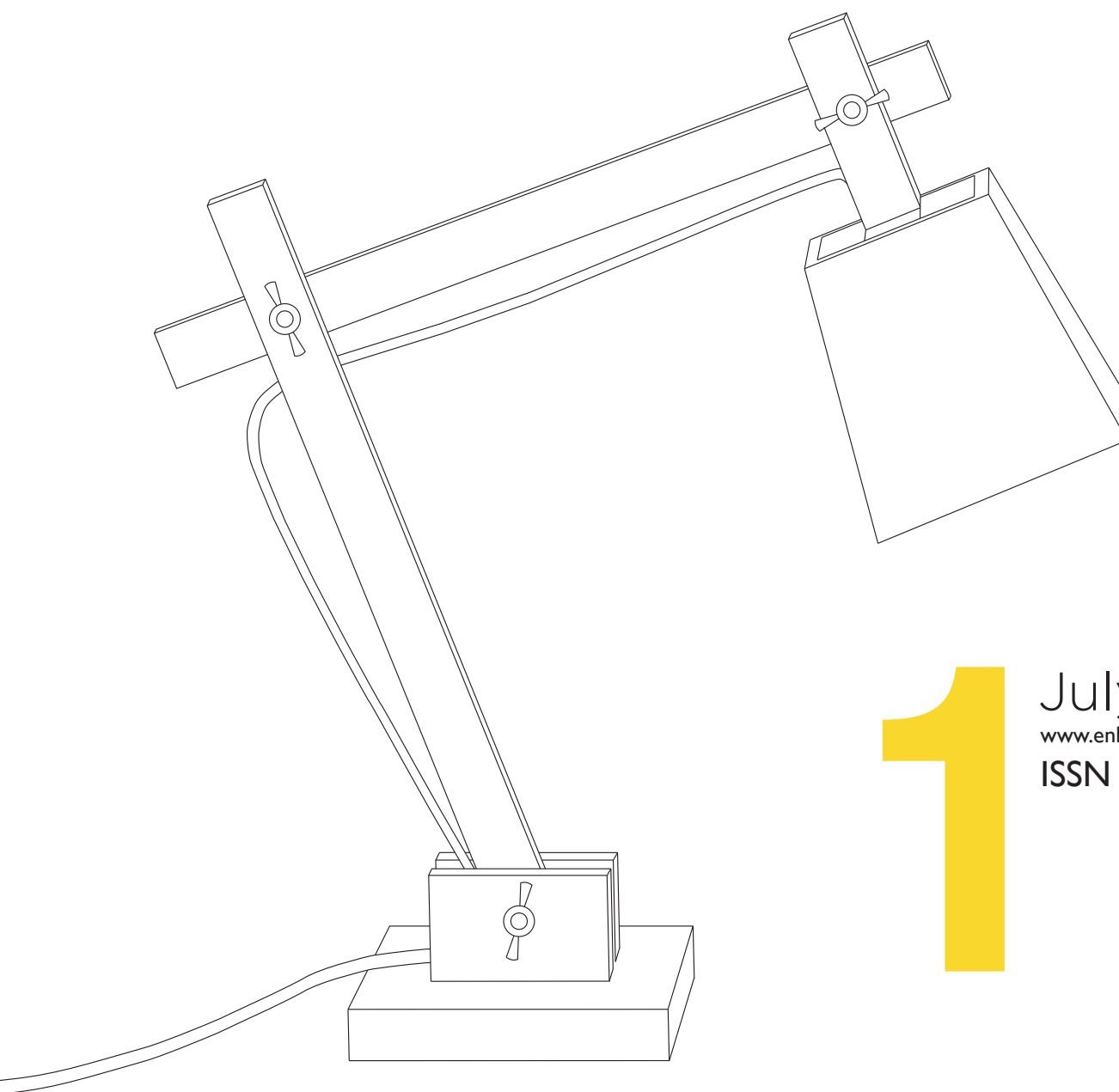


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*The e-journal for the
dissemination of doctoral
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All about the ArchiDoct E-journal

Maria Voyatzaki, Constantin Spiridonidis, Marianthi Liapi

Architectural doctoral research produced by academic institutions is, with architectural practice, one of the main pillars of the generation of new architectural knowledge. However, this research record is dispersed and isolated in many centers, with limited communication among them, belonging to different research cultures, traditions and approaches without evident possibilities of generating a synthesis representing contemporary architectural doctoral research.

As a step towards the above objective, the **European Network of Heads of Schools of Architecture-ENHSA** (www.enhsa.net), an EU funded Network in the framework of the **Lifelong Learning Programme** is initiating the **ArchiDoct e-journal**, linked to and complementary with the **ENHSA Observatory** (<http://www.enhsa.net/main/observatory/>). Archidoct is a peer-reviewed e-journal aiming at fostering, enhancing and promoting doctoral research in architecture. The first point that underlines the originality of this endeavour is that the authors of the essays published are doctoral students in architecture. The second point that underlines this originality is that the journal is a mentoring, educational tool that aims at improving the writing skills of the authors as this will be advised by the peer reviewers towards academically coherent and rigorous writings.

Within this framework, the Editorial Board has invited contributions from doctoral students who are active members of the **ENHSA Observatory**. While they are all based in the general field of architecture, their research directions include topics in architectural design, building technology, computation, history, theory, art, product design, conservation, landscape design, environmental design, urbanism, regional planning and town planning. Each issue will also include one essay by a member of the Scientific Committee or other eminent academic as a good practice example.

The changes occurring nowadays in architectural education and professional practice have a significant impact on the way innovation and new architectural knowledge are generated. Schools of architecture are directed by the current dynamics to reform their doctoral education strategies, structures and processes in order to have a more efficient contribution to architectural research and innovation.

The Higher Education of Europe has changed tremendously since the Bologna Declaration was signed. One of the results of the transformation is the renewal of doctoral studies. While the two-cycle education of under- and graduate levels has become quite universal, its final destination – the third cycle in doctorate is still emerging. Here both the traditions and innovations intertwine, different research cultures run parallel and three letters (PhD) standing for doctor philosophiae can mean several different things, especially in architecture.

Even though the discussion about doctorates in architecture appears to be popular between academics, proved by the number of conferences on the subject, investigating the nature of the research in architecture and of doctorates in Architecture, the Doctorate as part of an educational process leading to a profile of contemporary researcher of architecture is marginally discussed. Similarly marginal is the exchange of ideas through the opening up of students on their progress, topic definition, methodological approach, validity, generalisability of findings, originality and contribution to knowledge. A publication that would foster and encourage doctoral students to share their research venture has been the aim of this peer-reviewed e-journal.

The present issue includes the good practice example and five essays by doctoral students. We hope that this has been a learning experience for both students and reviewers that will, in turn, encourage more doctoral students to come forward, improving their academic writing skills, enrich their research record but above all communicate their research, theme, methodology and findings to other fellow PhD students, enhancing that way their own venture. We would like to thank the authors of the first good practice example for offering us their text to include in the issue, our reviewers for accomplishing the demanding and laborious reviewing process and last but not least all the doctoral students for their courage and perseverance to publish their work in this issue.

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Visual-Physical Grammars

Terry Knight, Larry Sass, Kenfield Griffith, Ayodh Vasant Kamath

Abstract

This paper describes a proof-of-concept study for a new kind of formal grammar—a visual-physical grammar. Visual-physical grammars are generative descriptions for the design and manufacture of building assembly systems that provide economical, visually rich, and structurally sound design variations for houses and other small structures. The building systems are aimed for communities in developing parts of the world, and incorporate decorative, vernacular design styles. A visual-physical grammar specifies the full-scale details of assemblies with rules that generate complete CAD/CAM data for fabrication. This paper reviews a pilot study for an automated, visual-physical grammar for an assembly system based on a vernacular language of Greek meander designs. The stages of the study from the development of the grammar to the full-scale construction of a wall section are discussed. The results demonstrate the potentials for embedding visual properties in structural systems through the integrated use of grammars and digital fabrication.

Keywords

Building assembly; digital fabrication; housing; shape grammars.

Note

The paper was originally published at the Proceedings of the 12th Iberoamerican Congress of Digital Graphics (SIGraDi 2008). La Habana, Cuba, 1-5 December 2008.

Introduction

This paper describes a proof-of-concept study for a new kind of formal grammar called a visual-physical grammar. Visual-physical grammars are generative descriptions for the design and manufacture of building assembly systems that provide low-cost, high-quality, visually rich design variations for houses and other small structures. The building systems are aimed for cultures and communities in developing parts of the world, and incorporate vernacular or other decorative styles into their design. A visual-physical grammar is comprised of rules that specify the full-scale visual, structural, and material details of the components of a building system, and the different ways components can be assembled. The rules apply to generate a visual-physical language of assembly design alternatives. Encoded as automated software, the grammar generates complete CAD/CAM data for the digital fabrication of components and their assembly.

This work is motivated in part by the urgent, global need for economical, quickly manufactured housing in developing parts of the world, in rural or underserved communities, and in post-disaster environments. Developing communities often have strong visual, vernacular traditions that are expressed in artifacts at all scales from utensils to clothing to houses. These traditions have important cultural and social functions that promote community identity. Too often, though, low-cost, prefabricated, or emergency housing solutions are generic and bland, ignore local design traditions, and are devoid of cultural sensibility. The research described here may lead to innovative new solutions for housing which not only provide shelter but also support important cultural values through the integration of familiar visual design features.

Two complementary areas of design computation are brought together in this research: shape grammars and digital fabrication. The visual, aesthetic aspects are developed through shape grammars. A shape grammar is a set of visual rules that apply recursively to a starting shape to generate a language of designs – that is, a set of design alternatives embodying a particular style. The structural and material aspects of the research are developed from current research on mono-material assemblies with interlocking components that can be fabricated with CNC machines. Components can be assembled by hand on-site with few tools and without additional binding material such as mortar. These physical aspects of the research are developed in a manner similar to physical design grammars.

We explored the potential of visual-physical grammars through a specific, proof-of-concept study: an automated visual-physical grammar for a wall assembly system based on a vernacular language of complex, ancient Greek meander designs. This vernacular language is no longer being practiced. However, the intent of this exploratory study was to determine if and how a visual language could be incorporated into a grammar for an assembly system. The study had four phases of development and testing. First, a visual-physical grammar for an assembly system for walls exhibiting meander patterns was developed “on paper”. Second, the assembly system was digitally modeled and physically prototyped at different scales. Third, the “on paper” grammar was automated to generate complete CAD/CAM data for fabrication of assembly variations. Fourth, a representative section of an assembly – a corner wall section – was constructed of concrete at full-scale. These four phases were cyclical and overlapping: work in each phase was often concurrent with, or entailed refinement of, work in another phase.

In this paper, we overview the four phases and conclude with findings, contributions to the field of design computation, and future directions for this research.

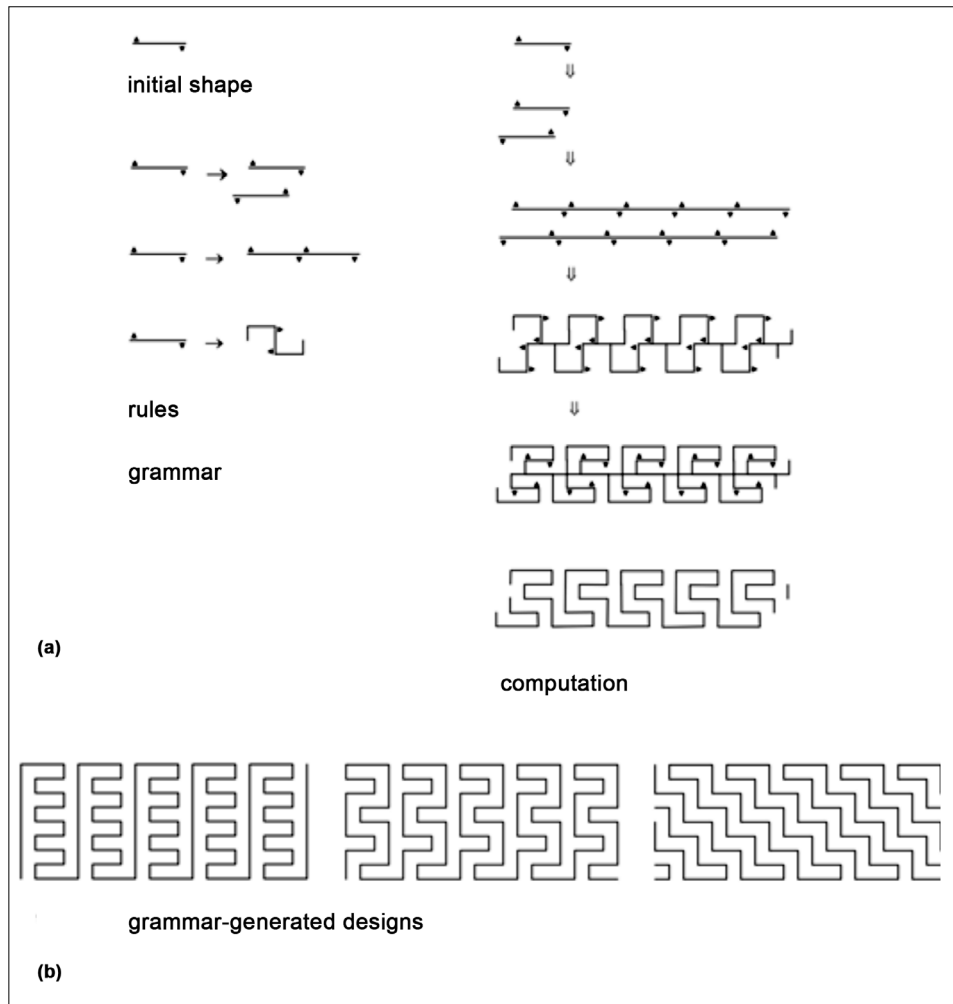


Figure 1.
(a) An excerpt from the Greek meander shape grammar and a computation of a meander design.
(b) Some designs generated by the shape grammar.

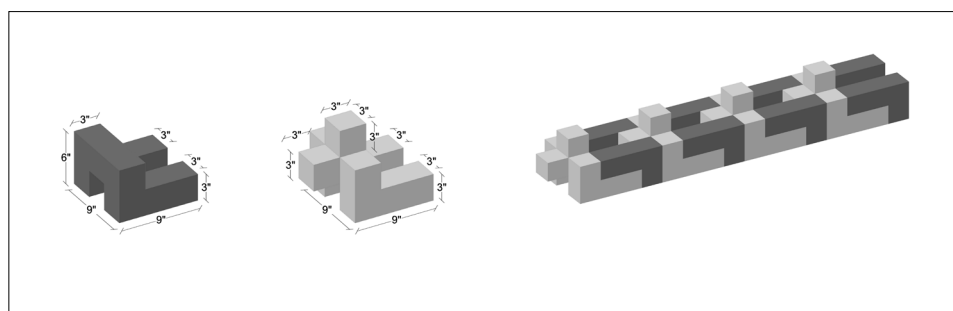


Figure 2.
The two main meander components and a meander course.

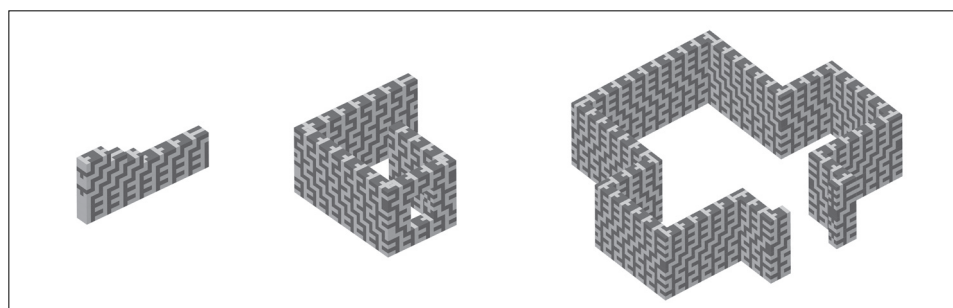


Figure 3.
Sample meander-walls generated by the visual-physical grammar.

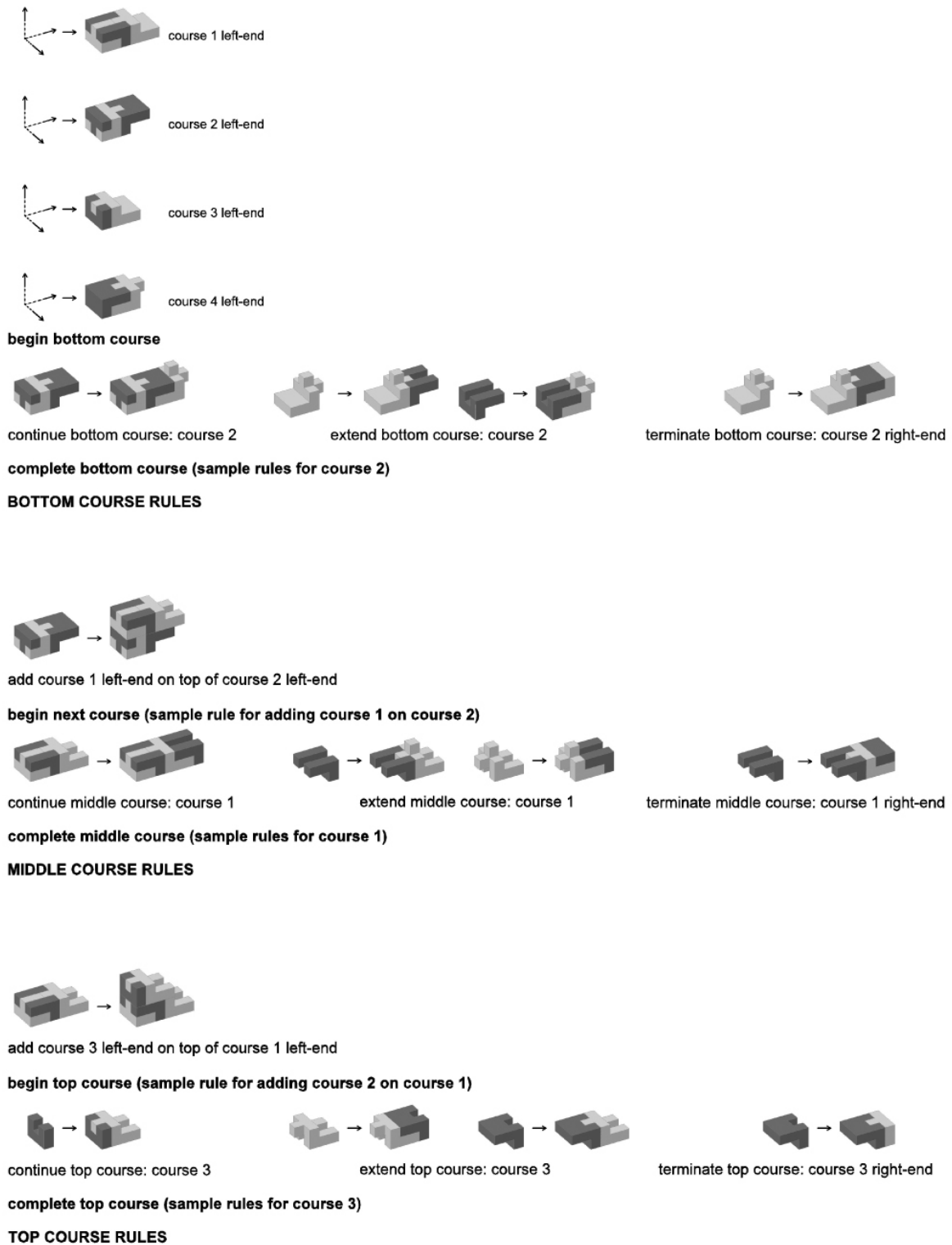


Figure 4.
Sample visual-physical
grammar rules.

Grammar Development and Testing

Phase One

We began with a shape grammar for a language of Greek meanders. The grammar generates meander variations by stacking and shifting rows of connected S-shapes (Fig. 1).

We translated this two-dimensional grammar into a three-dimensional grammar, on paper, that generates a language of “meander-walls”, that is, walls with elevations that express meander patterns. The meander-walls are intended to be the structural envelopes or walls of small buildings. The elements of the grammar are three-dimensional “meander bricks” –the components for a concrete, double-wall assembly system. There are two main, repeating components which come in two colors and create the main, overall wall patterns. There are also a number of specialized components for terminating the patterns at the boundaries of walls. The components have integrated aligners so that they can interlock securely both horizontally and vertically to form stacked “meander courses” without the use of mortar (Fig. 2). The components were dimensioned to satisfy both visual and physical goals. They combine to create meander patterns at an aesthetically pleasing scale and they are an appropriate size for lifting and placing by hand.

The rules of the grammar specify the different ways that the components can be assembled to generate different kinds of wall structures with different meander pattern variations. (See Fig. 4). Wall structures generated by the grammar include four-sided enclosures and orthogonal, non-intersecting wall structures with any number of sides – for example, free-standing walls, L-shaped walls, U-shaped walls, right-angled zigzag walls – all with window or door openings (Fig. 3).

Phase Two

Concurrent with, and following, the first phase, we developed and tested the structural and material aspects of the grammar components and their assembly. This involved digital modeling and then physically prototyping at various scales. Notably, we developed an innovative technique for digitally fabricating molds for the concrete components. The molds are made of layers of CNC-cut rubber sheets set within plywood, rockable “cradles”. Each cradle holds two to three molds for components. The cradles can be rocked by hand or by foot as the concrete mix is poured in to facilitate the distribution and settling of the mix. The modeling and testing of components and their assembly was a multi-stage process, including:

- a) Virtual modeling of components and their assembly in CAD to test the visual aspects of the assembly system and compliance of assembly variations with the original shape grammar.
- b) Physical prototyping of components with a layered manufacturing machine at desktop (1:6 scale) to test the physical assembly of components (Fig. 5).
- c) Physical prototyping of components cast using laser-cut layered molds at 1:4 scale to test our novel, digital mold-making technique (Fig. 6).
- d) Physical prototyping of components cast with CNC-cut layered molds at full scale. Here, we determined that the meander bricks could be cast relatively quickly and precisely by one or two people (Fig. 7).

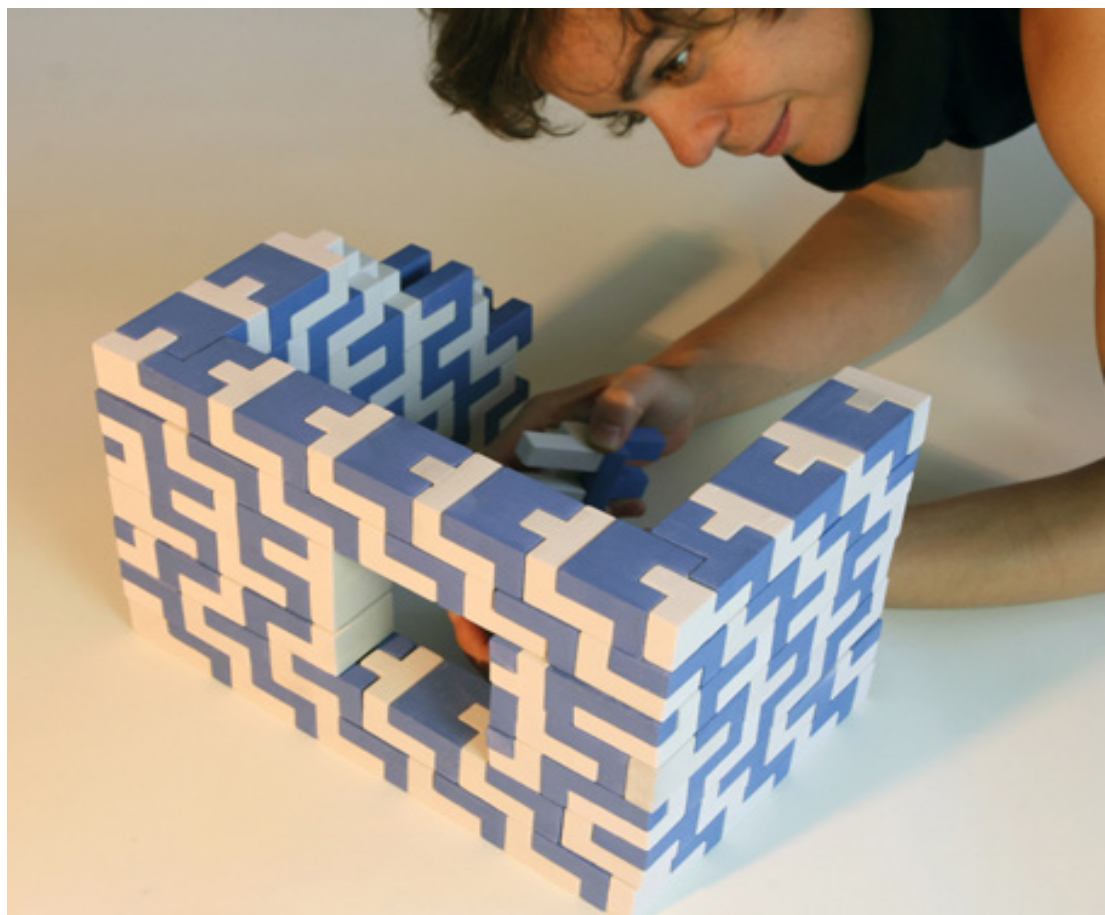


Figure 5.
A prototype 3D-printed
wall assembly.

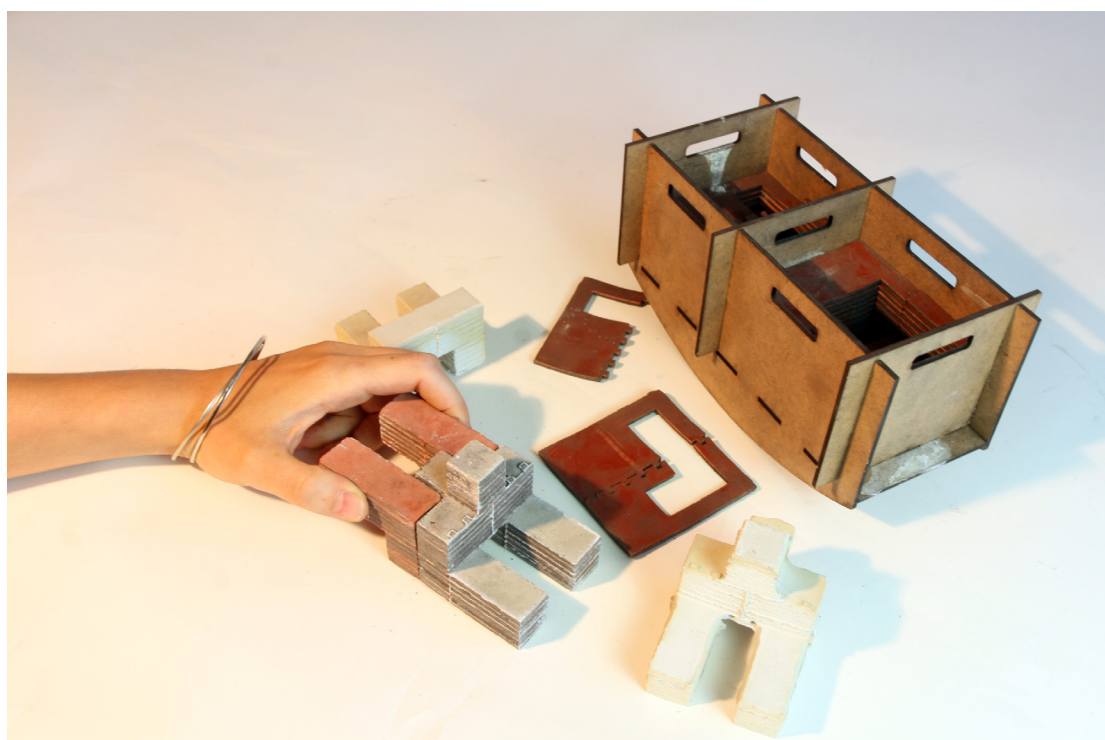


Figure 6.
A prototype laser-cut
mold-making device
with cast components.

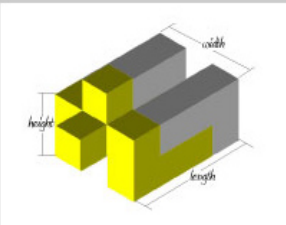


Figure 7.

Physical prototyping of CNC-cut layered mold system and casting of components.

Meander Designs

Welcome to creating Meander Wall Designs.
Construct wall designs by clicking on each course image (01-04) below.



course_01
course_03
course_02
course_01

Sequence of courses will show here...

Submit Delete

MODULE DIMENSIONS

Dim ☒ Length: 18 Width: 4 Height: 5





TYPE::	
Course_01	
Course_02	
Course_03	
Course_04	

Figure 8.

Sample user interface for the automated visual-physical grammar.

Phase Three

The “on paper” visual-physical grammar was automated using Ruby, JavaScript, and HTML on an Intel Duo Core CPU @2.00GHz on a 32-bit operating system. The program generates CAD/CAM data for the full-scale fabrication and assembly of all the meander-wall variations generated by the on-paper grammar, with the exception of openings, which we are continuing work on. The program interface allows users to control visual and physical criteria, including the configuration and dimensions of a wall structure and the choice of a meander pattern for it (Fig. 8).

The output of the grammar provides different functions for the designer (or potential occupant), the fabricator, and the builder of a wall structure. It includes:

- a 3D visual representation of the generated wall structure to show how the meander pattern looks (Fig. 9)
- an Excel spreadsheet indicating all the needed components for the wall, and a production schedule for manufacture and assembly given a user-defined completion date (Fig. 10)
- a visual assembly guide or diagram with each meander course shown separately.
- a digital file specifying all the cut sheets for the layered molds for wall components. This file is the input to a CNC machine which cuts the mold layers automatically.

Phase Four

While developing the automated grammar, we began testing its output by generating the design and CAD/CAM data for the manufacture of a corner wall section at full-scale. The wall had two sides, each with a window opening (Fig. 11). The wall was 7 ft high. One side was 8.5 ft long at the base with an unfinished, staggered side to show the components with an unfinished boundary. The other side was 4.5 ft long. The wall had a total of 265 blocks. The production schedule for the wall was guided by our program, and construction was accomplished over the course of a few weeks.

Findings

Our work demonstrated well the feasibility of our goals, particularly the real-world potential for designing and building homes using formal grammars combined with digital fabrication. In particular, we conclude that it is possible to define generative descriptions for the full-scale manufacture of building assembly systems that integrate vernacular pattern languages.

The vernacular language we worked with was very specific. For this language, it was straightforward to translate the main elements of the shape grammar into structural building components. However, we also needed specialized components to cap or bound the sides, tops, and bottoms of walls and wall openings, and specialized components to turn corners, all with the aim of continuing the overall pattern or terminating it in a visually pleasing way. The design of these specialized components was not straightforward, and we expect that this may be the one of the more challenging parts of the development of any visual-physical grammar for an assembly system.

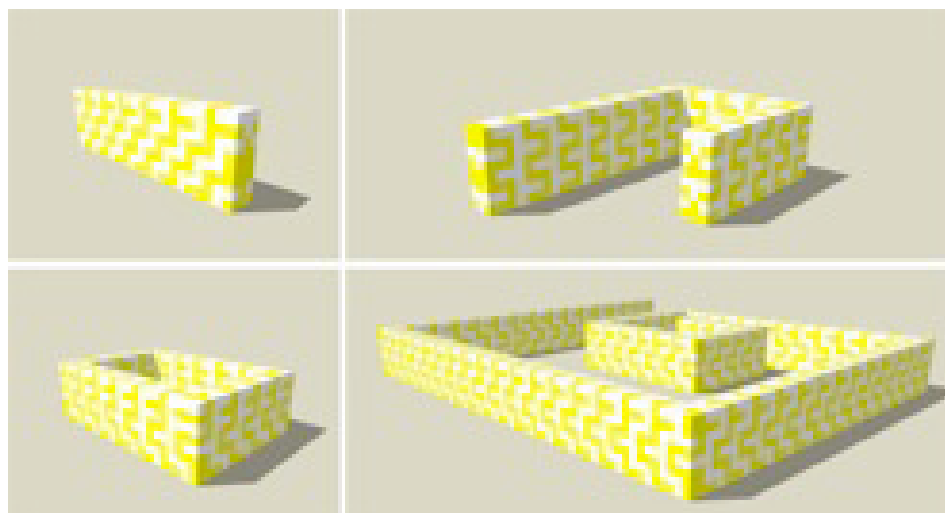
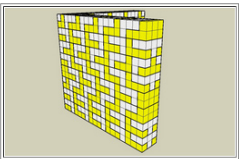


Figure 9.
Sample meander-walls
generated by the auto-
mated grammar.

Specifications for wall assembly and manufacture

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	Block_01	Block_1C_1	Block_1C_2	Block_1C_3	Block_1C_4	Block_1E_1L	Block_1E_2L	Block_1E_2R	Block_1E_3R	Block_1E_4	Block_1T	Block_2C_1	Block_2C_2	Block_2C_3	Block_2C_4
Level 1	7	1	0	0	0	1	0	0	0	0	0	0	0	7	1
Level 2	7	1	0	0	0	1	0	0	0	0	0	0	0	7	1
Level 3	6	0	1	0	0	0	1	1	0	0	0	0	0	7	0
Level 4	7	0	0	1	0	0	0	0	1	0	0	0	0	7	0
Level 5	7	1	0	0	0	1	0	0	0	0	0	0	0	7	1
Level 6	4	0	0	0	1	0	0	0	0	2	0	1	6	0	0

Figure 10.
Excel spreadsheet giving
the block inventory for a
meander-wall.



Figure 11.
Full-scale corner wall
mockup.

It was also straightforward to automate the visual-physical grammar. The initial output of the grammar is a set of building components for the user's selected wall variation. This initial output was then translated into CAD/CAM files for the negative shapes, that is, the layers for molds for the cast components.

The construction of the full-scale corner wall allowed us to test the feasibility of precisely translating data from design to physical production (via the automated grammar). It also allowed us to evaluate the visual and physical aspects of the assembly system. The visual appearance and scale of the meander pattern on the corner wall proved to be very appealing. The physical aspects of the system also proved to be mostly successful. The integrated aligners in the building components held the components in place and added greatly to the stability of the corner wall. At the same time, the built-in tolerances, or gaps between components, permitted some movement of the components. This might allow structures built this way to be less prone to collapse in earthquake conditions.

The wall construction also revealed issues beyond our control. Although the individual mold layers for the wall components could be CNC-cut precisely, the thicknesses of the layers (purchased from an outside source) varied by small amounts. This, in turn, caused small discrepancies in the heights of the components. Thus, the construction of the corner wall allowed us to assess which physical parameters within our research process were controllable and which were not. The parameters we were able to control were those dictated by our program and the data used for fabrication. The variance of the material thickness was not a controllable parameter. We will have to consider finding a direct correlation between the material thickness and a tolerance variable for future development. This is an important general issue to address. In order to incorporate visually complex design patterning into an automated system for structural assemblies, a general means for fabricating complex and precise physical components directly from digital data needs to be perfected.

Conclusions and Future Directions

Our project advances theories and applications of computation and digital technologies for the design and manufacture of building assembly systems for housing or other small structures. The results of our project suggest new solutions for economical, culturally sensitive housing. Although we are too early in our research to determine exact housing costs, our process points to areas of substantial savings. A major contributing factor to cost in traditional home building is the number of steps in construction from measuring, to cutting and assembly. Our system reduces the number and complexity of steps in on-site construction by eliminating on-site measuring and cutting of components. Workers manufacture blocks from precise CNC-cut molds and assemble only.

Beyond the specific context of housing, our work has the potential to contribute to the design and manufacture of artifacts at many scales, and in domains from product design to building design, particularly for artifacts where visual aesthetics need to be considered jointly with physical or material requirements and design customization or variation is important.

Our project also contributes to the advancement of knowledge and research on generative design systems, in particular, shape grammars. The primary intent of shape grammars has been to capture and represent design knowledge on paper or on a computer screen. Our visual-physical grammars not only generate visual descriptions of designs in a language, they also generate physical and material descriptions of designs for full-scale CAD/CAM production. Visual-physical grammars provide a new, important bridge from the virtual world of design on paper or in a computer, to the physical world of design and construction.

A critical next step in this research is the generalization of strategies for defining visual-physical grammars. Vernacular or other visual pattern languages, such as the Greek meander language, can often be characterized as languages of two-dimensional, infinite "wall-paper" designs. One technique for defining a visual-physical grammar from a set of wall-paper designs is to first parse the designs into a repeating motif or motifs, and define shape rules for recombining motifs to generate pattern variations. These repeating motifs would then need to be translated into interlocking building components. For example, the motif and main repeating element of the meander shape grammar is an S-shape. This S-shape was translated successfully into interlocking meander blocks. Alternatively, wall-paper designs might be divided into simple grids of cells with embedded motifs which could then be translated into grids of interlocking blocks with imprinted motifs. These are just initial ideas.

Another important next step in our work is to expand the ease of use and accessibility of visual-physical grammars for real-world applications. The issue of accessibility is crucial for global production and proper use of our system. The automation of our visual-physical grammar as a computer program integrated technology for local computing and processor use such as 3D software and Microsoft Excel spreadsheet data. We anticipate that our system will be used in rural and developing areas so would therefore need a different platform approach. Additionally, the design of the interface, currently very simple, would require more careful consideration of the users and cultural context.

The next stage of development will be to introduce a system that is completely mobile and can be accessed from any location using a mobile internet-connected technology. This will allow us to build a more sophisticated, yet simple system that can be accessed locally or globally with the appropriate technologies. We envision having the main processes calculated and computed on a distributed server technology that can be accessed using a simple drawing interface. The output of our system will be data for assembly as simple text that can be used as Excel input (if needed), and data to be used for CNC fabrication.

Acknowledgement

This project was supported by a grant from the National Science Foundation (Award Number 0748992). We would also like to thank Tal Goldenberg for her initial work developing the visual-physical meander grammar.

References

Knight, T., 1986. Transformations of the meander motif on Greek geometric pottery. *Design Computing*, 1, pp.29-67.

Knight, T., 1999-2000. Shape grammars in education and practice: History and prospects. *International Journal of Design Computing*, 2.

Sass, L., 2007. A physical design grammar: A production system for layered manufacturing machines. *Automation in Construction*, 7 (6), pp.691-704.

Stiny, G., 2006. *Shape: Talking about Seeing and Doing*. Cambridge, MA: MIT Press.

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Built rationally! Design approaches to housing within the limits of scarcity

Barbara Elisabeth Ascher // Oslo School of Architecture and Design

Abstract

This article presents alternative ways of discussing and reacting to conditions of scarcity associated with the delivery of affordable homes exemplified by the Norwegian builder Olav Selvaag. As one of the biggest and most influential private developers of social housing in Norway after the Second World War, he addresses the prevailing conditions of scarcity both through his writings, especially in his seminal books, “Bygg rasjonelt” (Build Rationally) and “Bo eller ikke bo” (To Dwell or Not to Dwell), and through his building projects. In line with the objectives of the research project on “Scarcity and Creativity in the Built Environment” (SCIBE), the article explores further how insights gained by this historical analysis could inform our understanding of design strategies of contemporary architectural practices whose work displays a similar approach toward working within conditions of scarcity, as opposed to fighting against it. The selected French studio “Lacaton & Vassal” and the Norwegian office “Helen & Hard” serve as interesting European examples of practices with strong principles of design in conditions of scarcity, which they showcase both in their housing projects and in writing.

Keywords

Affordable housing; scarcity; design approaches; welfare state; post-war architecture.

Note

The article is a further development of a presentation given at the 1st Annual Conference in Architectural Humanities Research at the Nationalmuseum for Architecture in Oslo in September 2012 and further research presented at the SCIBE PhD conference under the title “Within the limits of scarcity: rethinking space, city and practices” in London February 2013. I am grateful for all valuable comments I received in both occasions.

Within the limits of scarcity

This paper is part of a larger research project on “Scarcity and Creativity in the Built Environment” (SCIBE), a three year HERA-funded research collaboration led by Jeremy Till and teams from the University of Westminster, Vienna University of Technology and the Oslo School of Architecture, which investigates the various parameters that shape the construction of scarcity in different social, cultural, geographic, and temporal contexts. The aim of the research project is to identify the limits within which built environment professionals operate and to examine when and whether scarcity presents a set of inescapable constraints, or whether those conditions stimulate creativity in different and potentially innovative ways.¹

Scarcity is understood as a socio-material condition, influenced by the relationship between available resources and human needs and desires (Till et al., 2013). Even though scarcity is perceived as an absolute condition, for instance as water shortages in the desert, it is always contextual and relational. Scarcity is both situated in a local context and is therefore interrelated with allocation of resources in a geographical and spatial manner. The research is looking for best-practices that address this issues in an innovative way in architecture using qualitative and quantitative methods.

These alternative ways of discussing and reacting to conditions of scarcity associated with the delivery of social housing, are in this paper exemplified by the Norwegian builder Olav Selvaag. As one of the biggest and most influential private developers of social housing in Norway after the Second World War he addresses the prevailing conditions of scarcity both through his writings, especially in his seminal books, “Bygg rasjonelt” (*Build Rationally*) and “Bo eller ikke bo” (*To Dwell or Not to Dwell*), and through his building projects.

In line with the project’s objectives the paper explores further how insights gained by this historical analysis could inform our understanding of design strategies of contemporary architectural practices whose work displays a similar pragmatism² toward working within conditions of scarcity, as opposed to fighting against it. The selected architectural practices are the French studio “Lacaton & Vassal” and the Norwegian office “Helen & Hard,” both of which distinguish themselves in the European context through their strong principles of design in conditions of scarcity. Their approach is based on an understanding of the situatedness of their architecture in a wider socio-material context, which they showcase both in their housing projects and in writing.

1. For more information refer to www.scarcity.eu as well as to Goodbun, J., Till, J. and Iossifova, D., 2012. *Scarcity- Architecture in an age of depleting resources (AD)*. London: Wiley, p.218.

2. For a discussion of the term *pragmatism* refer to Saunders, W. S. ed., 2007. *The new architectural pragmatism: A Harvard design magazine reader*. Minneapolis: University of Minnesota Press.

Build rationally! Olav Selvaag and the austerity debate on housing

One of the most cited voices in the debates on post-war social housing in Norway is the Norwegian engineer and contractor Olav Selvaag. During his active career from 1948 until 1986 with his company Selvaagbygg, he produced 35,000 homes as a “commercial” provider of affordable housing in the Oslo region. His legacy, however, is strongly linked with the debates on alternatives for housing provisions under conditions of scarcity in the post-war period.

As only 13% of the planned 100,000 housing units built between 1945 and 1949 (Selvaag, 1990, p.76) had been provided, a debate on alternative solutions emerged in 1948 in the aftermath of these apparent poor results of the state housing program.

From an unknown engineer and contractor, Selvaag emerged as a public figure leading the debates at the point when the housing issue was discussed more forcefully and less optimistically than right after the war.

During the events of the Second World War, large parts of the country, especially in the North, had been destroyed, necessitating immediate large-scale action against housing shortages. The shortages of building materials, especially imported goods, workforce, and availability of financial means put extra constraints on housing production. The virtual standstill of housing production during the war-years was exacerbated by rural-urban migration to the larger cities, which created further challenges for the housing supply nationwide. The situation in Oslo, especially in the inner-city quarters, where large parts of the working class had been living in insalubrious conditions from before the war, was no exception.

During the post-war period, the demand for workforce, building materials, and financial means clearly outpaced the supply. This condition of economic scarcity enabled the government to actively steer the allocation of resources by rationing the availability of crucial materials, limit the size of housing units, and reduce the amount of available building permits, while simultaneously manipulating the access to financial means for building through the establishment of a state housing bank (Selvaag, 1951, p.32; Torstrup, 1948, pp. 33-35).

The introduction of measures to allocate resources efficiently, such as limitations on the availability of building permits, restrictions on the maximum size of housing units, and restrictions on building materials created further delays in deliveries.

Thus, the state housing programs were not only seen as an emergency reaction to the severe housing shortages, but also as an important cornerstone of the larger ambition to establish a welfare state based on the principle of universalism.³ The social security system, which the state was thought to supply for all citizens, regardless of their social and family background, included health care, unemployment benefits, pensions, education, and housing. It is therefore important to understand that due to these wide-reaching responsibilities of the government toward the citizens, decent and affordable housing was also seen as key in keeping costs down in other areas such as health. Safe and secure living conditions for everyone, with low levels of differences in living standards both nationally and locally, were seen as essential for individual freedom and stable political conditions.

Based on the concept of universalism, whereby ownership of decent housing for all was considered a social right, the government established a system of housing provision that financed housing via subsidized loans granted by the state housing bank. According to social-democratic ideals, profiting from someone else's housing needs was considered inappropriate. In consequence, using private contracting firms such as those of Selvaag for housing provision was viewed critically and housing co-operatives such as the Oslo Building and Housing Association (OBOS), which built and managed dwellings for their members, became the preferred institutionalized system of housing provision.

In this atmosphere, Olav Selvaag sent an open letter to the parliament, published in his book *Bo eller ikke bo (To Dwell or Not to Dwell)*, (Borge-Aaserud, 1949) emphasizing Norway's need to address the housing crisis and build more homes for less money, than was the current practice. As a provocation, he thus wrote in 1949: "With so little housing production, the housing crisis will be more severe in 1953 than it is today." (Borge-Aaserud, 1949, p.3).

He saw the allocation of resources as the crucial factor, as he illustrated in a speech to the student assembly in Trondheim in 1949: "Our society has limited resources, and of those we can only use a certain proportion on housing. We have only a certain amount of materials and a certain amount of work force available to build housing. How many houses we can build for these resources we can decide according to needs and desire." (Borge-Aaserud, 1949, p.17).

His starting point thus is the acceptance of scarcity as a fact and an attempt to improve the impact those conditions have on the housing situation for the greatest number of people. To achieve this goal, he demands a revision of housing standards for social housing. "The road we must walk to solve the problem is to build 30,000 homes per year for 15,000 kroner instead of 15,000 homes for 30,000 kroner" (Borge-Aaserud, 1949, p.3).⁴

3. For an elaborate discussion on welfare state regimes and the notion of equal rights for all independent of social background, refer to: Esping-Andersen, G., 1990. *The three worlds of welfare capitalism*. Cambridge: Polity Press.

4. Selvaag's point of departure was to take 30% of an average worker's annual wage of 3000 kroner, equaling a yearly amount of 650 kroner, and estimating 5% for down payment, interest, and maintenance costs, ending up with 13,000 kroner as the price for a house that an average worker could afford. (Borge-Aaserud, 1949, p. 9).

To keep homes within these limits of the affordable home of an average household income, Selvaag targeted technical innovation in construction and production methods. His design proposal was a semi-detached timber home for two families, vertically divided along the ridge with an area of 77 m². Each housing unit had its own entrance that led to a kitchen, living room, and bathroom on the ground floor and two bedrooms and a storage room on the second floor. Selvaag described the floor plan as “rational,” pointing at the distribution of spaces according to strictly functional criteria.

As his cooperating architect Sven Nicolaysen described in an article in *Bonytt*, 1949, titled “Selvaaghuset”: “The plans are simple, well ordered and the rooms cozy and provide good alternatives for furniture arrangements. [...] The requirements of the building codes for rooms in permanent habitation for people have apparently not been enforced” (Nicolaysen, 1949, p.38).

The reduction of necessary material-consumption led him to minimize the foundations to the limit of what was required for static reasons, resulting in small, ten-centimeter concrete foundation strips and pillars. The traditional storage function was therefore only provided under half the house. The second floor emphasized further economization, as here not only ceiling heights were lowered but also the attic was reduced to 90 m³ to minimize the space volume.

As timber was still a very scarce resource due to necessary exports of wood in exchange for foreign currency (Kielland, 1951), Selvaag aimed to reduce the amount of timber necessary for the construction of a home significantly by introducing American balloon frames as the main load-bearing construction in housing. In his proposed design for the semi-detached house, he optimized the roof-construction by applying a load-bearing division wall along the ridge. The compartments of the wall were filled with rockwool, a new material on the Norwegian market with enhanced thermal qualities compared to the traditional massive outer-wall constructions.

As nails were still scarce, due to shortages of steel in the post-war period, Selvaag suggested assembling the horizontal cladding-panels of the building envelope with clammed overlaps instead of traditional nailing.

Selvaag’s suggestions were widely debated in the media, leading to a challenge by the local newspaper *Morgenposten* to build a prototype of his proposed design for a semi-detached house in Ekeberg in the outskirts of Oslo. The house was erected in 1949 based on his original design sketches and was a success both regarding visitors to the project as well as convincing the critics.

Comparing the design to other homes from this period, for instance,

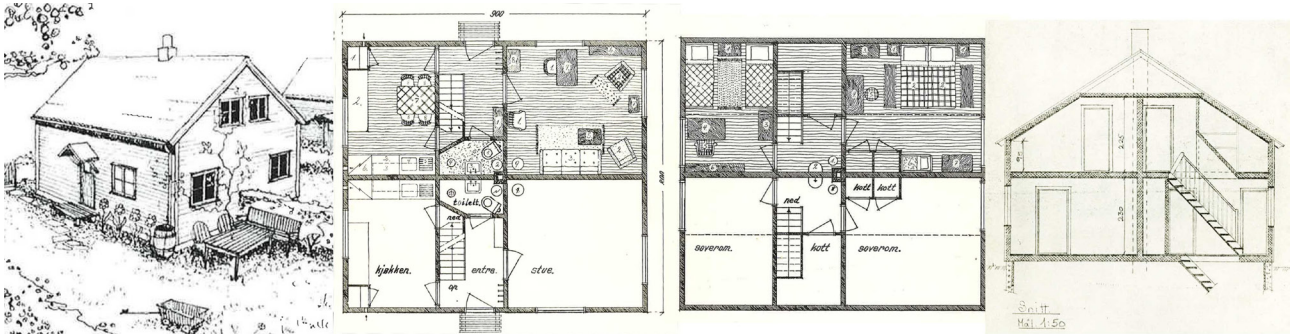


Figure 1.

a. Selvaag's prototype. b. Ground floor plan. c. Second floor plan. d. Section.
Source: (a, b, c, d) Borge-Aaserud, R., 1949. *Bo eller ikke bo?* Oslo: Cammermeyer.

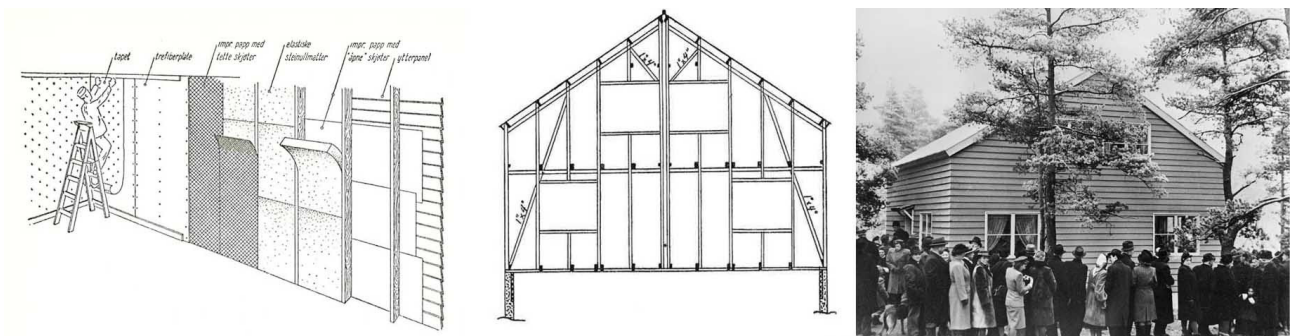


Figure 2.

a. Wall construction suggested by Selvaag. b. Adapted balloon frame construction. c. Opening of the prototype in 1949.
Source: (a, b) Skeie, J., 1998. *Bolig for folk flest: Selvaagbygg 1920-1998*. Oslo: Tano Aschehoug. (c) Unknown photographer, Oslo Museum.



Figure 3.

a. Housing type for housing reconstruction. b. Ekeberg house exterior and bedroom interior. c. Cartoon by Arne Wold.
Source: (a) Boligdirektoratet, 1947. *Gjenreisningens skissebok 1947: Hustyper for Finnmark og Nordtroms*. Oslo: Boligdirektoratet.
(b) Ørnelund, Oslo Museum. (c) Hasselknippe, O. and Selvaag, O., 1982. *Olav Selvaag: Mannen med ideene*. Oslo: Aschehoug.

the pre-approved small timber homes published in the Housing department's "Gjenreisnings skissebok," architectural sketches for reconstruction, published in 1948, the design does not introduce a new typology or architectural language. Due to the requirements set for subsidized loans from the State Housing Bank, the volume and floor plan are largely defined by the demanded three-room standard and the one-and-a-half storey rule. The archetypical form of a compact traditional rural house with a pitched roof,⁵ without additional ornamentation other than functional details, dominates the architectural language. Although the design of the Ekeberg-house is not fundamentally different from most of the other small timber homes of the reconstruction period in Norway, it redefines some of the technical and architectural features in a new way, diverging from the standard.

It was these technical aspects of his work that were met with the greatest skepticism. Although the Ekeberg-house proved to be structurally sound, thermally well insulated, and even exceeding the floor-area requirements, it was regarded as sub-standard and only suitable for temporary accommodation. As cartoonist Arne Wold commented in his drawing in 1949: "The Oslo Planning Department advises all inhabitants of health hazardous shelters against any dealings with Selvaag-homes, as they are violating all technical building standards" (Hasselknippe and Selvaag, 1982, p.35).

The critique on Selvaag's design might have been politically motivated. Although Selvaag and almost everyone else involved in the housing debate agreed on the principles of universalism for the provision of social housing within the welfare state, their respective strategies toward the goal of "decent housing for all" varied widely.

Selvaag described himself as apolitical (Skeie, 1998, p.179) and a technologist; nevertheless, his alternative approach to allocating resources for housing under conditions of scarcity was seen as a provocation. Especially noteworthy was his underlying critique of the government, which he claimed had failed to solve the housing crisis with their policy that simultaneously tried to raise building standards and provide housing for all of those in need.

In his book *Bygg rasjonelt (Build Rationally)*, his ideas become a manifesto against what he called "asocial sosialpolitik" (un-social social policy), regarding the allocation of (seemingly) limited resources: "In the building sector we thus have distributed ten oranges instead of the available five, with the result that only half the number of families that should have gotten a home did get one. [...] yes, after the war we have certainly distributed between ten to fifty oranges in this sectors, although we don't have resources available for more than five. As a result we only have achieved a half or a tenth of all the units we could have built, if we would have allocated resources smarter" (Selvaag, 1951, p.16).

5. Refer to Waaler, H., 1999. *Villaarkitektur på Østlandet 1945-1955: Bakgrunn og utvalgte arbeider*. Hovedoppgave: Universitet i Bergen., p.15, where the author states that the reintroduction of more local building styles, such as pitched roofs, were influenced by the restricted availability of asphalt-sheets necessary for flat roof constructions.

Selvaag's prototype was not only perceived as an innovative private proposal for re-thinking housing solution, but it was understood as an attack against the institutional framework on which Norwegian post-war social-housing policy was based.

He strongly disagreed with the definitions of "social" and "decent" as translated by the "Boligdirektoratet," the Housing Department, into normative building codes. Furthermore, Selvaag criticized the logic of quality ensured by the use of minimum and maximum floor-areas and restriction of materials as a funding criterion for loans by "Husbanken," the State Housing Bank, introduced in 1946 as a governmental institution for the financing of real estate. He further criticized the municipalities' ineffective organization of housing provision, which he attributed to their sole focus on "Boligbyggelag," housing cooperatives, as the only provider of subsidized social housing and the exclusion of private initiatives.

The institutional framework for post-war housing provision was an outcome of housing research conducted during the war with the intention of providing guidelines for rebuilding the country after liberation. Common ground for most of these documents seems to be the fear of missing the opportunity to combine the reconstruction of the country with the making of a new society.

As Jacob Christie Kielland, a Norwegian architect and the chairman of the team of the extensive housing survey on Oslo, "Mennesker og boliger" ("People and Homes"), (Brochmann et al., 1948) conducted during the war years, wrote in the architectural magazine *Byggekunst*: "It would be even worse if the reconstruction would be based on plans that do not provide an applicable groundwork for a modern, democratic community life" (Kielland, 1945, p.10).

The lessons learned from failed housing projects in the workers' districts of Oslo nurtured the understanding of housing not only as a hygienic, but also a psychological and social problem and contributed to a political atmosphere that was highly skeptical of precipitous decisions and stopgap activities.

Influential architects, such as Frode Rinnan, the architect behind the 1952 Olympics in Oslo and the planner behind Lambertseter, the first satellite town of Oslo, were thus representatives of the prevailing approach to social housing, which embraced the opportunity to introduce ideas of social engineering by building societies from scratch as "new towns" based on the concept of neighborhood clusters inspired by Ebenezer Howard's garden city.

This vision of a "modern society" that Social Democrats and functionalist architects addressed manifested itself in building standards rang-

ing from apartment sizes or number of rooms for homes to detailed technical specifications that were intended to achieve the ambitions of a “decent living standard for all.” These numbers became the core of their ideology and in some way the symbol of the welfare state that needed to be defended against people like Selvaag, who were accused of undermining the ideological objectives by proposing non-durable materials or what was considered bad craftsmanship.

When the Ekeberg-house was debated in those technical details, Selvaag’s reaction toward what he considered administrative stubbornness became obvious: “The first thing that strikes reading through the documents of the housing department is that the department does not seem to have understood the social or economic problems we are facing. [...] It seems as if the department sees that their task is to defend their paragraphs, even if you would expect them to evaluate the project in terms of housing, especially in the context of the housing misery and the productive and economic possibilities here in this country” (Borge-Aaserud, 1949, p.59).

A report by the authorities on the Ekeberg-house concluded that further adaptations had to be made to raise the building standard to an “acceptable” level, which added up to a required further investment of 2000 kroner. This amount was not too far from Selvaag’s original provocation that he would be able to produce homes for half of the current cost. (Skeie, 1998, p.77) Consequently, Selvaag considered his prototype Ekeberg-house a victory of his “rational” design approach under conditions of scarcity that aimed to optimize the cost-value ratio. As an engineer, he was especially pleased with the wide influence of his technical innovations,⁶ claiming: “After 1957, practically no single house has been built in the good old style that everyone in 1948 claimed was the only appropriate way” (Selvaag, 1990, p.79).

But not only his technical innovation had long-lasting effects, but also his general design approach, which he had developed under the conditions of scarcity that continued after the war, although the average income and the gross national product had almost tripled between the late 40s and 60s (Andersen et al., 1972, p.96) and turned Norway into one of the wealthier economies in Europe.

In 1956 Selvaag presented his design for what he claimed was the world’s first “terraced house,” as a reaction to the scarcities of affordable land in Oslo, which had occurred due to the enormous demand for land plots triggered by the rising living standards and reinforced by the implementation of the “markagrense,” the absolute limit to city expansion defined by a strict demarcation of the surrounding forest green-belt. Normally too steep to be found suitable to build on, Selvaag’s site in Ullernåsen, west of the center of Oslo, was still cheap to acquire despite increasing land prices in the Oslo surroundings.

6. This despite the fact that some similar ideas have been presented in a series of articles in search of more efficient solutions for timber construction, for instance in Thams, B., 1948. *Trehus av ferdigkappede materialer. Byggekunst*, p.65.

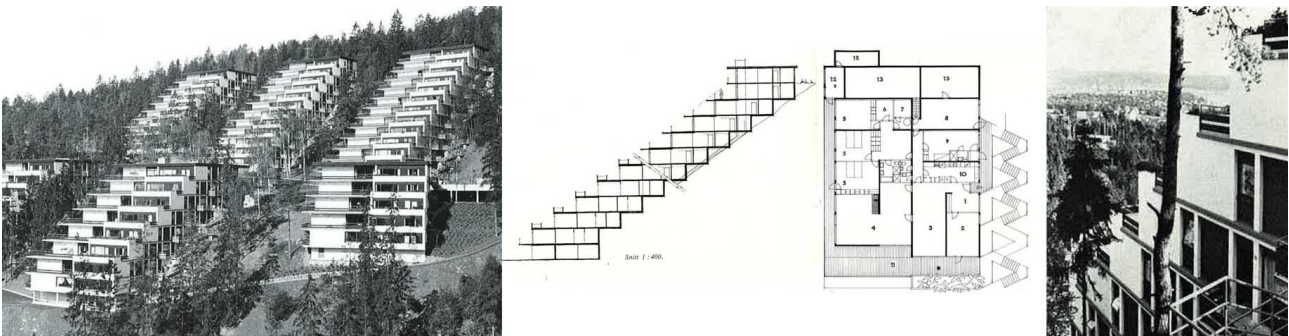


Figure 4.

a. Housing blocks in Ullernåsen. b. Section of one block. C. Plan of one apartment. D. Loping terrain of the site.

Source: (a, b, c) ANONYMOUS, 1965. Øvre Ullern Terrasser 3, Oslo. *Byggekunst*, pp.82-85.

(d) Remlow, A., 1964. Lykkelig løsning på "ubrukbare" tomter. *Bonytt*, pp.268- 272.

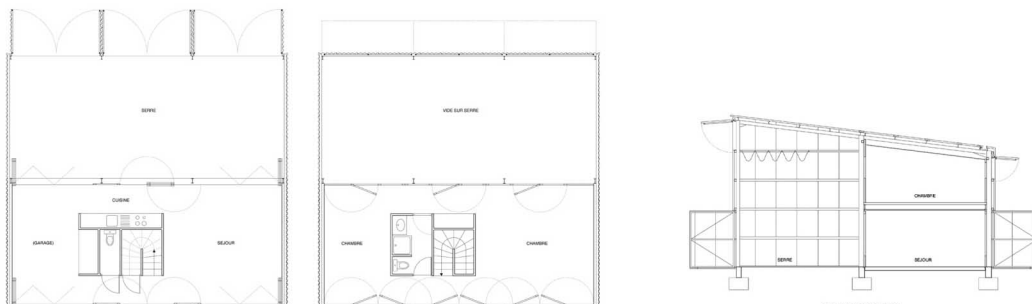


Figure 5.

a. Latapie house ground floor plan. b. Second floor plan. c. Section.

Source: (a, b, c) French studio "Lacaton & Vassal".

The architecture of the six individual blocks of the housing complex, finished in 1964, is defined by the slope of the hill. The 54 rather luxurious apartments are staggered to use the roof of the underlying apartment as a spacious roof-terrace and balconies. Due to this terraced design, the apartments became quite large, with the smallest one measuring 165 m². Large windows framing the view over Oslo added to a feeling of luxury.

Selvaag's focus on affordability led him to introduce prefabrication of the concrete structure, encouraging his cooperating architects Anne-Tinne and Mogens Friis to statically separate the wooden facades from the load-bearing structure. Selvaag's choice to encourage the reduction of excavation costs meant a necessary adaptation of the design to the landscape. As a consequence, the fourth wall, the one facing the hill, could not contain any openings, which led to the inclusion of an area of additional service functions within the flats.

Although the Ullernåsen project is not considered social housing as produced by the state, Selvaag managed to produce homes for the masses that contained architectural quality that was earlier considered a privilege of the financial elite. Although most of Selvaag's ideas are not completely new in a global context and his pragmatic scope as an engineer did not aim at fundamental changes of the conditions under which housing is produced, his proactive attitude toward scarcity as one of several constraints within the production of housing is unique in Norway.

The analysis of the financial and material constraints, regarding the shortage of building materials, time schedules, skills, workforce, or land resources, enabled Selvaag to invent different and innovative concepts by generating technical and spatial alternatives for housing within the limitations set by the given circumstances.

The pragmatic design approach Selvaag applies in the Ekeberg and the Ullernåsen is in both cases based on an underlying social concern, which sets the context for the architectural concept. The proposed technical innovations in the Ekeberg-project are directly linked to the political debate in the emerging welfare state on how to increase the housing supply and how to ensure its quality by national standards. The Ullernåsen project answers this social concern quite differently by manipulating the land demand as a crucial factor for affordability. Selvaag exploits the logic that land is expensive when it is scarce, unless it is not considered suitable for building according to known standards.

The redefinition of those standards by doing things differently seems to be the core of Selvaag's design approach, which he summed up under the title "det ideale krav, det godes fiende" ("The Ideal Requirement, the Enemy of the Good"), (Selvaag, 1990, pp.98-99) where he points

out that general requirements have to be derived from a holistic perspective and not from a singular interest in certain areas to be able to set priorities based on the limited resources.

Contemporary approaches to affordable housing

The historic example of the pragmatic design strategies of Norwegian builder Selvaag reveals valuable insights about housing provision under conditions of scarcity, which allow a comparative analysis of similarities and strategies that are applied by contemporary architectural practices and that emphasize a social concern in housing, such as those of the French office “Lacaton & Vassal” or the Norwegian architects “Helen & Hard.”⁷

Latapie House, a widely cited project by “Lacaton & Vassal” in Flouirac in the suburbs of Bordeaux, shares with Selvaag an ambition to maximize floor-area for the residents within very rigid budgets by systematically exploiting potentials of optimization within the entire framework of the project from load-bearing structure, to choice of materials.

The single-family home, finished in 1993, covering 185 m² over two floors, is based on an open floor plan with a kitchen-bathroom-core as an insulated and heated zone and an extended living space in a two-storey height conservatory. The simple volumes of the project are clad on the inside with wooden panels, contrasted by fiber-cement sheeting as the building envelope of the main space and the transparent polycarbonate sheeting of the conservatory.

To maximize the living area for the clients, the architects started on a journey to make the load-bearing structure more efficient and find better suitable materials and spatial configurations to keep building costs down. “As this project was still too expensive, the structural engineer was consulted again. Why use the same H profile everywhere? The solution: don’t think of Mies van der Rohe any longer and use the most logical element for each room, without any aesthetic concerns” (Lacaton and Vassal, 2009, p.29).

This is surprisingly similar to how Selvaag describes the main concerns in building social housing; “Lacaton & Vassal” express the same pragmatic attitude to form finding within their Latapie project. “The weight of the frame went from 13 to 8 tons. Given the price of the steel, this meant saving 50,000 francs, which brought the project into the budget planned. An unforgettable lesson. Henceforth we no longer thought of the aesthetics of a structure but, on the contrary, we always work as closely as possible on the systems’ efficiency” (Lacaton and Vassal, 2009, p.28).

The work of “Lacaton & Vassal” has been criticized due to the potential

7. “Lacaton & Vassal” and “Helen & Hard” have been chosen as they clearly outline their approach and exemplify a larger tendency. Exhibitions like *Small Scale – Big change – New architectures of Social Engagement at the MoMa and Architecture of Consequence: Dutch Designs on the Future of the NAI* bear witness of this.



Figure 6.

a. Latapie house from the street. b. Threshold between the inside and the conservatory. c. Kitchen area. d. Conservatory.
Source: (a, b, c, d) French studio "Lacaton & Vassal".

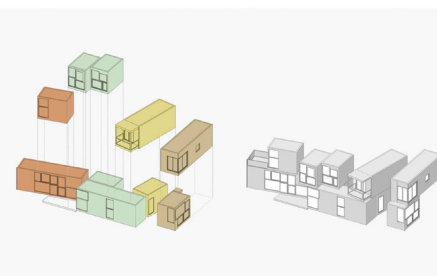


Figure 7.

a. Vindmøllebakken housing. b. Axonometric view. c. Facades made of recycled material.
Source: (a, b, c) Norwegian office "Helen & Hard".

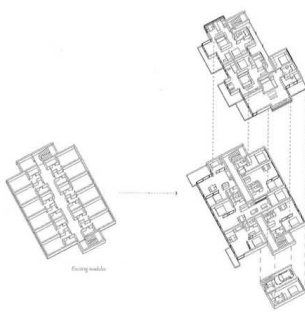


Figure 8.

a. Axonometric view. b. Exterior of the Buøy housing project. c. Interior view of bedroom and living area.
Source: (a, b, c) Norwegian office "Helen & Hard".

danger of encouraging housing associations and developers to further reduce their building budgets according to the lowered square meter price without providing the added architectural qualities.

The architects seem to be very much aware of this discussion, when they write: "Cost-effectiveness, like the terrain, is one constraint among others, but we think it's also an additional means. Furthermore, let's not mix things up: cost-effectiveness isn't the principle of less, of reduction, but that of hierarchy and the minimum" (Puente and Puyuelo, 2007, p.130).

This search for the minimum and the discussion on the right priorities within the existing context has been a debated topic since Ernst May's work on minimal dwellings, "Die Wohnung fuer das Existenzminimum," in Frankfurt in 1929, which had a parallel emphasis on rich architectural qualities, common facilities, and collective solutions that have often been forgotten in badly copied concepts of the original ideas. To understand the contextual aspect of architectural quality seems therefore to be crucial.

This seems to be the significant difference between Selvaag's approach and the design strategies of contemporary architects "Lacaton & Vassal," independent of all historic reference.

In an interview between Lisbeth Harboe and Anne Lacaton in Oslo in 2009, Anne Lacaton states "reality and the extraordinary [...] must be worked on in parallel," (Harboe, 2012, pp. 201-202) which sums up the super-pragmatic approach of their architectural practice, which focuses on the maximization of architectural qualities, such as sophisticated choice of materials, use of daylight, and site-specific qualities under conditions of scarcity, which goes far beyond the focus on cost efficiency in architecture based on the social concerns that Selvaag is displaying. This relational and situated approach of "optimisation" borrows concepts from ecology and cybernetics, where optimizing is not about a single part, but about the relationship of that part to the whole and the whole to the wider context.⁸

The Norwegian architectural office "Helen & Hard," who started their office in their early career with unusual low-cost housing projects such as Vindmøllebakken or Byøy in the oil-boom town of Stavanger, pursue a similar approach, which they describe in a larger context of "relational design." Vindmøllebakken, an experimental housing project made out of recycled dwelling units from the oil-industry, has been designed as a living and working alternative for young creative individuals on a low budget. The project consists of four studios that vary in size between 25 m² and 35 m². All of the units contain a living room and bedroom, a bathroom, and a small kitchen in a bi-level plan with access to individual terraces. Clad in diverse recycled materials and fitted with surplus win-

8. Refer to www.scarcity.is for further examples of this approach.

dows, the spatial quality of the apartments takes advantage of this material richness and generous daylight conditions.

Byøy, a more commercial follow up of these ideas, consists of 150 apartments, transformed into condominiums out of temporary barrack-style dwelling units of approximately 20 m². The units were grouped and opened up internally in order to create spacious, well-lit homes for first-time buyers for an affordable amount of money. Glass walls and sliding doors between the bedroom and living space maximize the perceived volume of the rather small apartments and add some flexibility within the spatial and economic constraints of the project. A simple steel façade on the outside is painted in different yellow tones, associated with the local oil-industry, and perforated with decorative floral elements.

In both projects, “Helen & Hard” share with Selvaag a pragmatic attitude toward the economic framework and perceived lack of resources, as they explain: “We have no problem accepting that the builder will require substantial profits and require attention. It’s important that we obtain insight into how resources are used, so that we can be party to reformulations of the use of resources. We always ask to have understanding of budgets to see if we can prioritize differently, economize at some point, and move the resources over to another item” (Braathen et al., 2012, p.252).

Interestingly enough, their statement about which kind of working method this would require, plus their approach to relational design have stunning similarities with Selvaag’s critique of predetermined solutions and requirements in housing. Siv Helene Stangeland from “Helen & Hard” specifies their approach in an interview with Martin Braathen in the book *Relational Design*: “In a way we’re also inspired by opposition in the tight conditions there. It’s always been a trigger for creativity. But you need great flexibility, when it comes to results. You can’t go into that kind of dialogue—and now we’re into the relational again -with a fixed concept” (Braathen et al., 2012, p.252).

This open approach to problem solving often results in bottom-up processes in their work and displays obvious anti-authoritarian attitudes. “Through the relational design method we try to formulate a broader, ecological angle of entry into all of our architectural production. Then it enters another dimension that doesn’t involve a battle between architect and builder or government, or between creativity and bureaucracy, but involves helping a global stewardship of resources to arise” (Braathen et al., 2012, p.254). “Helen & Hard” does not call this strategy “explicit politics,” but admits that it does involve aspects of it, through the values that are attached to the relations within design processes such as the influence on money, property, and political power (Braathen et al., 2012, p.253).

New directions

Starting from the historical example of Selvaag, looking at his Ekeberg and Ullernåsen project, the alternative approach to housing design that operates within, rather than against, conditions of scarcity becomes very obvious. Especially Selvaag's written statements, of a more political nature, illustrate his attempts to introduce a more pragmatic approach to welfare in the post-war period, as opposed to more visionary concepts of other, mostly modernist, architects that focus on the ideals of an affluent society, which they struggle to fulfill.

Although Selvaag's Ekeberg house is cheaper than the average standard home, it is also simpler than the average standard home. First in the second example we can truly understand the result of his exploitation of scarcity as a catalyst for creativity. In the Ullernåsen project Selvaag does not only substitute scarce resources but turns them into an architectural alternative that is more interesting and richer than the standard.

This analysis leads us to the more contemporary approaches to social housing by French architects "Lacaton & Vassal" and Norwegian architects "Helen & Hard," that seemingly operate within similar approaches, which are characterized by the same principles of not only accepting the constraints that occur through absolute or perceived scarcities but actively manipulating priorities and the allocation of resources.

This pragmatism displays a call for relational working methods without pre-determined outcomes, to be able to combine architectural quality with tight budgets, restricted availability of materials, or lack of workforce or skills. As a result, the consequences that the constraints set by local conditions of scarcity have on the architectural outcome are not only diminished but turned into positive qualities.

Further research will hopefully generate a deeper understanding of the architectural qualities that these alternative design strategies produce.

References

- Andersen, J. A., Moe, K. and Wiik, T., 1972. *Arbeiderboliger i Oslo*. Oslo: Arkitektthøgskolen i Oslo.
- ANONYMOUS, 1965. Øvre Ullern Terrasser 3, Oslo. *Byggekunst*, pp.82-85.
- Boligdirektoratet, 1947. *Gjenreisningens skissebok 1947: Hustyper for Finnmark og Nordtroms*. Oslo: Boligdirektoratet.
- Borge-Aaserud, R., 1949. *Bo eller ikke bo?* Oslo: Cammermeyer.
- Braathen, M., Kropf, R., Stangeland, S. H., Cook, P. and Hensel, M., 2012. *Helen & Hard: Relational design*. Ostfildern: Hatje Cantz.
- Brochmann, O., Waal, N., Størmer, F. and Anonsen, C., 1948. *Mennesker og boliger: Familieundersøkelsens resultater*. Oslo: Cappelen.
- Esping-Andersen, G., 1990. *The three worlds of welfare capitalism*. Cambridge: Polity Press.
- Goodbun, J., Till, J. and Iossifova, D., 2012. *Scarcity- Architecture in an age of depleting resources (AD)*. London: Wiley.
- Harboe, L., 2012. *Social concerns in contemporary architecture: Three European practices and their works*. Oslo: Arkitektur- og designhøgskolen i Oslo.
- Hasselknippe, O. and Selvaag, O., 1982. *Olav Selvaag: Mannen med ideene*. Oslo: Aschehoug.
- Kielland, J. C., 1945. Gjenreising og nyreising. *Byggekunst*, pp.10-12.
- Kielland, J. C., 1951. Boligbyggingen i 1951. *Verdens Gang*.
- Lacaton, A. and Vassal, J.-P., 2009. *Lacaton & Vassal*. Orléans: Éditions HXX.
- Nicolaysen, S., 1949. Selvaaghuset. *Bonytt*, pp.38-39.
- Puente, M. and Puyuelo, A. eds., 2007. *Lacaton & Vassal 2G Books*. Barcelona: G. Gili.
- Remlow, A., 1964. Lykkelig løsning på "ubrukbare" tomter. *Bonytt*, pp.268- 272.
- Saunders, W. S. ed., 2007. *The new architectural pragmatism: A Harvard design magazine reader*. Minneapolis: University of Minnesota Press.
- Selvaag, O., 1951. *Bygg rasjonelt*. Oslo: Gyldendahl.
- Selvaag, O., 1990. Folk vil bo fint- ikke i Selvaaghus-Nils Hønsvald. In: O. Børretzen, ed. 1990. *Vitner om 1950-årene*. Oslo: Stromboli.
- Skeie, J., 1998. *Bolig for folk flest: Selvaagbygg 1920-1998*. Oslo: Tano Aschehoug.
- Thams, B., 1948. Trehus av ferdigkappede materialer. *Byggekunst*, p.65.
- Till, J., Iossifova, D., Sengupta, U. and Cheung, E., 2013. *SCIBE* [online] Available at: <<http://www.scarcity.is>> [Accessed 31 June 2013].
- Torstrup, T., 1948. Diskusjonen om boligbygging. *Byggekunst*, pp.33-35.
- Waler, H., 1999. *Villaarkitektur på Østlandet 1945-1955: Bakgrunn og utvalgte arbeider*. Hovedoppgave: Universitet i Bergen.



Urban Storm Water Management: Possible Catalyst for Moving Towards a Water Sensitive City

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Abstract

Water sensitivity is the city's capacity to avoid water scarcity, flooding or waterways pollution, to express the community's values and aspirations regarding water and to quickly adapt to urban growth and climate change. Even highly recognized in the specific literature, the concept of water sensitivity failed to be institutionalized due to the lack of a benchmarking tool to globally understand it. In this idea, the article introduces the concept of water sensitive approach, developed for extreme climates, to different urban areas with a moderate climate and a low rate of water related disasters. Brussels Capital Region, the selected case study, has high institutional, technical, social and funding capacities to make a leap frog towards water sensitive practices in urban planning and design. Considering the city's large impermeable areas, demographical growth, density, and higher rate of precipitation every year, the administration has to change the current water management practices. In this idea, the transition to water sensitivity could come from storm water management practices. There is a large interest worldwide for sensitive storm water management practices and in order to be applied for Brussels' territory, an evaluation of their potential is necessary. A methodology that works in parallel with quantitative and qualitative evaluation tools and integrates a research by design approach is a valid solution to benchmark the concept of water sensitivity and to show its potential for urban agglomeration with moderate climates like Brussels. Based on this conclusion, the article introduces a future research that will analyze this hypothesis by investigating both traditional and sensitive storm water on the Brussels' territory, starting from the watershed scale to the neighborhood scale.

Keywords

Water sensitivity; storm water management; urban design, Brussels Capital Region; waterscape.

Water in urban planning

Water has an active role in the city's livability: temperature, humidity and the feeling of well being (Arnfield, 2003), but even so, the city's present vulnerability in maintaining a proper water quality and quantity (floods or droughts) comes in conflict with the aspirations of a sustainable urban development (Koester, 2010).

Since the 19th century, traditional urban water management policies failed to control the human impact on the landscape and ecological processes regulated by the water cycle (e.g. erosion, surface and groundwater levels, water chemistry...). This system evolved when energy was less expensive and water was plentiful, thus, the tendency was to implement management systems that optimized the infrastructure. Most of the urban rivers were piped and moved underground, separated from the public space and in less contact possible with the citizens. Progressively, the piped rivers became infrastructures for the sewer system and lead to *Waterway pollution*. In Europe, in the 1950's, most of the cities followed the traditional UK model of combined sewer system (See Figure 1, collecting storm and waste water in the same infrastructure). In addition to this, as the population grew, traditional water sources seem insufficient to satisfy the ever-growing demand (*Water scarcity*) and started to be imported; this resulted in a higher amount of waste water entering the system. Besides this, the present tendency of less and heavier rains challenges the system, making the city's drainage difficult, leading to *Urban Flooding*. To summarize, nowadays, *urban flooding and waterways pollution*, enhanced by the spread of impervious areas, the overloading of the sewer system and the incapacity of water treatment stations to balance the human impact are the major water related concerns in urban planning.

In this context, water in urban areas is seen more as a cause of damage than a resource. This perception is enhanced also by the hard work for the reconstruction, recovery, or prevention against tsunami, typhoon, or river flooding (eg. Japan, Southern-East Asia, The Netherlands). Placing water as a central point in urban planning was therefore a mandatory measure in urban areas with a high risk of water related disasters. Such measure was not as important for urban agglomeration that shows a lower risk and a moderate climate.

These days, the continuous population growth in cities and the expansion of urbanized territories increases the risk of water related disasters in urban areas (urban flooding, waterways pollution, water scarcity) and, thus, the necessity of reinvestigating the role of water in urban planning practices. The return to a previous state or the reinforcement of current water infrastructures to supply, distribute, and treat water could not solve all the problems and could not improve the city's livability.

In the current international urban water management practices, alternative solutions for flooding, water scarcity, or pollution, which could reduce or counterbalance the impact of human settlements on the natural water cycle (Kotola and Nurminen, 2003), enabled a change in perception. Nowadays, the urban water management passes from being a technical issue that solves by global means the city's water supply, treatment, and drainage through the construction of physical infrastructure, into an important catalyst for urban development by enhancing the city's livability and by reducing the human impact on the environment.

New solutions started to be searched (Brown et al., 2006; De Graaf, 2009; Kaufmann, 2007; Mitchell, 2006), mainly in the Anglo-Saxon community, in areas with extreme climate, where heavy rains

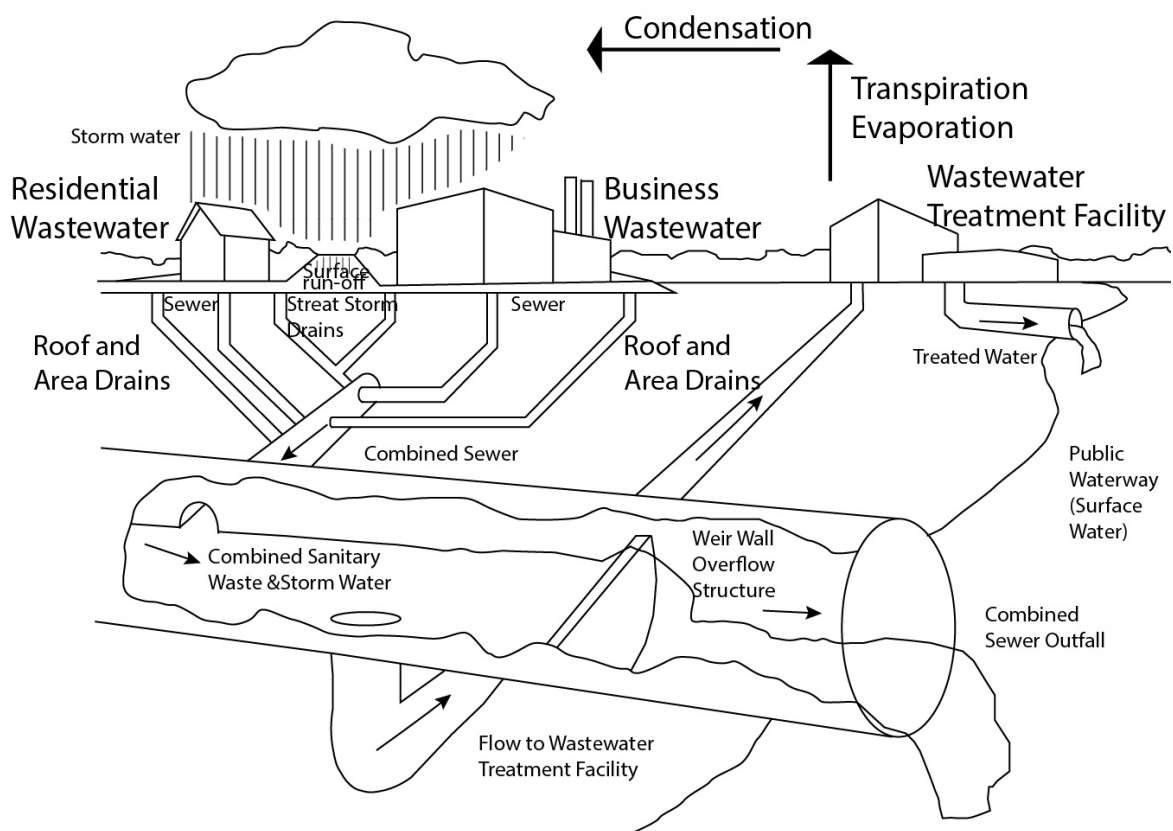


Figure 1.

Combined sewer system, the European model.

Source: St Louis MCD, Clean River Healthy, 2012. *Combine Waste Water Overflow* [jpg]. Available at: <http://ecobrooklyn.com/wpcontent/uploads/2012/06/CombineWasteWaterOverflow.jpeg> [Accessed 10 February 2013].

follow long drought periods, in Canada, United States, or Australia, for example. Among the solutions proposed, the concept of Water Sensitive City (the city that integrates the water sensitive approach in the process of urban regeneration and development, WsC) -the water seen less as a hazard and more as a resource, became part of the sustainable urban development (Wong & Brown, 2009) and enabled the link between environmental issues and urban planning through an innovative vision.

Water sensitivity approach is the city's capacity to avoid water scarcity, flooding, or waterways pollution, to express the community's values and aspirations regarding water, and to quickly adapt to urban growth and climate changes.

This approach translated into urban planning practices can be defined by a series of guidelines. First of all, water sensitivity is an integrative approach. The entire urban water cycle -blue water (potable water), green water (rainwater), brown water (industrial waste water), or grey water (waste water)- is considered in the process of water reuse and recycling. Diversifying the water sources could be vital during droughts, but could also protect the environment. This attitude helps in saving potable water by using other water types, according to their level of treatment. For example, rainwater can be directly used for irrigations or for toilet flushing and washing. Secondly, water serves for multipurpose, apart from human or industrial consumption. An example is the water integrated in the public space to raise its attractiveness and to enhance the green spaces. The third guideline regards the governance. By finding flexible, diverse, global, and decentralized, interdisciplinary solutions, a change in the city's resilience to climate change and urban growth is expected. Recycling water at the housing level in a decentralized manner could reduce the quantity of waste water that enters the sewer system and could reduce, as a consequence, the risk of urban flooding. A decentralized system can be subject to failure if it is not controlled and coordinated by a global or centralized management that ensures the quality of the water used and treated. By remaining flexible, taking into account various scenarios of climate change and by including interdisciplinary solutions, the system is prepared to support urban growth and, in the same time, to protect the ecosystem. At last, for all this to become possible, an increase in the awareness regarding water management practices and aspirations among government, business companies, communities, and professionals, is required and represents a vital point to ensure the well functioning of the Water Sensitive City.

To summarize, water sensitive practices follow to use water from various sources and for multipurpose, to operate in an integrated, centralized, and simultaneously decentralized system, and to be resilient to urban growth and climate change.

Architects and urban designers have an important role in confronting concepts like the water sensitive approach to the site reality. In this way, as European architect, the author of this article questions the application of this concept in different environments with a moderate climate and a preeminent topography, by contrast with the extreme climate and flat relief of the Australian cities, where water sensitive approach was developed. In Europe, practices of sustainable water management are advancing quickly, especially after the 2010 European directive on this thematic. The following sections will take as a case study Brussels Capital Region, known as the European capital, with ambitions of also becoming the continent's greenest city in 2015. Brussels has indeed the potential

to become an example of water sensitive city, but a better coordination and assessment of the ongoing initiatives is required. Storm water management, as a subset of the water sensitive practices, is the key point in this investigation and highlights Brussels' high institutional, technical, social, and funding capacities to achieve *water sensitivity*.

Water Sensitivity in moderate climates: Investigating the case of Brussels Capital Region, Belgium

The water sensitivity approach is a reaction to the extreme events related to water, but it does not necessarily mean that this condition is sufficient for the transition to this approach (eg. in Brisbane, Australia, the necessity for fast solutions to water scarcity made the administration return to traditional means like desalinization, (Brown & Keath, 2008), or that the concept can be applied just for extreme climates (eg. SWITCH project for European cities).

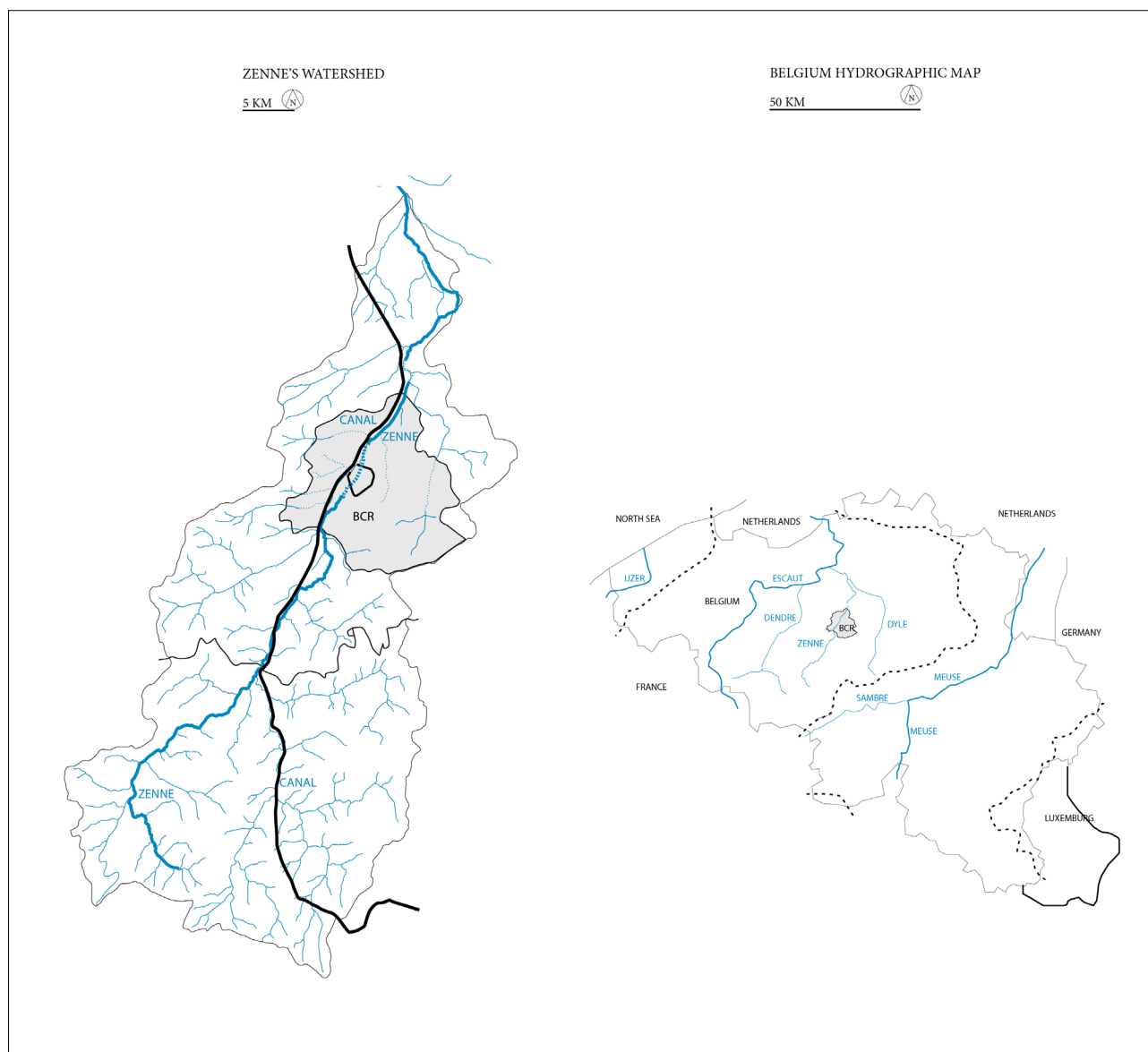
Following the concept of water sensitivity, most of the dense cities, with a low rate of water related disasters (windstorm, droughts, slides; Adikari and Yoshitani, 2009), like the Brussels Capital Region (or Brussels), could change to a more sustainable water management and solve the problems of waste and storm water system, water treatment, and urban flooding. In Brussels, the concept of water sensitivity has not yet been put in practice, but the context offers, however, important premises to support this city's transition. The following section investigates the capacity of Brussels to take in the water sensitivity approach and proposes storm water management as catalyst of transition.

Selecting Brussels as case study to evaluate the adaptability of water sensitivity approach in dense agglomeration with moderate climate is justified by the city's complex natural and institutional conditions. In present days, the city is defining its future directions of development. Placing water as central point for urban regeneration could provide a fresh direction and help architects, urban designers, and administrative to move towards a *sensitive* attitude regarding the surrounding environment.

The ecological, hydrographical, geological, meteorological, and institutional specificities of Brussels are important in the city's transition towards water sensitivity and they limit this concept's prospect applications.

First of all, it is important to mention that the city (see Figure 2) is situated in two river basins: Zenne's and Dyle's, tributaries to Belgium's main river, the Escaut. Even so, the waterways are little visible inside the city. Along the greatest part of its length, Zenne has been diverted into a system of culverts, starting from the 19th century, and replaced by an artificial channel in order to facilitate merchandises transportation to the North Sea (see Figure 3). Zenne's tributaries (see Figures 4 & 5) and basins are an important backbone of the city even if the watercourses were transformed into a drainage system using underground pipes (Water management plan, IBGE 2011). As a result, surface water lost its footprint in the city urban tissue.

Nowadays, citizens have direct contact with water just through artificial lakes, maintained partially with drinking water. Brussels' interesting topography is the only element that still shows that in the past Brussels was a water city. The new visions on the city's



Figures 2, 3.

Hydrographical map of Belgium Kingdom with the location of Brussels Capital Region.

Source Fig.2: Wallonie Geoportail, 2012. *Wallon Region Hydrogeological map*. Available at: http://geoportail.wallonie.be/cms/home/geocatalogue.html?search-theme=theme_10&search-subtheme=souththeme_1020# [Accessed 28 February 2013].

Source Fig.3: Centre Informatique pour la Région Bruxelloise (Computer Centre for the Brussels Capital Region), 2012. *Urbis Map*. Available at: [http://irisbox.irisnet.be/vip/servlet/CCRLWebRequestServlet?\\$\\$controller=ccrl.server.controller.Document-Browser&Idmunicipality=CIBG&Language=fr&Idparentcategory=1289&Documentdate=&Showarchiveddocs=0&Showforms=0](http://irisbox.irisnet.be/vip/servlet/CCRLWebRequestServlet?$$controller=ccrl.server.controller.Document-Browser&Idmunicipality=CIBG&Language=fr&Idparentcategory=1289&Documentdate=&Showarchiveddocs=0&Showforms=0) [Accessed 10 May 2013].

development should highlight its specificities and bring forward the importance of the valleys. Water should find again its place in the valley through a sensitive approach that takes into account the citizens' aspiration, and promotes, in the same time, the implementation of new innovative technologies. For some parts of the city exists already an increased awareness on water management among communities in the Maalbeek Valley through the program called New Urban Rivers (the harvesting of storm water permits the creation of new surface waterways that enhance the public space) or the revalorization of blue network in the Molenbeek and Woluwe Valleys. Even if they cannot be called sensitive approaches, these initiatives follow the same direction and stand as a proof of the city's capacity to take in water sensitive practices.

Brussels has a very diverse land specificities of: (i) the urban milieus: densely or sparsely built areas; (ii) the land use: mixed use, residential, tertiary; (iii) the geological conditions (East vs. West: sand vs. clay, relatively flat to hilly relief) (De Bondt and Claeys, 2010). This variety makes it difficult for the urban planners to elaborate a uniform plan for the city's development. A single approach can't be the solution. This is why the actions implemented in the valleys should be punctual and specific to the site, through a decentralized management.

On the other hand, the recent increase of heavy rainfall leading to falls within the sewer system is caused by the city's different hydro meteorological conditions than those observed in the 1960's, when it was designed. (Plan of the federal Belgian climate commission, 2010). In order to predict the changes required in the system, a series of climate change scenarios for a more precise effect on the amount of precipitations in Belgium (Environment Outlook 2030) can serve as guidelines: (i) wet climate scenario - increase in the level of precipitation generating runoff discharges, high level in the rivers, flooding, high soil water and groundwater levels in the winter; (ii) dry climate - low river flows, low soil water and groundwater levels during dry summer periods; (iii) moderate climate scenario (a middle scenario). This work of prevision is important. It obliges urban planners to find adaptable and flexible solutions to change the centralized system of water management and to make it more resilient to climate change and urban growth. Brussels' administration made significant steps forward in this direction by elaborating two directive plans: Storm Water Plan 2008-2011 and Water Management Plan 2011. Both of them enable new institutional concepts and high financial possibilities for water sensitive practices.

A last important issue concerns the position of Brussels in the centre of Belgium's Kingdom, a federal state, that makes it difficult to achieve an integrated regional water system due to the interconnectivity with the Walloon region for the water supply and Flemish Region (the Brussels' treated waste water and storm water drain reach the Scheldt basin). Even so, the impacts that a failed water system in Brussels might have had on the other regions transformed the city into a centre to start the transition towards water sensitivity.

Considering Brussels' characteristics, the transition towards a water sensitive approach could come from storm water management practices. Beside the favorable present context in terms of technological innovation, community awareness, institutional capacity and funding, a variety of land characteristics to implement the water sensitive approach,

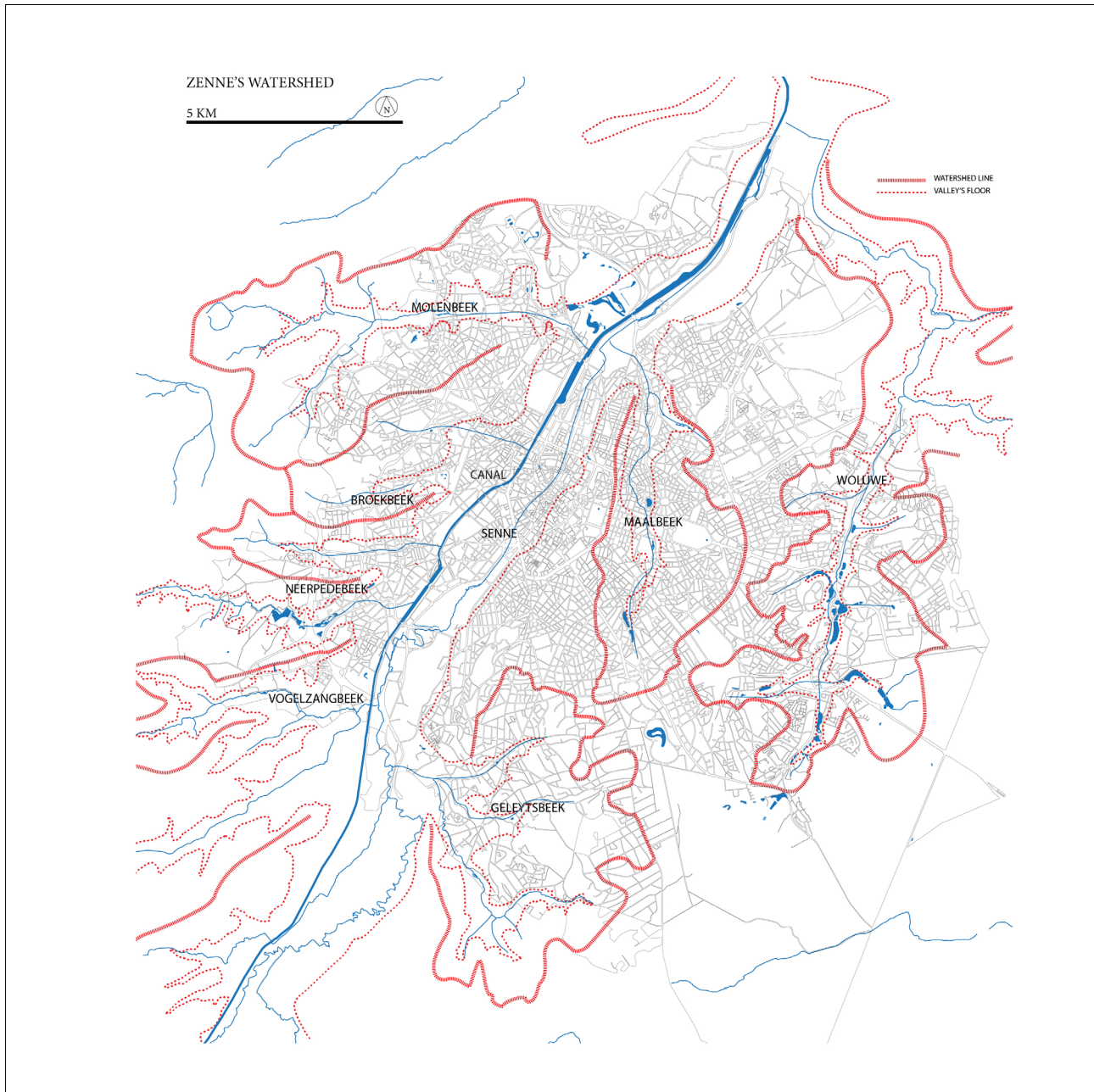


Figure 4.
Zenne and its tributaries: Brussels' Valleys.

Source: Centre Informatique pour la Région Bruxelloise (Computer Centre for the Brussels Capital Region), 2012. *Urbis Map* Available at: [http://irisbox.irisnet.be/vip/servlet/CCRLWebRequestServlet?\\$\\$controller=ccrl.server.controller.Document-Browser&Idmunicipality=CIBG&Language=fr&Idparentcategory=1289&Documentdate=&Showarchiveddocs=0&Showforms=0](http://irisbox.irisnet.be/vip/servlet/CCRLWebRequestServlet?$$controller=ccrl.server.controller.Document-Browser&Idmunicipality=CIBG&Language=fr&Idparentcategory=1289&Documentdate=&Showarchiveddocs=0&Showforms=0) [Accessed 10 May 2013].



Figure 5.

Surface water and the underground piping of Brussels' main urban rivers.

Source: Centre Informatique pour la Région Bruxelloise (Computer Centre for the Brussels Capital Region), 2012. *Urbis Map*. Available at: [http://irisbox.irisnet.be/vip/servlet/CCRLWebRequestServlet?\\$\\$controller=ccrl.server.controller.Document-Browser&Idmunicipality=CIBG&Language=fr&Idparentcategory=1289&Documentdate=&Showarchiveddocs=0&Showforms=0](http://irisbox.irisnet.be/vip/servlet/CCRLWebRequestServlet?$$controller=ccrl.server.controller.Document-Browser&Idmunicipality=CIBG&Language=fr&Idparentcategory=1289&Documentdate=&Showarchiveddocs=0&Showforms=0) [Accessed 10 May 2013].

the city has significant problems of urban flooding and waterways pollution. These problems urge a practical solution for storm water management.

The urban flooding in the city is mainly caused by the incapacity of the combined sewer system to host waste and storm water in the same infrastructure. Moreover, Brussels' is a highly dense city with a large area of impermeable surfaces and long underground infrastructures for vehicles and public transport. Each summer, the city is vulnerable to high tides, some of the streets become impracticable, and metro stations and buildings' ground floors are flooded. To build a new separated sewer system due to the high costs and large works involved it is almost impossible. It is true that the administration is engaged in various programs and initiatives to find solutions, but all these solve partially the problem. The most common actions implemented are for storm water retention. Present legislation obliges each owner of a new built project to install a storm water retention basin on their land. The law is an example of decentralized system, being just a temporally solution and not necessarily implying the reuse of the collected storm water. At the city level, large scale retention basins were also built and the overflow of the sewer system is just postponed, in the same way, but not solved.

Brussels' is currently in an ongoing process to move towards water sensitivity and find its critical point in the storm water management practices. An understanding of the practices and concepts that are developed worldwide at the moment could be a source of inspiration for the European city. Thus, the following section highlights the role of storm water management in water sensitive practices.

Storm water management as a catalyst for change towards water sensitivity

The water sensitive approach follows the impact of all interventions on the entire water cycle. In the same way, clean water, rainwater, and waste water are perceived as flows in a continuous system and each intervention should find balance between them and, in the same time, should ensure environmental protection and livability.

In contrast to clean and waste water, storm water has just recently become recognized as a critical point in the urban water cycle due to the incapacity of the current system to avoid floods and waterways pollution in case of a heavier rain. As the future previsions about climate change are actually uncertain, storm water management has to take into account a multitude of scenarios. Variation in the amount of precipitation, disturbance of nature process of water evaporation, transpiration, condensation and infiltration, urban growth, are all factors that could increase surface run-off and enhance the occurrence of floods.

Traditional storm water management models show their limitations to adapt to urban growth and to ensure the environmental protection of waterways (see Figure 1, combined sewer system). Worldwide, there is evidence that alternative models are required (Ashley et al., 2007, Novotny and Brown, 2007, Wong and Brown, 2009). In this context there is a constant pressure from the citizens, public media, and non-governmental associations to find solutions which integrate storm water management in the urban water cycle. The same tendency can be noticed in Brussels.

In this favorable context of innovation, among water sensitive practices, a significant attention on storm water is given in urban planning practices. Sensitive storm water management initiatives are in the present the most advanced subset of water sensitive practices in terms of ideas and concepts. Storm water resulted from a damage cause became an alternative resource for non-potable waters, part of urban landscape design, regeneration motor of urban waterways, and, most of all, the closest water source to the citizens (Wong & Brown, 2008).

Storm water management practices have enjoyed a large interest in developing urban design visions and proved their adaptability and efficiency in diverse environments. Even if not directly referred to as water sensitive practices at the time, successful projects demonstrated their "sensitivity" via practical results in: reducing quantity and velocity of run-off (New York 1980, the Blue belt Plan), increasing permeability by local interventions (Berlin 1980 - The Biotope/Green Area Factor for each parcel) or preventing sprawl (Taizhou City China 2006) (Arhen, 2007). These projects can be apprehended under green storm water infrastructure together with wetlands or retention basins and with a relatively recent concept, only partially researched in the current literature - New Urban Rivers, a contemporary vision on recreating new urban waterways as solution to avoid the overflow of the underground system, (Mauhaut V., 2011). All these initiatives envisage a new ecodynamic system that could reduce and delay the surface run-off and prevent urban flooding.

Although the above mentioned initiatives have defined the evolution of similar water sensitive practices in North America as Low Impact Development (LID), in UK as Sustainable Urban Drainage System (SUDS), or in the French speaking community as alternative measure to surface run-off, the recognition of their effectiveness depends on the case studies' specificities.

Disregarding their popularity, storm water sensitive practices, like most of the current water sensitive practices, are not yet able to orientate the process of planning and decision making about their potential due to the lack of a common understanding amongst institutions and citizens (Ison et al, 2009). This is ascribable to the lack of an appropriate assessment tool to evaluate the level of "water sensitivity" of different urban design initiatives (Priestley, Biermann and Laves, 2011). Without a proper evaluation framework, it is difficult to provide valid arguments that clearly show the adaptability of these solutions to different environments.

For this, a tool to evaluate and assess water sensitivity is useful to help communicate the effectiveness and adaptability of sensitive storm water management practices in different environments. In this way, an evaluation of the current situation can be achieved and an action plan for the future can be proposed.

Defining evaluation tools to measure sustainability is not a recent practice and a series of guidelines and indicators are already developed. After a short review of the present assessment of the available tools regarding water management, it can be concluded that generally they orientate and provide examples or toolkits to assess sustainability in terms of outcomes, rather than processes: performance indicators (Matos et al., 2003), guidelines (DRUPSSuC 2011, WaterTime 2009), decision-support tools dedicated to a

part or to the whole system (Forster et al., 2003), indicators for specific case studies WaterinCore and SWITCH indicators. On a first reading, the SWITCH indicators, together with WaterinCore, seem the most complete approaches on quantitative water assessment, but a qualitative assessment tool, such as questionnaire surveys and participatory research in evaluating water sensitivity are needed to complete the assessment (Sijbesma and Postma, 2008). To summarize, in the present does not exists a complete evaluation tool that follows the entire process and performance of a sensitive storm water practice. A mix of the available tools is crucial. Most of all, it is important the way this tool is applied on the case study. Indicators are important, but they need to be connected to the design solution. The role of architects and urban designers is to create this connection through a research by design approach were solutions are not unique, but various.

Conclusion: Benchmarking the concept of water sensitivity by using in parallel evaluation tool and research by design methodology?

In the present Brussels is not considered a water sensitive city, even if, as was stated above, it has an interesting policy to move towards. Recognizing its potential is important at this point. A clear plan of actions that continues this direction is needed. This article wishes to put in front the positive aspects of the current situation in the city, but also to point out that there are serious concerns that demand a quick answer. A solution could be the benchmarking of the concept of water sensitivity on the case of Brussels. While this article serves to define water sensitivity in rapport to urban planning and to inscribe it in the context of moderate climate, a future research will question the methodology needed. Now, a first direction can be given to the future research.

As it was stated in the previous section, various quantitative evaluation tools specific to water management are available that can measure the performance of water sensitive practices, but are less able to follow the process. Thus, the tools should be searched in various domains such sociology, for qualitative measures to understand the actions' impact on the citizens. The mix of the two types of evaluation is closer to the water sensitive approach that is to express the citizens' aspiration regarding water.

The better understanding of the land capacity to adapt to sensitive storm water practices could show its potential in urban planning to prevent hazards, to improve the city's livability, and to enhance the urban environment. The research by design methodology, the constant assay of various projects could be a means to achieve this.

Could a methodology that works in parallel with quantitative and qualitative evaluation tools and integrates a research by design approach be a solution to benchmark the concept of water sensitivity for urban agglomeration with moderate climates like Brussels? A future research will evaluate this hypothesis by investigating both traditional (such as combined storm water systems or end of pipe solutions) and sensitive (such as green storm water infrastructure and new urban rivers) storm water through an appropriate assessment tool, like quantitative and qualitative indicators and a research by design methodology on the Brussels' territory by looking in the same time at the impact at the watershed scale and at the neighborhood scale.

References

- Adikari, Y. and Yoshitani, J., 2009. *Global trends in water-related disasters an insight for policymakers*. [e-book] Paris: ICHARM. Available through: UNESDOC database website <<http://www.unesco.org/new/en/unesco/resources/online-materials/publications/unescodoc-database/>> [Accessed 20 February 2013].
- Ahern, J., 2007. Green infrastructure for cities: The spatial dimension. In: Novotny, V. and Brown, P., eds. 2007. *Cities for the future towards integrated sustainable water and landscape management*. London: IWA Publishing. Ch. 17. Available through UMass Amherst website <<http://www.umass.edu/umhome>> [Accessed 20 February 2013].
- Arnfield, A. J., 2003. Two decades of urban climate research: A review of turbulence, exchanges of energy and water, and the urban heat island. *International journal of climatology* [online] 23, pp. 1-26. Available at: <<http://onlinelibrary.wiley.com/journal/10.1002/%28ISSN%291097-0088>> [Accessed 15 February 2013].
- Ashley, R., Jones, J. and Schofield, D., 2007. Delivering more effective storm water management in UK and Europe – lessons from the Clean Water Act in America. In: NOVATECH. *6th International conference on sustainable techniques and strategies in urban water management*. Lyon, France 25 – 28 June 2007.
- Belgian National Climate Change Adaptation Strategy, National Climate Commission, 2010. *Belgian national climate change adaptation strategy* [pdf] Available at: <<http://www.lne.be/themas/klimaatverandering/adaptatie/bestandenmap/NASpublicatieweb.pdf>> www.climat.be > [Accessed 10 February 2013].
- Brown, R.R., Keath, N. and Wong, T., 2008. Transitioning to water sensitive cities: Historical, current and future transition states. In: IAHR/IWA. *11th International conference on urban drainage*. Edinburgh, Scotland, UK, 31 August - September 2008.
- Brown, R., Sharp, L. and Ashley, R., 2006. Implementation impediments to institutionalizing the practice of sustainable urban water management. *Water science and technology*, [online] 54 (6-7), pp.415-422. Available at: Unversite Libre de Bruxelles Library website: <<http://www.bib.ulb.ac.be/fr/bibliotheque-electronique/periodiques-electroniques/index.html>> [Accessed 25 February 2013].
- Butterworth, J. and McIntyrem, P. eds., 2011. *SWITCH in the city putting urban water management to the test*. The Hague: IRC International Water and Sanitation Centre.
- De Bondt, K. and Claeys PH., 2010. Flooding Risk in Brussels, Water retention capacity of geological units. In: Wynants, M., ed. 2010. *We can change the weather, 100 cases of changeability*. Brussels: Crosstalks, VUB press.
- De Graf, R.E., Dahm, R.J. and Icke, J., 2009. Receptivity to transformative change in Dutch urban water management sector. *Water science and technology*, [online] 60(2), pp.311-320. Available at: Unversite Libre de Bruxelles Library website: <<http://www.bib.ulb.ac.be/fr/bibliotheque-electronique/periodiques-electroniques/index.html>> [Accessed 20 February 2013].

DRUPSSuC. 2011. *Conception et rénovation des espaces publics urbains pour des villes durables* [pdf] Available at: <http://www.belspo.be/belspo/SSD/science/projects/DRUPSSUC_fr.pdf> [Accessed 15 February 2009].

Förster, M, Thévenot, D, Geldo, G, Svensson, G, Mikkelsen, PS, Revitt, M, Aftias, E, Krejčík, J, Sieker, H, Legret, M and Viklander, M., 2004. Urban stormwater source control management in European countries: DayWater project. In *NOVATECH 2004: 5th International conference on sustainable techniques and strategies in urban water management*, Lyon, France, June 2004. GRAIE, Villeurbanne, France, pp.341-348.

Kaufmann, I., Meyer T. and Kalsch, M., 2007. Implementation of sustainable sanitation in existing urban areas: Long-term strategies for an optimized solution. *Water science and technology*, [online] 56(5), pp.115-124. Available through: Université Libre de Bruxelles Library website: <<http://www.bib.ulb.ac.be/fr/bibliotheque-electronique/periodiques-electroniques/index.html>> [Accessed 9 March 2013].

Koester, M., Siekmann, P. and Staufer, S., 2010. *Water oriented city planning as key driver for sustainable urban development*. Aachen: Institute for Environmental Engineering, Aachen University.

Kotola, J. and Nurminen, J., 2003. Urban hydrology – runoff and pollution load in urban areas, part 2: experimental study, Helsinki University of Technology. *Water resources publication*, 8 (in Finnish, abstract in English).

IBGE, Brussels Environment, 2011. *Rapport sur les incidences environnementales du projet de programme de mesures accompagnant le plan de gestion de l'eau de la région Bruxelles Capitale* [pdf] Available at: <http://documentation.bruxellesenvironnement.be/documents/RIE_Plan_Eau_PrM2011_rapport_et_annexes1et2.PDF?langtype=2060> [Accessed 30 January 2013].

Ison, R.L., Collins, K.B. and Iaquinio, B., 2009. *Transitioning to water sensitive cities in Australia. A summary of the key findings, issues and actions arising from five national capacity building and leadership workshops*. [pdf] Clayton: NUWGP/IWC, Monash University. Available at: <<http://www.watercentre.org/resources/publications/attachments/Creating%20Water%20Sensitive%20Cities.pdf>> [Accessed 3 February 2013].

Mahaut, V., 2011. Les nouvelles rivières urbaines. *Escaut sans frontières info 54* [online] Available at: <http://www.gsesf.be/mailler/mailler-ESF-INFO-54/FR/ESFinfo54_t3.htm> [Accessed 12 July 2012].

Marbaix, P. and Ypresele, JP., 2005. *Impacts of climate change in Belgium*. Louvain: Greenpeace, Université catholique de Louvain, Belgium.

Matos, R., Cardoso, A. and Ashley, R., 2003. *Performance indicators for wastewater management*. London: IWA Publishing.

Mitchell, V.G., 2006. Applying integrated urban water management concepts: A review of Australian experience. *Environmental management*, 37(5), pp.589-605.

Novotny, V. and Brown, P., 2007. eds. *Cities of the future: Towards sustainable water and landscape management*. London: IWA Publishing.

Priestley, A., Biermann, S. and Laves, G., 2011. Towards assessment criteria for water sensitive cities, urban water security research alliance, *Technical report*, 43. Available at: <<http://www.urbanwateralliance.org.au/publications/UWSRA-tr43.pdf>> [Accessed 9 May 2013].

Sijbesma, C. and Postma, L., 2008. Quantification of qualitative data in the water sector: the challenge. *Water International*, 2 (33), pp. 150-161.

WATERinCORE, 2010. *Med program 2007-2013. Water management common list of indicators and database* [pdf] Available at: <www.waterincore.eu/deliverables/03_03_01_en.pdf> [Accessed 2 February 2013].

WaterTime, 2009. *D60: Good practice recommendations* [word] Available at: <<http://www.watertime.net/Docs/GPRs/complete/GPRs-final-eng.doc>> [Accessed 2 February 2013].

Wong, T.H. and Brown, R.R., 2009. The water sensitive city: principles for practice. *Water science and technology*, [online], 60 (3), pp. 673-682. Available through: Universite Libre de Bruxelles Library website: <<http://www.bib.ulb.ac.be/fr/bibliotheque-electronique/periodes-electroniques/index.html>> [Accessed 9 May 2013].

Wong, T.H. And Brown, R.R., 2008. Transitioning to water sensitive cities: ensuring resilience through a new hydro-social contract. In: IAHR/IWA. *11th International conference on urban drainage*. Edinburgh, Scotland, UK, 31 August - September 2008.



Generative Approaches in Tower Design Algorithms for the Integration of Tower Subsystems

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Abstract

“Generative Processes in Tower Design”, a PhD thesis in Architectural Design currently being developed at the Architectural Association (AA), proposes a new systematic design approach towards the re-creation of an architectural typology which has maintained a stable organizational structure since the end of the 19th century, the tower. The paper argues that the tower needs to respond to its environment by changing from a closed building typology towards a heterogeneous, differentiated open system that can adapt to the changing conditions within and around it. This argument is supported by focusing on the analogies and principles of specific biological examples in order to propose computationally-generated self-organizing systems. The goal of analyzing these models is to integrate their structural and geometrical characteristics with the aim of overcoming high lateral loading conditions in towers, as well as elaborating on the existence of multi-functionality and integration throughout the subsystems of the tower. A series of computational models which abstract the biological properties and articulate them with a generative approach through the use of agent-based systems are implemented according to designated evaluation criteria. The research posits new forms of design knowledge and practice by developing a design methodology that is set between architecture, biology, and computation.

Keywords

Tower; biomimetics; integration; differentiation; generative algorithms.

Note

This article is a newer version of a recent paper which will be published in eCAADe 2013 Conference Proceedings.

Introduction

“Not only biology has become indispensable for building but building for biology.”
(Otto, 1971)

The tower typology preserves the vision and ambitions of modern cultural and technological production. As the symbol of Modernism, the tower agenda is still defined today by standardization, repetition, segmentation, and orthogonal grid based structures. This agenda has instigated the potential of the tower to be reduced to binary axioms, such as tower and city, circulation and habitation, structure and skin (Aiello, 2008). Combined with the global economic and cultural motives for the tower, which are emphasized through parameters such as dense urban contexts, high real estate values, commercial opportunity, corporate demand, and iconic presence, the tower has become a self-referential object that has limited connection to its urban context.

In contemporary urban conditions, where the various social, economic, cultural and artistic systems are interacting in a constant flux of density and differentiation, the tower needs to respond to its current environment by changing from a closed building typology of repetitive floor plates towards a heterogeneous, differentiated open system that can adapt to the changing conditions surrounding it. Whether it is programmed for a single function or multiple uses, the contemporary paradigm of architecture will expect a differentiation of the tower along its vertical axis, its circumference, and within its volume that are interdependent with each other.

“Generative Processes in Tower Design” focuses on the principles of biological models in order to propose computationally generated dynamic systems for the tower typology, with the aim of achieving an integrated model for the tower subsystems that can coherently adapt to their climatic and cultural context.

The development of tall buildings in contemporary practices relates closely with structural developments. This is due to the fact that ‘tallness’ amplifies the significance of different loading conditions that act on a building. Due to the impact of loading in tall buildings, the structure of a tall building bears a significant role from the outset of the design process. In comparison with lower buildings, tall buildings are exposed to higher vertical loads, and more importantly higher lateral loads, mainly due to the wind stresses. The primary structural skeleton of tall building acts as a vertical cantilever beam with its base fixed on the ground.

Within the context of this research, tower is understood as a building system under considerable lateral loading conditions, with slenderness ratio ranging between six to eight. The focus is based on treating the tower as an inhabitable structure, whereby its footprint and internal spatial organization should allow for various programmatic requirements. In this respect, the correlation of footprint to height and how this correlation is influenced by lateral loading become more influential in the design research process rather than stating a predetermined height for the tower.

Current State of the Tower

From the end of the 19th century till the 1960s, the common practice of constructing tall buildings was the rigid frame with wind bracing, which resulted in the over-design of structure due to the excessive use of structural material, thereby causing it economically not feasible. Structural engineer and architect Fazlur Khan introduced the notion of the ‘premium for height’ for tall buildings in

1960's, and in 1969 classified their structural systems in relation to various techniques of resisting lateral loads for steel and concrete buildings. This initial classification according to different material systems introduced for the very first time a differentiated approach into examining tower structural systems with the aim of increasing tallness and stiffness while decreasing the amount of material. Due to the developments in structural systems in the last decades in conjunction with progressive material systems, construction technologies, and computer simulations, a refined classification has been proposed by Mir M. Ali and Kyoung Sun Moon, based on the first classification proposed by Khan. Accordingly, structural systems for tall buildings can be divided into two categories: interior structures and exterior structures (Ali, M.M. and Moon, K.S., 2007).

The development of tower structural systems reveal that even though there has been a continuous differentiation of material organization with the purpose of increasing height and rigidity simultaneously by decreasing material usage, each distinct tower system has a homogeneous and repetitive organization. The structural loading along the height of the tower varies drastically from bottom to top; however, the change in loading conditions is not reflected along the vertical axis of the tower as formal topological variation. This rigid and repetitive modality, characteristic of the Modernistic paradigm, has prevented any kind of rational transition within a specific type of tower structural system.

Furthermore, the notion of differentiation has not been integrated with the other subsystems of the tower. The differentiation of material organization in the tower structure has been limited to one subsystem only, the structure. As such, tower structural systems have developed with single objective optimization. Other performance related capacities, such as circulation, facade, and environmental aspects, have developed independently of the material organization of the tower structure. Moreover, the tower structure has become devoid of responding to the spatial differentiation that takes place within, acting merely as a homogenous container. It has not responded to the changes and shifts in its programmatic diversity, which in effect influences circulation, façade-related, and environmental differentiation. This additive approach, where each subsystem is considered as a separate layer, results in the inefficient and excessive use of tower material organization. In this regard, the current knowledge on tower design lacks an integrated approach towards its subsystems on two major levels, the first being the "topological variation" within one subsystem, and the second being the "inter-system differentiation" taking place between multiple systems. Therefore, it is necessary to explore and learn from existing systems which are capable of integration and co-adaptation.

The current organization of the tower subsystems, which are classified into five groups as the structural skeleton, habitable surfaces, circulation/navigation system, envelope, and environmental systems, have developed in an independent manner. The subsystems are partially related to each other in terms of taking minor secondary functionalities that primarily belong to another subsystem, as in the case of floor slabs having additional structural capacity. However, the potential of the additional capacity has not been exploited such that it can become a fully integrated part of the primary subsystem. As such, the conflation between the subsystems needs to be analyzed and explored with an innovative vision.

Biology in Architecture

There has been a broad body of research work on the relationship between nature and architecture throughout history. Biology particularly serves as a main resource for architecture due to the strong relationship between form, material, and function in its inherent formation. The analogies between biology and architecture can be classified into two groups, the first acting as the mimicry of biological forms and the second acting as the mimicry of biological materials, structures, and processes (Coucerio, 2005). Within the context of this research, processes of self-organization and material configurations have been examined as analogous models towards the generation of an integrated approach for tower subsystems.

Natural systems are complex organizations, characterized by the spontaneous emergence of interdependent subsystems, ranging from the cellular to the global level that can adapt to various external stimuli. The subsystems can carry on distinct functions at once due to the principles of differentiation and redundancy. In the case of plants, the plant stem can undertake structural, transportation, and storage functions due to the variation of its sections along its length and the ordering of its basic materials into complex hierarchical arrangements. The organization of materials in interrelated semi-autonomous hierarchies by means of redundancy and differentiation leads to the integration of distinct functional systems throughout the stem. On the contrary, in current architectural practices, the sub-systems of the tower, such as façade, structure, floors, roof, services, carry on specific functions. These subsystems are separated from each other with boundaries and joints which prevent the material and functional continuity between them. The sub-systems mostly perform their entitled functions; they do not have the balancing capacity of executing additional tasks, whereby they can only act as homogeneous entities.

Regarding the above mentioned explorations as a foundation for the research area, specific biological analogies which have been studied in this work include the mechanical properties of the bamboo stem and the geometrical properties of minimal detours systems. The common feature that these models share is their property of self-organization as well as their unique geometrical and structural properties.

Bamboo Stem

The mechanical properties of the bamboo stem prove to be beneficial for the tower structural system in various ways. Bamboo is formed of long cellulose fibers embedded in a ligneous matrix. The fiber distribution along the bamboo stem is differentiated along the height and circumference; the distribution of fibers is more uniform at the base compared with the middle and top portions. This occurrence can be explained by the fact that bamboo needs to carry maximum bending stress caused by wind and its own weight at the base (Koshrow, 2005). The radial differentiation of fibre density, increasing from centre to periphery matches the distribution of bending stresses. The phenomenon of differentiated distribution of fibers according to applied forces can serve as a model for the distribution of structural members of towers along the vertical axis and the circumference.

The bamboo stem comprises internodes and nodes. The stem itself is a hollow cylindrical shell along which the nodes correspond to the internal diaphragms, described as

transversal connectors located throughout the height of the bamboo stem. The diameter of the stem changes slightly at the nodes, which also function as location for new growth. Internodes are located in between the nodes, denoting the hollow portions surrounded by the culm wall. The diaphragms supply resistance against the buckling of culm wall over the height of the stem. There are two major outcomes of the material in the stem being positioned at the outermost location from the vertical axis. The material deposition enables greatest bending resistance as well as causing gravity loads to be carried only on the outside skin of the stem, minimizing overall weight and preventing uplift due to lateral loads (Sarkisian, M., Lee, P., Long, E., Shook, D., 2010).

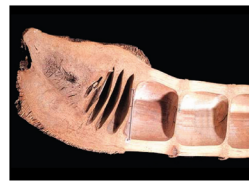
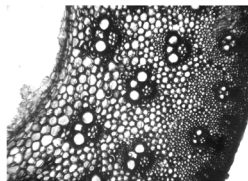
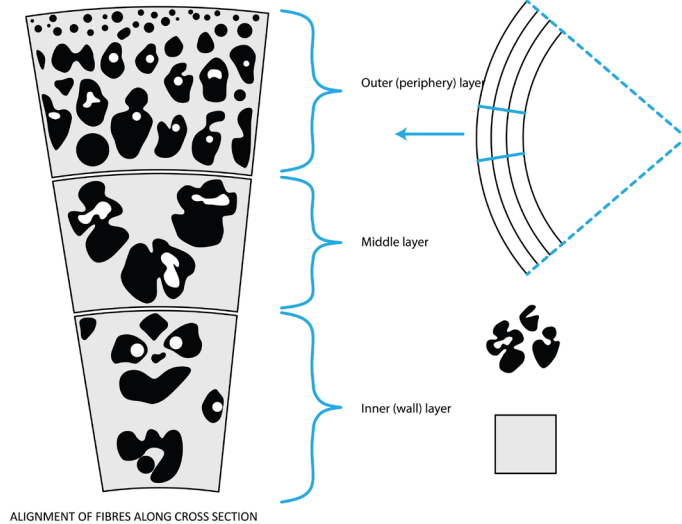
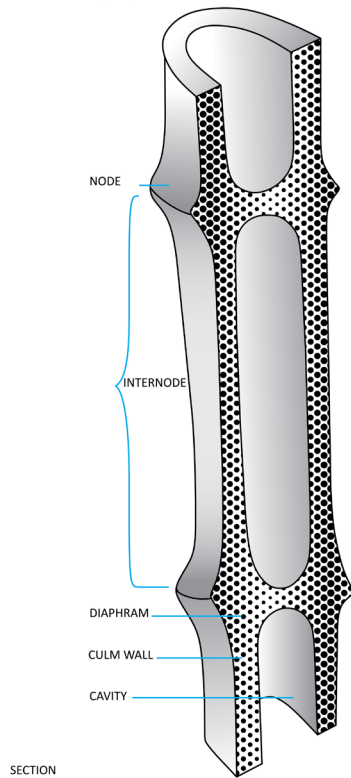
The position of the diaphragms, internode diameter, and the culm wall thickness are dependent on each other. The geometric relationships between these entities have been described by Jules Janssen (Janssen, 1991). The equations below summarize the correlations which can be observed in many bamboo species (Sarkisian, M., Lee, P., Long, E., Shook, D., 2010):

<p>Internode Number</p> $x_n = n \times 100 \div N$
<p>Internode Length</p> $y_{n1} = 25.13 + 4.8080 x_n - 0.0774 x_n^2 \text{ (below mid-height)}$ $y_{n2} = 178.84 - 2.3927 x_n + 0.0068 x_n^2 \text{ (above mid-height)}$
<p>Internode Diameter</p> $d_{n1} = 97.5 + 0.212 x_n + 0.016 x_n^2 \text{ (below mid-height)}$ $d_{n2} = 178.84 - 2.3927 x_n + 0.0068 x_n^2 \text{ (above mid-height)}$
<p>Wall Thickness</p> $t = 35 + 0.0181(x_n - 35)^{1.9}$

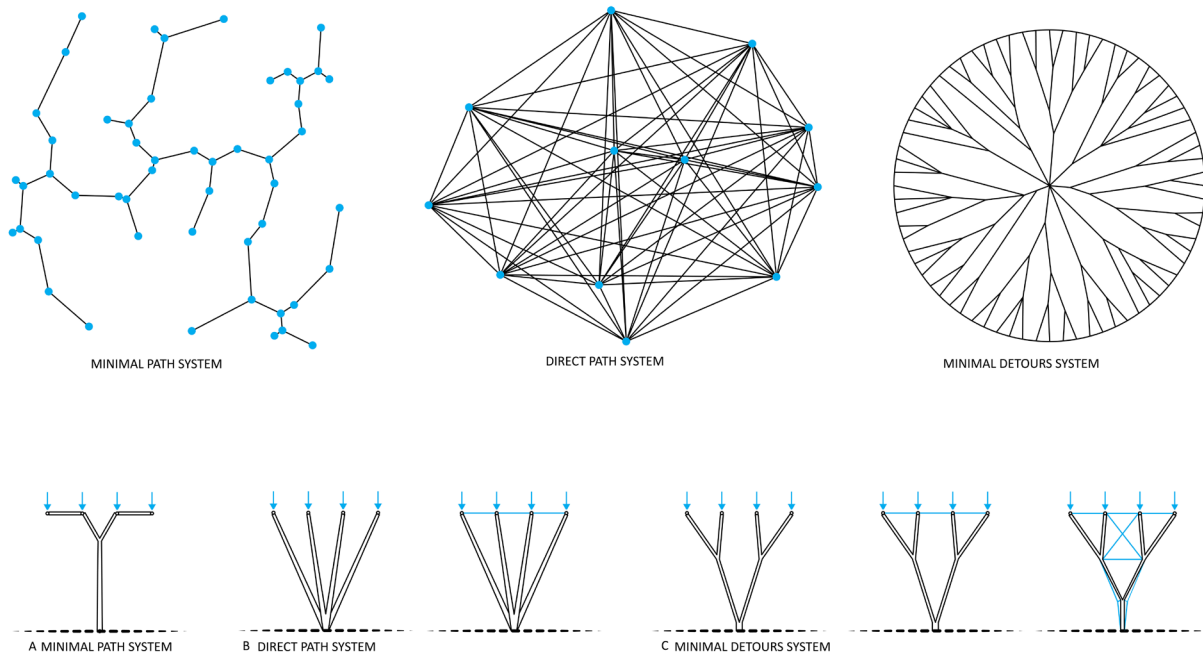
In these equations, x_n is the internode number, n is a shaping parameter; N is the height of the structure; y_n is the internode length; d_n is the internode diameter; t is the wall thickness. The information embedded in these relationships can be generalized in relation to the various forces the bamboo is subjected to. As the lateral loading condition and the weight from gravity is highest at the base of the stem, the internode heights at the base become shorter than the mid-height. As such, smaller internode heights increase moment-carrying capacity and buckling resistance. Above the mid-height of the culm, the internode heights decrease once more in proportion to the internode diameter as a reaction to increasing lateral loads (Sarkisian, M., Lee, P., Long, E., Shook, D., 2010).

The above-described morphological relationships of bamboo are applied to the structure of the tower on a global scale. The diaphragms of the bamboo stem can serve as an analogous model for an outrigger system in a tower. The position and the diameters of the outriggers can be predicted by using the above equations in order to resist lateral loading conditions in an effective manner. Moreover, the structural members of the tower can be differentiated in terms of amount and sectional size with regards to the changing loading conditions. However, a significant difference needs to be noted when the diaphragms of the bamboo are to be regarded as an analogous model to the outriggers of the tower. As an inhabitable structure, the tower is also under the effect of live loads,

BAMBOO PROPERTIES

**Figure 1.**

Bamboo cross section and horizontal sections.

**Figure 2.**

Differences between optimized path systems.

a dynamic type of load which is dependent on building use, such as human movements and snow loads. In this respect, since the outriggers are also exposed to live loads, their fibers/ structural members need to be designed by taking into consideration this extra

Minimal Detours System

Extensive research on branching structures has been pioneered by Frei Otto and his team as the 'Biology and Building' Working Group at the Institute for Lightweight Structures, Stuttgart University during the end of 1980's. The focus of this research has been to investigate the potential ways of covering large spans with optimized branched constructions. In this study, concentration has been kept on regulating the material organization of the system as a direct outcome of the force fields acting upon it, so that the load bearing capacity is increased while the amount of material deposition is decreased. As such, form-finding was investigated as a "single objective optimization" (Hensel, M. and Menges, A., 2009).

Branched constructions can be described as three dimensional supporting structures used in various material systems, such as steel, wood, and concrete. This structural system offers more stability than conventional beam structures as beam structures are more likely to overturn as a result of wind and earthquakes. Moreover, the use of branched structures enables the use of thinner structural members and covering larger spans (Otto, F. and Rasch, B., 1995).

The properties of branched constructions have been explored by Frei Otto and his team in order to formulate methods of transporting forces over a given distance in the most effective way. The first method, minimal path system, links given points with detours to produce the least overall distance. In nature, the minimal path system can be observed in the self-formation of soap films. Structurally, this system is less effective for the transport of forces as the outer support arms are loaded in bending. The second method, direct path system, connects every given point with a straight line to each other with no detours. Through this method, the forces are transported on the shortest possible path, but the overall path length increases drastically. This system becomes more effective if the points of force application are connected with beam ties so that the bars are compression loaded. The third method, namely the minimal detours system, can be viewed as a negotiation between the minimal path and the direct path systems. Synthetic analogy research about this method has been carried out by exploring the self-formation processes in moistened thread networks. Reviewing this method in a structural context yields the result that the forces to be transported are more optimized due to the concentration of paths, increasing the buckling resistance of structural members. Effectiveness of the system is increased more if the points of force application are connected with a beam tie. As a result, branched structures generated with minimal detours system use less material in a more effective manner than the ones generated with direct path system (Otto, F. and Rasch, B., 1995).

In nature, branched structures can be found in abundance throughout various plant systems. Materialized direct path systems can be observed in umbels, and materialized minimal detours systems can be viewed in bushes and shrubs. The difference between branched constructions in architecture and nature lies in functionality. Whereas the

branched structures built by humans are mainly designed to carry a structural function, the branched constructions of nature have the property of multi-functionality. In the case of plants, the branches need to transport water, minerals and products of photosynthesis for survival as well as maintain the necessary structural resistance against the various forces applied to the leaves (Otto, F. and Rasch, B., 1995).

The combination of the effective properties of the minimal detours system and the multi-functional quality found in natural branched constructions can be merged to serve as an analogous model for the structural components of the tower. Following the global geometrical rules of the bamboo stem described above, the structural members can be defined geometrically in relation to the mathematical rules of branching systems in order to devise a design method where the organization of structural members is set up to resist the loading conditions of the tower in the most effective way. As such, a hierarchical design system is proposed where the properties of the bamboo stem and the properties of branching structures are integrated on different levels.

Agent-Based Model

The computational setup for the design explorations reflects the characteristics of self-organization described above through various biological models. As a systematic approach, in biological systems self-organization refers to the process where pattern at the global level emerges from the interaction between lower-level components. The rules specifying the interactions between lower-level components rise from local information, without the interference of external directing instructions. The transition of this phenomenon from the biological world to the digital paradigm has been realized by swarm intelligence. Swarm intelligence describes the behavior exerted by natural or artificial self-organized systems, which are made up of boids/agents interacting locally with one other and their environment. These interactions lead to the emergence of complex systems demonstrating intelligent behavior on a global level. The simulation of swarm intelligence is realized by agent-based models, which are computational algorithms created to simulate the interactions of local boids/agents in order to evaluate their complex behavior. The term "boid" was first coined by Craig Reynolds in 1986 when he created a flocking algorithm for generic creatures.

An agent-based model has been devised for tower design explorations in the open source environment Processing. As an object-oriented programming language (OOP), Processing allows for the generation of procedures / objects on a local level (class) which can then be interacted with each other according to set rules in order to produce emergent patterns on a global level. In this respect, initially the global geometrical constraints have been defined through the setting of the slenderness ratio, which can range from six to eight. The height of the tower is calculated according to the defined base radius and slenderness ratio. On a local level, all the agents in the system interact with each other according to flocking principles, namely separation, alignment, and cohesion. Additional flocking rules in relation to the vertical speed of growth and rotational force of agents are assigned.

The primary agent setup is comprised of two sets of agent groups which form two helical intertwined structural frames. The main motive behind creating two structural

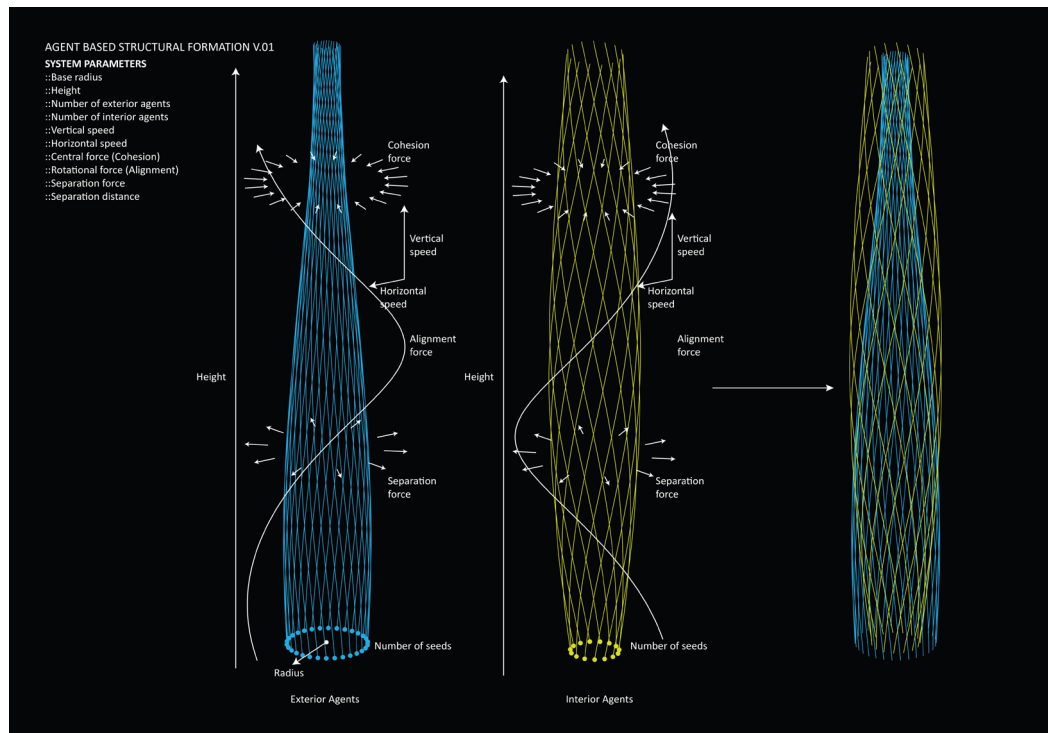


Figure 3.
Agent-based structural
formation model.

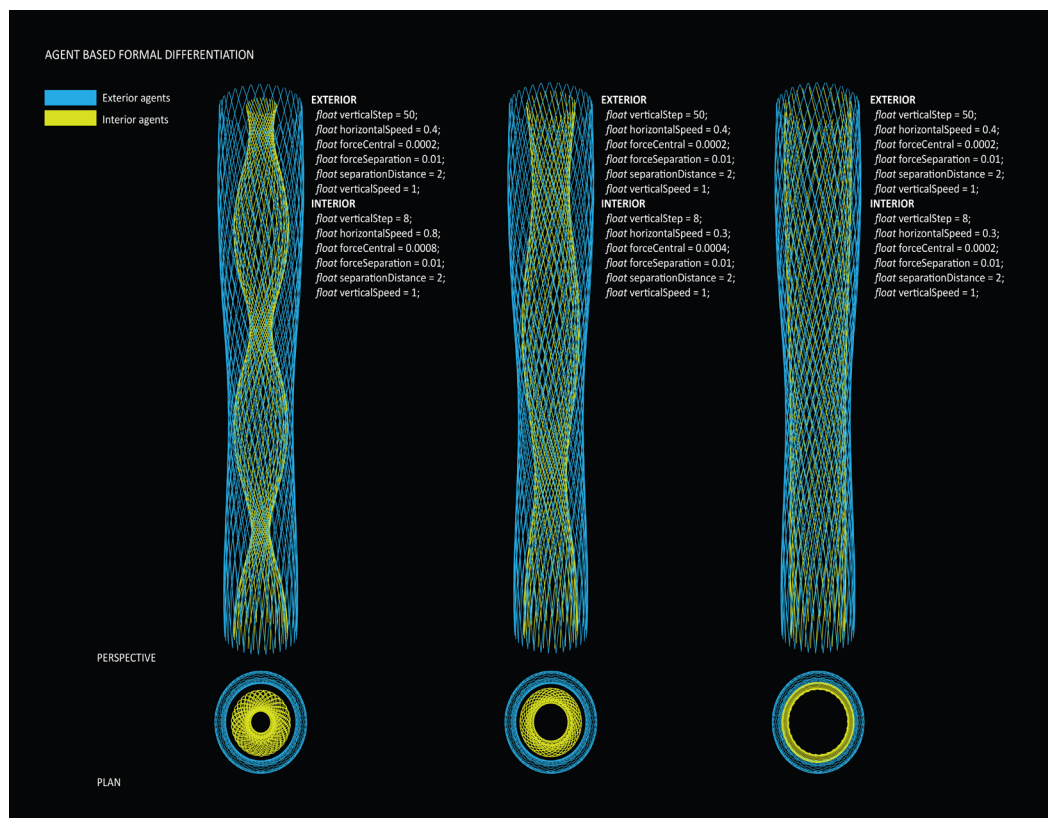


Figure 4
Agent-based Formal
Differentiation.

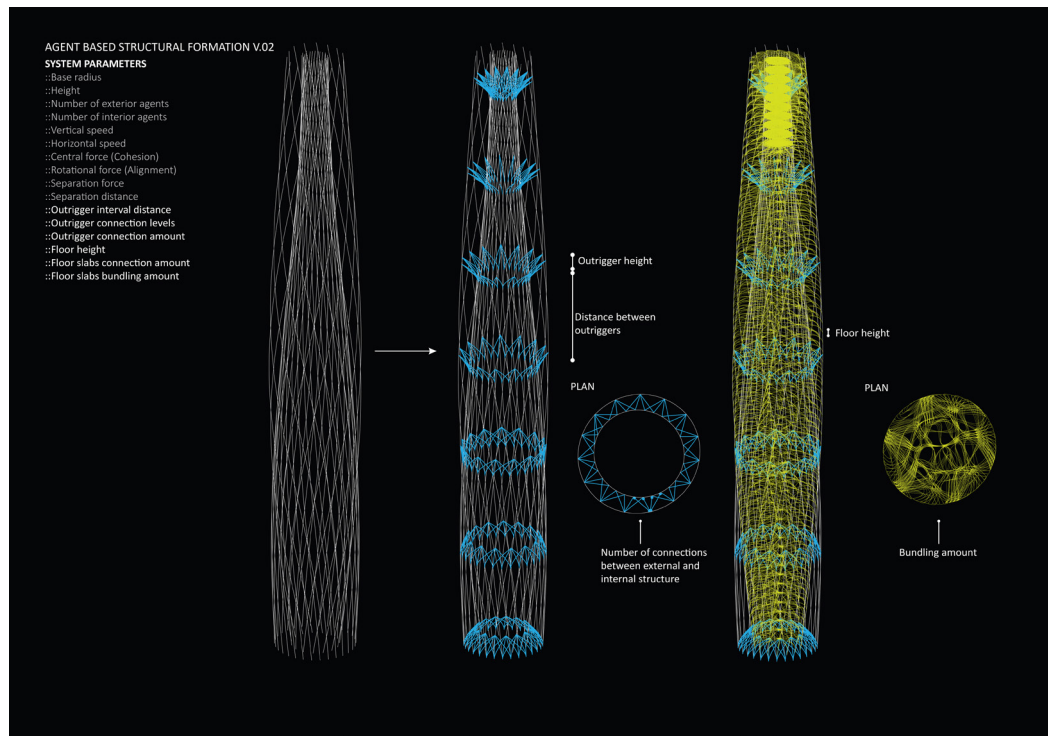


Figure 5.
 Generation of outrigger system and floor plates.

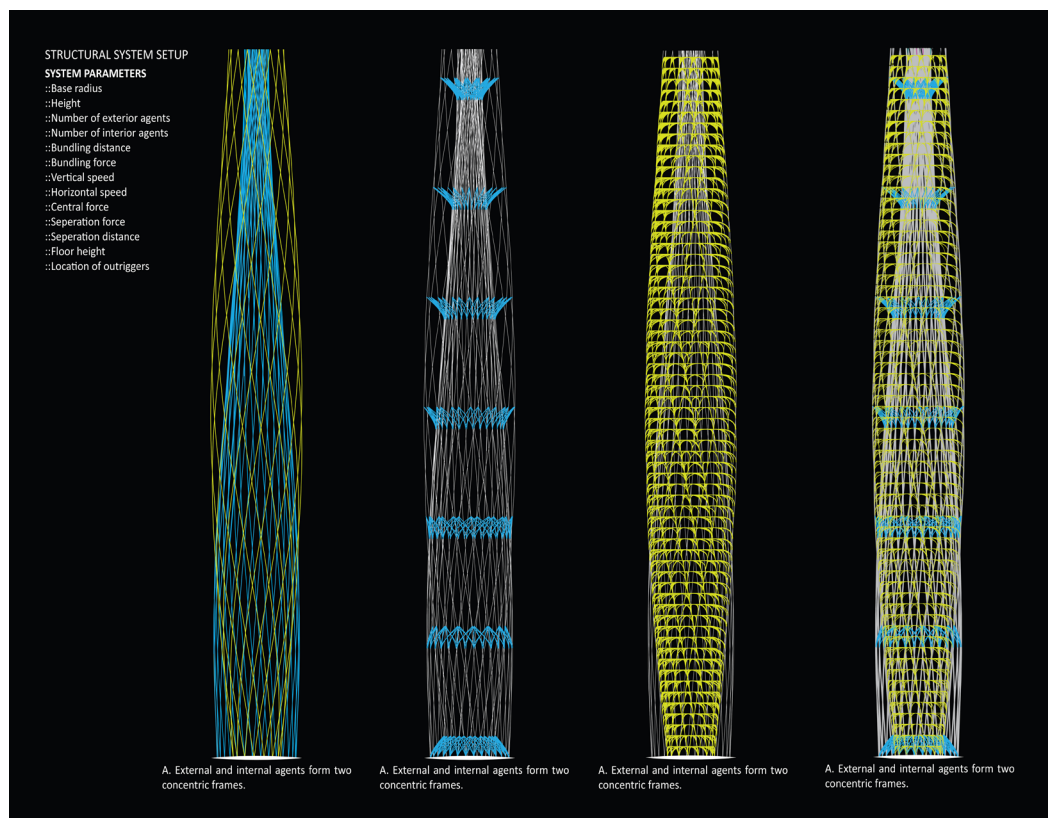


Figure 6
 Vertical structure,
 outrigger system
 and lateral structural
 system.

frames instead of a singular one is to infuse the structures with differentiation and redundancy by assigning related but discrete functionalities to each of them. Moreover, a double structural frame bears the potential of generating different spatial configurations in relation to the frequency and location of intertwining.

The helical double structure serves as a major framework for the generation of floor slab members, outriggers, and vertical circulation. As the agents grow vertically to form the double structure, they branch out to form the floor slabs using the specified floor heights for discrete programmes. The positioning of the outriggers throughout the height of the tower is defined according to the above described geometrical relationship between the bamboo stem internodes and heights. The outriggers serve to connect the external and internal structural frames, whereas the floor slabs are tied to the internal structure. While the external and internal structures act in compression, the floor slabs and outriggers act in tension. The double structure and the floor slabs / outriggers are interdependent systems, meaning the floor slabs and outriggers prevent the double structure from collapsing while the double structure, in turn, supports these horizontal members. Since the distribution of loads takes place over the entire fibrous members of the tower, vertical elevators can be located throughout the floor plate in desired locations. This approach, where the vertical structural members, horizontal structural members, and floor plates are generated together in a seamless fibrous fashion, presents a significant shift from the traditional method of relying on a rigid internal core and a series of columns for stability.

As the agent-based system builds up the double structure, vertical circulation, outriggers and floor slabs simultaneously, a bundling algorithm calculates the minimal detours system necessary to concentrate the fibrous paths and thereby optimize the forces traveling throughout the tower. The percentage of bundling can be manipulated according to the individual subsystems, the vertical position of the members, or the location of the members along the circumference of the tower. The minimal detours system has the potential to manipulate the behavior of the members on a local level, creating ways of fine-tuning the structural performance as well as defining various spatial configurations according to transparency levels, orientation, and views, thereby refining the interface between the tower and its contextual environment. As such, form-finding through the minimal detours system can move away from acting as a 'single objective optimization' and progress towards becoming a 'multi-parameter integration' tool due to its coexisting structural and spatial attributes.

Conclusions

Currently, design explorations for the integration of structure, floor slabs, and vertical circulation as one cluster of subsystems are being conducted. Structural analysis is being carried on via the FEA software Strand 7. The results of the structural analysis will serve as a feedback mechanism in order to refine the positioning and number of floor slab and outrigger elements. After this stage, the integration of structure, façade and environmental systems as another cluster of subsystems will be investigated through the agent-based system by setting up respective parameters. In this way, it is anticipated that the final integration of the two clusters of subsystems will be achieved by keeping the structural parameters the same for both clusters.

At this stage of the research, it has been observed that the behavior of the various subsystems can be manipulated simultaneously by modifying the parameters which coordinate the local interactions between agents. By using agent-based systems as a computational tool, a hierarchical systematic approach displaying the quality of emergence from lower level organizations, tower subsystems, towards a higher level integrated tower design can be devised. The biological analogous models which are being explored can serve as unique models in the generation of “topological variation” throughout the height and circumference of a singular subsystem. Moreover, these models can also perform to enable the “inter-system differentiation” taking place between multiple systems owing to their inherent geometrical and material organizations.

The research aims to reconfigure all the main elements of contemporary tower design, which in turn will liberate the fixed typology of the tower towards a novel tower system that is described with the qualities of adaptation, integration, and fluidity. Through this research, the major questions that are sought to be answered are: What can we learn from biological processes in order to form an integrated design approach that can create context-specific tower design which operates on multiple levels? Can we devise an evolutionary system for tower design which can continuously adapt to its environment? As such, the research aims to bring out new forms of design knowledge in the area of tower research by merging architecture, biology, and computation.

References

- Aiello, C. ed., 2008. *Evolvo: Skyscraper for the XXI Century*. USA: Evolo Publishing.
- Ali, M.M. and Moon, K.S., 2007. Structural Developments in Tall Buildings: Current Trends and Future Prospects. *Architectural Science Review*, Volume 50.3, pp.205-223.
- Coucerio, M., 2005. Architecture and Biological Analogies; Finding a Generative Design Process Based on Biological Rules. *Session 13: Generative Systems - eCAADe 23*, pp.599-607.
- Gruber, P., 2011. *Biomimetics in Architecture: Architecture of Life and Buildings*. Wien: Springer-Verlag.
- Hensel, M. and Menges, A., 2009. The heterogeneous space of morpho-ecologies. In: M. Hensel, C. Hight and A. Menges, eds. 2009. *Space Reader: Heterogeneous Space in Architecture*. United Kingdom: John Wiley & Sons Ltd., p.208.
- Janssen, J.J.A., 1991. *Mechanical Properties of Bamboo*. New York: Springer-Verlag.
- Khosrow, G., 2005. Bamboo as Reinforcement in Structural Concrete Elements. *Cement and Concrete Composites*, No. 27, pp.637-649.
- McMahon, T., 1973. Size and Shape in Biology. *Science, New Series*, Vol. 179, No. 4079, pp.1201-1204.
- Otto, F. and Rasch, B., 1996. *Finding Form: Towards an Architecture of the Minimal*. Germany: Edition Axel Menges.
- Otto, F., 1971. *Biology and Building: Part 1*. Germany: Universitat Stuttgart.
- Sarkisian, M., Long, E., Doo C.S. and Shook, D., 2011. Learning from Nature. *Civil Engineering-ASCE*, Vol. 81, No. 6, pp.60-65.
- Sarkisian, M., Lee, P., Long, E. and Shook, D., 2010. Organic and Natural Forms in Building Design. *ASCE/SEI 2010 Structures Congress*, Orlando, Florida.
- Vincent, J., 2001. Stealing ideas from nature. In: S. Pellegrino, ed. 2001. *Deployable Structures*. Wien, New York: Springer-Verlag, pp.51-58.
- West, G.B. and Brown, J.H., 2004. Life's Universal Scaling Laws. *Physics Today*, 57(9), pp.36-42.

Einführung and Architecture: About Language from Things to Design Criteria

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Abstract

The text tries to think about the impact that the discovery of mirror neurons might have in the field of architecture. Starting from the idea of empathy as a gestural prelinguistic language developed as extensive engine of a gradually more complex gestural communication of which word is the last stage and empathy as aphasic language of cultural transmission that allows us to have and pass on the cultural knowledge necessary to live in social groups, the text examines the most interesting experiences of the last century from the point of view of empathy and links them to contemporary design experiences, trying to understand what contribution can provide a critical concept as old as empathy, but now extremely topical as it is biologically justified, in the Information Technology era, tracking down a common basis of social experiential sharing for a heterogeneous and fragmented landscape as the contemporary one is.

Keywords

Einführung; information technology; empathy; mirror neurons; architecture.

Introduction

Recalling such a controversial subject, studied as *Empathy*, which over time has almost become a Penelope's web (Pinotti, 2011), woven to even compulsorily cover many concepts that collide with each other, and unsewn when required by the times of history, is not an easy task, but assumes a critical importance considering how the latest neuroscientific discoveries may open the door to a new architectural conception that, binding to Information Technology (Saggio, 2007), is able to give new life to structures, cities, territories, which, though no longer static, but more and more dynamic and interactive, are however still "different" from us.

The term *Einfühlung* and the four seasons of it

The choice of the term *Einfühlung*, which might seem synonymous to *empathy*, does not only refer to its original formulation in terms of the German philosophers Robert and Friedrich-Theodor Vischer (1873), but also to the physiological conception of the empathic feeling.

Now, not taking into account, except for some brief mention, the three seasons of the concept of empathy, which passes from the German *Einfühlung* to the English *Empathy*, and opens to the Anglo-Saxon psychological research (the first two seasons, primarily German, are of the late XVIII and XIX century), we are interested in the fourth season, launched by neurosciences in the recent years.

Origin of term

Starting from Herder's studies (1778) on *corporeal truth* (*Einfühlen*), F.T. Vischer begins to change the millenary philosophical concept from "beautiful - complexity of parts" to "beautiful - complexity of subject-object acts," mutual implication (Ineinander, 1873, cited in Pinotti, 2003).

The body structure becomes the material absolute of the beautiful artistic form. The result of the spatial relationship with an object is an increase or decrease in our vital sensation.

These studies are then recalled by Adolf von Hildebrand in his work *The Problem of Form in Painting and Sculpture* (1907), who admits a "sympathy" between man and external reality, by Aby Warburg, who coins the word *Pathosformel* (1905, cited in Pinotti, 2003), a relationship which is established between typical form and affection and by Theodor Lipps (1923), for whom empathy is the condition of possibility for an object to be aesthetic.

Many studies are also carried out in the field of art and architecture, outlining on the one hand the so-called Herder's "body truth" (Plastic Art, 1778), as we said before, and, on the other, ranging in the studies of Schmarsow and Wolfflin (1886) that connect breathing and cardiac movements with spatial experience.

Neurons of empathy and implications

In 1996, the discovery of neural areas active both when you perform an action and when that same action is performed by others, made by a team of scientists led by Giacomo Rizzolatti, in Parma, on the F5 area of the frontal cortex of the macaque monkeys, opens the doors to the organic codification of the emphatic feeling as an instrument of cultural transmission and social cohesion (Rizzolatti and Sinigaglia, 2006).

We may sum up, as our interest is not addressed to the scientific-biological process, but to the obtained results and the foundations provided to us for our research in the field of art and architecture, in three main phases:

- The biological basis of empathy
- The key role of empathy in the creation of language
- The development of empathic language and the social group

In the first phase, in which Rizzolatti was followed by many scientists, we worked on defining the mirror-neuron "system," called by the scientific circuits *neurons of empathy*, which, along with other areas of the brain, such as the insula, the superior temporal cortex and the medial prefrontal regions, form the so called "resonance circuit." The conclusion we reached was that we are "programmed" to empathy and this makes us social animals. Moreover, it falters the biology-culture dualism that saw animals driven by instinct and man, instead, as a culture builder (Rifkin, 2010).

Starting from the widely shared assumption of care between adults and play (*homo ludens*) (Huizinga, 1939) as the most basic form of communication among social animals, we have come to define empathy as the means by which a gestural pre-linguistic language has developed as extensive engine of a gradually more complex gestural communication of which word is the last stage.

Finally, the development in primates (50%) and humans (80%) of the cerebral cortex, seat of mirror neurons, is directly related to living in gradually larger social groups. This development is in fact linked to the monitoring of the empathic stimuli in an increasing number of individuals. With the development of the communicational society, the language complexity and strength of the empathic species have gradually increased. This leads us to few but important considerations: If empathy is the aphasic language of cultural transmission that allows us to have and pass on the cultural knowledge necessary to live in social groups and is essential to social life, as it steadily grows along with the growth of the group, what implications has this in the studies of art and architecture that had well understood the emotional transmission but not the social one?

Key points

The *Einfühlung Theory*, as we have already said, is one of the most controversial and successful theories in the history of architectural criticism: from Art Nouveau to organic architecture, passing by the Futurists and the experiential branch in today's architecture, not to mention primitive, rural or regional architecture, in any architecture, we can find some empathy related roots.

But the problems are at least three:

- To understand whether the physiological and psychological dual-component, until now applied to the concept of empathy, is adherent to new discoveries or whether speech should be re-calibrated.
- To understand if and how this new socio-didactic component is present and allows us to read as belonging to it architectures seemingly unrelated to the concept of empathy.
- To understand whether this new neuroscientific season of empathy can be fruitfully applied to architecture.

Architecture, in many times and in a multimode, has more or less consciously dealt with the *Einfühlung*.

Design and architectural field: focus on some remarkable experience since 1900 to today's information era

Force, motion and embodiment

The most interesting studies in the architectural field regard the concept of *lines of force*, which from Van de Velde comes up to Paolo Portoghesi. Van de Velde built the well-known definition of "line is a force" (1923, cited in De Fusco, 1964) when as a painter he begun to move towards non-naturalistic forms and ornamentations. With an expired interest in natural forms, Van de Velde imagined the possibilities of organic line with physio-psychological reactions that potentially the semantics of *Einfühlung* gave it (De Fusco, 1964).

A line. Ultimately derived from nature, it is abstracted into a controlled pattern. The artist Walter Crane stated that "Line is all important. Let the designer, therefore (...) lean upon the staff of line -line determinative, line emphatic, line delicate, line expressive, line controlling and uniting" (1892, cited in Tschudi Madsen, 2011).

In the works of Kandinsky and Boccioni, there is a long path that connects empathy to the *lines of force* as the element that springs from nature, draws a man as a natural being and designs architecture as movement.

Also Mendelsohn, rather, especially Mendelsohn, with his wonderful compliance with Einstein's theories, realizes that the curved universe is permeated by energy moving through lines and grids that form the living matter. John Wheeler once summarized *general relativity* as "*matter tells space how to curve and space tells matter how to move*" (1973, cited in Wheeler and Ford, 1998) while Bruno Zevi (1972) said "*The energetic creation of space is the genetic reason of each act of Mendelsohn's design [...] the mass breaks, pressed by an explosive inner strength.*"

Moreover, starting from the Greek *έντασις*, until motion capture, man has always empathically felt the uniformity of matter, energy matter, lines and movement in the whole universe. "The movement generates the form, the form generates the movement. Every point, every line, every surface, every body, every shadow, every light and every color are forms generated by movement, which in turn generate motion. *Pain and pleasure, love and hate, repulsion and attraction, are forms of the mind generated by movement*" (Wingler, 1987, p.97).

Furthermore, the writings of Lipps and Worringer were the inspiration for many architects and artists, from Endell to Kandinsky (Pinotti, 2011).

Additionally, during the historical period after World War I, we can say without a doubt that there was a bloom of thought about line, movement, and empathic feeling. Just think about a figure, that of Johannes Itten, charismatic but often relegated to a position of historical-critical subordination for his extravagant behavior due to the strong influence of Eastern philosophy, meditation, and Zoroastrian religion. Itten endorses the most

convincing theories of the Art Nouveau period related to Van de Velde's *lines of force*, covering them, however, with the mystical afflatus that had characterized them as pulsating tangle in Gothic architecture and strictly connecting them to the newly formed Freudian psychoanalytic theory that a few years before had led to the theory of 'Es' or unconscious ego, binding to the romantic philosophical schools that had rediscovered the material body as an instrument of knowledge.

In his *Vokurs*, students were invited to gather in meditation doing breathing exercises to then spring into action and draw with both hands moving lines on canvas or paper. As written by Itten himself in 1964, in the book *Design and Form*: "To execute the following exercises it is necessary to choose a very flexible, expressive medium which *reacts immediately to the slightest motion of the hand*, such as India ink brush..." (cited in Dearstyne, 1986).

This type of exercises are an example of expressive work based on the listening of the corporeal intellect. The aim is to translate in the gestures of the creative act one's own pre-reflexive sensory-affective condition, thus creating intuitive abstractions of an imaginal kind. The reflective processing and the prereflexive component are therefore undividable and essential to making the emotion corporeal (Alessandrini, n.d.).

This very close bond shown in Itten between movement, strength and emotion, is a recurring theme of the Modern and marks a new multiple and fourth dimensional visual point *from the inside*. The phenomenon of discretization (Saggio, 2010) that breaks the perspective frames of the vision of reality, the centripetal system of space conquest, are present in Itten's research and are linked on one side to Boccioni's "uncontrollable" man (Larcan, 2006), whose movements, rather, whose lines of force are nothing more than the manifestation of the dynamism innate in the figure, which makes the individual's vital force overflow, burst, explode, crystallizing it in thousands introflected freeze frames, and, on the other side, to the Russian current of the modern movement, in the figure of Jakov Černichov.

In his "*Construction of the forms of architecture and machinery*" of 1931, Černichov speaks of the functional complementarity of strength and construction, explained in various forms. The fourth and last is precisely the strength of the dynamics which is defined as the subtle union of complex events operating in our mind with a coordinated way that gives us the opportunity to try a higher form of emotional feeling (Cohen, 1986).

Returning to the contemporary years, in Giancarlo Priori's book "*Sympathy for things*" on the designer Paolo Portoghesi, the architect's work is explicitly linked to the concept of *Einführung*, after all implicitly underlying much contemporary design.

"The constituent element of all his compositions is *the line*. Portoghesi's works do not primarily consist of masses or spaces, but of bundles of lines which unify and separate, fan out and come together, curve and straighten, extend and rise" (Priori, 1982, p.7) [fig. I].

"The *sympathy for things* evokes the concept of *Einführung* that discovers, analyzes and expresses the symbolical relationship which is established between the observer and the natural object. This theory includes at the same time its opposite: the perceived object



Figure 1.

The constituent element of all his compositions in the line. Portoghesi's works do not primarily consist of masses or spaces, but of bundles of lines which unify and separate, fan out and come together, curve and straighten, extend and rise.

Source: [Moschea, 1974-1989] n.d. [online image] Available at: <
<http://www.gophoto.it/view.php?i=http://www.atlantedellarteitaliana.it/immagine/00016/10686OP2024AU17177.jpg>>
[Accessed 10 April 2013].

endows the perceiving subject with the model and the scheme of a given psychological process. In this way the observer experiences again, through the interior imitation, the perceived object: it is a question of formal *Pathos* which is in harmony with nature and which places the produced object in the forefront" (Priori, 1982, pp. 50-51).

Also in the book *Olandesi Volanti (Flying Dutchmen)*, published by Testo&Immagine in 2002, the perceptual world of the *Einführung* is connected to line through the work of architects dedicated to movement like Oosterhuis and Bouman, and that, taking the threads of a current flowing from Invernizzi's Casa Girasole, with Fagioli and Carapacchi, Aldo Rossi (Theatre of the World), Herron (Walking City), attributes to these works the words of Ruskin, "*This is what I call living architecture*" (cited in Jormakka, 2002).

However, if Oosterhuis (2007) speaks of "*single detail*" of the architectural object, that is architectures that are designed-programmed on a single parameter, e-motional hyperbodies, his work, dropped in Information Technology, becomes reductionist there where the term e-motive [fig.2] is very far from any emotional involvement.

More interesting is the work carried out by the architect Juvenal Baracco [fig.3], which, mainly in the field of academic experimentation, recalls the bergsonian concept of Embodiment, bodily experience, proprioceptive knowledge, as essential cornerstone of design. Through a process that lasts for the period of training, he starts from the design of a body copy mannequin to get to architectural perception and design of complex buildings.

Emotional transmission

Another important branch of empathic design and architecture, closely tied to Information Technology, is, without a doubt, the one that exploits the possibilities not of movement and corporeal mimesis, but of emotional communication between objects, architecture and men.

The 'man' has as primary home the 'nature' and where nature entering architecture the man understands the language (Prestinzenza Puglisi, 2011) (Matassoni A. and L., 2013). Not surprisingly, the revolutionary Ronchamp evokes a cave for the mystery of faith, for meditation, for the internalization. A place where the lost man of the post World War II finds the primordial womb, the refuge. The cave. Le Corbusier speaks to the man and does this through an emotional language. In his work *Vers une architecture* he says "The architecture is a fact of art, a phenomenon that elicits emotion, outside of the problems of construction, beyond them. Construction is to take on: the Architecture is to move" (Le Corbusier, 1923).

Zaha Hadid, speaking of the not yet built MAXXI, said "It's about giving life to a space in a variety of ways that offers people pleasure, fun, comfort and well-being similar to those experienced in a landscape" (Giuliani, 2002).

Alice Rawsthorn (2009), famous reviewer of the New York Times, explains the new frontiers of design in her article "*The Demise of Form Follows Function*." "One possibility is what techies call 'human interaction systems.' An example is g-speak, which is now being developed by Los Angeles-based Oblong Industries as a means of operating computers through physical movements and gestures, rather than keyboards and mice. Think of how Tom Cruise "controlled"



Figure 2.

The emotive house is fully industrial, flexibel in programmability, demountable, innovative, places domotics in an onther spotlight but will be general applyable in the near future.

Source: ONL (Oosterhuis_ Lénard), 2002. *E-motive House* [image online] Available at: <<http://www.oosterhuis.nl/quickstart/index.php?id=348>> [Accessed 10 April 2013].

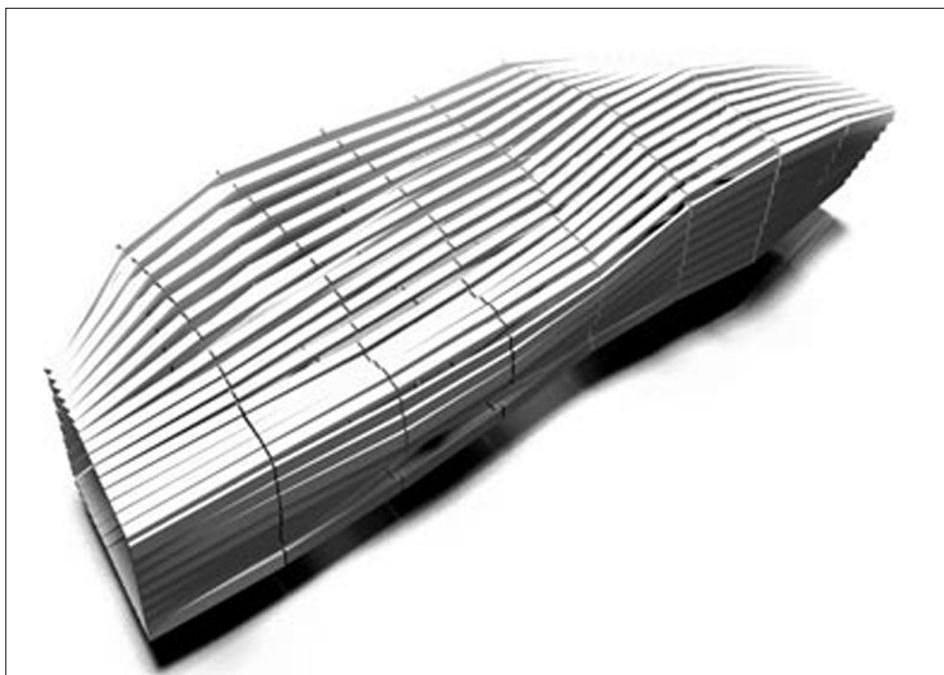
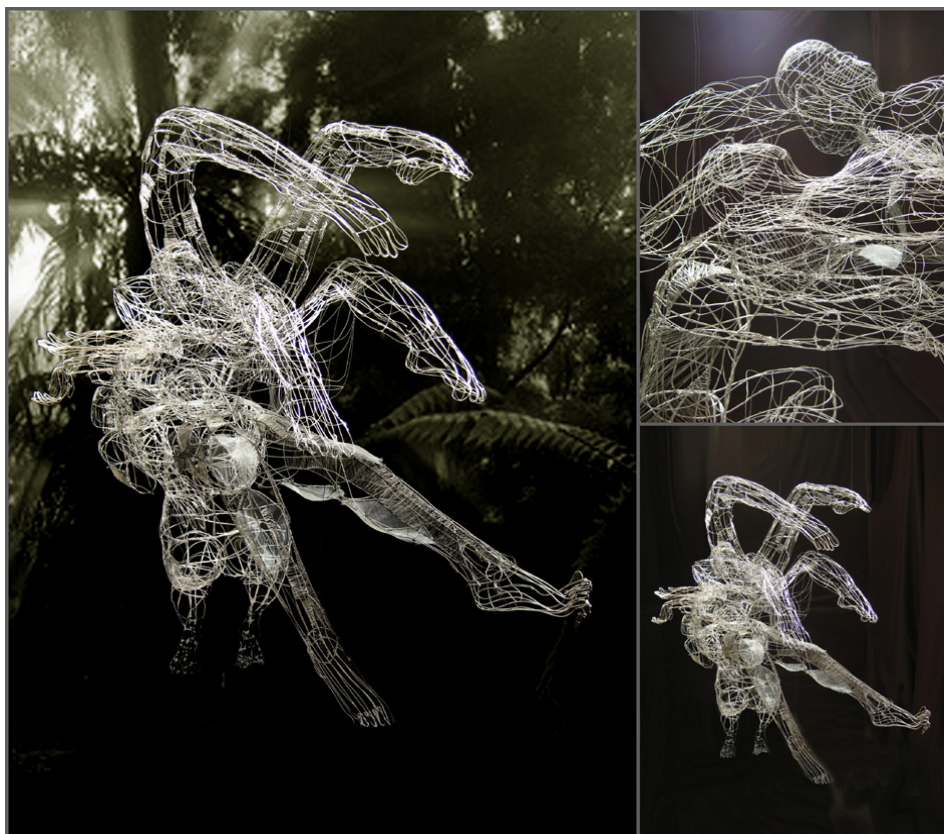


Figure 3.

Imaginary shelters, mental landscapes, metaphors, and design experimentations in the teaching method of the architect Juvenal Baracco. He unravels an interesting empathetic training throughout the five years of the course in architecture starting from the neurological ability of proprioception to recreate the dummy of own corporeal shape and make it a planning operational tool and the esthetic parameter of ownership of space.

Source: Leon, 2011. *La Hydra de Lerna* [image online] Available at: < http://www.gophoto.it/view.php?i=http://basicobaracco.files.wordpress.com/2011/08/img_2430zww.jpg#.UZk6y-MotU4x> [Accessed 10 January 2013].



computers remotely in the 2002 movie “Minority Report.” The students at the Rhode Island School of Design did that this spring in experiments with g-speak. Another option is to swap physical means of controlling technology with voice recognition systems, which are already used in some devices, or pure intuition. San Francisco-based Emotiv Systems worked with the IDEO design group to develop the Epoc, a headset that enables you to play video games by monitoring electrical activity in your brain. It literally reads your mind through 16 sensors, which then relay your instructions to the console. “People are always ready for new or better or more sophisticated experiences, digital and physical,” said Kara Johnson, a material scientist at the IDEO design group. The role of the designer is to make them simple and meaningful.”

Without going far, the *Blinkenlights Project* in 2001 [fig.4] transformed Alexanderplatz into an active screen using messages coded in lights by a computer, while the MoMA tried to put together all these new “isms” in a great exhibition titled “Talk to me” in November 2011, with 194 projects [fig.5].

Paola Antonelli (2011), Senior Curator, says “‘Talk to Me’ explores the communication between people and things. All objects contain information that goes well beyond their immediate use or appearance. In some cases, objects like cell phones and computers exist to provide us with access to complex systems and networks, behaving as gateways and interpreters. Whether openly and actively, or in subtle, subliminal ways, things talk to us, and designers help us develop and improvise the dialogue. The exhibition focuses on objects that involve a direct interaction, such as interfaces, information systems, visualization design, and communication devices, and on projects that establish an emotional, sensual, or intellectual connection with their users. Examples range from a few iconic products of the late 1960s to several projects currently in development including computer and machine interfaces, websites, video games, devices and tools, furniture and physical products, and extending to installations and whole environments.”

“I communicate, therefore I am” (Antonelli, 2011) is definitely one of the most important statements of our contemporary world, from everyday objects you don’t expect anymore the bare function for which they are bought, but an inborn communicability.

Certainly the world of the contemporary architect can not ignore the need for representativeness and emotional communicability sought by the user at every level. And you can not even ignore the level at which we have already arrived in the planning of “living” objects with the aid of graphical interfaces, diagrams and home automation smart programming.

The new buildings of today are already the Tamagotchi of yesterday. Interfaces, emotional involvement, automation. An interesting example, among others, is the IKEA universe. Interesting for endless reasons. The sale not of design products, but of emotional environments [fig.6], both in the catalogue and inside the store, the customization to which the user is driven, who is able to create, through furnishings that are cheap just because they are highly industrialized and serial, hyper adaptive environments, flexible, thanks to modularity, and personal, in fact, thanks to the range of possible solutions, all compatible with each other, makes IKEA an example of an empathy-based company.

The website management is also interesting, which provides for Anna, the virtual assistant, with the graphical interface of an IKEA salesgirl, complete with smile and uniform,



Figure 4.

On September 11th, 2001 the famous “Haus des Lehrers” (House of the teacher) building at Berlin Alexanderplatz was enhanced to become the world’s biggest interactive computer display: *Blinkenlights*. The upper eight floors of the building were transformed into a huge display by arranging 144 lamps behind the building’s front windows. A computer controlled each of the lamps independently to produce a monochrome matrix of 18 times 8 pixels.

Source: Fiedler, 2003. *Blinkenlights, Berlin - Alexanderplatz* [online image] Available at: <<http://www.archdaily.com/296275/media-architecture-oscars-awards-announced/blinkenlights-reloaded-alexanderplatz/>> [Accessed 10 January 2013].



Figure 5.

Talk to Me explores the communication between people and things. Whether openly and actively, or in subtle, subliminal ways, things talk to us, and designers help us develop and improvise the dialogue.

Source: Anne Helmond, 2011. *Talk to Me #moma* [online image] Available at: <<http://www.mobypicture.com/user/silvertje/view/10456960>> [Accessed 20 April 2013].



with which you can literally interact. The emotional contact developed by the company is impressive, since it brings, among other things, to a cultural fusion that makes you perceive the industrial giant as “close”, “positive”, “trusted”. With the obvious catalogue exceptions from country to country, IKEA has developed a housing *κοινή* and at the same time a potentially unlimited particularization.

Social instrument

After all, there is no doubt that architecture is emotional and this is bestowed on society. Just think of the interventions related to the *Favela Painting Project* in Rio De Janeiro, which, thanks to the recoloring of Santa Marta’s favelas (2010), have succeeded in emotionally communicating with the residents, who have collaborated in “taking care” of the urban environment [fig.7].

Same goes for the English “Idea Stores,” authors of the not only urban, but also social re-development of Tower Hamlets, London’s East End town, thanks to, among other things, transparency and color (Muscogiuri, 2009). Color and empathy. We are not saying anything new, as we can already talk about color feeling in Klee, reader of Worringer and Lipps.

Talking about the social component of *empathy*, how not to look at the studies on the *Disney Concert Hall* of Daniel G. Geldenhuys (2008), at Department of Art History, Visual Arts and Musicology, University of South Africa, who speaks of “*Empathy is not the sole preserve of human beings, and that a city or buildings can also relate with empathy to people and the environment. The Walt Disney Concert Hall, designed by the architect Frank O. Gehry in downtown Los Angeles, is taken as primary embodiment of such empathy. [...] Walt Disney Concert Hall as an act of architecture and work of art, where the macro and micro design have lead to an intelligent strategy of hybridization and inclusiveness. Gehry has in his ingenious design of the theatre complex managed to draw many differences together, allowing various cultures and art forms to meet, thus giving empathy a new meaning.*”

So what are the new empathic frontiers? How does a designer work? Where does he go? Towards motile architectures? Towards talking architectures? Towards socially shared architectures? And where does the discovery of an empathic biological basis lead?

Research outline

First we must split empathy in *Learning Aimed Transmission* and *Emotional Transmission*, concepts born from the discovery of empathy as a means of knowledge transmission (*substance*) through an aphasic language of emotional involvement (*medium*).

Architecture, for its extreme visibility, has always been the subject aimed at transmitting messages related to society. Yet, its correspondence with the society in which it is built includes architecture among the empathic means of knowledge transmission. But to human development, is the new knowledge necessary or can we consider as empathetic those architectures carrying inside them the so-called architectural archetypes?

This was the first consideration that made me call *empathetic*, in the *Learning Transmission* subgroup, the architectures which bring new and eternal values. It is clear that an evolu-



Figure 6.

Emotional environments and particularization potentially unlimited of IKEA.

Source: [IKEA Catalogue]n.d. [online image] Available at: < http://onlinecatalogue.ikea.com/IT/it/IKEA_Catalogue/ > [Accessed 20 April 2013].



Figure 7.

Using a flexible concept of colourful rays which can easily be expanded, they made a design for the houses around the square and part of the street, including the local Sambaschool.

Source: Haas & Hahn, n.d. santa-marta-pano-large [online image] Available at: <<http://www.archilab.org/public/1999/artistes/noxa-16fr.htm>> [Accessed 20 April 2013].

tionary biological means such as empathy can not exclude cultural archetypes, working for the sum of knowledge and not for subtraction.

The architectural archetype is not the *tout court* architectural construction, but the underlying emotional concept. The archetypal house is not a hut, a cave, a fence, but the underlying information data of sociality, the gathering of the group around the fire, as to make Antonino Saggio talk about Dolmen as primitive home (cited in Garramone, 2013).

Whether we are talking about new values or archetypes, we are definitely part of a series of socially shared information. This brings us to the part of pattern classified as *Emotional Transmission*. In designing a highly emotional architecture is important, in a logic aimed at defining empathy, the subject-object relationship and therefore the reaction of the spectator.

Emotions being equal we can have an architecture that makes explicit the mental landscape of a society, new or archetypal, and therefore also becomes didactically empathetic, or we can have an extroflexion of the architect's mental landscape, that we can more correctly call poetic. If this mental landscape expresses a series of values, needs and ideas of a society, giving it a somewhat codification, an interpretation, we have the eversion of the spectator's mental landscape and therefore of society. Instead, the introjection of the spectator in the architect's mental landscape, does not meet the requirement of transmission of a social value. Clearly the spectator's consent and participation become essential as well as his involvement and the immediacy of the language that transmits knowledge, are essential requirements of the biological inheritance of culture.

Therefore, in order to answer to the new "isms" within the vision of society, the architect creates a mental landscape, an explanation key of the mental landscape of society, through the use of a *breakthrough aesthetics* (Saggio, 2010) as to the previous one, with the aid of an active instrumentation and only thanks to that, possible through new scientific discoveries.

In the second part of our model, we take the classical division into physiological and psychological interpretation of the phenomenon of *empathy*, considering the content and therefore the medium of empathic communication. To understand how the physiological aspect is the content of information, we take Van de Velde's concept of *lines of force*, as the anthropomorphic architecture from Vitruvius and onwards (Viollet-le-Duc, Thiersch, Matila Ghyka) seems less interesting.

In today's *data era*, the lines of force find both an astonishing and precise correspondence, as vehicles of information, data, images, and even emotions, in the form of computer *network*. In this sense, as virtual highways, they themselves become information and then content. To the emotional component, the medium of information surprisingly matches the concept of the *knot*, which is represented by *sculptures-architectures*, and by the complex scenographies of buildings and public places, in the best sense of the word. These knots do not only serve as urban-social attractors and therefore emotional catalysts, but within the network, knots represent the interchange of information, which are empathically perceived and placed back in circulation after social exchange.

Figure 8.

The deformation of the object extends to the constant metamorphosis of the environment which responds interactively to the visitors to the water pavilion via a variety of sensors that register this constant reshaping of the human body called action.

Source: Frac Centre, 2007.
Fresh H2O eXPO - Water pavilion and interactive installation, Neeltje Jans, Hollande
[online image] Available at: <http://www.archilab.org/public/1999/artistes/noxa16fr.htm> [Accessed 20 April 2013]

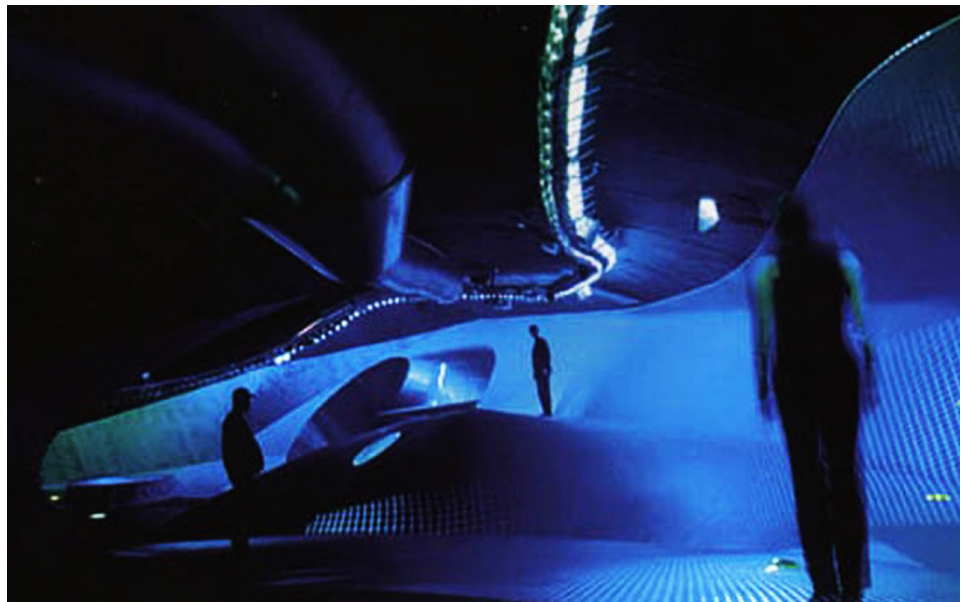
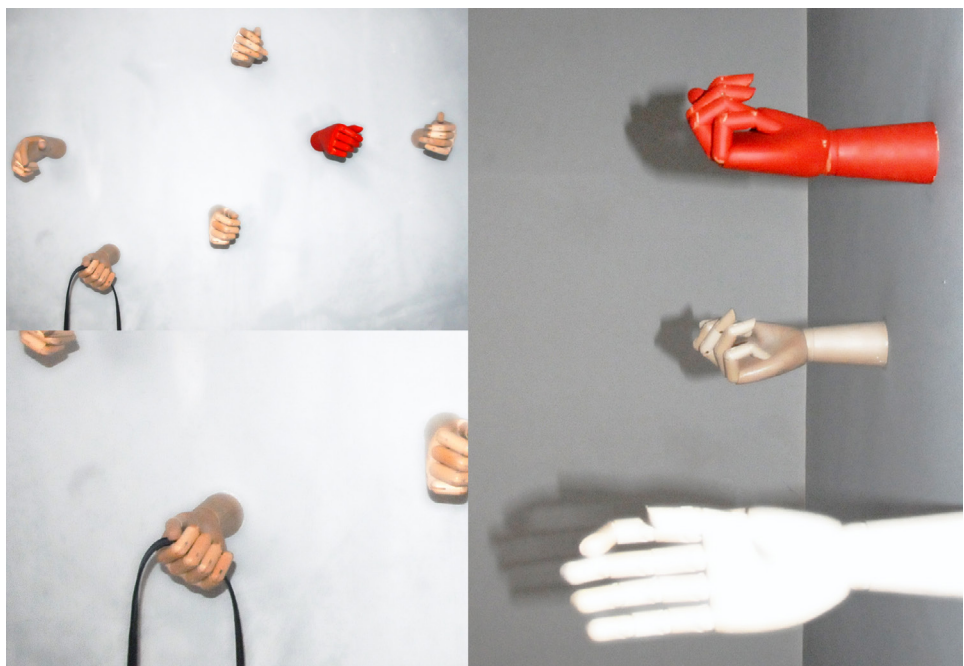


Figure 9.

Han(D)ger is a e-motional hanger. The hands move, embrace, grab clothes. Never equal, leaving gestural messages, make up a history of research and empathy. *Han(D)ger* communicates with the man and it makes itself medium of communication between the various inhabitants of the house.

Source: Arlotto, 2013.
Han(D)ger, E-motional hanger. Designed by VM Ideas Factory [online image] Available at: <http://vmideasfactory.weebly.com/> [Accessed 20 May 2013].



The concept of *network* and *data era* finds solid theoretical basis in the philosophical argumentation of Gilles Deleuze and Felix Guattari (1993), who introduce the concepts of geography of knowledge and *rhizomatic society*, which is nothing but a horizontal networked society where new knowledge and new places of learning emerge. Kari Jormakka (2002) speaks of this when he writes, referring to Deleuze's language, of the visitors' "becoming water" as they come into the Fresh Water Pavilion of the NOX Architects [fig.8]. A visit to the Sayamaike Museum of Ando in Osaka leads to the same feeling.

Conclusions

So, can we imagine a new architecture? And if these architectures, computerized totems of a computer network, were talking architectures, moving architectures, however able to interact with the human emotionalism, with the aphasic mind, through inputs dictated by brain imaging technologies? If architecture possessed an empathic mapping, a virtual soul?

If we could make ours the information flow turning outward our neural network, making alive the world of *Blade Runner*, or even better, of *Strange Days*? If architectures would respond not only to the environmental stimuli (heat, cold, ventilation, rain, and so on) but also to the emotional ones? If E-motive architecture became emotional-motive architecture? [fig.9]

If there was no longer any mind-body-architecture-landscape distinction but we moved all in unison, not in a fake and sugary emotional drift, but in an extremely complex computer network, in a swarm where men and community, public and private space, nature and architecture, progressively lose their thresholds to achieve an organic hyper-rationalism, where rationalism means efficiency, economy, ecology and democracy, welfare, social sustainability.

Do Androids Dream of Electric Sheep? The answer is obvious. In 1968 Philip J. Dick already had responded negatively. Inquiring about what is human and what is not, in a futuristic Metropolis. As in the Modern world the glass emptied the building, even man today empties his skin. It now becomes transparent surface, the threshold disappears again. Tendons become lines of force, the same elastic material which creates the canvas of the universe. Body-mind, fragmented body in motion, corporeal intellect: emotion emerges through physical and mathematical ways. But emerges. And the threshold disappears. Between man and machine as we did for machine and city, now between man, architecture and territory. Men dream of electric sheep. But they are also the ones who dream.

References

- Alessandrini, M., n.d. *L'intelletto corporeo o immaginale. Uno strumento per le psicoterapie espressive*. [on line] PSYCHOMEDIA Telematic Review. Available at <<http://www.psychomedia.it/pm/arther/art-ther/alessandrini5.htm>> [Accessed 15 Novembre 2012].
- Antonelli, P., 2011. *Talk to Me: Design and the Communication between People and Objects* [on line]. Available at <<http://www.moma.org/visit/calendar/exhibitions/1080>> [Accessed 2 October 2011].
- Cohen, J.L., 1986. Il "progetto" costruttivista. *Casabella*, pp.520-521.
- De Fusco, R., 1964. *L'idea di architettura. Storia della critica da Viollet-le-Duc a Persico*. Milano: Etas Libri.
- Dearstyne, H., 1986. *Inside the Bauhaus*. New York: Rizzoli International Publications.
- Deleuze, G. and Guattari, F., 1993. *Geofilosofia, il progetto nomade e la geografia dei saperi*. Milano: Mimesis.
- Di Maio, D. and Tedesco, S. ed., 2010. *J.G.Herder, Plastica*. Palermo: Aesthetica Editore.
- Favela Painting, 2010. *Santa Marta, Praça Cantão, Comunidade da Santa Marta, Rio de Janeiro*. [on line]. Available at <<http://www.favelapainting.com/santa-marta>> [Accessed 23 april 2013].
- Garramone, V., 2013. *Paesaggio senti-mentale*. [on line]. Available at <<http://imagocrisis.weebly.com/concept.html>> [Accessed 20 April 2013].
- Geldenhuys, D. G., 2008. *Empathy as perception in downtown Los Angeles and the Walt Disney Concert Hall as an act of architecture*, [e-journal] SAJAH, volume 23, number 1, 2008: 1-13. Available at <http://www.rosales.com/instruments/op24/SAJAH_VOL_23.pdf> [Accessed 20 October 2012].
- Giuliani, F., 2002. *Zaha, l'architettura è un'emozione* [on line]. May 11, 2002. Available at <<http://ricerca.repubblica.it/repubblica/archivio/repubblica/2002/05/11/zaha-architettura-un-emozione.html>> [Accessed 10 July 2013].
- Huizinga, J., 1939. *Homo Ludens*, ed. 2002. Torino: Einaudi.
- Jormakka, K., 2002. *Olandesi volanti. Il movimento in architettura*. Roma: Testo&immagine.
- Larcan, L., 2006. La rivoluzione di Boccioni, *Repubblica* [e-journal] october 24, 2006. Available at <<http://www.repubblica.it/2006/10/sezioni/arte/recensioni/boccioni/boccioni/boccioni.html>> [Accessed 27 November 2012].
- Le Corbusier, 1923. *Vers une architecture*, ed. 2001. Milano: Longanesi & C.
- Lipps, T., 1923. *Ästhetik: Psychologie des schönen und der Kunst*, ed. 2013. Cleveland: E-Books Delivery Service.
- Matassoni, A., Matassoni L., 2013. *Attitudine Verde, Presstletter* [on line]. March 13, 2013. Available at: <<http://presstletter.com/2013/03/attitudine-verde-di-alessandro-e-leonardo-matassoni/>> [Accessed 10 July 2013].

- Muscogiuri, M., 2009. *Biblioteche. Architettura e progetto*. Repubblica di San Marino: Maggioli Editore.
- Oosterhuis, K., 2007. *Ipercorpi: verso un'architettura e-motiva*. Roma: EdilStampa.
- Priori, G., 1982. *Sympathy for things*. Roma: Stoà Edizioni Arte.
- Pinotti, A., 2011. *Empatia. Storia di un'idea da Platone al postumano*. Bari: Laterza.
- Pinotti, A., 2003. *Robert Vischer, Friedrich Theodor Vischer, Simbolo e Forma*. Torino: Aragno Editore.
- Prestinzenza Puglisi, L., 2001. *L'architettura parla?*, *Architettura.it* [on line]. January 06, 2001. Available at <http://architettura.it/seminario/prestinzenza/prestinzenza_01.pdf> [Accessed 10 July 2013].
- Rawsthorn, A., 2009. The Demise of 'Form Follows Function', *The New York Times* [e-journal] may 30, 2009. Available at <http://www.nytimes.com/2009/06/01/arts/01iht-DESIGN1.html?_r=0> [Accessed 17 November 2012]
- Rifkin, J., 2010. *La civiltà dell'empatia*. Milano: Arnoldo Mondadori Editore.
- Rizzolatti, G. and Sinigaglia, C., 2006. *So quel che fai. Il cervello che agisce e neuroni specchio*. Milano: Raffaello Cortina.
- Saggio, A., 2007. *Introduzione alla rivoluzione informatica in architettura*. Roma: Carocci Editore.
- Saggio, A., 2010. *Architettura e modernità. Dal Bauhaus alla rivoluzione informatica*. Roma: Carocci Editore.
- Scarpa, L. and Fornari, D. ed., 2010. *Heinrich Wölfflin. Psicologia dell'architettura*. Milano: Et Al Edizioni.
- Tschudi Madsen, S., 2011. *The Art Nouveau Style: A Comprehensive Guide With 264 Illustrations*. Translated from Norwegian by Christophersen, R. Dover: Dover Publications.
- Von Hildebrand, A., 1907. *The Problem of Form in Painting and Sculpture (1907)*. Translated from German by Meyer, M.F. and Morris Odgen, R., ed. 2013. Whitefish: Kessinger Publishing.
- Zevi, B., 1972. *E. Mendelsohn, attualità del suo messaggio*. Roma: Officina.
- Wheeler, J.A. and Ford, K., 1998. *Geons, Black Holes, and Quantum Foam: A Life in Physics*. New York: W.W. Norton & Company.
- Wingler, H. M., 1987. *Il bauhaus. Weimar, Dessau, Berlino 1919-33*. Milano: Feltrinelli Editore.



Kinetic Hybrid Structure: Design and Motion Planning

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Abstract

The interactive relationship of society, technology and architecture has increased the demand on our built environment for kinetic structures that are capable to respond to changing external loading, functional and environmental conditions. Within this broader frame of consideration, the development of a reconfigurable hybrid structure is presented in the current paper. Hinge connected members, stabilized through a secondary system of struts and continuous diagonal cables with closed circuit compose the planar primary system. The kinematics of the structural system is based on the application of the effective 4-bar method, by using a sequence of 1-DOF (degrees of freedom) motion steps through modification of the cables' length. Motion planning is conducted through simulated models and is based on structural and kinematic criteria, in order to adjust the systems' joints to the desired values during the motion steps involved in any respective transformation sequence. The active control system applied for the reconfiguration sequences includes position sensors installed on the individual joints to provide feedback information, a minimum number of only two single motion actuators located at the structural supports, as well as hydraulic linear actuators installed on each strut. Specified criteria evaluate the kinetic behavior of the prototype according to the static braking torques, the cable axial forces and relative length variation. Following the construction design and motion planning of the kinetic structure, integration aspects of an adaptable tensile building envelope are discussed in the last part of the current paper.

Keywords

Adaptable structures; reconfigurable mechanisms; motion planning; envelope structure.

Introduction

The interactive relation of society, technology and architecture expanded the area of research, design and application of static structures aiming at transformability and adaptability. The necessity for an architecture that is not static, instead it has the ability to adapt in time and change through systems with embedded kinetic mechanisms was initially demonstrated by Zuk and Clark (1970). The design philosophy of kinetic architecture aims at the development of timely transformable buildings or components with variable mobility, location, or geometry as to differing external loading, functional and environmental conditions (Fox, 2001). Especially significant in terms of the kinetic operability is the development of the structure in two aspects by ways and means: The structural mechanism that enables different geometrical configurations of the lightweight components through among others, folding, sliding, expanding and transforming in size and shape, and the output system that directs the structure towards specified transformations, through pneumatic, chemical, magnetic, natural or mechanical processes. Undoubtedly, interaction comprises the main characteristic of a system in order to recognize, control and respond to different external stimuli, instead of simply following any respective linear patterns of locomotion. Types of interactive architectural spaces outlined by the convergence of kinetic systems and embedded computation, enriched with capabilities of reconfiguration, adaptation and automatization of the physical change (Fox and Kemp, 2009). In this frame, the human body may be considered as the most representative example. As Fox pointed out, a kinetic environment without computation is like a body without brain: incapable of moving. Inextricably linked to biological survival is the capability of adaptability, which addresses issues of transformation and optimization in response for accommodating changing variables. In numerous applications, major part of the structure can be reduced through the ability of a singular system to facilitate multi-uses via transformative adaptability. In this aspect, Buckminster Fuller favoured through "Ephemeralization" reduction of material (Krause and Lichtenstein, 2000). Robert Kronenburg illustrated the advantage of such systems in that, buildings that use fewer resources and adapt efficiently to complex site and programmatic requirements are particularly relevant to an industry, becoming increasingly aware of its environmental responsibilities (Kronenburg, 1997).

In structural terms, minimum self-weight is directly related with aspects of structural modularity, in limiting the complexity of the system and supporting constructability, connectivity, in producing a complete structural system on modular basis, loading, in providing feedback about load transmission with changes in stiffness, and shape, in accurately testing the geometrical shape limits of the structural system. From a static systems' point of view, tensegrity structures, i.e. self-stressed systems composed of tension and compression members (Pugh, 1976), may achieve minimum self-weight and controllable high stiffness values. Tensegrity structures combine parts mutually supportive in such a way that the compression members do not touch one another, but press outwardly against nodal points in the tension network to form firm, triangulated, prestressed, tension and compression units (Snelson, 1965). Such member structures have the ability to transform in space, while enabling optimized conditions in the mass and load transfer. Furthermore, discontinuous compression, as in classical tensegrity systems, may not always be necessary, whereas more efficient static structures can be achieved, if compression elements are allowed to join (Robbin, 1996, pp. 25-37). Such typologies may further lead to hybrid systems. In principle the latter are defined through linkage of different components in parallel and/or in series that are combined to resist forces by developing a specific mechanical behavior due to their different resisting nature (Schlaich, et al., 2005). The potential of hybrid systems lays in the synergetic possibilities emanating from exploiting the systems disparities: reciprocal compensation of critical stresses, system-transgressing multiple functions of individual components and increase in rigidity through opposite systems deflection (Engel, 2009). Even though

the development of optimized lightweight structures is highly acknowledged in research and applications, their transformation into kinetic systems follows in most cases linear, sequential processes of development within respective multidisciplinary teams of operation, rather than non-linear, iterative ones in an interdisciplinary context. Linear, sequential modes of development have as a result in most cases member structures, i.e. planar and spatial trusses and hybrid systems, stressed in compression, tension and bending, with respectively articulated joints and embedded mechanical actuators.

An example of structural joints' activation for obtaining controlled flexibility is the "Kinetic Tower", a development of the movable guyed mast vision of Frei Otto (Kilian, et al., 2006). The resulting outrigger system of rhomboid shaped core units and vertical interconnecting tension-only members provides different spatial bending shapes through integrated dampers at the joints. An adaptable structure with integrated hydraulic actuators as primary compression diagonal members comprises the planar truss with lower horizontal elastomeric tubes, presented in Merali and Long (2010). Further developments in this direction are the Variable Geometry Truss, a planar or spatial member structure with embedded hydraulic actuators (Miura and Furuya, 1985), an adaptable aluminium tensegrity structure presented in Sterk (2003), and a tetrahedral truss with a number of actuator diagonals of shape memory alloy (Sofla, Elzey and Wadley, 2009). In the prototype of the "Muscle Tower" of six actuated trapezoidal vertically positioned tensegrity units, the actuators are in place of the tension members (Hwang, et al., 2006). The structure demonstrates high flexibility due to possible elongation, shortening and rotation of the units. Active tensegrity structures of struts and cables are further analyzed in Fest, et al. (2003) and Sultan (2009).

The above-mentioned projects identify design strategies of replacing main components of the structure with actuators. Consequently depending on the actuators number used and their specific characteristics, the structures overall weight and the energy consumption for their kinematic reconfigurations are disadvantageously affected. The design and analysis of the kinetic hybrid structure presented in the current paper reflexively addresses these considerations with regard to the integrative development of the systems static and kinetic operability. For achieving optimal load-bearing and energy performance, the transformability of the prototype structure is envisaged to arise primarily from the inherent integrative composition and dual capabilities of its members, than exclusively from the mechanical control system. The development refers primarily to the hybrid nature of the structure on one side and the application of the effective 4-bar method for its kinematics by using a sequence of 1-DOF motion steps through modification of the cables' length on the other side. In this way, reduced self-weight of the structure, dual capabilities of its members with regard to their static and kinematic operability and minimum number of actuators with reduced energy consumption are possible. Previous work conducted by the author in this direction refers to an adaptable spatial tensegrity structure presented in Phocas, Kontovourkis and Matheou (2012). The proposed reconfiguration concept of the system was based on general motion planning principles introduced in Christoforou, Müller and Phocas (2012) and Christoforou, et al., (2013).

The prototype structure presented in the current paper builds upon a previous proposal made by the author on an adaptable planar hybrid structure and motion planning concept of multi-body articulated systems (Matheou, Phocas and Christoforou, 2013). The

hybrid structure consists of hinge connected beams and a secondary system of struts and diagonal cables. The system is initially analyzed in its static behavior with regard to the secondary members' geometrical and mechanical characteristics. The proposed reconfiguration concept requiring only two motion actuators tensioning each corresponding cable at the structural supports as well as hydraulic brakes at the joints, and the selection of an optimal motion pattern are demonstrated through a simulation example. Finally, two structural alternatives are proposed for the building envelope integration, so that the membrane units may follow elastically respective shape alterations of the primary structure.

Structural System Development

The typological development of the adaptable hybrid structure clarifies decisive geometrical and mechanical characteristics of the secondary members and their connections through a comparative static analysis of hinge connected horizontal beams with all joints conservatively considered to be moment free, Table 1. A two-hinge supported beam with span of 17.5 m, system: A-I-I, is initially modified into eight, hinge connected beam members with individual lengths of 2.5 m and 1.25 m at the edges. The members are stabilized through a secondary system of continuous struts with overall length of 1.0 m and diagonal cables connecting adjacent upper and lower strut points to the beams at the respective mid-spans, system: ST-I-I. The diagonal cables may also comprise continuous members between adjacent upper and lower strut points, system: STI-I-I, and rotating discs may be applied at the cable-strut joints, system: ST3-I-I. In the latter system the cables obtain a closed circuit, meaning that in any transformation, the resulting alteration of the diagonals length is ideally zero. The geometrical characteristics of the struts are further modified to accommodate the kinematics of the system. The total length of the members is set to 1.5 m, whereas their effective length above the beam axis amounts to 1.0 m, system: ST3.I-I-I. Finally a refinement of the kinematic mechanism of the system is achieved with pulley elements at the respective joints and continuous cables, system: WM.

The sections of the members have been designed for a vertical uniform load of 2.5 kN/m, based on Eurocode 3. The beams consist of pairs of interconnected UPN320 sections facing outwards and positioned at a relative horizontal distance of 12.5 cm. The struts consist of rectangular sections with dimensions of 85/40/3.2 mm and the cables diameter amounts to 40 mm. Nonlinear analysis of the systems has been conducted with the Finite-Element software program SAP2000. The cables have been modelled as frame objects with zero compression limits. No prestress has been assigned to the members for enabling a direct comparison of the results. The rotating discs have been modeled as compositions of two short-length frame objects, each assigned with large stiffness values to represent the real property of a mechanical discs shaft. The absolute maximum internal forces developed in the members, maximum axial force N_{max} , shear force Q_{max} , and bending moment M_{max} , and the systems deformations f , are presented in Table 2.

Compared to A-I-I system of reference, the first three alternatives have a significant increase of the maximum shear force of the primary members, of on average 73 %. In addition the contribution of the secondary system in the load-bearing behavior of the structure is reflected by the development of the respective axial forces in the members.

Table 1. Typological development of planar hybrid system.






Type	Structural system
A-I-I	
ST-I-I	
STI-I-I	
ST3-I-I	
ST3.I-I-I	

Table 2. Static behavior of the planar structural systems.

Type	Structural member	N_{max} [kN]	Q_{max} [kN]	M_{max} [kNm]	f [cm]
A-I-I	Beam	-	29.61	129.42	15.37
ST-I-I	Beams	112.91	110.51	135.49	16.56
	Struts	221.21			
	Cables	298.01			
STI-I-I	Beams	90.30	110.26	135.20	16.53
	Struts	220.91			
	Cables	297.92			
ST3-I-I	Beams	104.49	110.93	135.99	16.19
	Struts	222.19			
	Cables	279.22			

Table 3. Static braking torques, T_i , axial cable forces, N , and relative cable length variation, Δl .

Sequence	$T_{i, max}$ [kNm]	$N_{1, max}$ [kNm]	$N_{2, max}$ [kN]	Δl_{max} [cm]
1 Type A	19.29	19.63	15.24	-8.00
1 Type F	18.87	19.31	11.91	-8.00
2 Type B	19.61	19.01	13.95	-10.00
4 Type D	19.64	19.05	11.48	-7.00
5 Type F	20.13	19.60	13.79	-11.00
6 Type B	20.05	19.55	12.21	-6.00
-2 Type E	34.53	19.25	19.72	-8.00
-2 Type F	29.69	17.09	14.37	6.00
-6 Type E	33.64	19.56	19.31	-6.00
-6 Type F	34.86	15.98	12.07	-6.00

The maximum bending moment of the primary members increases only slightly, by on average 4.74 %, as well as the maximum deformation, by 6.87 %. The differentiation of the strut lengths as to the beam axis followed in ST3.1-I-I proves to be disadvantageous for the structure resulting in a high deformability. The replacement of the rotating discs with pulleys in WM improves the load-bearing behavior of the system only in terms of uniform axial force distribution in the continuous cable members. The stability of ST3.1-I-I and WM under vertical loading was verified in the frame of the succeeding respective motion analysis with the software Working Model. In the kinematic model of WM-System the transfer of motion driven by respective modifications of the cables length is realized through a hydraulic brake system and a pair of diagonal links symmetrically-installed on either side of each strut, Figure 1.

The linkage effectively ensures a centering of the struts while the corresponding joint angles vary.

Spatial Structure

The spatial structure follows general configuration principles of member structures with hierarchy in one direction. For ensuring spatial operability, especially in cases of non-symmetrical motion sequences between the primary structures, the horizontal structure needs to be geometrically variable. Therefore the secondary compression members consist of telescopic tubular steel sections of variable length, Figure 2. The compression members are connected to the primary beams over flat steel diagonals and elastomeric washers at the joints with the beams. The secondary diagonals consist of tension-only members with closed circuit, i.e. continuous cables connected at the end-compression members at a fixed and an electromagnetically controlled joint. In this way, once a new position of the primary elements is obtained, the horizontal members are redefined in their length and the diaphragm at the roof plane is ensured.

Motion planning

The planar kinematic mechanism, n -bar linkage of WM, has the capacity to develop different reconfiguration schemes. The supports provide one link to the linkage and the remaining kinematic chain consists of $(n-1)$ members. In general, a planar n -bar linkage has $(n-3)$ DOF and complete control of its motion requires equal number of actuators to be installed. However, installing many actuators on the system increases the overall structure's weight, structural deformations and cost. Moreover, operation will be energy inefficient given that the system will have to move about its own massive components. Therefore, it is proposed to use two single motion actuators at the structural supports corresponding to each one of the cables, as well as electromagnetic brakes corresponding to each one of the remaining articulated joints. By selectively locking $(n-4)$ joints at a time, the mechanism is reduced to an "effective 4-bar" (E4B) mechanism that will have 1-DOF, Figure 3. A group of consecutively locked joints formulates an "effective link". By using the available actuators, any joint angle of the E4B linkage can be adjusted to its desired value and from then on it remains locked until a reconfiguration is completed. For each successive step of the control sequence a different E4B linkage is defined and one angle is adjusted. The final E4B realization is used to adjust the last remaining four joint rotations. Assuming that during every step one joint adjustment is fully completed the overall reconfiguration of the n -bar requires a total of $(n-3)$ steps.



Figure 1.

Primary structure unit of WM-System.

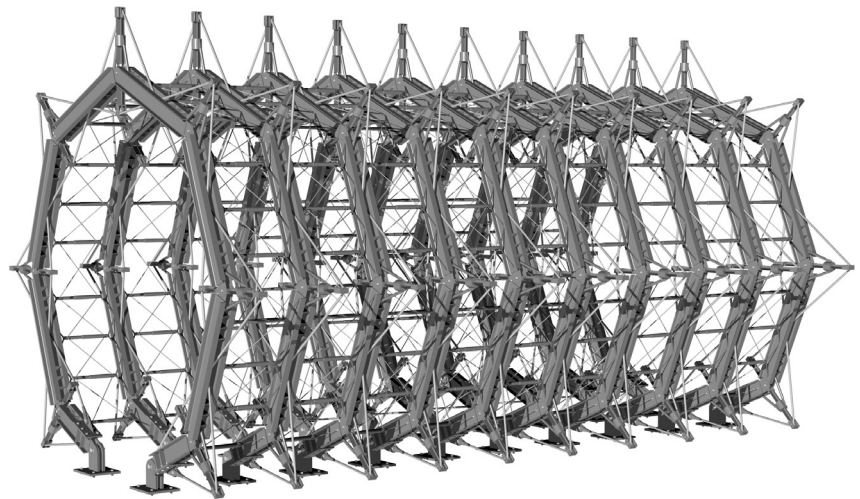


Figure 2.

Spatial structure.

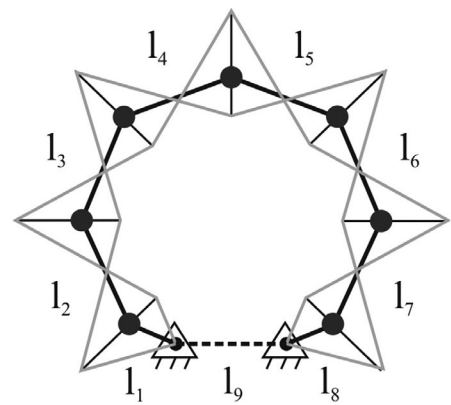
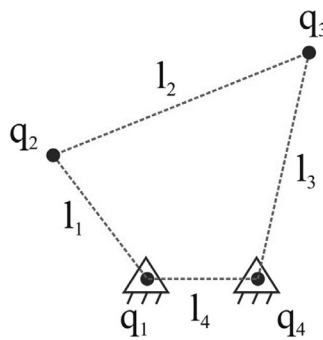
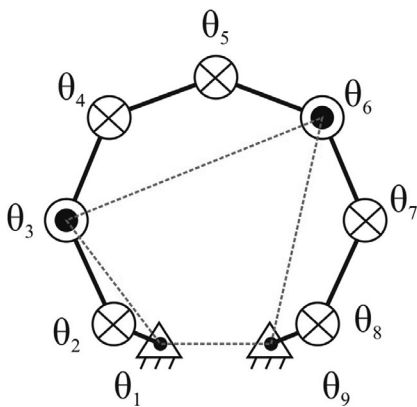
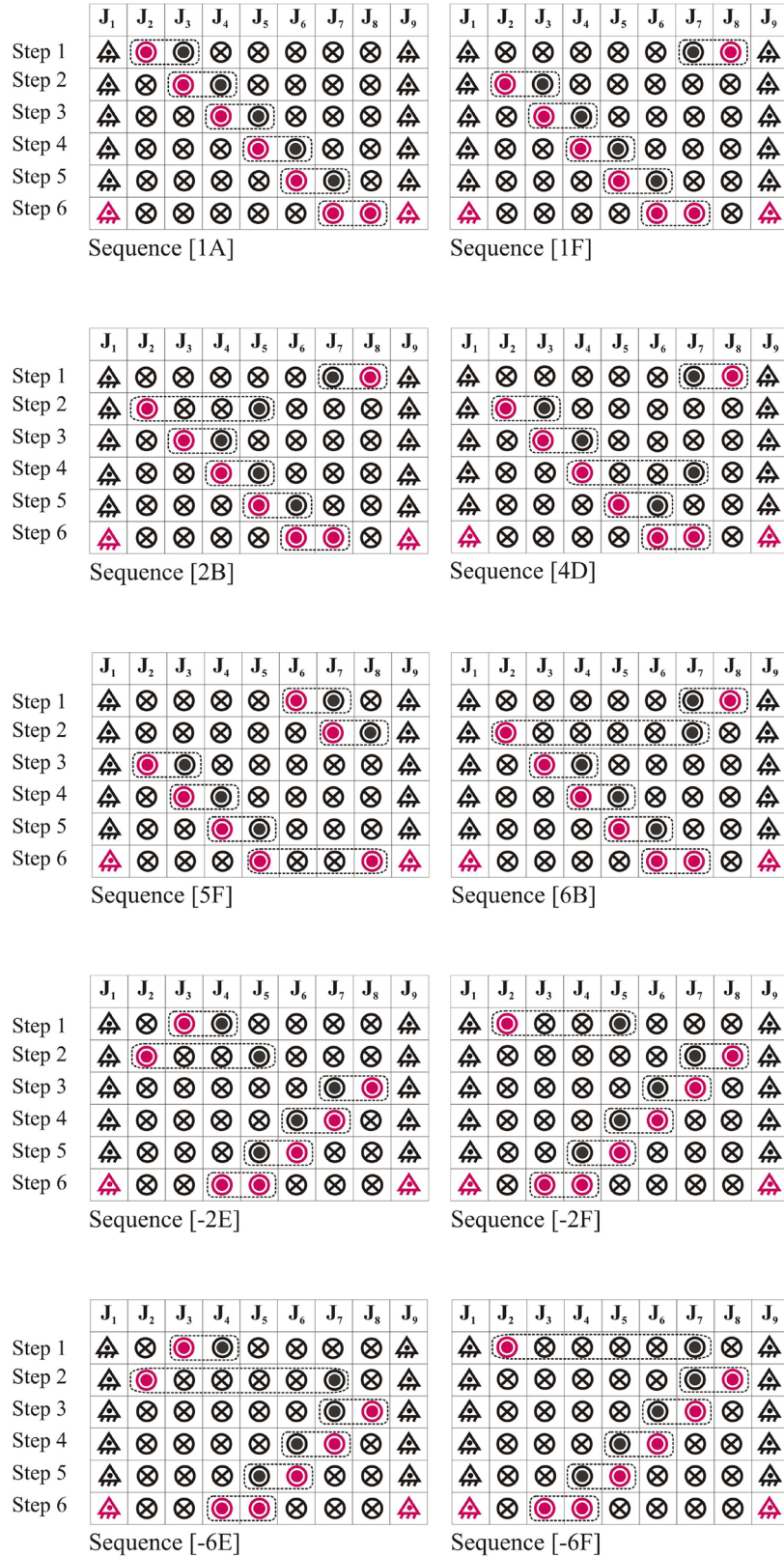


Figure 3.

The effective 4-bar concept (⊙: locked joint, ⊗: unlocked joint, △: pivoted-to-the-ground joint) and the cables actuation approach.

**Figure 4.**

Feasible control sequences for implementing the required shape adjustment (@: locked joint, ○: unlocked joint, △: pivoted-to-the-ground joint, symbols in red color represent the currently adjusted joints).

Motion patterns

The motion planning of the system is based on the E4B concept. The 9-bar linkage configuration considered in the simulation example is composed of perfectly rigid primary members. The initial position (Figure 5, left column) of the symmetric system has joint angles defined by the corresponding joint rotations vector, $\Theta_i = [156, 135, 135, 135, 135, 135, 135, 156]^T$ degrees. The target configuration (Figure 5, right column) is given by $\Theta_f = [164, 133, 125, 138, 140, 138, 125, 133, 164]^T$ degrees. The link lengths follow the geometrical prepositions of the structural system, their mass amounts to 297.5, 6.0 and 178 kg for each 2.5 m long beam, strut and an approximately 20 m long cable respectively. Given the initial and target configuration of the system, intermediate stages define various possible motion patterns and an optimal one may be selected on the basis of specific criteria, e.g. required actuator forces/torques, tension forces of the cables.

Moreover the following requirements had to be satisfied for the specific prototype simulation example: (i) Both pivoted-to-the-ground joints always remain unlocked; (ii) No link can move below the horizontal ground level; (iii) A flattening of the cables joint angles practically deprives the system from the mechanical advantage required to develop motion of the joint angles. Therefore a respective upper limit of 1750 of any unlocked cable joint angle was set in the analysis for avoiding infeasible sequences; (iv) Any motion sequence, clockwise or counterclockwise, requires two consecutively unlocked joints, or two, or four locked joints between any unlocked ones, so that the cable actions on the primary system do not compete with each other. Taking into account the operability of the system, there exist ten feasible motion sequences of six adjustment steps each, shown in Figure 4. The simulated reconfiguration results for the ten feasible sequence types are shown in Figure 5.

Control criteria

The braking torques in the primary joints, the cables' axial forces and relative length variation between the struts in each motion sequence type prescribe the actuators requirements and provide criteria for selecting the most appropriate sequence. The respective maximum values of the motion sequence types are shown in Table 3. Type F of sequence -2 develops the lowest values of maximum torques. The lowest tension forces of the cables are developed in type F of sequence -6. Types B, F, E and F in sequences 6, -2, -6 and -6 respectively yield smaller variations of the cables' length. Therefore, type F of sequence -2 would be the choice of preference for realizing the reconfiguration case example.

Envelope Structure

At the structure level the envelope should enable optimized lightweight of the material, structural efficiency, capability to cover relative large span spaces with only elastic deformations, without stress interactions with the primary structure (Knippers, et al., 2011). In addition the envelope structure is required to be flexible in order to accommodate for cases of dissimilar configurations assumed by any adjacent n-bar linkages that constitute the primary member structure. In the specific case example, any adjacent THV-membranes, Terpolymer of Tetrafluoroethylene- Hexafluoropropylene-vinylidene fluorid, are interconnected through horizontal double-paraboloid shaped surface elements of higher elasticity. The membrane units have initial overall dimensions in plane of 1.0 x 2.3 m and

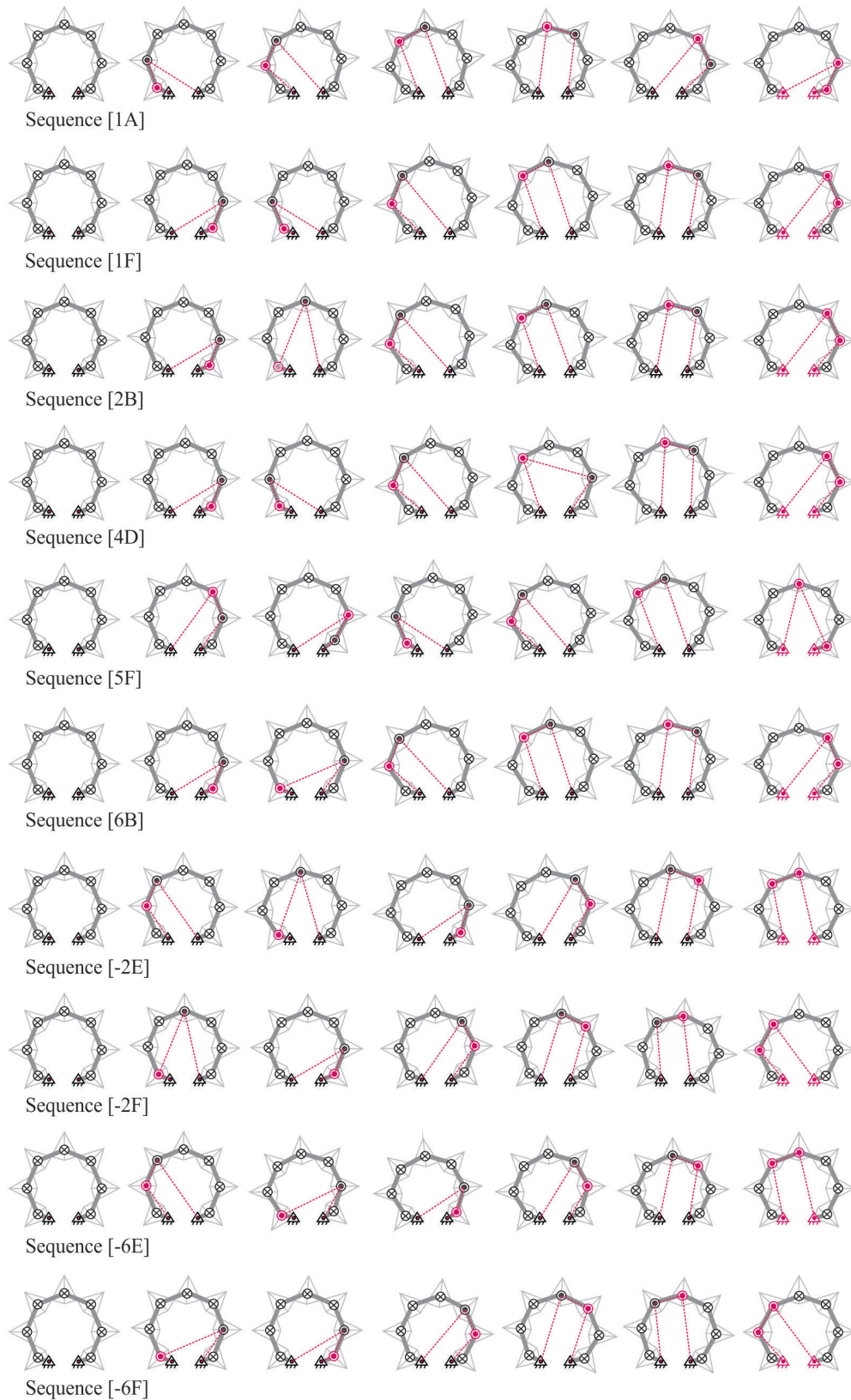


Figure 5.

Simulated stepwise changes of the 9-bar linkage for the required shape adjustment.

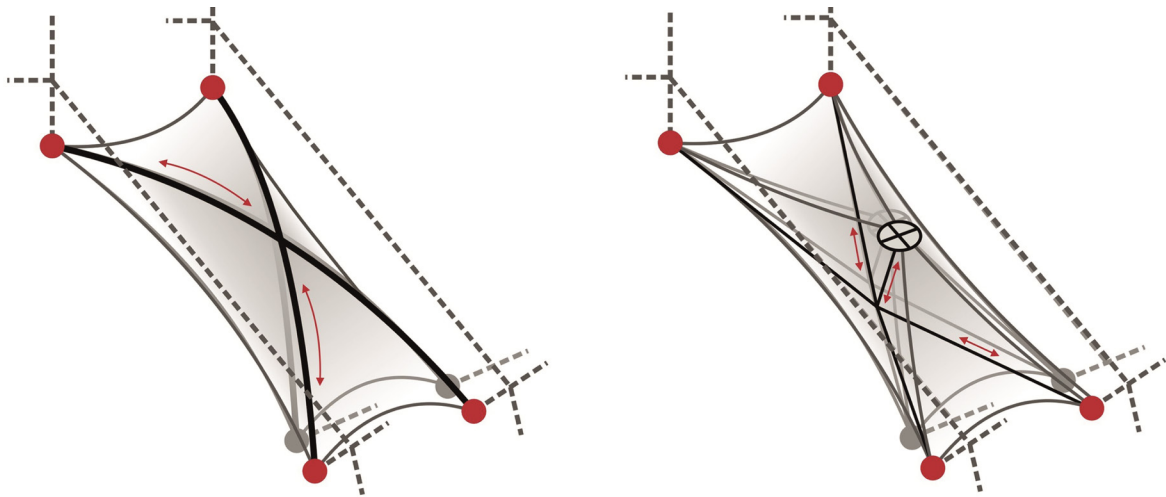


Figure 6.

Adaptable envelope structure concept enabling passive responses to reconfigurations of the primary structure (left) and active control for improving stress conditions in the membrane (right).

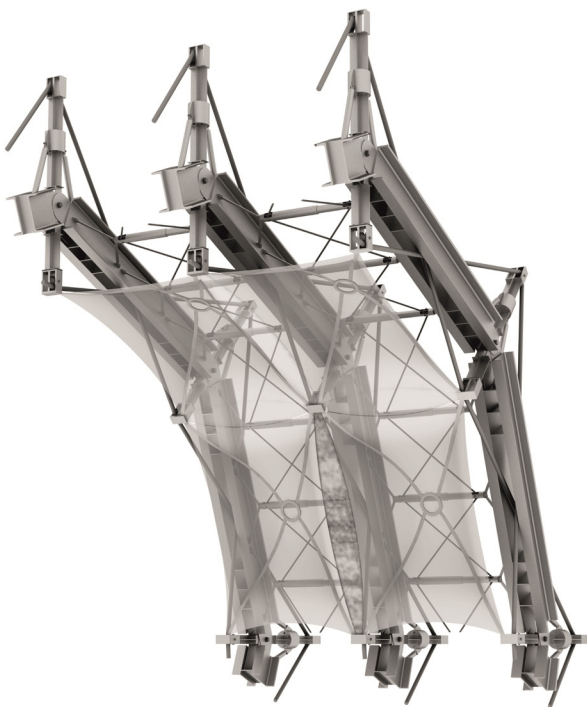


Figure 7.

Passive adaptable envelope system with bending active members.

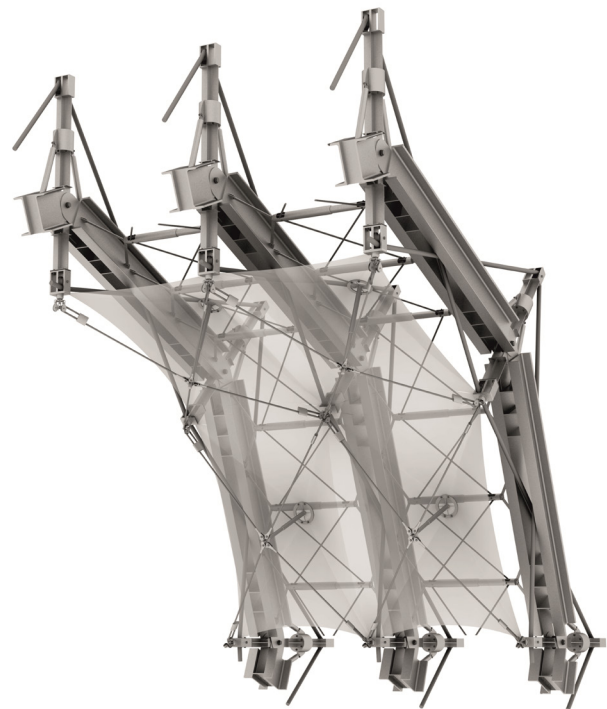


Figure 8.

Active adaptable hybrid envelope system.

paraboloid curvature radius of 20-25 cm. The envelope system is positioned at a distance of approximately 30 cm underneath the primary structure for preserving continuity in the cover material. The membrane units are to be supported on a dedicated secondary structure rather than being directly affixed to the members of the primary structure. The secondary structure is supported on short-length auxiliary links located at the primary strut joints, and the membrane double curved surfaces, at their edge corners and middle points. Conceptually this means that the envelope system exploits the best structural qualities inherent in the tensile material and therefore the latter becomes an integral part of the envelope system, Figure 6.

Passive Envelope System

Following a passive structural concept, any adjacent strut joints are connected to bending active members that form scissor-type configurations in the horizontal planes. The members are curved on their weak section axis, in the perpendicular direction, so that relative alterations of their projected length induced through the kinematics of the primary members, are followed by their own respective bending deformations, Figure 7. This structural arrangement passively responds to the motion of the primary members. The membranes with double curved saddle shaped surfaces accordingly adjust their shape resulting from the position of their respective point supports.

Active Envelope System

By replacing the bending active members with double curved anticlastic membranes and integrating a secondary system of tension-only members with closed circuit and struts of telescopic tubular steel sections, the membranes act as primary components of the hybrid structure, Figure 8. In any operational mode the hybrid structure acts together with regard to the load transfer. The introduction of axial forces in the secondary members enables a stiffness related decrease of the tensile forces in the membranes. While the primary structures change their shape, the envelope structure will actively respond with a modification of the cables and struts length. Of-course, throughout the transformation shapes of the system each interacting envelope unit may obtain its own initial shape and stress based on its position within the global system. The active system is expected to ensure a uniform stress distribution in the membrane material.

Conclusions

A hybrid structure of hinge connected primary members and a secondary system of struts and continuous cables with closed circuit that inherently enables static operability and kinematic transformability has been presented in the current paper. The interdisciplinary modes of operation followed throughout the prototype development included a parametric analysis of the static systems, construction design of the structural members and connections, motion planning of the kinematics, as well as a conceptual development of the adaptable tensile envelope structure. The synergistic static and kinematic characteristics of the hybrid system and its motion planning through application of the effective 4-bar method provide a reliable and optimized reconfigurable system. The structure may obtain different geometrical reconfigurations according to external criteria of the users and the environment by following the transformation paths specified throughout its motion planning, whereas in between transformation stages from an initial to a target



configuration define respective temporary transformation phases. Although the transformation phases constitute only transition intervals with regard to the usages of the building, the reconfiguration envelope implies the high flexibility made possible for the transformability of the structure through the control method proposed herein.

Further interdisciplinary work is necessary for the development of automated optimally efficient motion trajectories according to the building operations. This involves also the development of appropriate control system architectures that would indicate the various functions that the system will be required to perform, the functional relationships between them and their hierarchy. The flow and processing of information within the system will also need to be specified for the structure to become interactive. This includes among other, the particular information that the system will expect from its environment, the form in which this information should be provided, as well as the information the system itself will return to the users regarding its current status.

References

- Christoforou, E.G., Mueller, A. and Phocas, M.C., 2012. Motion planning for shape-controlled adaptable buildings resembling topologically closed-loop robotic systems. In: *Proceedings of the International Design Engineering Technical Conferences IDETC and Computers and Information in Engineering Conference CIE, ASME 2012*. Chicago.
- Christoforou, E.G., Mueller, A., Phocas, M.C., Matheou, M. and Arnos, S., 2013. Towards realization of shape-controlled adaptable buildings following a robotics approach. In: *Proceedings of the International Design Engineering Technical Conferences IDETC and Computers and Information in Engineering Conference ICE, ASME 2013*. Portland.
- Engel, H., 2009. *Structure Systems*. Stuttgart: Hatje Cantz.
- Fest, E., Shea, K., Domer, B. and Smith, I., 2003. Adjustable tensegrity structures. *Structural Engineering*, 129(4), pp.515–526.
- Fox, M., 2001. *Ephemerization*. Cambridge: Massachusetts Institute of Technology.
- Fox, M. and Kemp, M., 2009. *Interactive Architecture*. New York: Princeton Architectural Press.
- Hwang, I., et al. eds. 2006. *Verb Natures*. Barcelona: European Union Publications, Actar.
- Kilian, A., Block, P. Schmitt, P. and Snavely, J., 2006. *An Evolving Language for Actuated Structures*. Boston: Department of Architecture, MIT.
- Knippers, J., Cremers, J., Gabler, M. and Lienhard, J., 2011. *Construction Manual for Polymers + Membranes*. Munich: Institut für Internationale Architektur-Dokumentation.
- Krausse, J. and Lichtenstein, C. eds., 2000. *Your Private Sky. R. Buckminster Fuller Design als Kunst einer Wissenschaft*. Baden: Lars Mueller.
- Kronenburg, R., ed., 1997. *Transportable Environments: International Conference on Portable Architecture*. London: E&FN Spon.
- Matheou, M., Phocas, M.C. and Christoforou, E.G., 2013. Adaptable hybrid steel structures. Kinetic modeling and simulation study. In: *Proceedings of Second International Conference on Structures & Architecture, ICSA 2013*. Guimaraes.
- Merali, R. and Long, D., 2010. Actuated responsive truss. In: *Proceedings of the Workshop on Modular Robotics: State of the Art; IEEE International Conference on Robotics and Automation, ICRA*. Alaska.
- Miura, K. and Furuya, H., 1985. Variable geometry truss and its application to deployable truss and space crane arm. In: *35th Congress of the International Federation of Astronautics*. Switzerland, 12(7-8), pp.599-607.
- Phocas, M.C., Kontovourkis, O. and Matheou, M., 2012. Kinetic hybrid structure development and simulation. *Architectural Computing*, 10(1), pp.67-86.
- Pugh, A., 1976. *An Introduction to Tensegrity*. Berkeley: University of California Press.
- Robbin, J.L., 1996. *Engineering a New Architecture*. Princeton: Yale University Press, pp.25-37.

Schlaich, J., Bergermann, R., Boegle, R., Cachola, A. and Flagge, S.P., 2005. *Light Structures*. New York: Prestel.

Snelson, K., 1965. *Continuous Tension, Discontinuous Compression Structures*. U.S. Pat. 3,169,611.

Sofla, A.Y., Elzey D.M. and Wadley, H.N.G., 2009. *Shape Morphing Hinged Truss Structures*. Bristol: IQP Science.

Sterk, T.E., 2003. Using actuated tensegrity structures to produce a responsive architecture. Connecting crossroads of digital discourse. In: *Proceedings of the 2003 Annual Conference of the Association for Computer Aided Design in Architecture, ACADIA 22*. Indianapolis, pp.86-93.

Sultan, C., 2009. Tensegrity: 60 years of art, science and engineering. *Advances in Applied Mechanics*, 43: pp.69-145.

Zuk, W. and Clark, R.H., 1970. *Kinetic Architecture*. New York: Van Nostrand Reinhold Company.



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Larry Sass is an architectural designer and researcher exploring digital design and fabrication across scales. As an associate professor in the Department of Architecture at MIT, Larry has taught courses specifically in digital fabrication and design computing since 2002. He earned his PhD '00 and SMArchS '94 at MIT, and has a BArch from Pratt Institute in NYC. Larry has published widely, and has exhibited his work at the Modern Museum of Art in New York City. Larry's research builds on his belief that hand crafted, hand operated construction will soon be a thing of the past, and that in the future, buildings will be printed with machines run by computers. He proposes that the practice of architecture must incorporate new and emerging means of machine operation within fields of design and construction, and that these changes require the development of a new knowledge base for design where designers will plan a larger role in the delivery process. The challenge for architecture schools and the profession will be the development of new research and teaching agendas related to creative digital design and fabrication across scales - from furniture to skyscrapers. Larry will share findings from current research projects, including large-scale prototyping of design artifacts from CAD data, and digitally fabricated houses.

Kenfield Griffith is CEO and Founder of mSurvey, a data and insights company, offering a customizable mobile survey platform for research, data collection, and product tracking. Prior to this, he developed technologies in collaboration with the University of the West Indies collecting data from fishing communities distributed throughout the islands of Trinidad and Tobago. During 2010-2012 he worked as an Inter-American Development Bank Data Consultant in Washington D.C. and as a data researcher under the auspices of the MIT Committee on the Use of Humans as Experimental Subjects (COUHES). Kenfield's work has been presented at the international CAD, SIGRADI, CAADRIA and Connected conferences. Kenfield developed and contributed to design workshops in emerging markets, including the Caribbean, Africa, Chile, and Peru. He received a PhD in Design and Computation from MIT studying and developing Information and Communication Technologies for improve design, data collection, and insights in remote regions. Kenfield also holds a SMArchS degree from MIT and a Bachelor degree in Computer science from the University at Buffalo.

Ayodh Vasant Kamath is a Partner at Kamath Design Studio, New Delhi. Here he is involved in critical architectural projects dealing with the application of digital design technologies in non-industrial settings. He has been a visiting faculty member at the University College of Architecture and Planning, Delhi (August 2012-May2013), and Sushant School of Art & Architecture, Gurgaon (August 2011-June 2012) where he has taught design studios and electives, and conducted workshops. He has lectured at Lawrence Technological University, Michigan (2013); the Architectural Association Visiting School, Bangalore (2011); the Massachusetts Institute of Technology, Cambridge (2011); and the Centre for Environmental Planning and Technology, Ahmedabad (2010). Ayodh has a post-professional degree in architecture with a specialization in Design Computation from the Massachusetts Institute of Technology, Cambridge, and a B.Arch degree from the Sushant School of Art and Architecture, Gurgaon. He has also studied photography and worked on installation art projects. His abiding interest is to explore the interplay between the computational and physical aspects of design.

Barbara Elisabeth Ascher was born in Germany and trained as an architect and urban planner at Bauhaus University in Weimar and the Oslo School of Architecture with a scholarship from the German National Academic Foundation. She has worked as an architect in award-winning offices in Egypt, Austria and Germany, before she moved to Norway after her graduation in 2006. Her professional experience includes working on exhibition projects and publications such as the “Atlas of Shrinking Cities”, housing schemes, cultural centers and experimental public spaces such as “Geoparken” in Stavanger, as well as large scale urban regeneration projects for the public sector. She joined the Oslo School of Architecture and Design as a PhD research fellow in 2012. Her research is part of the HERA-funded project on “Scarcity and Creativity in the Built Environment” and focuses on the design and process of social housing provisions in the Norwegian welfare state.

Catalina Codruta Dobre is a Romanian architect that started her architecture studies in Bucharest and later on, chose to continue her master degree at the Universite Libre Brussels. In July 2012, she graduated with high honors. Currently she is a PhD candidate and joined the urban design and planning research centre LoUIsE, inside the Universite Libre Brussels. Based on her experience in research and urban design in cities from different cultures -Brussels (BE), Ishinomaki (JP), Bucharest (RO) and Astana (KZ)- she began to research urban water management practices, one of the critical points in urban development worldwide. Her PhD thesis is based on Brussels, as a city with a high potential in integrating new concepts like the *water sensitive approach* in water management. Besides this, Catalina Dobre is a founding member of Risk and Architecture Workshop, a non-profit association that aims to bring together architecture students worldwide under the topic of *How to live with risk?*

Elif Erdine is an architect and researcher. Currently, she is a PhD in Architectural Design Candidate at the Architectural Association (AA), researching on “Generative Processes in Tower Design: Algorithms for the Integration of Tower Subsystems”, under the advisory of George Jeronimidis, Michael Weinstock, and Patrik Schumacher. She is the Programme Director of AA DLAB Visiting School and AA Istanbul Visiting School. She has been working at Zaha Hadid Architects since 2006. She received her B.Arch. degree from Istanbul Technical University in 2003 (High Honors), and M.Arch. degree from the AA Design Research Lab (AA DRL) in 2006 (Project Distinction). Her projects have been printed widely in international and national architecture publications. She is a registered architect in Turkey.

Valentina Garramone is an architect, an assistant professor since March 2010 and the winner of a grant for PhD studies in Interior Architecture at the “Sapienza” University of Rome in November 2010. Her research is titled “Study of Empathy in Architecture: Analysis, Methods, Experiments.” The members of her thesis committee are

Prof. A. Saggio and Prof. D. Scatena. She curated the exhibition “NEW ITEMS: Show, equip, furnish,” held at the “Sapienza” Faculty of Architecture in May 2011. She is currently working on the publication of the exhibition catalogue. Regarding her academic activities as a PhD candidate, she collaborated for the organization of a series of lectures titled “Introspection - Meeting of Architecture”. Moreover, she is working on a book spin-off of the publication “Architettura e Modernità. Dal Bauhaus alla Rivoluzione Informatica” by prof. A. Saggio. She is a member of the Scientific Committee of the web portal ArchiDiAP at the Department of Architecture DiAP of “Sapienza”. She has presented her research work in several national and international workshops and conferences, the last one in November 2012 in Paris. Furthermore, she participated in several international design competitions, aimed at designing an emotionally connected to nature and history proposal, collaborating with the group of Prof. Arch. D. Scatena. She is co-founder of the Archethic Studio.

Maria Matheou is currently conducting her Ph.D. research at the Department of Architecture of the University of Cyprus, where she is an adjunct faculty member in the area of architectural technology. She holds a B.Sc. in Architecture, 2009, and a Diploma of Architect–Engineer, 2010, both degrees from the University of Cyprus. Her Diploma thesis on kinetic and interactive architecture was awarded the Prize for Excellence in Architectural Design 2010. Her research interests are in the areas of structural and architectural design, kinetic architecture, automation systems, design methods and digital tools.

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