by Dido Tsigaridi & Christoph Hölscher

Participants: Alessandro, Ruth, Thanos, Christian, Saif, Eduardo, John, Victor, George, Dido.

Discussion Notes by Dido:

Significance of Ambiguity and Chaos [Eduardo]
Evolution depends on error, ambiguity and selection. A poor set of criteria may hinder the selection process. Having a large pool to select from seems better, regardless of high load.

Importance of Early Awareness [Christian]
It's better to know early on, rather than realizing that a design is not fulfilling in the end. Become aware of fulfillment and failures early in the process. Also analyze in retrospect, learn from past errors, to improve new designs.

Wayfinding is not the first/only Concern [Victor]
Breadth of considerations an architect needs to make. "Space as a meeting space" might be more important than wayfinding, for example. In certain scenarios the goal/intention might be to create circumstances for getting lost. The intention of the architect might be disorient the user, to slow down navigation [to generate "flâneurs"].

What is left in architectural design?
Emotional responses. New generation of experiments. [John]
We "outsource" so many things that it is worth asking: what is the man function left to Architecture? The program is defined by the client; sustainability is ensured by engineers; and so on, … maybe emotional response is what is left to architects to seek/orchestrate. A new set of experiments is needed to reveal the connections between space and emotional responses. How can psychology and linguistics contribute to this "next generation" of experiments? What are the measures and metrics for quality?

Plethora of available software - Tools to tell me something I do not know [Dido]
AutoCAD, 3dMax, Rhino, Maya, ArchiCAD, …, Ecotech, Solidworks, Catia, Generative Components, … so many tools out there to address general design and special needs (e.g., daylight simulation, etc). These tools (a) help me visualize an idea I already have, and (b) confirm to me an intuition/knowledge I have. Need to (a) compute something hard for me to predict due to it complexity, and (b) reveal to me something new, unexpected. Parametric design generative tools could be an example along these lines: in RhinoScript I

set up my algorithm and let the software "surprise" me with the form-outcome. Restriction of these type of software: ontologies fixed early on, hard to define new ontologies on-top of the outcome of my first algorithm to continue my form-finding process.

Need for one more tool? [Saif]

Maybe the architect has already many tools to choose from. Would other sort of recommendations be more helpful?

Ease of visual computation [George]

New tools do not allow for the flexibility the eye has in constantly redefining ontologies. In a way, the eye can compute more.

Manifesto on SpatialCognition-informed design [Ruth]

What if we were to write one? What would it be in there?

Even the body of knowledge coming from spatial cognition is not clearly defined yet.

Maybe thinking of the format of the desired final product (e.g., sketches) can help us define the type of information we are seeking, and the type of experiments to be designed respectively.

Recommendations instead of strict Standards [Dido]

Building on Ruth's comment: "101 Things I learned in Architecture" is nice and handy not only because of the visualizations of key architectural concepts, but also because it does not provide fixed/strict rules, it's a vocabulary.

LEED standards, for example, are outdated and poorly-informed. Are we seeking to inform the regulations, to create new regulations that will soon be equally outdated, or give the architect general/flexible recommendations? If the latter is the case, we should focus on the medium too (e.g., sketches, ranges of principles rather than one-to-one correspondences of stimulus-effect).

Ever-changing Knowledge [George]

Standards may be unnecessary. "I am willing to take the risk." If someone tells me that we cannot be certain that a particular layout will be good for wayfinding, for example, "I am willing to take the risk!" Driving was stressful a few decades ago, but not today. Knowledge [and behaviors] is/are ever-changing. No strict rules, adaptability.

Different types of knowledge [Dido]

Maybe we need to differentiate between (a) ever-changing knowledge (socio-cultural factors) and (b) human-specific limitations (e.g., no matter what, we have a grounded body, three types of cones in the eye, etc… human nature).

Importance of perspective taking [Alessandro]

Student experiment described; building on the importance and implications of egocentric /allocentric perspectives.

Broadband learning vs. Narrowband learning [John]

Competition follow-up [Ruth/Christoph?]

Success of SCAD competition. However, the architects who participated said they followed the regular professional process –no special consultation for wayfinding. How would they improve/change their designs if they knew more? What would it be different following the feedback they could get from spatial cognition scientists?
Discussion on competitions. More time is needed, more than a month. Cost associated.

Publication of Interdisciplinary research [Ruth/Saif?]
Difficulties associated with publishing interdisciplinary work. It took quite some time for Space Syntax work to get published to "Environment and Planning B" [or was it "Environment and Behavior"?]. What are the best venues? Is a book better?

Goal: improve design [Eduardo?]
We should not only try to "learn from design," the goal should also be to "improve design."

Tailored Recommendations - Respect the architect's "vocabulary" [John]
If one were to "inform" Mies van der Rohe's work on the basis of spatial cognition, how would s/he best do it? It would be absurd to suggest to Mies to build traditional walls in his glass-house to account for privacy..! [architects in the room laugh]
Maybe a psychologist needs to understand Mies' vocabulary first (i.e., transparency, elongated walls that do not reach the ceiling, etc) and suggest tailored modifications to his design. Collaboration with respect to the architect's intentions.

Discussion Notes by Christoph:

Tensions:

- what are the tools doing?
- Often a sketch does it easily

Ambiguity is important

- design creation
- serendipity encounters in wayfinding (people, learn new places)

precision high? -> wayfinding advice tends to be on precise level, not conceptual

consultants in refinement, and they bring tech tools

architects hold on to cognitive and emotional/experiential qualities of the building (don't give it to tools)

how to design the next generation of research studies and questions?

Can I measure the cognitive and emotive qualities/reactions to buildings?

Develop measures of QUALITY (Wang)

Getting the CLIENT involved as a stakeholder, convincing him of the value of evidence and tools

Tools to calculate something that is too difficult to calculate in the head (unlike isovists!) or that I cannot otherwise predict at all.

Parametric tools, CATIA
Like Braitenberg Vehicles:
Set a stage and experience the unexpected

Many people develop tools, all for designers -> is that TOO MUCH HELP?

Provide examples of relevant buildings to illustrate principles (of design, good practice, behavior, cognition)

Should we have the designs (from the competition?) in the CAVE?

Competition of the other side:

- architects provide materials
- challenge tool makers to derive new knowledge from ti
- apply our collective knowledge to the designs and provide feedback to designers. They then refine.
- Provide extra training & information to designers

Difficulty of publishing interdisciplinary stuff in relevant journals!

What are the research traditions in architecture? (Saif Haq)

What can behavioral scientists learn from the designers' work?

Translate generic advice into a specific design language and into the intention of the designer.

Don't be patronizing!

Standards can be limiting. How do they fit into the design process?

A manifesto of aims, methods and standards (Ayuso)

- define the scope of spatial cognition and of its impact/relevance for architecture

scientist to analyse: "Hey, this design causes stress" (Macagno), but not do the designing.

Egocentric vs. allocentric people

Design is often commissioned for the public, so we have to make it good for people; scientist acts as a consultant for architects

Taxonomy, policy

Question existing published codes / guidelines for lack of support (Dido)

Narrowband (find cheese) vs. wideband learning (react to change in environment)
Distinction of place vs. intelligibility of environment per se
Wayfinding vs. search?

Seattle Library: Did they appreciate the building? Did they stop to experience the building? Did they learn the structure of the building?

101 Things I learned in Architecture School (book)

- compile the knowledge, identify the gaps from architects' perspective
- compile methods and define (in the gaps) how to design specific experiments

Spatial cognition for Architectural Design: Report of Group discussion (group 4)

The main themes that our group explored were:
1. strategies for developing effective computational tools to assist in the design process, and facilitating the adoption and use of these technologies by architects;
2. the role of computationl tools in the architectural design process;
3. broadening the 'target audience' of technology - focusing not only on supporting architects during design, but looking to support all stake holders in an architecture project.

Spatial cognition researchers may feel a need to persuade architects to take results on human wayfinding into account when planning complex buildings and city layouts, for example when offering a design tool that highlights where navigation problems may arise. However, since excellent design results are of genuine interest to any serious architect, no further persuasion should be needed if support is offered precisely for those issues and processes where support is felt to be useful. Design tools therefore need to take into account not only the cognitive demands of the wayfinder, but likewise the thought processes of the architect, who focuses on a range of intricate issues throughout an extended design procedure. Ideally, an architectural design tool should therefore support architects' intuitive ideas by offering precisely the kind of information that is required at any given moment and that may not be readily accessible by simple intuition. This may mean considerations of navigability and intelligibility just as well as constraints imposed by the client, the environment, materials, costs, plus innovation and creativity, aesthetics, and whatever else may guide an architects' train of thought while designing.

As far as the issue of synthesis of analytical research in terms of building design and computational tools is concerned; the main challenge is to form true collaborative between disciplines. As a part of modernist tradition in architectural design, there is too much of emphasis on “function” of built space. The computational tools largely act as ‘clean up” tools for the mess this modernist tradition has created, in the form of modern building designs.

The whole approach of tool design should go beyond “context of Architecture”. In case of any urban infill/ big architectural project, there are broader general questions about social and environmental relevance of the project. And there are some specific questions about quality of architectural spaces such as intelligibility, navigability, functionality, etc. Which type of questions needs to be addressed first?

Broader general questions are usually taken care of by political/ bureaucratic set up; wherein architects have a little say. What kind of tools can help to address these questions? Do we need a more neutral tool to help evolve “thinking”? or as a support to improve design?
Do we need enabling tools or measuring tools, to evolve better/more humane designs?

Tools are in a way to keep check on biases/ subjectivities on part of architects. But they should not subdue the subjectivities on the part of users in terms of the variations… it should not end up generalizing characteristics of users…as they vary with socio-cultural contexts.

Analytical tools like space syntax are quite successful in generating a scientific basis to convince society at large; thus, space syntax is one tool that has been successful in achieveing popularity and acceptance within the discipline - how can we learn from this? There are different starting points such as beliefs/ metaphors. These keep on changing with person to person, from time to time. So can there be one useful way of starting? Can there be tools to transfer “metaphors” into building designs?
Or can there be any start up tools for triggering imaginations/ exploring ideas?

Tools are more predictive like space syntax, which need lot of data. They are also mostly deterministic. Can tools be developed that addess the needs of all stakeholders of a built environment, instead of only for architects? How can we establish a ‘common ground’ between all stake holders for decision making ;through ‘computational tools”?

Proceedings

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