PERFORMATIVE ARCHITECTURE AS A GUIDELINE FOR TRANSFORMATION OF THE DEFENCE LINE OF AMSTERDAM

A THESIS SUBMITTED TO
THE GRADUATE SCHOOL OF NATURAL AND APPLIED SCIENCES
OF
MIDDLE EAST TECHNICAL UNIVERSITY

BY

CANAN ALBAYRAK

IN PARTIAL FULFILLMENT OF THE REQUIREMENTS
FOR
THE INTERNATIONAL JOINT DEGREE OF MASTER OF SCIENCE
IN
THE DEPARTMENT OF ARCHITECTURE
IN
COMPUTATIONAL DESIGN AND FABRICATION
TECHNOLOGIES IN ARCHITECTURE
BY
MIDDLE EAST TECHNICAL UNIVERSITY
DELFT UNIVERSITY OF TECHNOLOGY

JANUARY 2011

Approval of the thesis:

PERFORMATIVE ARCHITECTURE AS A GUIDELINE FOR TRANSFORMATION OF THE DEFENCE LINE OF AMSTERDAM

submitted by **CANAN ALBAYRAK** in partial fulfillment of the requirements for the degree of **Master of Science in Architecture Department, Middle East Technical University, and Delft University of Technology** by,

Prof. Dr. Canan Özgen ______________________
Dean, Graduate School of **Natural and Applied Sciences**

Assoc. Prof. Dr. Güven Arif Sargın ______________________
Head of Department, **Architecture**

Prof. Dr. Can Baykan ______________________
Supervisor, **Architecture Dept., METU**

Examining Committee Members:

Assoc. Prof. Dr. Arzu Gönenç Sorguç ______________________
Architecture Dept., METU

Prof. Dr. Can Baykan ______________________
Architecture Dept., METU

Assoc. Prof. Dr. Rudi Stouffs ______________________
Building Technology Dept., TU Delft

Assist. Prof. Dr. Bige Tunçer ______________________
Building Technology Dept., TU Delft

Assist. Prof. Ir. Huib Plomp ______________________
Building Technology Dept., TU Delft

Date: 28/01/2011

I hereby declare that all information in this document has been obtained and presented in accordance with academic rules and ethical conduct. I also declare that, as required by these rules and conduct, I have fully cited and referenced all material and results that are not original to this work.

Name, Last Name: CANAN ALBAYRAK

Signature :

ABSTRACT

PERFORMATIVE ARCHITECTURE AS A GUIDELINE FOR TRANSFORMATION OF THE DEFENCE LINE OF AMSTERDAM

Albayrak, Canan
International Joint M.S. Programme of Computational Design and Fabrication Technologies in Architecture, Department of Architecture
Supervisor: Prof. Dr. Can Baykan

January 2011, 107 pages

The main topic that is researched in this study is: what performative architecture is and its role in the design process and product. In the scope of performative architecture the aim is to focus what a building does rather than what it is and the fact that architecture should have the capability of being adaptable to changing time, conditions and environment. A design problem is taken under consideration and designed from the scope of performative architecture. The design problem is the transformation of the Defence Line around Amsterdam, designing new buildings with the recent technologies as additions to the forts remaining from 1900's. A "performative model", which supports design from the conceptual stage until production of scale prototypes is structured by the author for this specific design problem. This performative model is used as a case study for the research of the role of the computational design tools in the design process and product of performative architecture. In addition to the design process, the role of using computer-aided manufacturing to increase performativity is envisioned and the proceeds of it to the relationship of design is also researched.

Keywords: Performative Architecture, Performance Evaluation, Parametric Modelling, Computational Design Tools, Computer Aided Manufacturing

ÖZ

AMSTERDAM SAVUNMA HATTININ DÖNÜŞTÜRÜLMESİNDE KILAVUZ OLARAK EDİMSEL MİMARLIK

Albayrak, Canan
Mimarlıkta Sayısal Tasarım ve Üretim Teknolojileri Uluslararası Ortak
Yüksek Lisans Programı, Mimarlık EABD
Tez Yöneticisi: Prof. Dr. Can Baykan

Ocak 2011, 107 sayfa

Bu çalışmada öncelikli olarak edimsel mimarlığın ne olduğu, tasarım sürecindeki ve sonucundaki rolü incelenmiştir. Edimsel mimarlık kapsamında binanın ne olduğu değil ne yaptığı üzerine odaklanıp mimarlığın zamana, şartlara ve çevreye adapte olabilmesi özelliğine sahip olması amaçlanmıştır. Bir tasarım sorunu edimsel mimarlık kapsamında ele alınıp, tasarlanmıştır. Tasarım sorunu Amsterdam etrafındaki savunma hattının dönüşümü, 1900lerden kalma kalelere ek olarak günümüz teknolojilerini yansıtan ek binalar tasarlanmasıdır. Tasarımı konsept aşamasından ölçekli prototip oluşturma aşamasına kadar destekleyen bir "edimsel model" bu belirli tasarım problemi için yazar tarafından oluşturuldu. Bu edimsel model sayısal tasarım araçlarının, edimsel mimarlığın tasarım süreci ve sonucundaki rollerini araştırmak için örnek incelemesi olarak kullanılmıştır. Tasarım sürecine ek olarak, üretim aşamasındaki bilgisayar destekli üretim sistemlerinin kullanımının edimselliği arttırmadaki rolü de öngörülüp, tasarım ve üretim ilişkisine getirileri incelenmiştir.

Anahtar Kelimeler: Edimsel Mimarlık, Performans Değerlendirmesi, Parametrik Modelleme, Sayısal Tasarım Araçları, Bilgisayar Destekli Üretim

To my grandfather Kazım Albayrak

ACKNOWLEDGMENTS

I wish to express my sincere gratefulness to my thesis supervisor, Prof. Dr. Can Baykan, for his guidance and contributions throughout this study.

I would also like to thank my jury members Prof. Dr. Can Baykan , Assoc. Prof. Dr. Arzu Gönenç Sorguç, Assoc. Prof. Dr. Rudi Stouffs, Assist. Prof. Dr. Bige Tunçer, and Assist. Prof. Ir. Huib Plomp for their valuable critics, suggestions and comments.

I would also offer sincere thankfulness to my studio tutors, for the graduation project in TU Delft: Ir. Huib Plomp, Dr.ir. Bige Tunçer, and Ir. Sander Mulders for their encouraging criticisms and meaningful guidance.

I wish to express a very special appreciation to Dr.ir. Rudi Stouffs, as the program coordinator, and Dr.ir. Bige Tunçer. Their endless support and mentoring was precious, and to them I owe deep gratitude.

I would like to thank to my family, my parents Neslihan and Ertuğrul Albayrak and my sister Ceren Albayrak, for their support and encouragement in all aspects of life. My gratitude can never be enough.

Finally, I am grateful to Rui Colaço for his continuous support and motivation in all terms.

TABLE OF CONTENTS

LIST OF TABLES

TABLES

LIST OF FIGURES

FIGURES

CHAPTER 1

INTRODUCTION

Development of new instruments and methods redefine the practice and theory of architecture. They contribute to a new understanding of the way buildings are imagined, constructed and experienced. In the digital age, buildings give more difficult messages. Rather than a call for aesthetics, buildings request the understanding of their functionality and its reason (Hagan 2008). Due to the recent developments, technology, cultural theory and the emergence of sustainability as a defining socio-economic issue, there is an increasing interest in performance as a design paradigm (Kolarevic 2005).

Architecture is a material practice. Therefore, it performs its social, cultural and ecological relevance through its material arrangements and structure. How we (re)think architecture is presented through the way we conceptualize these material interventions and the technology that enables their construction. Over a number of decades the progress of Cad/Cam is groundbreaking. The inertia in design thinking in the context of technological progress should lead to a rethinking of architecture and its materialization (Menges and Hensel 2008). These developing technologies together with accelerated global urbanisation and climate change have increased the important role of performative design.

Being performative is usually associated with environmental sustainability and complex digital models analyzing the environmental behaviours of the buildings. This is limiting performance only to a technical interpretation. Structural and environmental performances are, with no doubt, obvious criteria for categorization as performative. However, several other aspects are included: social, cultural, semiotic, basic (shelter) and contrarian ones. Architecture has always performed socially, semantically, basically and ideologically (Hagan 2008). Therefore, what is architectural performance in the digital age? Is it like a performance of a car's engine or like the performance that could be seen on the theatrical stage?” There is no single answer for this question because of the multiplicity of the meanings of the word performance.

performance
(a) the execution of an action; (b) something accomplished
fulfilment of a claim, promise, or request
the action of representing a character in a play; (c) a public presentation or exhibition
(d) the ability to perform; (e) the manner in which a mechanism performs
the manner of reacting a stimuli (Merriam Webster’s dictionary)

Within the scope of this thesis, performative architecture is the shift in the orientation of architectural theory and practice from what the building is to what it does. Therefore, it defines the architectural object, not by how it appears, but rather by its capability of affecting, transforming and doing; in other words, by how it performs. It uses digital generation and modification to search for design alternatives. The generated emergent effects of the architecture (on nature, site, people, climate and time) are analyzed both qualitatively and quantitatively in performative architecture.

Different architects have different approaches to performative architecture; therefore in order to understand these redefinitions in architectural theory, it is necessary to do a re-examination of current design theories and methodologies. For this reason the literature research of this thesis starts with categorization of digital models to form a background (Chapter 2). Secondly, the study specifically based on performative architecture is presented in Chapter 3. This is done by classifying the different approaches towards performative architecture and reviewing the literature related with them; moreover a selection of buildings related with performativity is explored to express the wide span of performative architecture.

A definition is not enough to address performative architecture as a guideline. The criteria for performance assessment and variety of the tools should be studied, because in architectural theory building performance assessment lacked a coherent basis multidisciplinary research until recently. A general theoretical framework for performance assessment is presented in Chapter 4 using a taxonomy of building performance criteria and computational tools.

In consequence of the research summarized above, this thesis deals with performative architecture to address a guideline for generation of design alternatives for a current design problem of Dutch Landscapes. This design problem is the transformation of the Defence Line of Amsterdam. This transformation includes conservation of 41 forts, assigning them new functions and designing additions. In Chapter 5 general information about historic and recent situation of Defence Line is presented along with the author's conceptual ideas about the transformation.

A "performative model", which supports design from conceptual stage until production of scale prototypes, is structured by the author for this specific design problem. This performative model is used as a case study for the research of the role of the computational design tools in the design process and product of performative architecture. In Chapter 6 offers the details of the "performative model". This study specifically focuses on a design problem which involves of the transformation of an element of the cultural heritage; thus the potential of performative design is explored as a digital design methodology to redesign historic artefacts (in this case historic forts, landscape and water elements). In other words it is an experimental work to combine developing technologies with cultural heritage.

CHAPTER 2

CATEGORIZATION OF DIGITAL MODELS

Digital design and its growing impact on design and production practices have resulted in redefinitions of architectural theory such as performative architecture. Therefore, in order to understand, explain, and guide future research and development in performative architecture, it is necessary to do a re-examination of current design theories and methodologies.

Oxman categorizes digital models in the following classes:
1-CAD models
2-Formation Models
3-Generative Models
4-Performance Models

This categorization proposes the requirements for a conceptual framework and theoretical basis of digital design; it reviews a basic background and the recent theories; moreover it defines a generic schema of design characteristics through which the paradigmatic classes of digital design are formulated. The effects of digital techniques on the processes, which are related to basic components of design, are identified. The categorization of the models is based on the explications and relationships between basic components of design which are representation, generation, performance and evaluation (Oxman 2006).

2.1 CAD models

Traditional CAD models are commonly used for controlling graphical representations of digital objects. Firstly, CAD technologies enable data flow between digital and physical objects. By means of using various digital material processing techniques, data can be transferred from digital models to physical objects and vice versa, such as translating psychical objects into digital models. Eventually, Cad models create a seamless integration of virtual and material (Kolarevic 2003).

Secondly, they are also used in evaluative analytical processes, e.g. related with cost estimation, structural behaviour, and environmental performance. They are used to integrate advanced construction level modelling and evaluation software. This is achieved through different stages of design. They help to support collaboration among different design team groups, such as combinations of architects and engineers. However, in this kind of models, generation is not explicit. Generation, representation and evaluation take place consequently, not simultaneously. They are not directly linked, which means any change and modification in digital model requires a re-evaluation. Manipulations and transformations needed to be employed manually for representation and evaluation processes (Oxman 2006).

Various designers have experimented with this approach. For instance the design processes of M.art.A. Museum and Kunsthaus Graz demonstrate the integration of virtual and material, how CAD technologies enable data flow between digital and physical models.

2.1.1 M.art.A. Museum, (Museum for Furniture, Culture and Fine Arts), (2000–2004), Herford, Germany, Gehry Partners, LLP

M.art.A. Museum in Germany is a museum for art, design, fashion and architecture (Figure 1a). The fundamental design strategy involved the incorporation of an existing building with new buildings. Design did not have its genesis in a virtual environment. Gehry manually built a series of physical models to explore the relationships between the existing building and the new buildings as shown in Figure 1b. He focused on the effects of the exterior surface and the interior spaces. Afterwards, these models were three dimensionally digitized using CAD technologies. In Figure 1c the digital models are illustrated. Catia, software was used for precise three-dimensional models. This digital model was used to correct and check the shape with respect to the site and program. Having more accurate data was important to create a precise form fitting the existing building. From these digitized data, more accurate physical models were created in order to explore the shape in more detail (Kloft 2005).

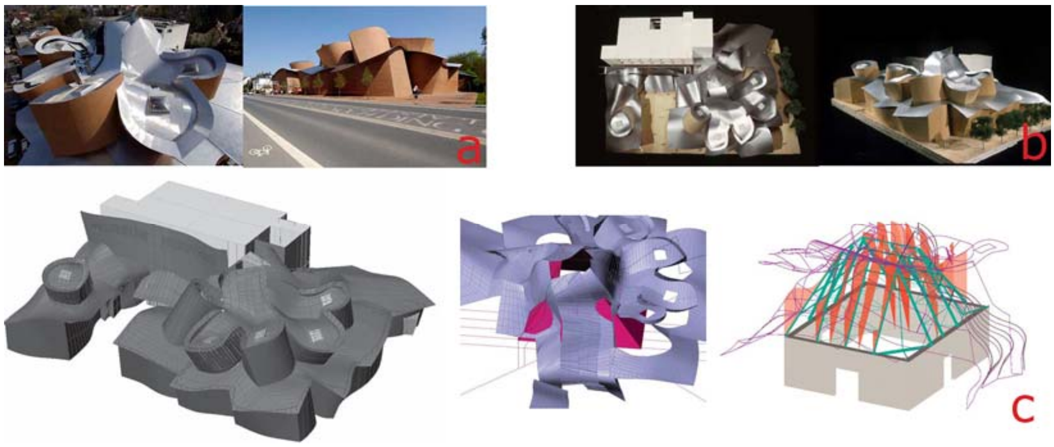


Figure 1: Museum for Furniture, Culture and Fine Arts
a- photos of the building (http://www.arcspace.com/architects/gehry/herford/ Last accessed 10 January 2011)
b- physical models (http://www.arcspace.com/architects/gehry/herford/ Last accessed 10 January 2011)
c- digital models: 3d model for buildings geometry, the architectural non-structural skin, structural system (Kloft, H. (2005). Non-standard structural Design for Non-Standard Architecture. Performative Architecture Beyond Instrumentality. B. Kolarevic and A. M. Malkawi, Spon Press: 135-148)

Works of Frank Gehry are recognized for their contribution to the development of design methodology. He was the first one to introduce Catia software, which is a parametric 3D modelling programme mainly used in aerospace industry, to building design. In his design process, he applied a dual-directional relationship between physical and digital models.

2.1.2 Kunsthaus Graz, Graz, Austria, (2003), Peter Cook and Colin Fournier

Kunsthaus Graz Museum, shown in photos in Figure 2a, was built as part of the European Capital of Culture celebrations in 2003. It is placed in a site containing a productive dialogue between tradition and the avant-garde. Consequently, the Kunsthaus functions as a bridgehead at a point where the past and the future meet.

The conceptual design phase did not rely on computers heavily. The initial design for the competition was created by making a handmade physical model (Figure 2b). This model was three-dimensionally scanned to produce an initial 3D model for design development. The resultant digital model is accomplished as illustrated in Figure 2c; however architects and engineers have decided to generate a new 3D models (Figure 2d) when they considered the form optimization both structurally and in its materials. Rhinoceros 3D modelling software was used for the new model, which closely followed the shape proposed by the physical model without directly containing digital data taken from it. The generation process did not end up with a rigid master geometry. The geometry was open to optimization while still capturing the design intent of the original scheme. Consequently, the structural behaviour was allowed to have influence on the final geometry (Kloft 2005).

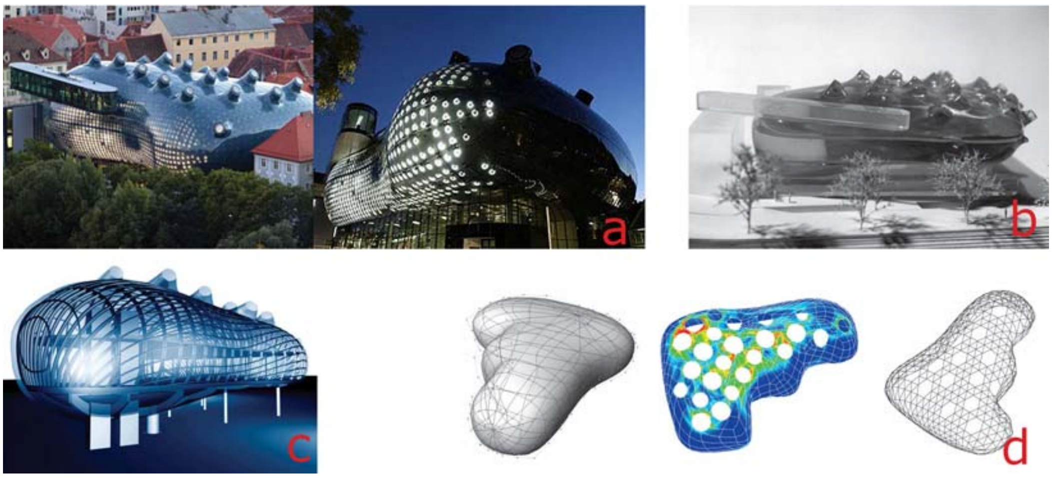


Figure 2: Kunsthaus Graz
a- photos of the building (http://www.arcspace.com/architects/cook/ Last accessed 10 January 2011)
b- handmade physical model (Kloft, H. (2005). Non-standard structural Design for Non-Standard Architecture. Performative Architecture Beyond Instrumentality. B. Kolarevic and A. M. Malkawi, Spon Press: 135-148)
c- early computer rendering from the digital model accomplished by scanning the physical model (Kolarevic, B. (2005). Computing the Performative. Performative Architecture Beyond Instrumentality. B. Kolarevic and A. M. Malkawi, Spon Press: 193-202.)
d- digital models generated by engineers digital design model, the finite element analysis of complexly shaped skin, triangulated structural engineering pattern (Kloft, H. (2005). Non-standard structural Design for Non-Standard Architecture. Performative Architecture Beyond Instrumentality. B. Kolarevic and A. M. Malkawi, Spon Press: 135-148)

2.2 Formation Models

Formation models are different from CAD models in their use in the representation process. Digital formation models are much more than static abstractions of formal representations. The use of dynamic concepts in digital design helps creating a new definition for the role of the representation itself. Advancements in digital design not only transform design representation but the design thinking as well. The concept of form is thus transformed into the concept of formation. In formation models, digital techniques are used in the generation of form and shape. In contrast, CAD models are only used for representation and data flow. Designer operates the non deterministic logic of form generation process along with digital techniques, such as scripting and parametric design. The designer becomes a digital toolmaker for form generation.

Formative models concern design of the topology, which consists in the study of relational structure of objects rather than studying its geometry. Properties of the objects do not change when homeomorphic transformations are applied (Oxman 2006).

Dynaform designed by Bernhard Franken demonstrates how the dynamics of forces produce the motion and particular transformation of from; therefore his project demonstrates an example for the formation models.

2.2.1 Dynaform BMW Pavilion, (2001), Frankfurt, Germany, Bernhard Franken and ABB ArchitektenI7

Dynaform, designed by Bernard Franken, is an example of how the dynamics of forces produce the motion and particular transformations of form. It is an exhibition pavilion of 5500 square meter for the IAA 2001. The photos of pavilion are illustrated in Figure 3a. The focus in this project was on the world premiere of the BMW's new series and its dynamic shape was aiming to be an inspiration coming from the BMW brand essence. The building had to be a good representation of this new series of the brand. Therefore, the space around the vehicles was accelerated so as to suggest the sensation of driving. As a result, the beginning of the design process started with an initial idea only regarding the representation of the BMW's new series without any preconceived formal idea in the beginning of the design process.

Computational tools were used exclusively for form generation. Franken defined virtual forces by means of specific parameters of the site and program. He used Maya software to create animations of these forces. By using the virtual forces of driving a car a three-dimensional matrix was shaped. The adjacent buildings were also translated into virtual force fields, which had additional impact on the shape. The initial shape was deformed and altered by the software, through time based (4D) modelling processes (Figure 3b). After correcting the geometrical errors, this form was used as the 3D master geometry of the project, shown in Figure 3c. In addition, it was used as a dimensional reference during design development and construction (Kolarevic 2003). The structural frames of the building are designed as sections through the master form (Figure 3d).

The entire structure is three-dimensionally modelled (Figure 3e), including all connections such as bolts and all systems such as sanitary, ventilation and lighting. Potential conflicts were finally overcome this way. These files were used for computer controlled manufacturing of the structural frames, which provided high precision in production and minimized manufacturing defects.

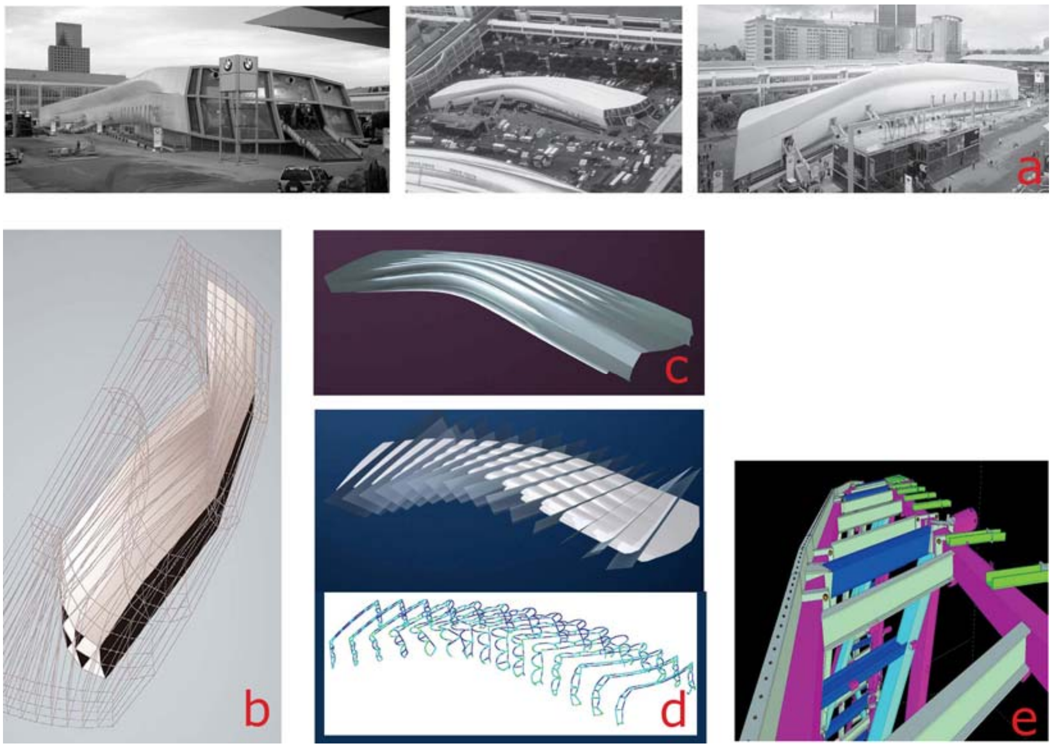


Figure 3: Dynaform BMW Pavilion
a- photos of the pavilion
b- sampling of the form generation process
c-the master geometry
d- sectioning of the master geometry for the structural frames
e-the full detailed 3D model of the building data
(Kloft, H. (2005). Non-standard structural Design for Non-Standard Architecture. Performative Architecture Beyond Instrumentality. B. Kolarevic and A. M. Malkawi, Spon Press: 135-148)

2.3 Generative Models

It was mentioned above how digital formation models can provide topological control of variant form generation. By contrast, in generative design geometrical aspects of structural relationships are defined; however, formal qualities are not defined. This formation prevents explicit formal representation in the conventional sense of visual design thinking.

Generative design models create computational mechanisms for formalized generation processes in contrast to formation models, here the designer interacts with and operates the generative mechanisms. The generative model consists of complex mechanisms that address the emergence of forms derived from generative rules. This pre-formulated generative process results in shapes and forms. The designer may control the selection of desired solutions. Evolutionary processes in the generation of design solutions can aid the designer to achieve a most desirable solution. This is similar to evolutionary processes in nature or in traditional architecture. However, in digital architecture this process is accelerated. Decades are not needed for producing successive generations. Many generations can be produced by the same generative mechanism by using computational tools. For instance, by changing parameters in a script, many different design solutions can be produced by one algorithm. These design solutions can be handled in two ways: the first one, the evolutionary process ends in the design stage. Built object is in a fixed stage, which is the most desirable one chosen from generated design solutions. On the other hand, evolutionary process can still continue, as well, in the built object, such as designing generative building with the ability of adapting itself to the changing conditions, while keeping its defined structural relationships the same (Kolarevic 2003)

There is rich research in the application of generative models, mainly focusing on two approaches; shape grammars (Stiny, 1980 and Knight and Stiny, 2001) and evolutionary models.

2.4 Performance Models

Building performance has been an important issue in design for a long time. In the context of design performance it represents various roles and has many implications. Design for performance is traditionally considered as an evaluative act. Evaluation by simulation is an assessment of the expected performance of the architectural design solution (Kalay 1992).

Y.E. Kalay proposes performance-based design paradigm as opposing process-based paradigms. This approach suggests that quality can only be determined by a multi-criteria, multi-disciplinary performance evaluation, developing a performance-based design methodology. Kalay defines this methodology. He proposes a design process which is an iterative process of exploration, where desired functional properties are defined, forms are proposed and a process of evaluation is used to determine the desirability of the confluence of forms and functions. The process ends when the designer finds a form that fulfils the function or is satisfied by the functionalities afforded by the chosen form (Kalay 1999), this process is illustrated in the Figure 4.

The determinations of Kalay about performance based design inadequate; due to current developments in the theory and technology of digital design which are giving a wider meaning to performance based models. This results in a shift from evaluative models to formative and generative ones. In other words, conventional cyclical process models of ‘generate and test’ are shifting to integrated performance design models. They are used in the process of formation, driven by desired performances and resulting in generation of form. In this approach, performance can be defined as a formation technique or a generative process. The problem conditions, such as site and program, derive the variants parametrically. This category of design models is represented under two sub classes: performance based formation and performance based generation models of design (Oxman 2006).

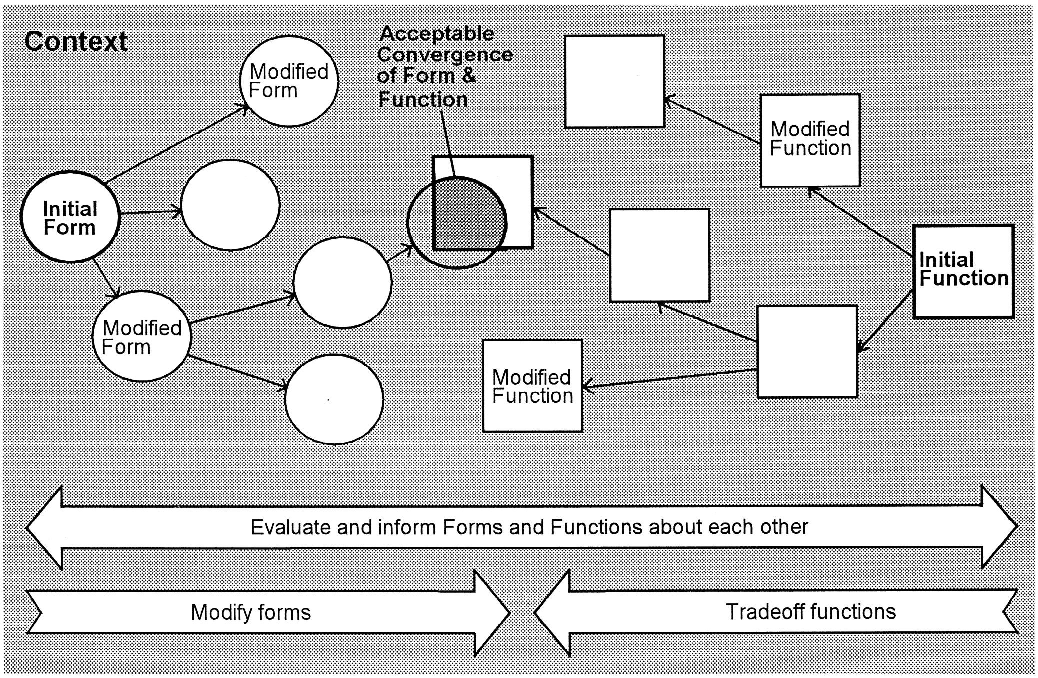


Figure 4: Diagrammatic sumarry of the processes to reach convergence of form and function
(Kalay, Y. E. (1999). "Performance-based design." Automation in Construction 8: 395–409.)

2.4.1 Performance based formation models

> Performance-based formation design can be regarded when digital simulations of external forces are applied in driving a formation process. Design performance may include among the following parameters: environmental performance, financial cost, spatial, social, cultural, ecological and technological perspectives. Performance-based design employs analytical simulation techniques that produce detailed parametric expressions of performance. These in turn can produce formation responses to complex classes of performance requirements. (Oxman,2006)

The design of the City Hall London building demonstrates this approach.

2.4.1.1 City Hall, (1998-2002), London, UK, Foster and Partners

City Hall consists of the headquarters of the Greater London Authority, which comprises the Mayor of London and London Assembly. The main concept was to design a building that expresses the transparency and accessibility of democratic process and demonstrates the potential for a sustainable, virtually non-polluting public building. The main design approach was to generate the architectural form by environmental performances with respect to light, heat, energy, movement and sound; so both the design and design development are integrated in this project.

The shape of the building as seen in photo in Figure 5a, is derived from a geometrically modified sphere, which has a surface area 25 % smaller than that of a cube of identical volume. This was the result of a process of energy performance optimization. Figure 5d illustrates the solar diagram for the building. The surface area exposed to direct sunlight was minimized, and consequently, there was a reduction in solar heat gain and heat loss though the skin of the building (Kolarevic 2005).

In the design of the interior space, the main criterion was the transparency. In order to provide visual connections, a huge spiral (Figure 5b) was located in the building. Its function is to connect all ten floors of the building. Consequently, the building provides the feeling of light and open space. This openness is only obvious to pedestrians after dusk, when its lighting transforms the building into a transparent form.

Acoustics also played a role in the final form of the structure. While designing the outer form, architects noticed that its shape resulted in some acoustic problems. The initial scheme for the assembly hall, which had a very smooth profile, was excessively reverberant. Arup developed a process for visualizing the reflection and absorption of sound by surfaces (Figure 5e). After several iterations, a solution emerged which was considered both architecturally and acoustically acceptable (Kolarevic 2005).

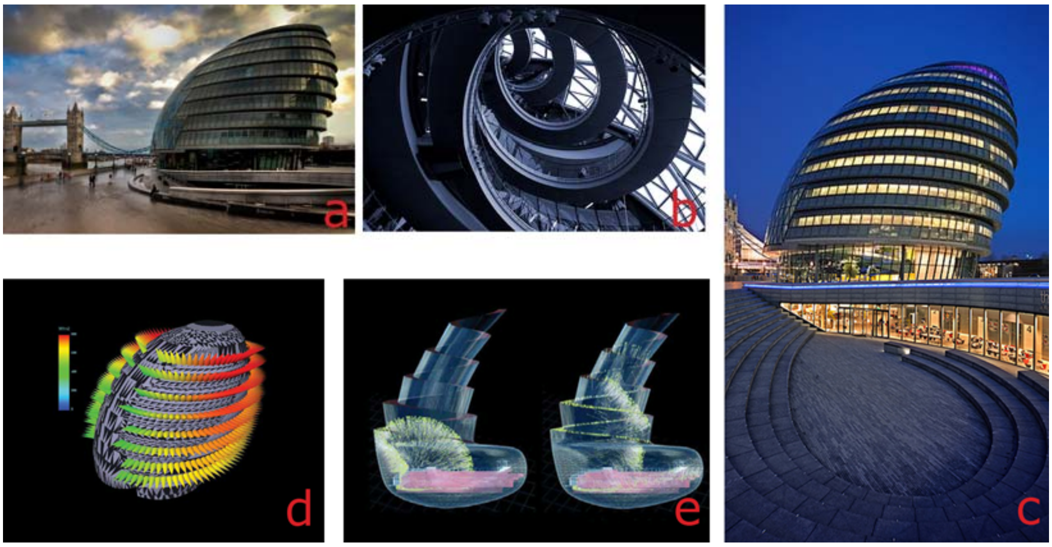


Figure 5: City Hall London
a- photo of the building, geometrically modified form of the building along its historic context of London
b- spiral stair cases located in the building
c- photo of outdoor theatre located at the sunken ground floor
(http://www.greatbuildings.com/buildings/London_City_Hall.html Last accessed 10 January 2011)
d- the solar diagram for the building Kolarevic, B. (2005). Towards the Performative in Architecture. Performative Architecture Beyond Instrumentality. B. Kolarevic and A. M. Malkawi, Spon Press: 203-213)
e- the acoustical analysis of the debating chamber in the City Hall by Arup (Kolarevic, B. (2005). Computing the Performative. Performative Architecture Beyond Instrumentality. B. Kolarevic and A. M. Malkawi, Spon Press: 193-202.)

The form of this building is not only designed according to the thermal and acoustic simulations of the inside space of the building but also the wind. The wind directions formed in its surroundings are also taken into consideration. Pedestrian comfort at the 1,000-seat outdoor theatre (Figure 5c), located at the sunken ground floor, is another important criterion. The effect of the building form on wind directions was simulated by computational fluid dynamics. The building is designed in such a way that it would not direct wind to this open air amphitheatre (Kolarevic 2005).

The building is designed so that its mechanical systems consume fifty percent less energy than a typical air-conditioned office building. The final form of the building derived from multi criteria performance evaluation came under heavy criticism, because at first glance, no one would believe it is a public service building. This unusual, bulbous shape, intended to reduce surface area and improve energy efficiency, has been likened to many things, such as Darth Vader's helmet, a misshapen egg, a woodlouse or a helmet for a motorcyclist or for a futuristic gladiator.

2.4.2 Performance based generation models

> Performance-based generative design is based on generative processes driven by performance and potentially integrated with formation processes. This develops in the direction of the ultimate condition of integrated enabling digital design media. Forces in a given context are fundamental to form-making in digital design. External forces may be considered as environmental forces including structural loads, acoustics, transportation, site, program etc. Information itself is also considered as an external 'force' that can manipulate and activate responsive digital design processes that are transparent to the designer. (Oxman,2006)

In a performance-based generation model, data of performance simulations drive generation and/or formation processes in order to generate the form. The designer can interact with representation, generation and performance, by defining the performance, generation criteria and interacting directly with the digital representation.

Digital design concepts that are associated with performance based generation can be found in Lynn's Port Authority Gateway, through animation techniques he used for building form generation.

2.4.2.1 Port Authority Gateway (1995), New York, U.S.A., Greg Lynn

This was a competition project which involved the design of a protective roof and a lighting scheme for the underside of the bus ramps leading into the Port Authority Bus Terminal, in New York. Greg Lynn used animation software, a medium for finding shape rather than for representation alone. "Animate design", which is a name given by the designer of this process, is defined by motion. Forces are the effects on motion, affecting consequently the form (Greg 1999).

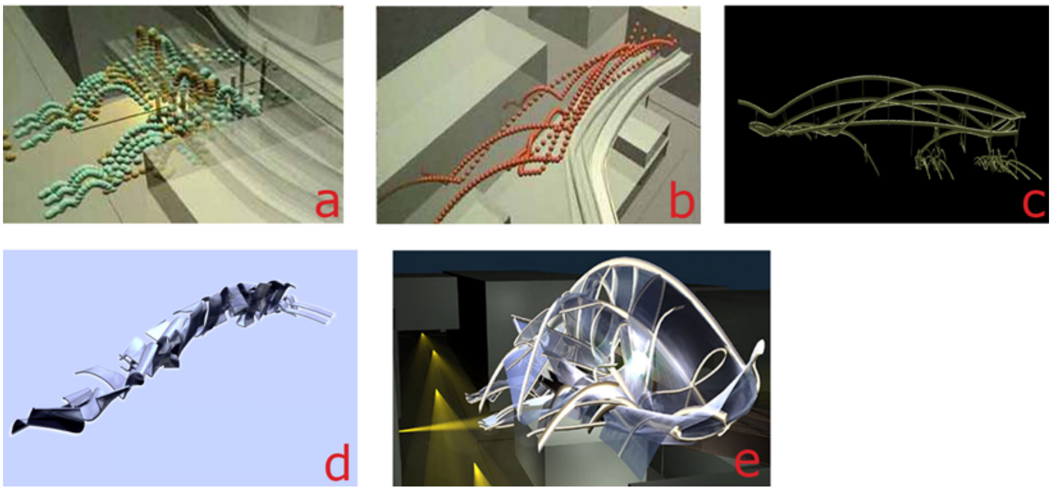


Figure 6: Port Authority Gateway
a- particle study of the Ninth Avenue motion forces
b- view of Lincoln Tunnel approach particle study
c- view of phase portraits as curvilinear vectors
d- view of tensile surfaces
e- view of structural vectors and tensile surfaces
(Greg, L. (1999). Animate Form, Princeton Architectural Press.)

The site was modelled using forces that simulate the movement and flow of pedestrians, cars, and buses across the site. Each of them had differing speeds and intensities of movement along the Avenue, streets, and four elevated bus ramps emerging from below the river. These various forces of movement are defined by forces, establishing a gradient field of attraction across the site. To define a form from these forces, Lynn introduced geometric particles that change their position and shape according to the influence of these forces. These particle studies, which are shown in Figure6a and Figure 6b, are done by using animation techniques. Consequently a series of phase portraits of the cycles of movement over a period of time were captured. These phase portraits are swept with a secondary structure of tubular frames linking the ramps, existing buildings and the Port Authority Bus Terminal (Greg 1999). The view of phase portraits as curvilinear vectors is illustrated in Figure 6c. Eleven tensile surfaces are stretched across these tubes as an enclosure and projection surface as shown in Figure 6d and e.

CHAPTER 3

PERFORMATIVE DESIGN

Performance is one of the most used, even sometimes misused and abused words in architecture. The ways in which performance is understood in architecture are often contradictory and the meanings associated with it are often articulated as opposites (Kolarevic 2005). The descriptions of performative architecture are also numerous. Its paradigmatic appeal lies precisely in the multiplicity of meanings associated with the performative in architecture; however, performance is still one of least defined concepts in architecture. Recent developments in technology, cultural theory and sustainability increased the interest in performance as a design paradigm (Kolarevic 2005). In this expansive span the definitions of performative architecture can be grouped under two categories. The first group is the one which has a narrow point of view towards performative architecture and sees performative architecture as a technical development in digital design and manufacturing processes. This approach sees performative architecture as a technical (structural, thermal, acoustical, etc.) issue. Second group searches for the theory and meaning of performative architecture and their definitions spans multiple realms (financial, spatial, social, cultural, etc.).

Both approaches are operative in many levels beyond just the aesthetic and utilitarian. Determining different performative aspects in a particular project and reconciling conflicting performance goals in a creative and effective way are a key challenge in performative architecture.

3.1 Performative Design as Technical Development

Recent technologies in design enable more complex design models, resulting in transition to a new model of performance based design, which is defined as performative design. The first step of performative architecture is to combine performance ideas with the design from the conceptual stage. Consequently, performative ideas are a shaping and generative factor rather than just being an evaluation criterion. In performative architecture, the digital model should have a special logic, in which performance and form generation must be synchronized. This way, the model can act as a mechanism to generate and modify designs, which also requires closer integration between evaluation and design. It is based on a formation process driven by analytical techniques that can directly modify the geometric model. Performative models create a seamless and integrated process of performance based design (Oxman 2009).

3.1.1 Morpho-Ecological Approach for Design

Achim Menges and Michael Hensel's 'Morpho-Ecological' approach to design is an example for performative architecture. Their approach is from a technical aspect focuses on environmental issues in the generation process; however, their definition has a wider perspective. Hensel and Menges also include utilization and creation of emergent effects and innovative spatial arrangements in their analysis process, which takes place after the generation of design alternatives. Their approach is an alternative understanding of performance. It is an understanding of multi-parameter effectiveness rather than single parameter optimization. This is an approach where the start of the design includes both the logics of how material constructions are made and the way they will interact with environmental conditions and stimuli. This sort of understanding of performative architecture uses computation in a key role in analytical and generative modes and in combination with computer-controlled manufacturing processes. It is the integration of materialisation, production and construction which provides a higher level of design synthesis. It uses computational design and manufacturing technologies to support the evaluation of performative effects. It is the design of morphological complexity and performative capacity without differentiating between form-generation and materialisation processes (Menges and Hensel 2008).

Morpho Ecological approach uses multicriteria performance in a wider span rather than being simple efficiency models. The compound models used in this approach enables the emergence of unanticipated design solutions, which results in the ensuing potential for different modes of habitation. Effectiveness in this design approach is the ability to generate emergent effects which requires creativity, intelligence and instrumentality in devising integral analytical methods.

3.2 Performative Design as a shift of orientation in architecture

> Is there any sustained discussion of the social dimension of architecture, beyond general references to a shiny bendy new world or the change in construction methods that CAM/CAD may bring about? What about global warming and global urbanisation? Engaging with global warming and global urbanisation requires a willingness to understand and work with the materiality of the built environment, to complete the loop from built space to cyberspace to built space, not simply in terms of getting one's digital confection built but in terms of building in ways that are materially responsive to material conditions. (Hagan, 2008)

These words of S. Hagan are an inquiry into a deeper meaning of instruments and methods in architecture. This should not be interpreted as a dedication of performative architecture to a technical interpretation. It is a new understanding of the way buildings are imagined, made and experienced. But this understanding will not result from the development and deployment of new techniques and instruments alone. It is also related with the meanings of these technologies. In this approach, performative architecture is the marriage of virtual reality capable of accurately simulating physical experience, and physical reality capable of a total incorporation of cyberspace (Hagan 2008). In performative architecture the building gives a more difficult message. Rather than look at me, the building requests the understanding of the way it works and why.

To understand the message of performative architecture, an understanding of the marriage of binary oppositions in avant-garde architecture is needed. In the current era, there are several binary oppositions, such as body- mind, nature- culture, digital-material, urban space- cyberspace, virtual space- real space. These binary opposites are dependent on each other rather than standing alone; in addition they do not have any superiority on each other. They are complementary and the reason for the existence of the other. In architecture, the fusion of binary opposites, such as matter and intelligence, is required, and this can be achieved only with developing material technology. Responding to user needs and maximising the conservation of energy is just the beginning. In computational architecture, cyberspace is used to see the incalculable. It consists of sophisticated tools for analysis of the forces of the real world. As computational models embody more information, the more nature-like they will become. The developing technologies of CAD/CAM strengthen the relation between material and digital.

Performative architecture also widens new territories of architecture, such as responding, moving and evolving. Even some visual dynamism can be seen in non-orthogonal forms. In addition, CAD/CAM technologies enable the production of non- linear forms, costing more or less the same as orthogonal ones; however, the dynamism of digital architecture should go beyond this. The building should be designed in such a way that it could interact with site, people, climate and time, and change according to this interaction (Hagan 2008). Therefore, the general outline of performative architecture can be defined as the shift of orientation in architectural theory and practice from what the building is to what it does, defining the first by means of the second. Accordingly the new territories of architecture that unfold with performative architecture are going to categorized under three headings such as: performance as controlling the unbuilt, architecture as performance and movement as performance.

3.2.1 Performance as controlling the unbuilt

> No doubt the building is a technical and aesthetic work, but it is known as such through its workings. The building is its effects and is known mainly through them, through its actions or performances. What is true for people is also true for buildings – character shows itself in what they do. (Leatherbarrow, 2005).

Performative architecture suggests a different kind of understanding of building. It is not a technical preparation, nor a representation of such preparation. It is both a non-technical and non-aesthetic performance. It is the intelligence of designer of which acknowledges a continuous need for readjustments in order to reclaim its own equilibrium and sustain its engagement with unbuilt or previously built eventualities (Leatherbarrow 2005).

During the design stage of a building, unforeseen aspects should be transformed into the foreseen. For instance, one can answer to how the designed object acts with ambient conditions (gravity, wind, sunlight…) or to how it works with and against site (forces of the site). The term bad building is used for the ones which can not respond to unexpected conditions. So, the first step of performative architecture is the capacity to respond to both the foreseen and the unforeseen. Leather Barrow names works of Jean Nouvel as “engagement between what was and what was not constructed and the building’s willingness or need to interact with what is not.” (Leatherbarrow 2005). The design of Louvre Museum for Abu Dhabi is an example for such an understanding.

3.2.1.1 Louvre Museum, (2007-2012), Abu Dhabi, United Arab Emirates, Jean Nouvel

In the Louvre Abu Dhabi, Jean Novels aimed to design a tremendous dome (one hundred and eighty meters in diameter) over a bunch of museum buildings and outdoor spaces, as illustrated in the computer rendering of the aerial view in Figure 7a. He focused on creating this dome as a "seemingly floating dome structure" whose web-patterns would allow the sun to be filtered through. He focused on creating a micro-climate that would give the visitor the feeling of entering a different world. Therefore, the dome was designed as a translucent ceiling which would let a diffuse, magical lighting as illustrated in the computer renderings of interior in Figure 7b. The most crucial point in this design was to create the desired atmosphere, while fulfilling the precise natural lighting requirements of the museum.

Computational tools are used for the design of the perforated dome. The manipulation of light with designed patterns in the interior was achieved by combining architectural design with shading and structural optimization. The desired intricate effect of light patterns was achieved in the final design, after eight months of workshops and computer and physical modelling, along with a great deal of trial and error, and a dose of intuition in order to reach the stage where the roof structure was not visible.

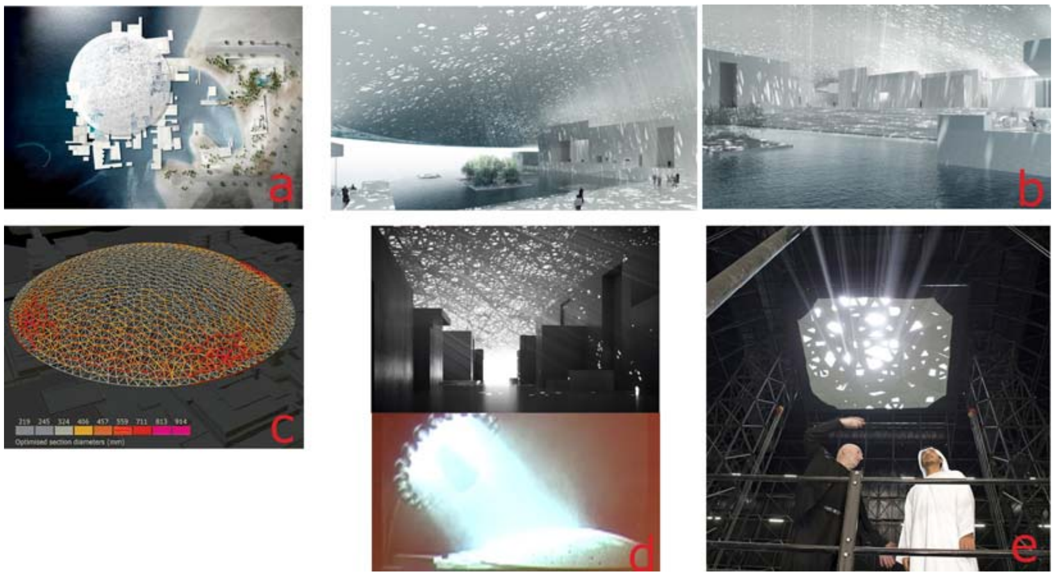


Figure 7: Louvre Museum Abu Dhabi
a- computer rendering of the aerial view
b- computer rendering of the interior
(http://www.dezeen.com/2007/05/07/jean-nouvel-in-abu-dhabi/ Last accessed 10 January 2011)
c- a snapshot from the computer program that is developed by Buro Happold's Smart Solutions Team
d- 1/200 scale physical model
(Al Fisher and Buro Happold's presentation: The Louvre
http://www.metudelft.net/comparch/video%20sgop.html Last accessed 10 January 2011)
e-Sheikh Sultan and Jean Nouvel under the 1/1 scale prototype
(http://www.e-architect.co.uk/dubai/louvre_abu_dhabi.htm Last accessed 10 January 2011)

Buro Happold's Smart Solutions Team developed a computer modelling program to design a structural form that optimised the roof's structural efficiency a snapshot from the program is shown in Figure 7c. The initial generation of the structural geometry is based on a unit. After much iteration, the design of the dome was achieved so it would fit the structural requirements, which also provided the differentiated and desired lighting conditions for different spaces. The web patterns in the dome were designed so that translucency amounts were differentiated for different functions, such as museum galleries, corridor spaces or outdoor spaces.

A number of physical models of the dome were created from 1/200 scale (Figure 7d) to 1/1 scale. The real scale prototype is a 6m x 6m replica of a section of the roof, which has been built close to the site and used to verify the roof pattern and complex light paths. This huge model has enabled the design team to assess the effects of different layers of cladding and track the shafts of light as the sun moves. Figure 7e illustrates Sheikh Sultan and Jean Nouvel this 1/1 scale prototype.

Jean Novel claims to put nature to work in his architecture. The beauty and richness of the surfaces of his work do not result from the design or construction technique alone, but also from ambient lighting. Jean Novel sees the environment as internal to his buildings.

3.2.2 Architecture as performance

Another point of view in performative architecture is thinking of architectural performance as an art performance; like what might be seen on theatrical stage instead of accepting it as the performance of a car engine. However, if compared to dance and music, the building seems inert and inactive, and when compared to film architecture, it seems positively motionless. So what does the architectural work do as performance?

The house, theatre and museum just sit where they have been built. They wait for a visitor's arrival and experience as if they could only be enlivened by a visitor's existence. But is the building only what we make of it? There is something more to it. If it was only the consequence of an inhabitant's intentions, it would be impossible to understand why buildings depress and delight us.

To understand architectural performance, an analogy to musical or theatrical improvisation can be useful. The stops and positions of a building's elements describe the guidelines of a performance; they enable spontaneous qualifications that adapt the ensemble to particular conditions as they vary over time. Then, building performance comes alive with architectural drama. So, it can be concluded that first step of architectural performance is to outline strategies of adjustment (Leatherbarrow 2005).

The urban sculpture in Doetinchem named D-Tower and the skin of the museum building Kunsthaus Graz can be literally seen as architectural performance pieces.

3.2.2.1 D-Tower, (1998–2003), Doetinchem, the Netherlands, NOX/ Lars Spuybroek

The D-tower consists of three parts: a website which is accessible to anyone; a questionnaire accessible to a hundred different people that have a special password each year, and a tower. The tower is a 12 meter high structure standing on 4 columns as shown in the photo in Figure 8a. The complex surface was made of epoxy panels (Figure 8b) which are shaped by a computer generated moulding technique (CNC milled styrofoam).

The tower changes its colour (Figure 8c) according to the emotional state of the city's residents which is computed from the responses of the city's habitants to the questionnaire. Daily emotions such as hate, love, happiness and fear are mapped into four colours; green, red, blue and yellow. By looking at the tower, one can see the dominant emotion of the city. The tower also acts as a capsule in which the city inhabitants could leave love letters, flowers, etc. This is a project where the intensive (feelings, qualia) and the extensive (space, quantities) exchange roles, where human action, colour, money, value and feelings all become networked entities (Kolarevic 2005).

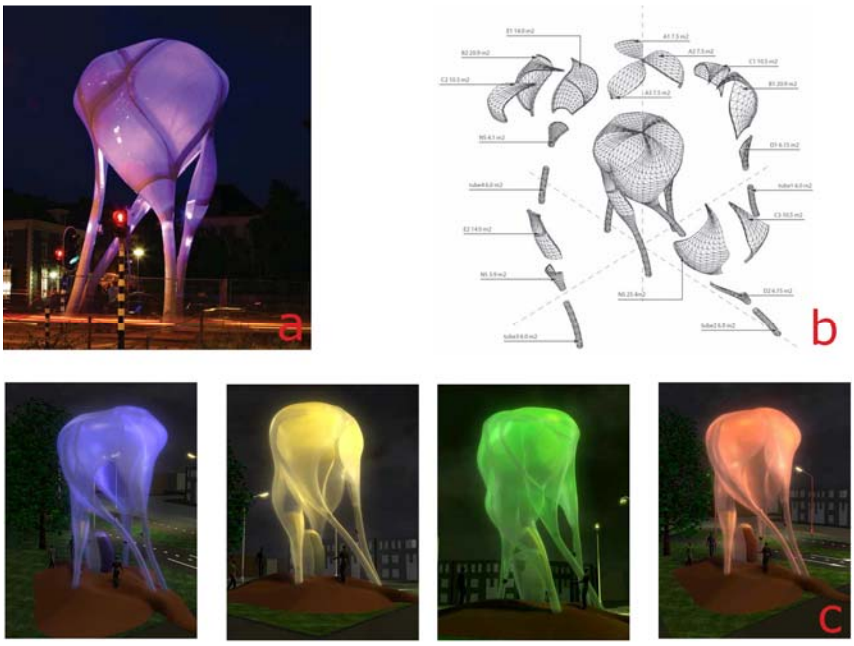


Figure 8: D-Tower
a- photo of the tower
b- complex surface of the tower made of epoxy panels
c- color changes of the tower
(Kolarevic, B. (2005). Towards the Performative in Architecture. Performative Architecture Beyond Instrumentality. B. Kolarevic and A. M. Malkawi, Spon Press: 203-213.)

3.2.2.2 Kunsthaus Graz, Graz, Austria, (2003), Peter Cook and Colin Fournier

In Kunsthaus Graz, by Peter Cook and Colin Fournier, shown in Figure 9, dynamic display of light in the form of changing light patterns is a primary performative dimension. The eastern façade acts as an alterable, performative membrane to transmit internal process of art institution to public. The attempt is to create an experimental laboratory for the development of urban communication strategy, synchronized with the architecture and its users.

This is achieved with an additional architectural concept called BIX, a matrix of 930 fluorescent lamps integrated into the main eastern Plexiglas façade of the Kunsthaus. The brightness of the lamps can individually be adjusted, with an infinite variability at speed of 20 frames per second. Images, films and animations can be displayed on the skin using these lamps. The original architectural concept of the skin was radically redefined. Kunsthaus transforms its façade into a low resolution computer display, a "communicative display skin", fusing architecture, technology and information (Edler 2005).

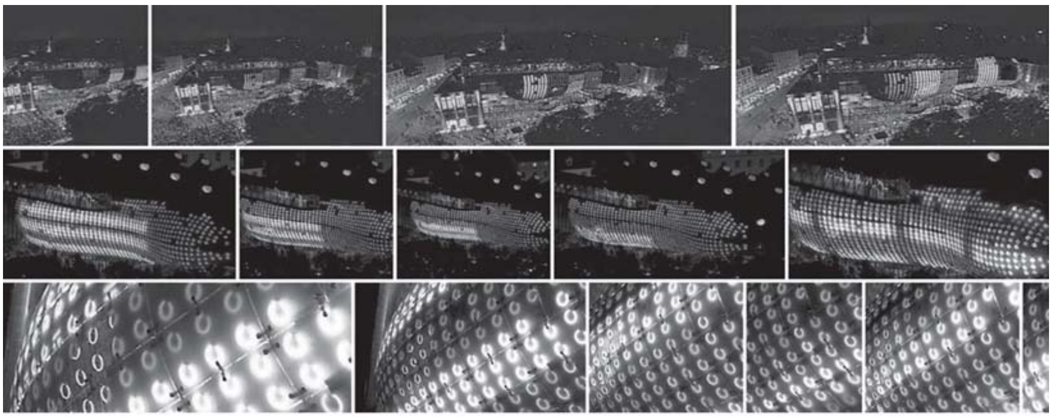


Figure 9: BIX-Performative skin of Kunsthaus
BIX as an artistic communication laboratory: video stills from the live audio visual performances by artists John de Kron (Berlin) and Carsten Nicolai (Berlin) for the inauguration of the BIX installation in September 2003. (Edler, J. (2005). Communicative Display Skin For Buildings: BIX At The Kunsthaus Graz. Performative Architecture Beyond Instrumentality. B. Kolarevic and A. M. Malkawi, Spon Press: 149-160.)

3.2.3 Movement as Performance

It is often the movement of people around and through a building that gives architecture its performative capacity. It is the experience of the building's materiality and spatial presence. In some recent projects, performativity is in the kinetic effects of the architecture. Rather than the subject that moves, the object itself creates an architecture of spectacle and architecture of performance.

Because of the acceleration caused by the advent of computers, these concepts are no longer just a dream. Due to developing digital technologies, the simulation capacities of cyberspace are increasing. In the future, virtual reality will be capable of exactly simulating physical experience, and physical reality will be capable of a total incorporation of cyberspace. This will result in a future we can only imagine now: architecture and cities that swell and shrink, extend and circle, in direct response to what is going on in the collective mind of cyberspace.
Exploration of new formal territories preoccupies the works of contemporary digital avant-garde on its surface; the building skin or building unit, and not usually in the structure. On the other hand, works of the Tristan d'Estree Sterk's office explore kinetic and responsive structure.

3.2.3.1 Filamentosa: Ultra-Lightweight Skyscraper, (2004-now), Chicago Illinois, U.S.A., Orambra

Filamentosa: the Ultra-Lightweight Skyscraper in Chicago Illinois, U.S.A. (2004-now) by Orambra (Office for Robotic Architectural Media& Bureau for Responsive Architecture) is a new type of ultra-lightweight skyscraper. In Figure 10a collage of the Chicago silhouette with computer rendering of the Filamentosa is shown. It is a skyscraper that is responsive to nature. Its structural frame and living skin adapt to reduce the amount of material and energy required to live within, construct and maintain.

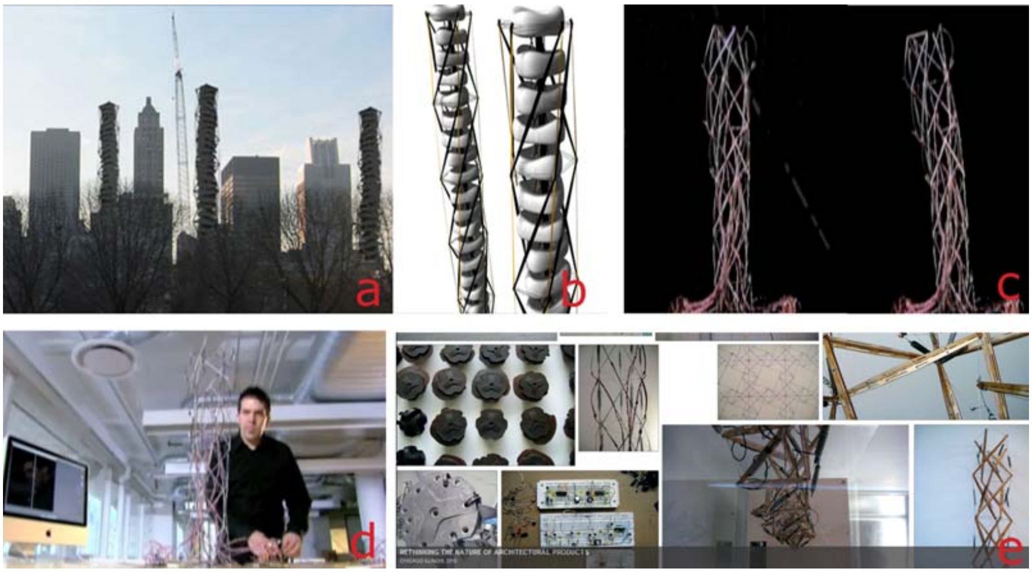


Figure 10: Filamentosa
a- collage of the Chicago silhouette with computer rendering of the Filamentosa
b- computer renderings of the Filamentosa illustrating smart systems and building frame
c- prototype of the adaptable structure
d- Tristan d'Estree Sterk working with the physical prototype
e-different components of the physical prototype (http://www.orambra.com/ Last accessed 10 January 2011)

Tristan d'Estree Sterk started the design with the objective of creating a building which was taller, lighter and, more importantly, more sustainable and cheaper. For this reason, he desired more for his building than being a series of smart systems attached to a dumb building frame (Figure 10b). He designed an intelligent building with the ability of readjusting itself to changing stimuli. For instance, in extreme cases such as storm and earthquake, the building could readjust its structural balance. In addition, it could even adjust its shape to improve shading in summer or day lighting in winter.

Tristan d'Estree Sterk ended up designing a skyscraper consisting of intelligent frames, skins and systems. He designed a generative system with defined structural relationships, which had the ability to evolve according to changing environmental conditions; Figure 10c illustrates the adaptable structural system that responds to environment.

In his prototype, he managed to build a stable structural system, consisting of struts and cables of adjustable tension. He used sensors to detect displacement due to an uneven distribution of forces in a case of external loadings of various causes, such as wind, storm and earthquake. These sensors send this information to a centralized computer which can adjust the tension in the cables and turn the model into upright position. Therefore, the building can stand up by itself (Orambra 2010). Figure 10d shows Tristan d'Estree Sterk working with the physical prototype composed of the sensors, centralized computer and the adaptable structure and Figure 10e shows these different components of the physical prototype.

In nature, it is possible to observe many examples of flexible structure, such as the behaviour of trees bending and responding to the wind to prevent breaking. If buildings are designed to have more flexibility, the damage due to natural disasters, such as hurricanes and earthquakes could be lowered. The prototype of Sterk proves that this can be achievable in the near future; besides he manages to build this system with using less material than the conventional skyscrapers.

3.3 Definition of performative architecture

After reviewing the papers and the example buildings, it can be concluded that performative architecture consists of a new model of performance based design with a wider span of realms. Therefore, it is necessary to define of performative architecture and performance criteria that are used below.

Performative architecture is the shift of orientation in architectural theory and practice from what the building is to what it does. It defines the architectural object, not by how it appears, but rather by its capability of affecting, transforming and doing; in other words, by how it performs.

The understanding of how a building performs is a more difficult message than merely aesthetic messages. Therefore, instead of appealing to the aesthetics, the buildings request the understanding of their functionality and its reason. (How do the buildings work? For which reason?) They can be: structural, environmental, economic, ecological, spatial, and technological. The aim of performative architecture is to prevent clashing ideas between these reasons by optimization methods.

Optimization should not be limited to a technical interpretation. If performative architecture is limited to simulation and evaluation, then there will not be any difference between performative architecture and engineering. Performative architecture should have the capability to generate.

It uses digital generation and modification to search for alternatives for a design. The generated emergent effects of the architecture (on nature, site, people, climate and time) are being analyzed both qualitatively and quantitatively in performative architecture. As a paradigm for architecture, performance describes the processes through which culture, technology and architecture become interrelated to form a complex field of relations which produce new and powerful effects. Instead of describing the architectural object, performative architecture focuses on how the architectural object performs by producing new effects that transform culture; therefore, the qualitative analysis of the alternatives should also be done taking into account the ability to produce powerful effects.

CHAPTER 4

PERFORMANCE ASSESSMENT

Performative architecture is defined in the previous Chapter as an approach which consists of search for alternatives, quantitative and qualitative analysis, and emergent effects. Such a design model with generative capabilities enables generation of large number of instances. Taxonomy of these instances is needed for control, categorization and selection of a large set of generated instances. In performative architecture, a categorization and selection depending on performance is an obvious criterion for taxonomy of generated instances.

The study for constituting taxonomy of building performance criteria is done in four steps. After defining performative architecture, taxonomy of performance criteria is needed for further research in performative architecture. After defining performative architecture, a taxonomy of performance criteria is needed for further research in performative architecture. This study is done in four steps. First step is literature search related with the categorizations of basic building performance evaluation levels. Second step is to combine the literature search with case study examples by reviewing the projects that are related with digital models according to building performance assessment levels. As a conclusion of these two studies a categorization of architectural performances can be structured. The final step is the inquiry of the computational tools related with performance.

4.1 Building performance evaluation levels

Building performance assessment is multidisciplinary and it has generated applied research that lacked a coherent theoretical framework until recently. Three categories of criteria for building performance were defined centuries ago by Roman Architect Vitruvius. These were firmness, commodity and delight. This historic approach to setting priorities on building performance has been transformed into three levels of priority.

They are listed below:

1-health, safety and security performance

2-functional, efficiency performance

3-psychological, social, cultural and aesthetic performance (Preiser and Vischer 2005).

Level 1 pertains to building codes and life safety standards projects must comply with. Level 2 refers to the state of the art knowledge about building types and systems. Level 3 pertains to research based design guidelines, which are less codified, but nevertheless equally important for designers.

Each category of objectives includes sub-goals. At the first level, one sub-goal might be safety; at the second level, sub-goals can be functionality, affective and efficient work process, adequate space, and the adjacencies of functionality related areas; and at the third level, sub-goals include privacy, sensory stimulation and aesthetic appeal. For a number of sub-goals, performance levels interact. They may also conflict with each other, requiring resolution in order to be effective.

This framework relates elements of buildings and settings to building users and their needs and expectations. While applying this approach, the physical environment is considered as more than just a building or shell because of the focus on settings and spaces for particular activities. Performance variables can be seen in terms of ascending hierarchies from small to large scale or from lower to higher levels of abstraction. For each setting and user group, performance levels for sensory environments and specific quality performance criteria need to be established, for example, the acoustic, luminous, olfactory, visual, tactile, thermal and gravitational criteria (Preiser and Vischer 2005).

In summary, these levels of building performance create the basic framework which is commonly accepted and used in Building Performance Evaluation (BPE). BPE systematically relates buildings and settings to users and their environmental needs (Preiser and Vischer 2005).

Besides these three, there are also differences between the quantitative and qualitative aspects of building performance and their respective performance measures. Many aspects of building performance are quantifiable, such as lighting, acoustics, temperature, humidity, durability of materials, amount and distribution of square footage etc. Qualitative aspects of building performance pertain to ambiance of space; in other words: the appeal to the sensory modes of touching, hearing, and smelling, kinaesthetic and visual perception, including colour. The qualitative aspects of the building, such as aesthetic beauty or visual compatibility with a building's surroundings, can be the subject of consensus among the public. The recent research on computational aesthetics indicate that the rules of aesthetics and beauty might also be formulated such that they can be used in computational methods.

4.2 Review of projects that are related with digital models

Building performance evaluation levels are an engineering point of view; therefore, in order to see its counterparts in design, the buildings discussed in the previous chapter are reviewed according to BPE levels. The review is done for three stages of each building such as: project goals, process to achieve the goals, and shortcomings. The performance criteria for each stage are listed as below.

M.art.A. Museum

Project goals: aesthetic appeal, become a landmark as a tourist attraction like the Bilbao museum;

Process to achieve the goals: aid from CAD to enable data flow between digital and physical models;

Shortcomings: environmental, structural and economic optimization, the building is expensive to construct and maintain.

Kunsthaus Graz

Project goals: urban communication;

Process to achieve the goals: transmit the internal process of the art institution to public, structural optimization, prevent high costs.

Dynaform BMW Pavilion

Project goals: communicating the message of the BMW Company, launching BMW's new series;

Process to achieve the goals: virtual forces by means of specific parameters of the site (flows of site, adjacent buildings) and program, standardization of structure to achieve structural optimization, mass customization.

City Hall

Project goals: to give social message of transparency and accessibility of democratic process and to represent an image of a sustainable and non-polluting city;

Process to achieve the goals: optimization of energy performance, optimization of the form of the assembly hall to meet acoustic requirements, optimization of the form according to wind patterns at the pedestrian level;

Shortcomings: mass customization, innovative aesthetic form.

Port Authority Gateway

Project goals: integration with site;

Process to achieve the goals: simulation of site flows such as pedestrian, car, or bus, to establish a gradient field of attraction across the site.

Louvre Museum

Project goals: appearance, create desired atmosphere with light patterns;

Process to achieve the goals: simultaneous lighting simulations, structural and architectural design.

D-Tower

Project goals: urban communication;

Process to achieve the goals: adjustable colour that can change according to the emotions of the city.

Filamentosa: Ultra-Lightweight Skyscraper

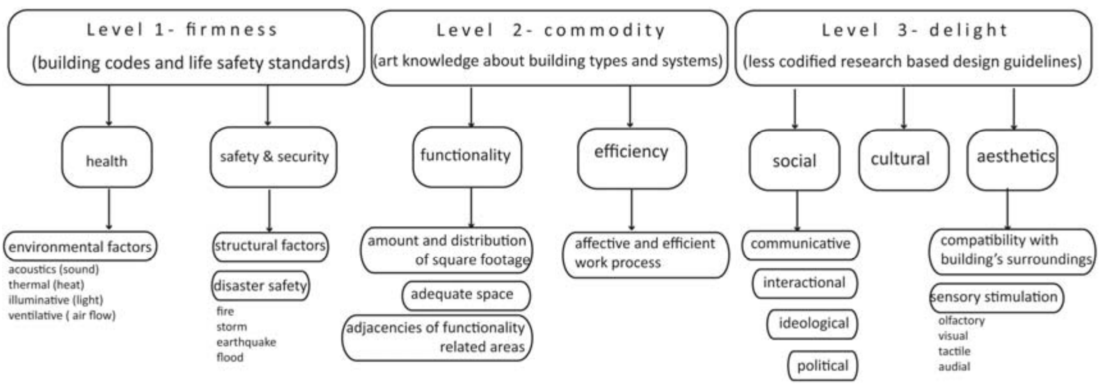
Project goals: adjustability according to changing environmental conditions, reduce the amount of material and energy required to construct, live and maintain.

Process to achieve the goals: prototypes with an adjustable system which is composed of struts, tension cables, sensors, and a computer.

4.3 Categorization of architectural performances

As seen in above performance criteria for each building differ depending on many reasons, such as functions, site and etc. Architectural performances can be divided into three, as illustrated in Table 1, similarly to building performance assessment categorization. However, the only difference is that architectural performances do not flow the hierarchic structure of BPE levels. What causes architecture to be classified as performative is the correct selection of performances and relationships. Either environmental performances can clash with economic performances, or aesthetic ones can clash with social ones. Defining the adequate geometrical relationships to prevent these conflicts is the main categorization for performative architecture.

Table 1: categorization of architectural performances



4.4 Computational Tools Related with Performance

The wide range of digital tools is opening up new territories for conceptual, formal and tectonic exploration, articulating an architectural morphology focussed on the emergent and adaptive properties of form. The conventional design and drawing understandings are shifting to digitally generated forms, which are calculated by chosen generative computational method. Digital generative techniques bring the shift of emphasis from making of form to the finding of form (Kolarevic 2003).

In generative system of formal production, the designer controls the behaviour over time, and selects forms that emerge from its operation. This time based modelling technique is used as an invisible dynamic process that is shaping the physical context of architecture, which is driven by socio-economic and cultural forces. Greg Lynn uses these words: “the context of design becomes active abstract space that directs form within a current of forces that can be stored as information in shape of the form” (Greg 1999).

These generative techniques used for representation and formal appearance in avant-garde contemporary architecture should not be limited only to these issues. If in the conceptualizing process the dynamic forces that affect architecture are visualized by also introducing the dimension of time, then we can begin to qualify their effects. It also opens the potentials to qualify them in certain technical aspects. There is a range of digital analytical tools that can help designers to assess performance aspects to their projects.

4.4.1 Analytical

The research in digital performance analysis and simulation tools dates back more than three decades. Many of concepts and techniques were pioneered in late 1960’s. The first use of computer graphics for building assessment was in 1966, and the first building performance assessment package appeared in 1972. The 1970’s, the architects were enabled to obtain highly accurate predictions of building performances. For instance: heat loss, daylight analysis, shadow predictions and acoustic performance (Cross and Maver 1973).

Algorithms were used to develop computational systems to assist designers in their activities by providing either guidance through advice or optimization. The contribution of knowledge based systems and complex problem solving methods has been significant in initiating the use of computational techniques to solve performance based decision making problems.

In early 1970's, PACE (Package for Architectural Computer Evaluation) was developed at ABACUS (Architecture and Building Aids Computer Unit Strathclyde). This program written in FORTRAN would instruct the designer on how to change geometrical or constructional information, as for instance, of how to modify the design concept to improve performance and then submit the modified design for reappraisal. This repetitive designer tool interaction would result in optimum design solution (Kolarevic 2005).

In the end of 1980's, with the first parametric CAD tools, another new concept and mathematical construct has introduced: parametric modelling. To define shapes, parametric modelling uses geometric constraints, dimensional relationships and data. When the designer modifies values within parametric expressions, they automatically propagate through the model. In other words, associative geometry enables dynamic manipulation of user defined dependency relationships by means of graphical representation (Shea and Aishb 2005).

Both conceptually and technologically, much of these early works in digital performance based design was far ahead of its time. These works accelerated the research done in this field so that today the performance ideas are coming to the front of architectural discourse. They formed the foundation of the digital quantitative and qualitative performance based simulation techniques.

As computer power becomes less expensive, the use of Computational fluid dynamics (CFD**)** began to spread. CFD uses numerical methods and algorithms to solve and analyze problems that involve fluid flows. CFD provides an approach to solve the conservation equations for mass, momentum and thermal energy. In relation to buildings, CFD has been used in many applications such as: natural ventilation design, building material emissions for indoor air quality assessment, complex flows of fire and smoke in the buildings, noise prediction in relation to the ducting. Other applications are more complex and may integrate alternative building simulation models (Malkawi 2005). Some examples from different applications are illustrated in Figure 11.

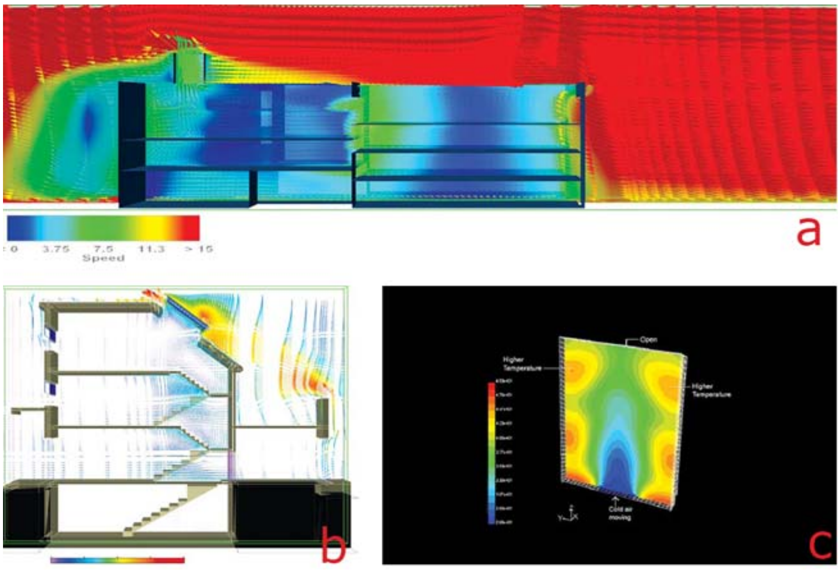


Figure 11: Computational fluid dynamics simulations
a- CFD simulation and analysis for the PennDesign building during the schematic design phase
b- CFD simulation and analysis of Civic House, University of Pennsylvania, for renovation and retrofitting purposes
c- Study of double-skin facade (New York Police Station) using CFD simulation.
(Malkawi, A. M. (2005). Performance Simulation: Research and Tools. Performative Architecture Beyond Instrumentality. B. Kolarevic and A. M. Malkawi, Spon Press: 86-95.)

The technology of CFD is still under development. Studies illustrate the importance of validation to ensure the accuracy of the CFD results. Besides, CFD remains an expert tool. Its use requires knowledge of fluid mechanics to set up simulation model, populate its boundary conditions and interpret the results.

Another method that analytical computational models are based on is the finite elements methods (FEM). In this method, the geometrical model is divided into small pieces and connected by mesh elements. FEM is used for the accurate analyses of structural, energy and fluid dynamics of buildings of any formal complexity. In Figure 12a, snapshots from the structural analysis program iDiana, which is a software based on finite element method are illustrated. It provides improved graphical output and visualization techniques. Some graphical outputs are illustrated in Figure 12b.

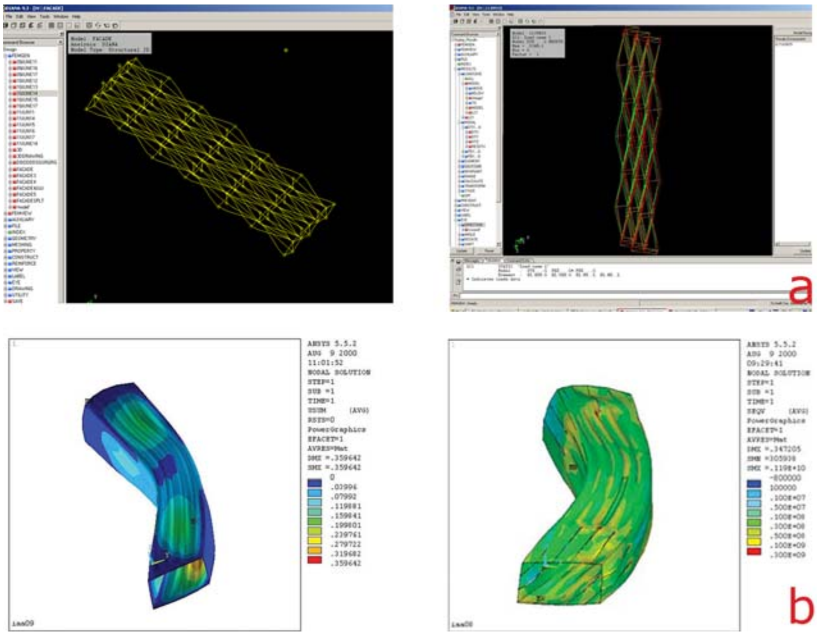


Figure 12: Finite element analysis

a- Snapshots from the structural analysis program iDiana, which is a software based on finite elements method (Images are from a previous design of the author)

b- Finite-element analysis stress analyses of the Dynaform BMW Pavilion , by Bollinger+ Grohman Consulting Engineers (Kolarevic, B. (2005). Computing the Performative. Performative Architecture Beyond Instrumentality. B. Kolarevic and A. M. Malkawi, Spon Press: 193-202.)

Generally, FEM is the method of choice in all types of analysis in structural mechanics. For example, for solving for deformation and stresses in solid bodies or dynamics of structures. Conversely, CFD tends to use fused deposition modelling or other methods like finite volume method. CFD problems usually require discretization of the problem into a large number of cells/grid points (millions and more).

Project Zed (1995), London by Future Systems, is part of a wider research initiative to explore the feasibility of zero emissions developments. The design of this mixed-use building, which is illustrated in Figure 13a, exploits the wind as a free energy source. Naturally lit and ventilated spaces together with the building's form and design which harness the wind and sun as free energy sources, this building is almost entirely self sufficient in terms of energy over a typical year.

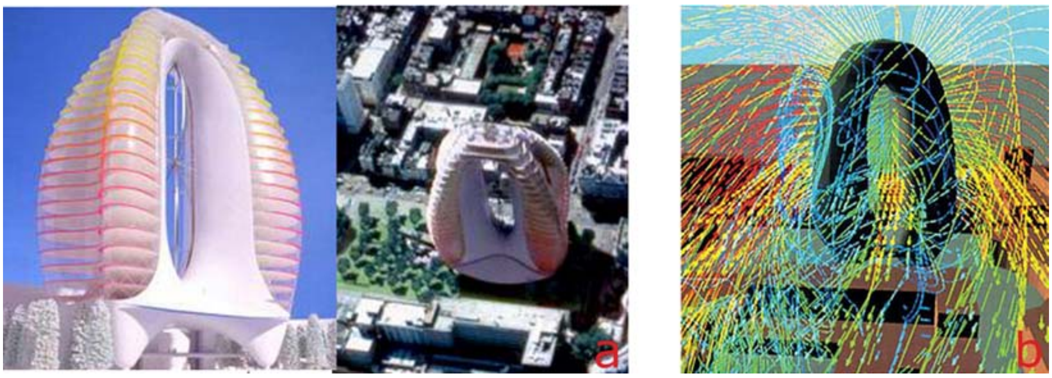


Figure 13: Project ZED
a- Images from the design
(http://www.future-systems.com/architecture/architecture_19.html# Lasy accessed 10 January 2011)
b- The CFD analysis of wind flows for Project ZED by Arup (Kolarevic, B. (2005). Computing the Performative. Performative Architecture Beyond Instrumentality. B. Kolarevic and A. M. Malkawi, Spon Press: 193-202.)

The building is formed around a central opening that acts as a wind concentrator, with the wind turbines generating a significant percentage of free energy. Photo-voltaic panels create another free energy source and are integrated into the external shading fins. These fin-like louvers are brightly coloured on the underside to give an animated view of the building's form from the pedestrian's vantage point (Future Systems 2011).

CFD used for the analysis during design as shown in Figure 13b. The curved form of the façade was designed to minimize the impact of wind at the building's perimeter and to direct it towards the turbine at the centre. The CFD analysis was essential in improving the aerodynamic performance of the building envelope.

Peter Cook and Colin Fornier's competition winning design for Kunsthaus Graz was altered by the structural engineers in Bollinger + Grohmann. After digital structural analysis, they improved the structural performance with minor adjustments to the overall form (Figure 2d). They extracted the isoperimetric curves for the envelope definition from the structural analysis instead of the underlying NURBS geometry (Kloft 2005). This is similar to what Arup did for the design of the main chamber of London City Hall to increase acoustical performance (Figure 5e).

Most of the commercially available building performance simulation tools (structural, thermal, lighting, and acoustical or airflow) require high resolution, detailed modelling;

consequently, they are rarely used in conceptual design development. Another problem with evaluation tools is that certain performative aspects can be analyzed in one software while other performance analysis must be done in some other environment. This results in redundant remodelling; therefore, integration of a range of low resolution performance simulation tools is a necessary step for a more efficient use of computational design.

Another shortcoming of the commercially available building performance simulation tools is the communication between simulation models and the architectural design representation. For instance, when the building form is articulated, analytical computation should also dynamically alter itself, like how animation software is used in contemporary architecture. Thus, performance assessment has to be generative not only evaluative.

4.4.2 Generative

Performance based generative design is giving priority to form generation rather than performance evaluation; therefore, performance is considered as a shaping factor rather than evaluative criteria. Performance simulations directly inform the generative processes in such a way that external forces can potentially be applied in form generating process. The emphasis shifts to formal responsiveness to the data input of performative simulations. Such simulations represent a simulation force, which may include structural, environmental, cost, spatial, and ecological and technological perspectives.

In addition to computer's more conventional roles as drafts person, visualizor, data checker and performance analyst, by generative methods it becomes a design generator. This can be achieved by a defined set of production or grammar rules. Generative systems are aimed to provide design assistance and extend designers' current capabilities by sparking new design ideas and solving difficult tasks.

Ulrich Fleming and Ardeshir Mahdavi developed SEMPER in 1993, which is an important progress to assign generative capabilities to evaluation tool. SEMPER is a bidirectional multi domain building design support. They presented a computational environment for coupling of form generation and performance evaluation in conceptual design stage. SEMPER provides a seamless and dynamic communication between the simulation models and architectural design representation. It uses object-oriented space-based design environment using the structural homology of various domain representations. Therefore, it allows the designer to make desired changes in performance variables and observe the corresponding changes in design variables and also vice versa. Alternatively, the designer can change the design variables and observe the resulting changes in other design variables when one or more relevant performance variables are constrained. This is achievable by means of the preference based performance to design mapping technology used in the programme (Mahdavi and Mathew 1997). The seven incorporated performance simulation modules are: thermal analysis, HVAC systems, air flow, thermal comfort, lighting, acoustics and life cycle assessment.

Another example of experimental software was the one developed by Shea in 2005. It is an integration of generative structural design system called eifForm and an associative modelling system. XML models are used for the integration between eifForm and Generative Components. The generative method in eifForm is an optimizing process. It combines structural grammars, performance evaluation (structural analysis), performance metrics and stochastic optimization.

Figure 14: eifForm developed by Shea
a- eifForm: progressive generation of the canopy design by the program
b- canopy design developed using eifForm for the courtyard of the Academie van Bouwkunst in Amsterdam(2002) (Computing the Performative. Performative Architecture Beyond Instrumentality. B. Kolarevic and A. M. Malkawi, Spon Press: 193-202.)

Generative Components is a modelling system that combines geometric modelling and programming. It uses a graph-based associative geometry modelling (Shea and Aishb 2005). As a result of the integration of eifForm and Generative Components, Shea's program, based on a structural shape grammar, can generate design topology and geometry. It also enables the transformation of form while simultaneously maintaining a meaningful structural system. The software develops the overall form of a structure dynamically by repeatedly modifying an initial design with the aim of improving a predefined measure of performance. This takes into account many different factors such as: structural efficiency, economy of performance, member uniformity and even aesthetics, while at the same time satisfying structural feasibility constraints (Kolarevic 2005). Figure 14a illustrates an example for the progressive generation of the canopy design by the program and Figure 14b illustrates the canopy design developed using eifForm for the courtyard of the Academie van Bouwkunst.

4.4.3 Performative

The performative capacities are unfolded by integrating a fundamental revision of functionalist and mechanical approaches towards performance based design with the spatial qualities inherent in the material systems promote. Thus, performative approach to design is not limited to a purely instrumental level; the capacity to generate new designs still highly depends on the designer's perceptual and cognitive abilities. Moreover, another important point is that the relationship between the designer and computer is not the output of the software. It is defined by the designer (by scripting, parametric modelling). The architect chooses the parameters and sets the relationships and the rules. If the designer does not like the results, he can adjust the rules until they do meet the initial objectives, or those initial objectives are changed to fit the results.

Michael Hensel and Achim Menges' Morpho Ecological approach takes performance based generative design one step further by its use of computational tools and combining them with computational manufacturing techniques. Some examples from their use of computational tools are illustrated in Figure 15.Their approach challenges to integrate the form generation, material behaviour, manufacturing and assembly, environmental modulation and spatial conditioning, as discussed in the second chapter. Therefore, their computational models hold the information about manufacturing constraints, assembly logics and material characteristics so that they describe behaviour rather than mere shape. This enables the designer to conceive the performative effects resulting from the interaction of material and construction systems, the system's behaviour and interaction with external forces and environmental influences (Menges and Hensel 2008).

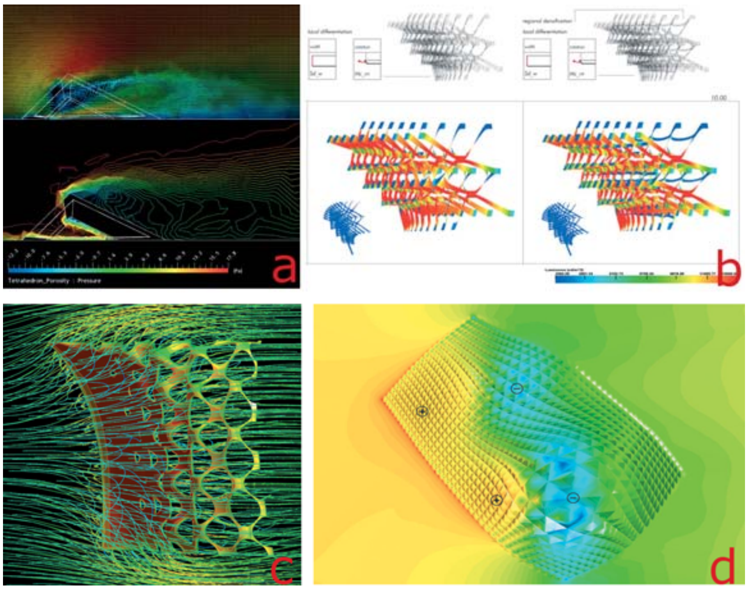


Figure 15: a Morpho-Ecological approach for Design
a- CFD model of the aerodynamic performance of a local component where the analyses of system behaviour and performative capacity becomes an integral part of the system's computational generation
b- different models produced through the geometric adaptation of a multi-component system in response to particular parametric settings
c- CFD analysis of the system's performative capacity to modulate airflow through regional and local porosity gradation
d- the regional and global articulation is derived through the aerodynamic behaviour of the system tested in CFD
(A. Menges Hensel, M. and (2008). Inclusive Performance: Efficiency Versus Effectiveness - Towards a Morpho-Ecological Approach for Design. Architectural Design. 78: 54-63.)

This potential of computational design and its computer-controlled fabrication depends on two aspects: first, a closer relationship between the processes of designing and constructing, by integrating material capacity and behaviour; and second, the utilisation of this capacity as a means of creating spatial arrangements. This can be done by introducing the concept of material systems within an integral computational model of form, material, structure and behaviour as complex interrelations, rather than as separate elements.

In their computational framework there are three essential elements. The first one is the parametric set up based on the material system's constraints. These parameters can only be operated coherently with the constraints. The second element is the interaction of individual system instances with external influences and forces. Therefore, the processes that trigger and drive the advancing development of the system are the third constituent. The integral computational model is, initially, an open model which is then informed, step by step, by a series of additional parameters, restrictions and characteristics inferred from material, fabrication and assembly logics and constraints. Only through these processes the framework is able to operate coherently with the variable input to the defining parameters (Menges 2007).

4.4.4 Need for yet to be Made Tools

As conclusion of the research done in this chapter about computational tools related with performance, it can be seen that parametric design is well suited for material constraints, environmental and structural factors because they are translatable into binary code. As mentioned in previous chapters, the parametric model for performative architecture needs to be directed further outwards, since it represents a shift in orientation in design. The digital parameters should be used for environmental design and more, since the task of performative architecture is not just designing less damaging relationships between built and natural environments, but also to configure a built fabric that produces benefits. Environmental and structural performances are obvious criteria that are included in parametric model. However, so much else should be included. By means of parametric models, many complex flows and relationships can be defined and the results of actions can be foreseen. This is not for only environmental, but also true for cultural, demographic, economic, and traffic flows. Since they have the same rules as natural flows, they can also be mapped digitally and, to some extent, predicted digitally.

This sort of performative approach to design requires yet to be made digital tools that can provide dynamic process of formation/generation based on specific performative aspects of design. There are many digital analytical tools that can help the designer to assess certain performative aspects of their projects after an initial design is formed. None of those commercially available tools provide dynamic generative capabilities for conceptual explorations during architectural design.

CHAPTER 5

GENERAL CHARACTER OF THE DEFENCE LINE AND ITS TRANSFORMATION

This thesis deals with performative architecture to address a model of design to generate transformation alternatives for a current design problem of Dutch Landscapes. This design problem is the transformation of the Defence Line of Amsterdam. The transformation includes conservation of 41 forts, assigning them new functions and designing additions.

Defence Line of Amsterdam (Dutch name Stelling van Amsterdam) is a 135 km long ring of fortifications around Amsterdam, constructed between 1880 and 1920. It consists of 42 forts located between 10 to 15 kilometres from the centre, as shown in Figure 16a, and lowlands that can easily be flooded in time of war. The flooding was designed to give a depth of about 30 cm, insufficient for boats to traverse. Despite the fact that only the forts might be seen as the most visible part, Defence Line needs to be understood as a logistical system, in combination with the circle of flooded areas (Figure 16b).

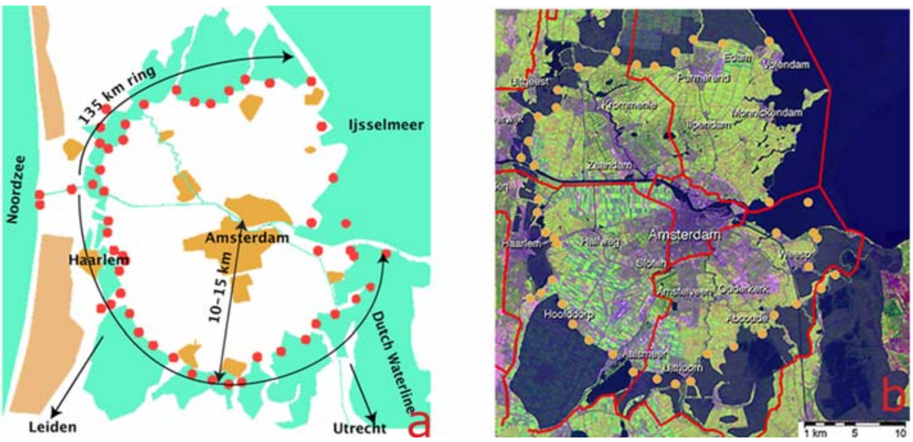


Figure 16 Defence Line of Amsterdam
a- diagram of the general configuration
b- satellite view of the possible circle of flooded areas
(http://www.stelling-amsterdam.nl/english/forts/index.html Last accessed 10 January 2011)

The forts were built where roads, railways or dikes cross through the water line, at locations where there would be no water to stop the enemy. Moreover, any buildings within 1 km from the line had to be made of wood, so that they could be burnt and the obstruction removed the open view on field of fire, as illustrated is Figure 17a.

The invention of the aeroplane and tank made the forts obsolete almost as soon as they were finished. Today, the dike through the Haarlemmermeer is cut by the A4 Motorway. This motorway also goes under the Ringvaart at Roelofarendsveen, making flooding of the Haarlemmermeer Polder and future military use of the forts no longer possible.

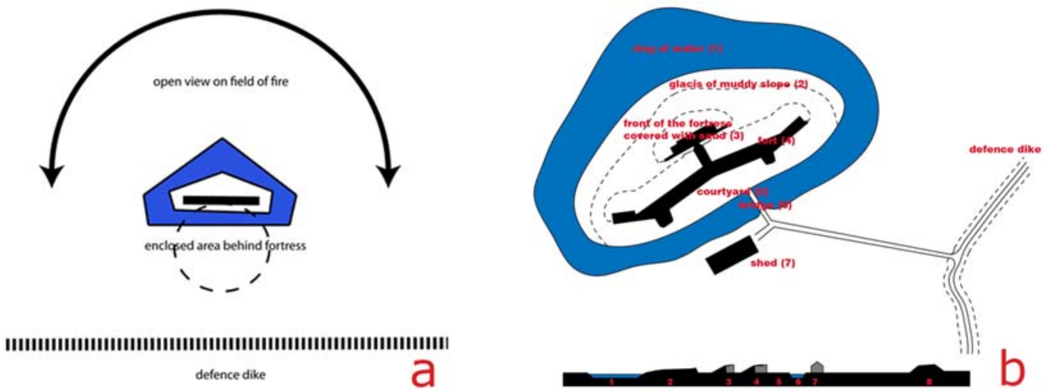


Figure 17: Elements of forts
a- diagram of configuration of fort
b- elements of the fort

The forts are designed to meet military requirements, and they all consist of the same elements. These are: ring of water, glacis of muddy slope, front of the fortress covered with sand, fort, courtyard, bridge, shed and defence dike (Figure 17b). The forts are designed as artificial hills for camouflage reasons. Owing to the fact that the front of the fortress is covered with sand, it is impossible to notice the fort from the outer side of the ring. Photos of some forts from different viewpoints are shown in Figure 18.

Figure 18: Photos of the forts
a- Fort near Krommeniedijk (photo from front courtyard)
b- Fort North of Spaarndam (photo from front courtyard)
c- Fort South of Spaarndam (photo from front courtyard)
d- Fort South of Spaarndam (photo from from the side)
e- Fort South of Spaarndam (photo from from the ring of water side)
f- Fort near Penningsveer(photo from front courtyard)

This characteristic of the forts can be interpreted as forces that deform the flat Dutch landscapes to create the required spatial forms. The inner surface of the massive structure consists of vaults to provide stability in case of bombing. The drawing of the section and front view are illustrated in Figure 19. The building is designed to be self sustainable. For example, water on the sand side of the fort can be collected and used in order to survive under enemy attacks. Although the forts are designed with a functionalist sense, they create innovative forms in Dutch landscape; so they can be seen as performative architecture of the era in which they were built.

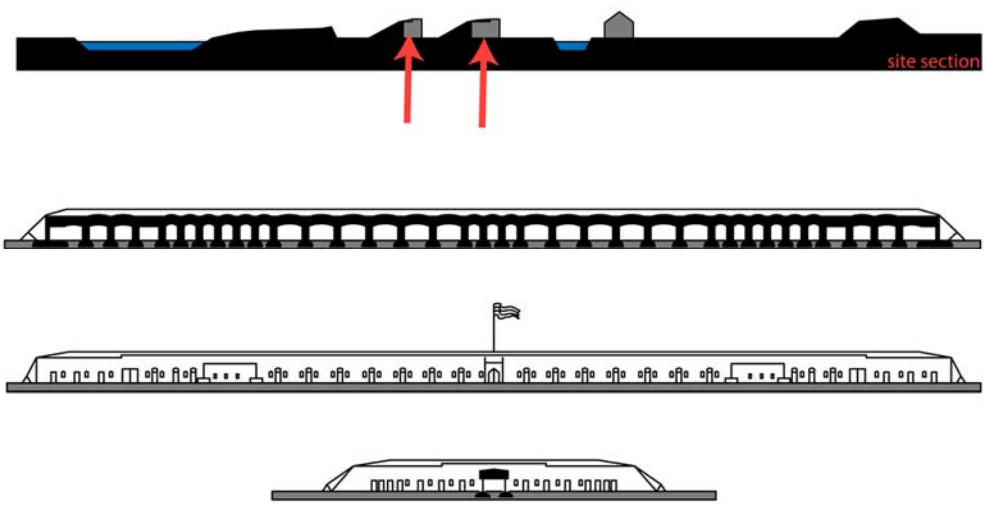


Figure 19: Section and front views of the forts

5.1 Today and Future of the Defence Line

Today, the influence of the Defence Line is remarkable. The army is scarcely present but the country planning and infrastructure can largely be attributed to the Defence Line. Because of a special law, building along the Defence Line has hardly taken place and new rail and roadways had to run along the forts. The Defence Line was inscribed to the UNESCO World Heritage List in 1996 because of its historic value for all mankind (UNESCO/WHC 2011). Moreover, they are important elements of Dutch landscape by creating rich landscapes while demonstrating a unique historic example of defence and water-management technology.

Presently, almost all forts remain in good condition. Only two forts are fully demolished, and interest in the Defence Line and its preservation was ignited after the demolition of the main building of Fort near Velsen by the company owning it. Recently, a very limited number of forts have been renovated. These renovations were achieved mainly by private investors transforming the forts into house restaurants and wine trading companies. The fort near De Kwakel, which is now surrounded by the village and the terrain, is also used for housing. The fort watchmen's house and engineering shed are converted into houses.

Following 1996, after being inscribed as the UNESCO World Heritage List, privatization of the forts had given way to their allocation to charitable organizations. For instance, forts along the Drecht and Vijfhuizen are owned by charitable foundations and are now in use as restaurants, galleries and workshops. The fort along Den Ham is being established as a volunteer Defence Museum and the fort near Veldhuis in renovated as the Air Warfare Museum of the Aircraft Recovery Group Association (Stelling Amsterdam 2010).

Besides these, some of the forts are used for various purposes without being renovated such as, sport shooting, fire brigade training centre (Fort near Marken-Binnen), industrial estate (Fort north of Uitgeest), distribution centre for the transport of valuables (Fort near the Liebrug) a yachting-club for retired military personnel (Fort near Kudelstaart). Figure 20 illustrates the recent situation of the forts along with photos of some recent functions attributed to them.

The transformation of the Defence Line should not be understood as renovating the forts and assigning them new functions individually. As mentioned above, the original design of Defence Line involves a holistic understanding; therefore, redesigning the Defence Line requires defining a general guideline rather than focusing on its parts separately. For this reason, performative architecture is used to define a guideline for the generation of alternatives for this recent design problem of Dutch Landscapes. To define a guideline for the transformation of the Defence Line, an analysis of the whole site in urban scale is needed in relation to future scenarios of the Randstad.

Figure 20: recent situation of the forts along with photos of some recent functions attributed to them

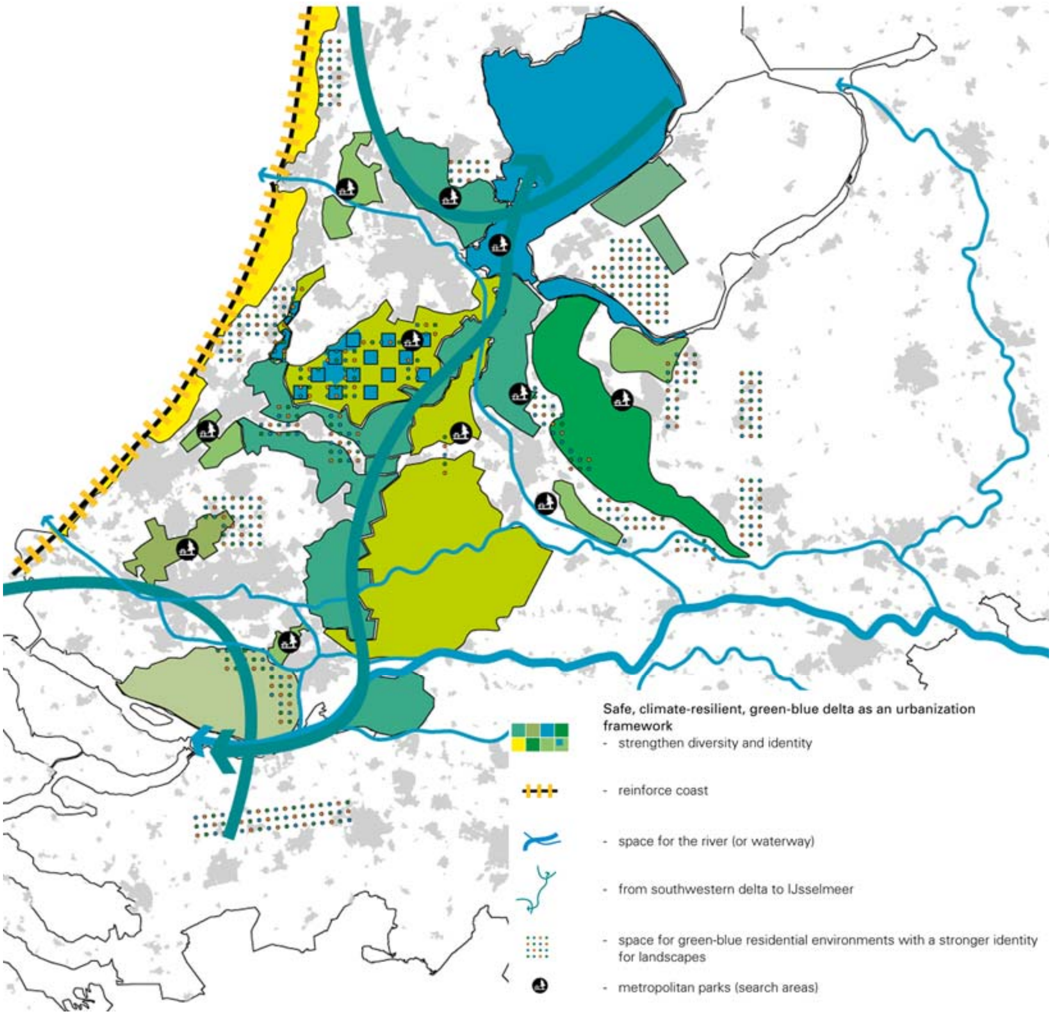


Figure 21: conceptual design for the one of the future scenario for Randstad (http://www.rijksoverheid.nl/onderwerpen/randstad/randstad-2040 Last Accessed 10 January 2011)

Amsterdam region occupies a leading position because of its highly versatile economic profile and metropolitan character which thus leads a sharp increase of the built environment in the region. The government intends to balance dense built environment in the region by creating a landscape belt around Amsterdam where former Defence Lines are considered as landscape templates as illustrated in the conceptual design for one of the future scenarios for Randstad (Figure 21) (Rijksoverheid 2011). The transformation of the forts needs to be done in harmony with these planning decisions and new functions to the forts must be defined accordingly.

5.2 Computing Urbanization Levels for Each Site

After having a look at history, recent situation and future of Defence Line, it can be concluded that 100 years after the construction of forts, many new relationships are formed between forts, water, infrastructure and urban areas. Some forts are surrounded by urban fabric, while the others remain in rural areas. Some forts are in the middle of land surrounded by only a ring of water, and some lie along important water connections as shown in Figure 22.

Figure 22: satellite views of some forts

The first step of transforming the Defence Line as a green belt is to analyze relationships between forts and the whole system of the area. Concentration of infrastructure and urbanization affect the number of potential users for each fort; therefore, the scale of the transformation and the size of needed additions differ. Eventually, the definition of the guideline for the transformation is initiated by a parametric model that computes urbanization levels for the sites of the forts.

The aim of this parametric model is to calculate urbanization levels for the region of Defence Line using waterlines, land transportation connections (rail lines and highways), urban areas, Schiphol airport noise level contours, green zones (forests, nature reserves and recreation areas), and greenhouses as inputs (Figure 23). As a result, the concentration of infrastructure and urbanization are computed. One important point in computing this kind of concentration is to define the strength and area of influence for each kind of input.

Grasshopper® software, which is a graphical algorithm editor tightly integrated with Rhino's 3-D modelling tools, is used for the ease it offers in manipulations of the input. The fundamental logic behind the parametric urban model is very simple: a surface populated with boxes whose height varies in relationship to an attractor point.

To start with, a surface that covers the region is created and divided into a grid. Then, the input data mentioned above is used to deform the height of the grid cells successively. The inputs, whether lines or surfaces, are turned into points, so that the distance between each point to the grid can be calculated for the step of deforming the heights.

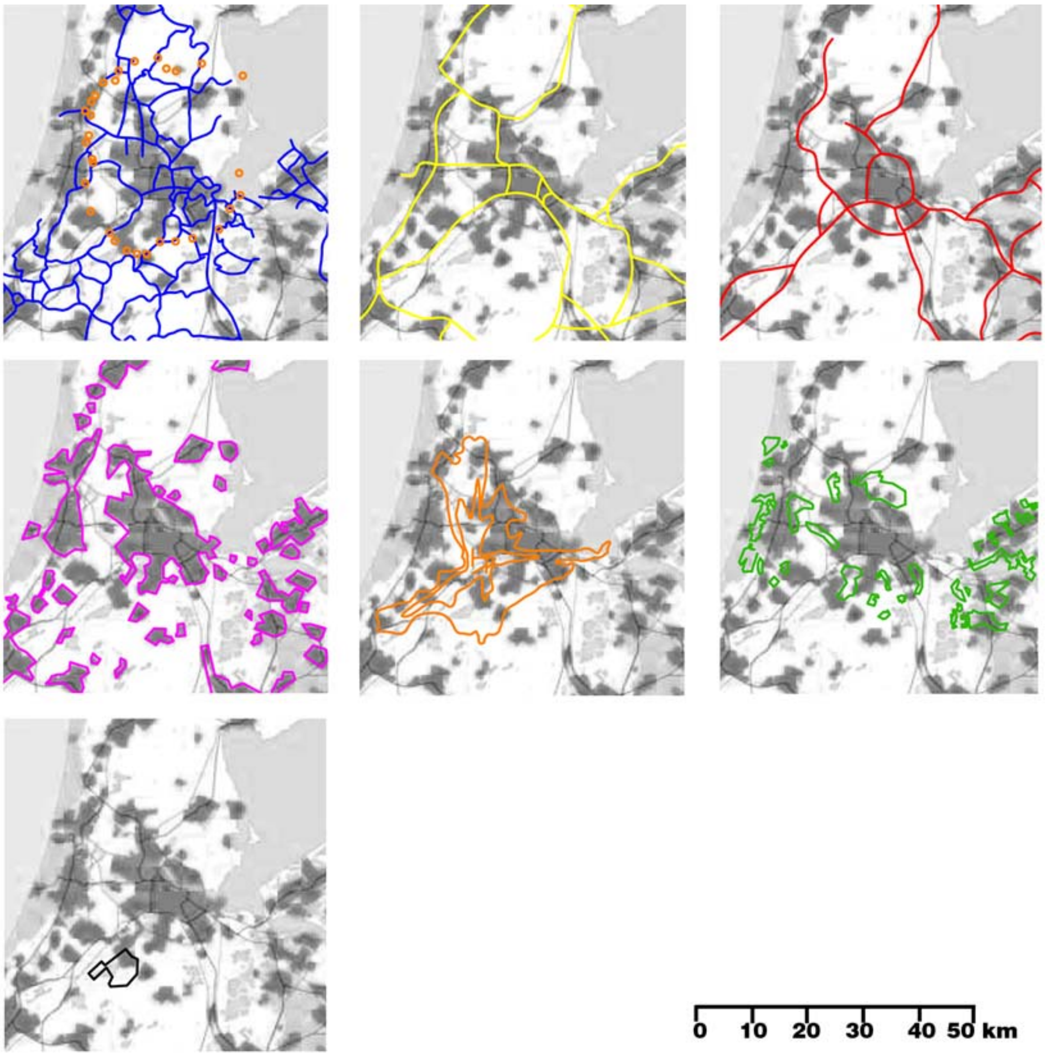


Figure 23: different inputs to calculate the urban levels for the region of Defence Line
These inputs are: waterlines, rail lines, highways, urban areas, Schiphol airport noise level contours, green zones (forests, nature reserves and recreation areas), and greenhouses

Two other factors are also used for the deformation: the strength and area of influence (Figure24). The "number sliders", which is a component offered by the Grasshopper® programme for the manipulation of the input, is used to control these two values. The designer determines the importance of the specified input in the computation of urban levels by controlling the height of the deformation of grid cells. This control is done by the number slider which is called *strength*. Similarly, the area of the influence of the specified input is determined by controlling a number slider called *area*.

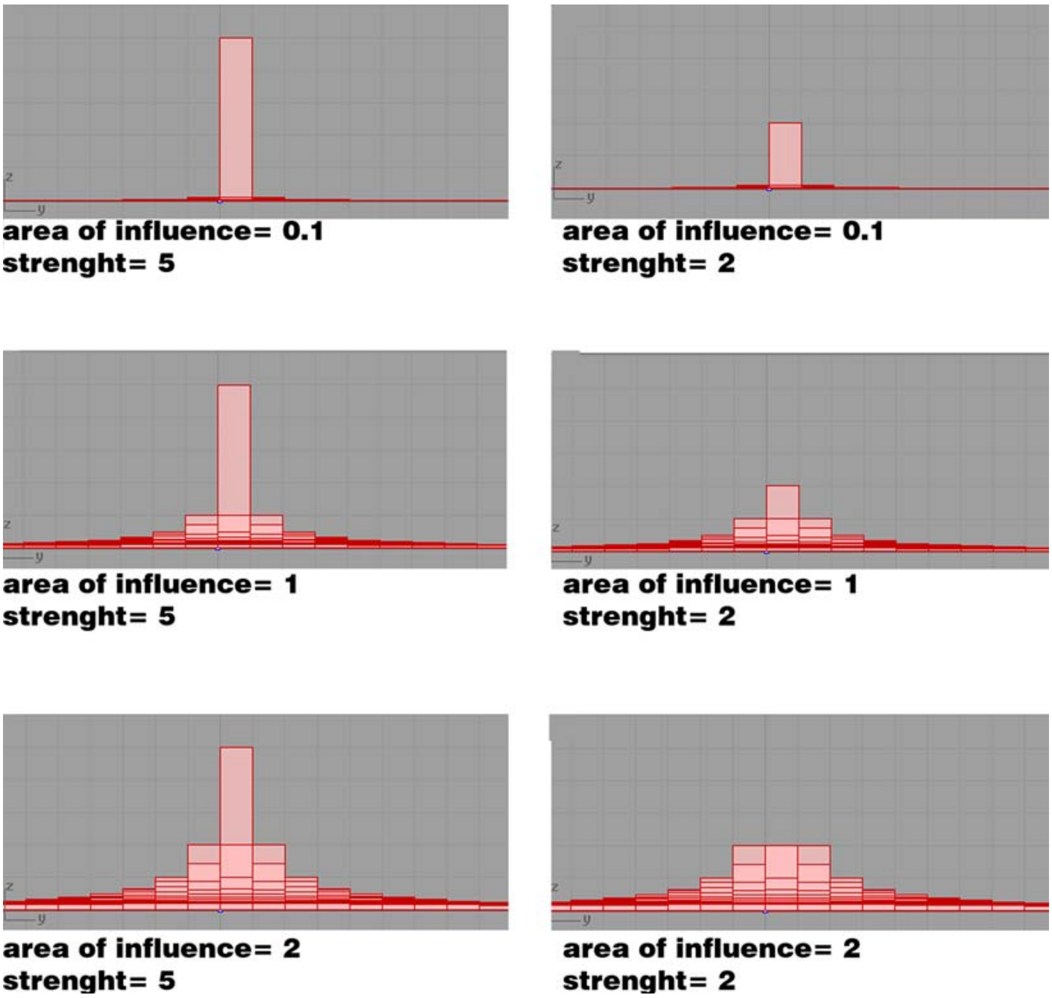


Figure 24: different influences of the controls 'area of influence' and 'strength'

Strength and area values are defined for each kind of input, as shown in Figure 25. The inputs that increase the urbanization levels and size of additions to forts are waterlines, rail lines, highways, urban areas and greenhouses. Waterlines have the biggest influence. Due to the fact that transformation of the Defence Line requires to be understood as a system, waterlines play a significant role in connecting the forts. The forts which have a direct connection to waterlines gain priority in the transformation process.

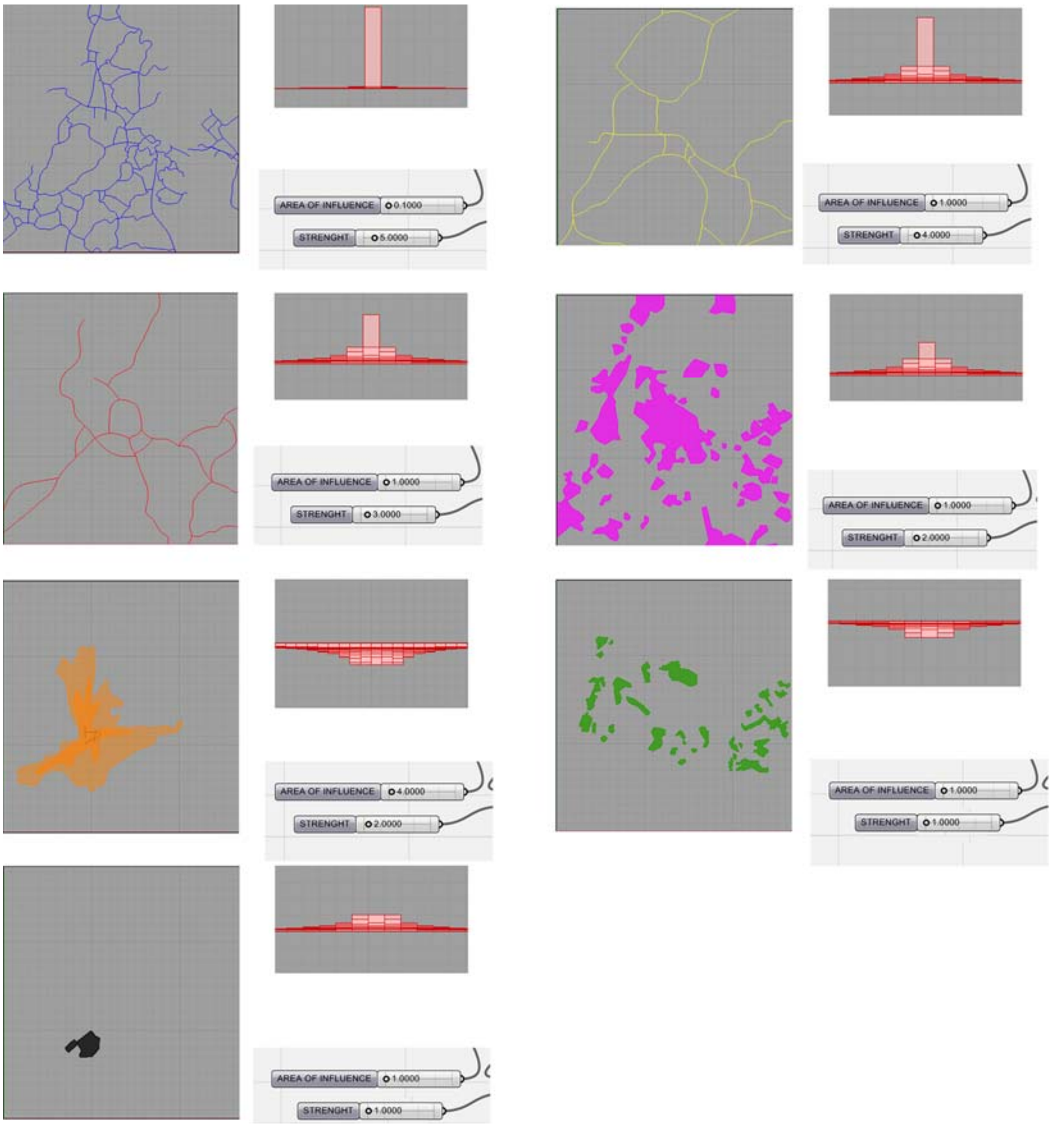


Figure 25: Different definitions of ‘area of influence’ and ‘strength’ for different inputs

The inputs that decrease the urbanization level and the size of additions to forts are Schiphol airport noise level contours and green zones. In order to cover the whole area under the impact of the noise of Schiphol airport, the biggest value for area of influence is given to this input. The green zones are used as a reducing factor to constrain the size of addition to the forts that are in forests, nature reserves and recreation areas.

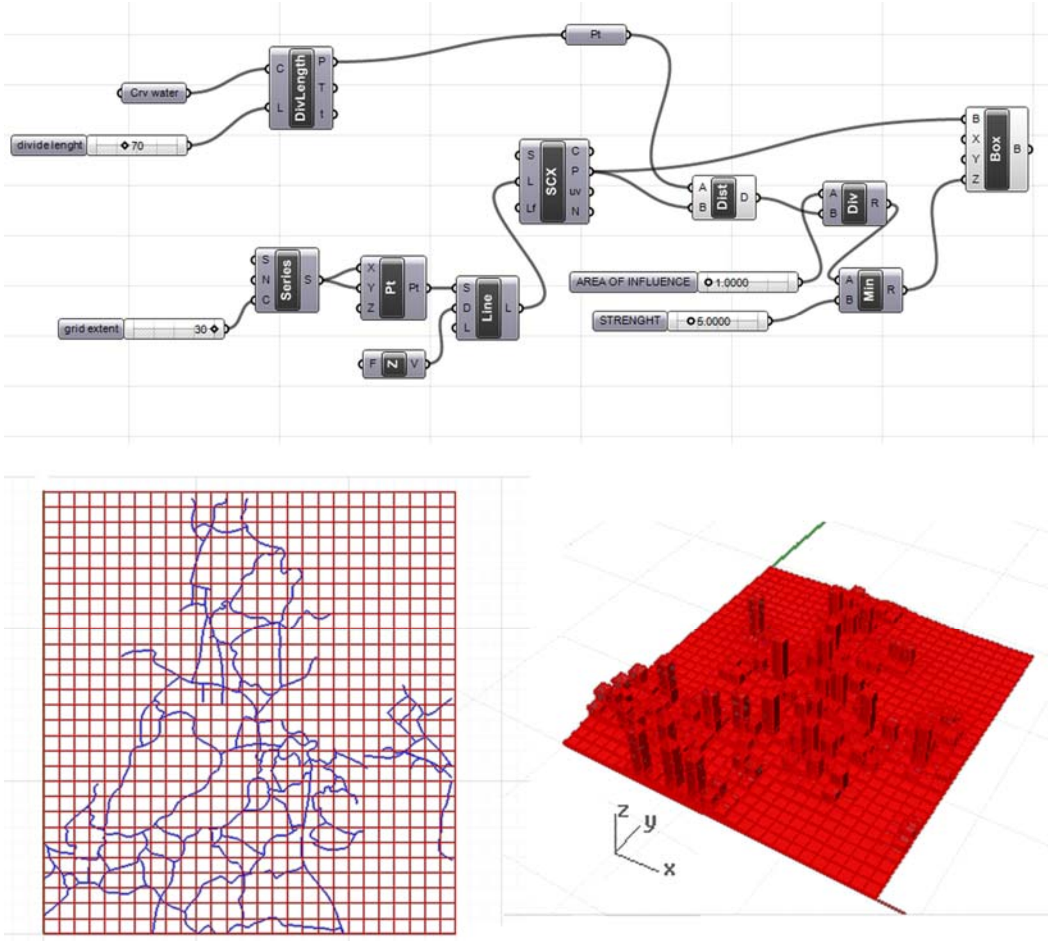


Figure 26: process for the waterlines
a- print screen from Grasshopper®
b- grid lines and first input: waterlines
c- output of the first step

Figure 26 illustrates the process for waterlines. The grid, illustrated in Figure 26b, is deformed by the input of waterlines and differentiated height of grid cells are formed as an output. In the end, the urbanization levels for each site are computed by adding the deformation values of each input. This urbanization level is used to give an understanding of the number of potential users, the scale of the transformation and the size of needed additions for each fort. The result is shown in Figure 27.

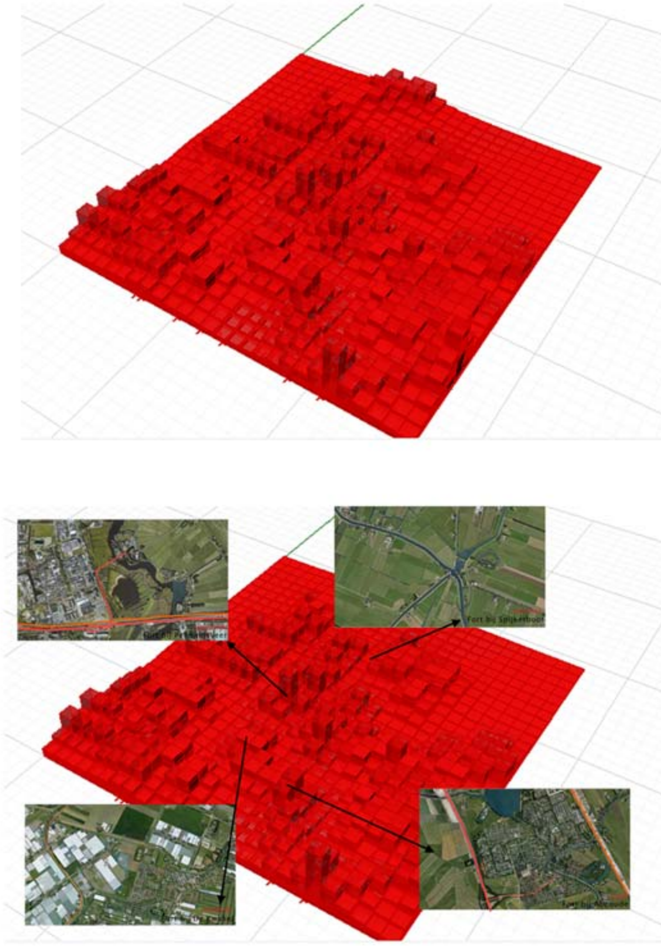


Figure 27: final output of the model

5.3 Defining New Functions and Additions

The defence Line is transformed into a green belt around Amsterdam as indicated in planning decisions. Accordingly, the forts are transformed into nature parks and botanical gardens. However, as seen in the calculation of urbanization levels, the character of the sites varies greatly.

The forts within the sites with high urban levels will be selected as transit points. They will become official visitor centres and all the forts will be connected by boat tours, biking and hiking trails. Guided tours take the visitors through this green belt around Amsterdam. The forts that host the visitor centres will provide a wider range of activities. They will be used by two groups of users; those that use the fort as a transfer area that connects the urban elements within the site, and those that aim to do sight-seeing and spend time around the fort. The forts with low urbanization values will be used by a small number of users such as locals living in neighbourhood and biking or hiking trail groups.

The relationship of the urbanization levels and complexity of the activities shows an exponential relationship. The simplest functions are the ones that provide space for basic human activities like: walk, relax, sit, climb, play, picnic, sleep, eat, talk, swim and sunbathe. Complex functions hold cultural, commercial and educational activities. The botanical displays in the interior of the forts educate visitors to the region's flora. They provide workshop spaces where visitors can experience and learn how to grow plants or places for presentations to increase environmental awareness.

The complexity of the function defines the size of addition needed. For basic activities, the additions can be urban furniture, a floor or a roof structure. For instance, some structures provide shade and shelter, while some only provide suitable seating areas. Closed spaces are needed only for more complex functions, which can also be used to create suitable spaces for what are, basically, greenhouses or the compartmentalization of nature by humans.

These additions are designed as stripes, similar to the design of the forts. As previously mentioned, the forts needed to be camouflaged from the outside of the water ring (Figure 28a). The front of the fort is covered with sand so that they look like little hills that lie along the flat Dutch landscape. This character of the forts is very inspirational for the initial design ideas. In this manner the form of the fort and the islet in which the fort lies are interpreted as deformed stripes (Figure 28c). The forts are designed as artificial hills that meet the requirements of the weapons and soldiers that would use the fort (Figure 28b). Similarly, the complexity of function and needed space, (in relation with the computation of urban levels) deforms flat land into stripes to meet the spatial requirements.

There are two additional objectives of the deformed stripes besides providing a setting for various activities. These are adding an extra layer to the existing topography of the islet while connecting it to the existing urban elements and landscape behind the dike.

Therefore, the additions have not itself been made independent, but have been connected with the different pieces of land, landscape and nature. Also with the new topography, they aim to become "hill-like architecture" with a continuation between indoor and outdoor space. The stripe’s integration of existing urban structure, architecture and landscape is a strategy for creating a recreational and educational place for visitors.

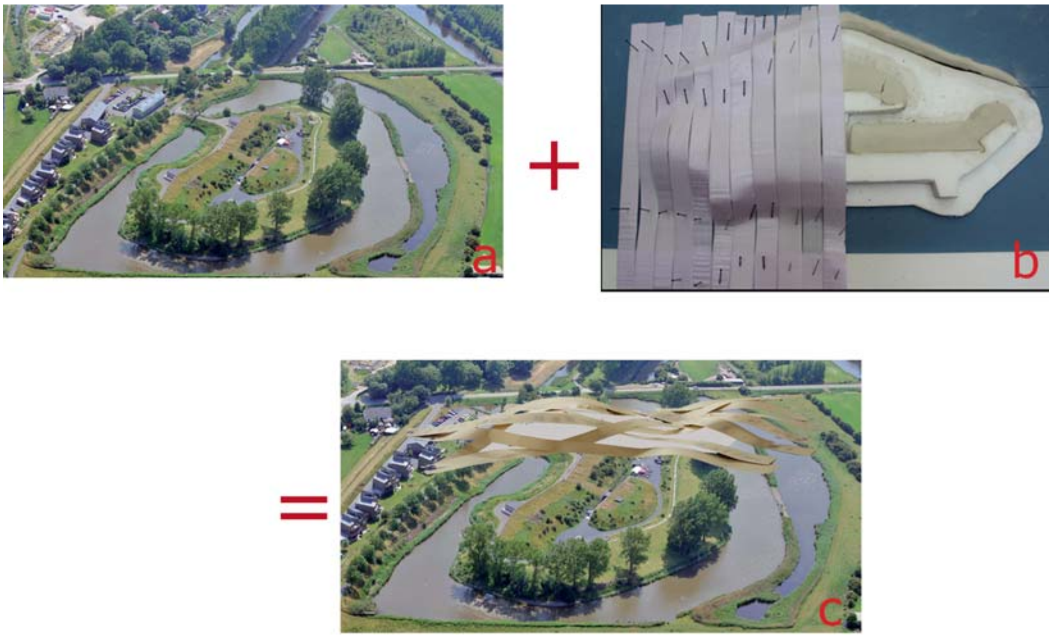


Figure 28: the camouflage of the fort as an inspiration for the design
a- satellite view showing the camouflage of the fort
b- reinterpretation of the design of fort: stripes of land are deformed to meet the requirements of the functions
c- deformed stripes for the design of new building

5.4 Defining Performance Criteria

The objective of this thesis is to address performative architecture as guideline for the transformation of the whole Defence Line. After the urban analysis of the site and configuring the initial ideas about the design, we can start the definition of the guideline by setting up a hierarchy of the performance criteria for the transformation. In chapter four, building performance criteria were divided into three. The sub categories of performance criteria for transforming The Defence Line of Amsterdam as a green belt, are defined as the following three:

1-health, safety and security performance

- structural
- illuminative

After computing urbanization levels, different functions are assigned to different sites. However, since this design model aims to deal with the Defence Line as a whole, the additions must be done using the same language. For this reason, design of the structure is done with parameters, which are fed with the input that are related with site and assigned functions. Thus the structure can adapt its form from smaller spans to bigger spans while creating space for different functions.

Another performance criterion of transforming the Defence Line into a green belt is the preservation of nature. The proposed additions should not damage the natural richness of the area. They should conserve and contribute to nature while providing suitable and diverse conditions for human habitation. Solar analyses of the designs are carried out to see if they let through enough sunlight for the nutrition of plants on the site.

2-functional, efficiency performance

- provide adequate space for required functions
- provide connections between urban elements of site

Due to the fact that these forts lost their original military function, new functions need to be defined for them, so that the space they define can be utilized in a new way. The required spaces for new functions are improved by providing additions which also connect the fort to the existing urban elements and landscape behind the dike. The additions play an important role in connecting the islet of the fort to the surrounding.

3-psychological, social, cultural and aesthetic performance

- conservation of the UNESCO Heritage site
- compatibility with the surrounding

This conventional hierarchy of building performances is not valid for the transformation of the Defence Line. The most important performance of transforming the Defence Line is the conservation of the UNESCO Heritage site. Therefore, this performance criterion has a bigger impact than the ones related with structural, illuminative, functional, and efficiency performances.

The assessment of this performance criterion is different from the previous ones. Rather than numeric values such as solar position, stability and area, it also requires qualitative analysis. For this reason, generation and evaluation of alternatives is needed. Performance analysis of this criterion can only be done through qualitative and quantitative analysis of the emergent effects of the additions (on fort, site, landscape, nature and site), where the qualitative analysis of the alternatives also includes the abilities of producing powerful effects. The evaluation of the alternatives does not only depend on how they appear, but also their capabilities for affecting, transforming and doing; in other words, by how they perform. The design model for transformation of the Defence Line is named performative rather than performance based design because of its wider span of multiple realms.

5.4.1 Structural Performance: Catenary Arches

Over the last century the engineering and architectural approach to the relationships between form, force and mass has changed significantly, both on a conceptual and methodological level. The study of the relationship between structural form and force began, in the 17th century, with the understanding of the catenary and its correspondence to the arch (Remo Pedreschi 2008). The catenary is the curve that an idealized hanging chain or cable has when supported at its two ends.

The equation of a catenary in Cartesian coordinates has the form:

$$y = a \cosh\left(\frac{x}{a}\right) = \frac{a}{2}\left(e^{x/a} + e^{-x/a}\right)$$

The curve is the graph of the hyperbolic cosine function, and has a U-like shape, superficially similar in appearance to a parabola though mathematically quite different, as shown in Figure 29a. All catenary curves are controlled by chain length and position of the supports. Figure 29b illustrates changing the parameter *a* is equivalent to a change in the position of supports within the same chain length.

If the curve of the cable is flipped around its anchor points, the resulting geometry is the corresponding ideal form for an arch resulting in uniform axial compressive forces. The arch endures almost pure compression, in which no significant bending moment occurs inside the material.

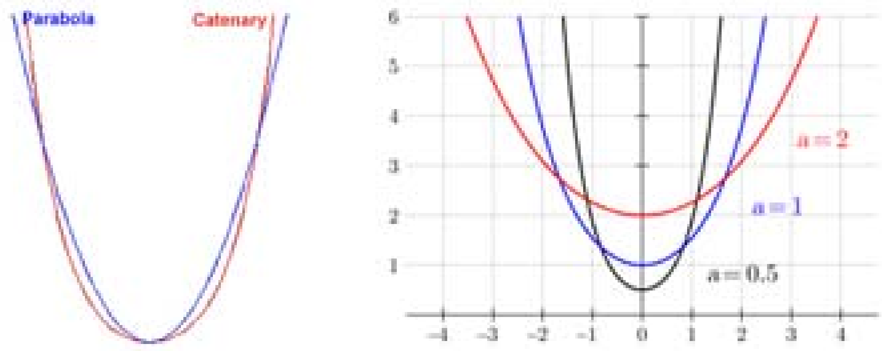


Figure 29: graph of catenary equation
a- parabola versus catenary
b- graphs of catenary equation in relation to variable a
(http://en.wikipedia.org/wiki/Catenary Last accessed 10 10 January 2011)

The roof of the Taq-i Kisra in ancient city of Ctesiphon (Iraq today) constructed in 540 AD was one the largest vaults constructed at the time (Julian 1999). As illustrated in Figure 30, the vault is roughly a catenary. The vault spans 24 meters with an arch height of 16.6 meters, supported on vertical faced buttress walls with a height of 11.1 meters. To study the relationships between form of the arch and resultant stresses the following calculations are done using iDiana software, which is a finite element analysis program.

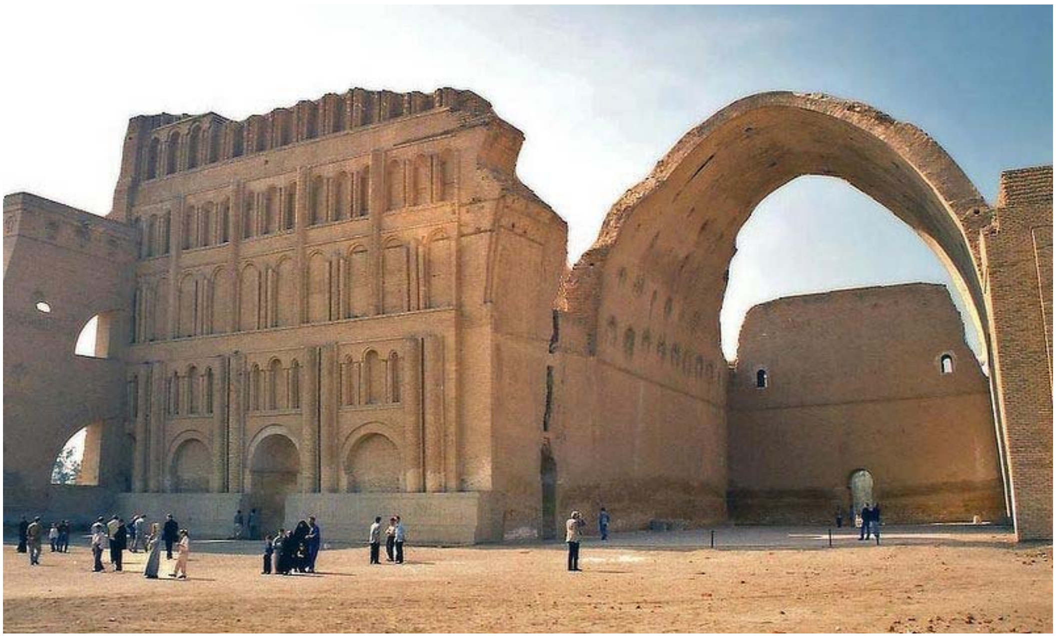


Figure 30: photo of Taq-i Kisra
(http://en.wikipedia.org/wiki/Catenary Last accessed 10 10 January 2011)

The aim is to compare stresses in the Taq-i Kisra assuming either a catenary or parabolic profile. Also constant depth sections are compared with increasing in depth towards the supports. The section depth was taken as 0.85 metres, increasing to 1.7 metres at the supports for the variable depth profiles. Four analyses were carried out as illustrated in Figure 31:

Run 1: Catenary with varying section depth

Run 2: Catenary with constant section depth

Run 3: Parabola with varying section depth

Run 4: Parabola with constant section depth

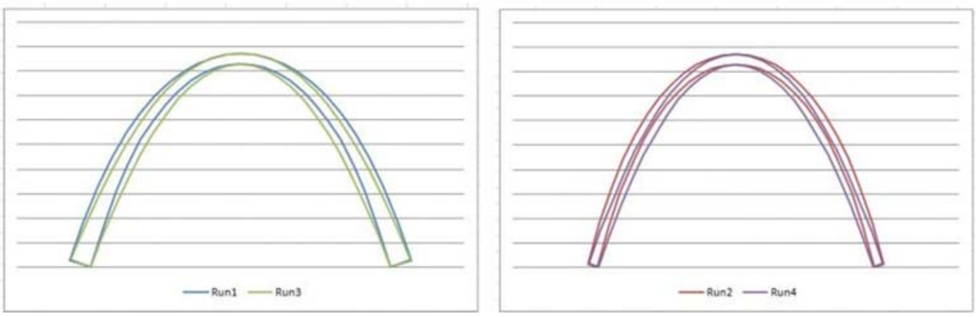


Figure 31: Run 1,3 and Run 2,4 (http://newtonexcelbach.wordpress.com Last accessed 10 10 January 2011)

Bending moments and axial stresses for these four runs are illustrated in the graph in Figure 32. It can be seen that axial forces are similar, with the constant depth sections having a significantly smaller force. Bending moments for the constant depth catenary (Run 2) are close to zero throughout. Bending moments for the constant depth parabola (Run 4) and the variable depth catenary (Run 1) are similar, with a maximum of 50 kNm/m. The variable depth parabola (Run 3) had bending moments more than twice as high.

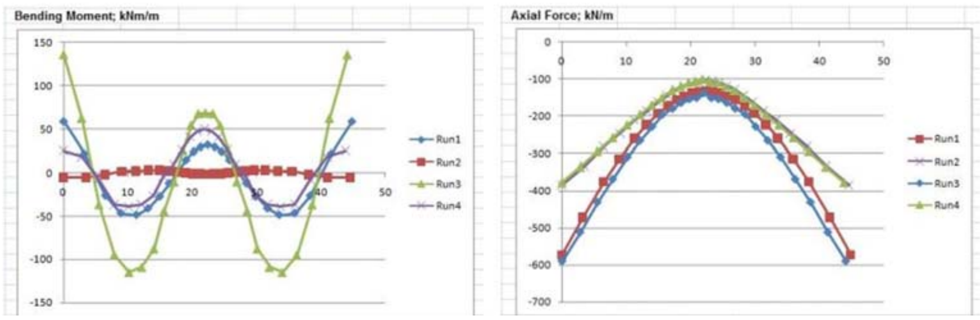


Figure 32: Results of bending moment and axial force
(http://newtonexcelbach.wordpress.com Last accessed 10 10 January 2011)

Axial stresses for these four runs are shown in Figure 33. It can be seen that stresses are compressive throughout for Run 2, and tensile stresses increases progressively through Runs 1, 4 and 3 respectively. The maximum tensile stress from Run 3 is 400 kPa, which would leave little reserve capacity for wind or earthquake loads.

This comparison between catenary and parabolic curve proves that catenary with constant section depth is an ideal curve form for arch structures. Since the bending moments are almost zero and maximum tensile stress was about four times smaller for the catenary profile than the parabolic profile. Therefore catenary arches are used as a main definition to generate the forms of additions to the forts of the Defence Line of Amsterdam.

The parameters in the catenary arch equation are fed with the inputs that are related with functions and site. Consequently structural performance is attributed to the morphological advantages of this ideal form; the catenary arches are proper to create the desired effects of the conceptual design. Deformed stripes which will act as an extra layer to existing topography can be obtained from series of catenary arches.

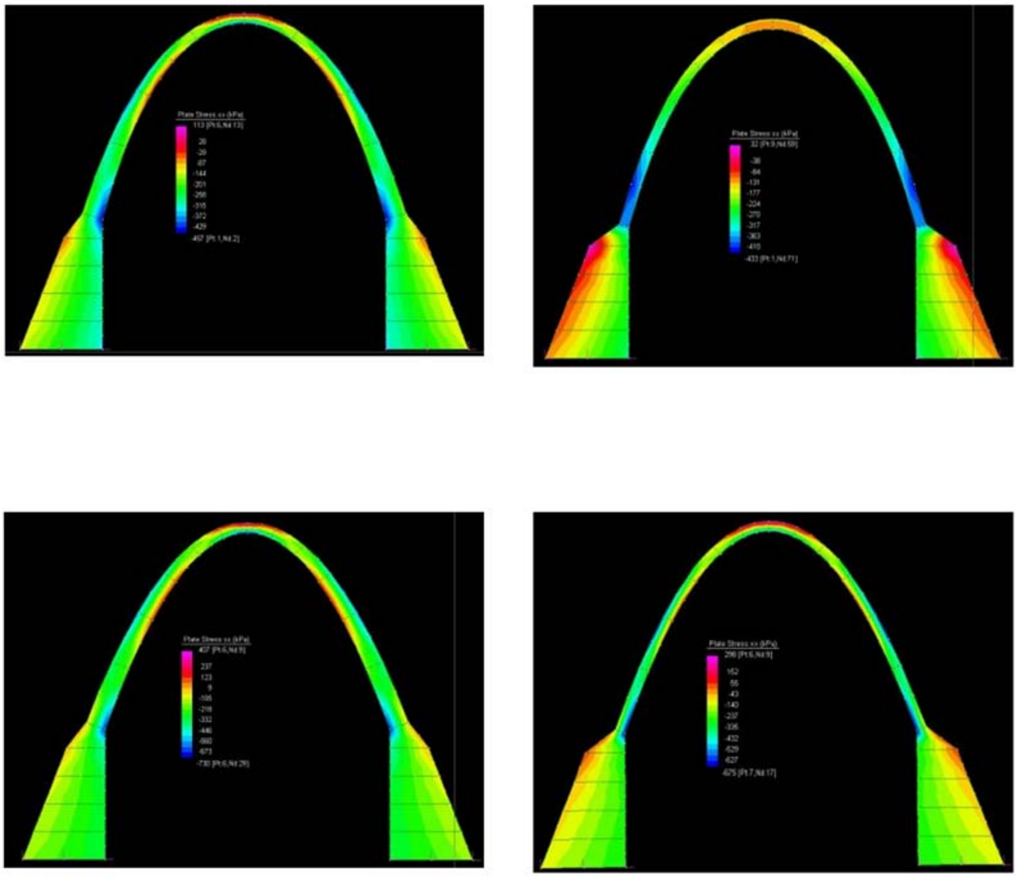


Figure 33: Stresses
(http://newtonexcelbach.wordpress.com   Last accessed 10 10 January 2011)

5.4.2 Illuminative Performance: Categorization of Plants According to Needed Sunlight

The Netherlands has a variety of nature reserves and diverse fauna. According to the statics of World Resources Institute, Netherland's ecosystem shows the following distribution: forest 2%, crop/grass vegetation 88%, urban and built up area 4%, wetlands and water bodies 6% (World Resources Institute 2007). As mentioned in chapter 5.2, the 135 ring of Defence Line of Amsterdam is in the presence of all those different types of ecosystems. All forts have a relationship with water bodies, some lie within urban areas while some lie along natural vegetation. Consequently, one of the most important performance criteria in the design of the transformation Defence Line as a green belt is the conservation of nature. Data about existing flora around the islet of the forts and the optimum sunlight angles/amounts for the nutrition of those plants are important.

Landscape architects divide plants into 3 classes according to their needs for sun, as illustrated in Figure 34. These are: full sun plants, little sun plants and shade plants. Little sun plants have two sub classes: morning sun and afternoon sun. Full sun plants require sun exposure and should be planted to take in as much of it as possible. Little sun and shade plants grow well in cool and moist environments. These plants need morning sun; weaker, gentler and more pleasant than the much brighter, harsher and intense afternoon sun**.** Three hours of direct afternoon sun will fry most full shade plants.

The mapping between the ecosystem classification of Word Resources Institute and the classes of the plants according to sun exist to inform the performative design model for the transformation of the Defence Line of Amsterdam.

5.4.2.1 Woody Plants

The common woody plants that grow in Holland are oak, pine, elm, little leaf linden and beech. Scrubs such as: *Crataegus*, (hawthorn or thornapple) are classified under woody plants. Evergreens, deciduous tress and shrubs, they all do great in full afternoon sun.

5.4.2.2 Grassland

Except cropland and woody plants, the natural vegetation of Holland is generally based on grassland and flowering plants (both wild and cultivated ones). The main types pf grasses are: *Poaceae* (true grasses), *Juncaceae* (rushes) and *Cyperaceae* (sedges).

Some examples for flowering plants that grow in Holland are: *Achillea millefoliu (*yarrow)*, Asteraceae (Daisy), Campanula rotundifolia (Harebell), Centaurea jacea (Brown Knapweed), Potentilla, Convolvulus arvensis (Field Bindweed), Crepis (Hawksbeard), Allium vineale (Wild Garlic, Crow Garlic), Galium verum (Yellow Bedstraw)*

Grasses and flowering plants, except the cereals, grow in moist and moderate climates and prefer diffused light. Direct sunlight exposure fades the colour of the leaves and flowers. The best treatment to get the better results is sun exposure during morning and watering in the afternoon shade.

5.4.2.3 Water Bodies

The configuration of forts (each is on an islet surrounded by water) creates a combination of water and wetland ecosystem. The flora of wetlands around the forts consists of: Lychnis flos-cuculi, (Ragged Robin), Prunella vulgaris (selfheal), Phragmites (common reed), Veronica (speedwell, gypsy weed), Sagittaria sagittifolia (arrowhead) *(Vesters and Baas 2003).* This flora provides a habitat for birds such as kingfisher, grebe and duck. For the fauna and flora of wetlands dehydration is not a problem. This makes water land ecosystem tolerant to strong sun; on the other hand, the design of closed spaces for these ecosystems must prevent strong sun exposure to eliminate moisture due to evaporation. Accordingly, the most appropriate sun exposure for closed spaces containing water bodies is morning sun.

5.5.2.4 Micro climates

The camouflage characteristic of the forts creates a special microclimate. The back of the fort which is covered with sand provides additional shadow and moisture. Some examples of the flora of the surrounding of the fort are: *Viola odorata (sweet violet), Thyme, Vicia (vetches), and Echium vulgare (Blueweed). (Vesters and Baas 2003).*

As a conclusion, one of the main goals of the transformation of the Defence Line of Amsterdam is the preservation of the natural richness of the area. While designing an addition to the forts, the specific sunlight needs of the plants must be incorporated. Only in this way the shadow of the additional building can be prevented from destroying the flora.

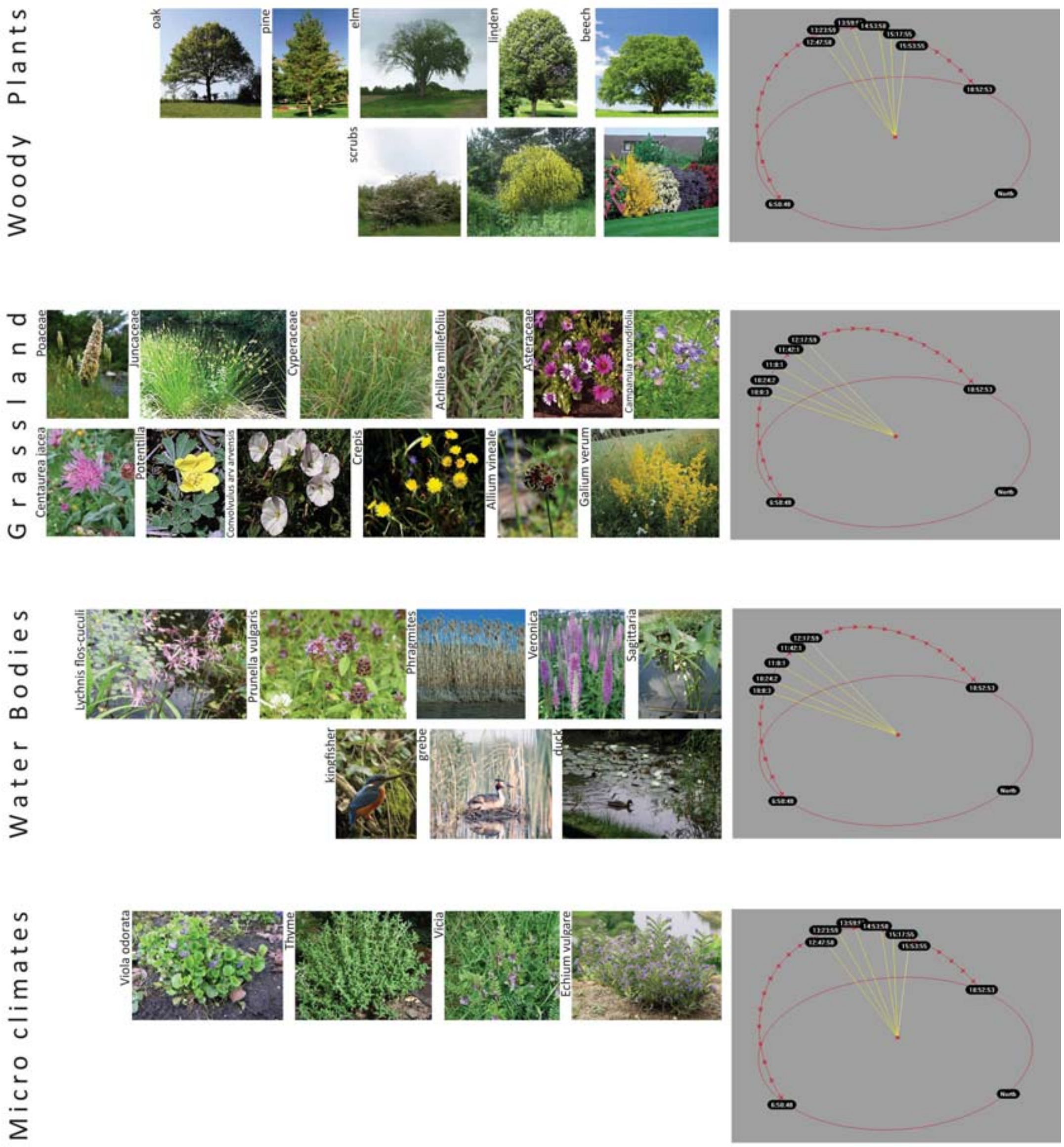


Figure 34: categorization of plants according to their optimum sunlight requirement

CHAPTER 6

PERFORMATIVE DESIGN MODEL

The transformation of the Defence Line of Amsterdam involves the transformation of 42 forts, which show similar characteristics but also some disparities. Due to the fact that the location of the forts is different, they require different transformations. A parametric model is defined for the transformation which consists of a series of parametric models through the design stages. This model is named 'performative design model' by the author. The choice of using parametric techniques is based on their capacity for creating design alternatives while managing the complex system of relationships. In other words, once parametric models are introduced, different design alternatives for different forts can be computed rapidly, in order to explore variations within their design solution space.

The performative design model is introduced to manage a network of dependency relationships between different stages of design. Through the parametric model a network of dependencies is described using two kinds of attributes, dependent and independent. The first kind is described by independent values which are inputs to the model. The other attributes are the ones that vary in relation to other attributes. The dependent attributes receive data from their related attributes. This flow of data keeps the network of dependencies consistent. While it remains constant, it processes the input values by generating variations of the output. These variations are produced as different solutions of the model and are called instances of the model (Turrin and Kilian 2009).

Grasshopper® software, which is used for the parametric design, allows the visualization of the network of dependencies along with the visualization of the geometry. Since besides the outputs, both inputs and data flow are also kept explicit, the designer is capable of both controlling the parameters and the dependencies of the network. If the designer does not like the results, he can adjust the parameters and the rules until they meet the initial objectives.

6.1 Parameterization and Articulation of the Model

In the previous section, the potentials of parametric techniques for generating geometrical alternatives are discussed. These potentials amplify the geometrical representation by providing a model of the design which is actually a large set of possible configurations of the parameters and dependencies. While working with such a complex system, the parametric models are introduced in stages. If it was a single compound model, it would take more time to compute for every simple parameters change. Instead, dividing the model into stages provides ease of intervention to the rules and parameters, while shortening computation time. The performative design model for the transformation is articulated in four stages which are parallel to the stages of a conventional design process. These stages are: regional design (1/50.000); urban design (1/1.000); building design (1/200); and the production of scale models.

After the definition of design states, the effort is moved directly to two other levels of the design: one is the parameterization process, which is preliminary to the computational generation of alternative solutions; the other one is the selection process among the large set of generated instances. Parameterization is the fundamental step. It is required to exploit the potential and advantages offered by parametric modelling. They are the definitions of the components of the model that vary and how this variation occurs. In other words, parameterization determines the attributes and the rules they are subject to follow (Turrin and Kilian 2009).

Parameterization describes the dependency chain used in the model, starting from independent parameters. The conceptual structure defined during the parameterization process is in fact the one that guides and determines the variation of the geometrical output. The result of the parameterization process is a dependency chain described as a hierarchical structure. This makes the earlier choice of model focus so important. The hierarchical structure is an abstract elaboration of the design which needs to be addressed through a selection of relevant criteria (Turrin and Kilian 2009).

The hierarchical structure of the model cannot be exhaustive since it cannot include all the design aspects or all the factors affecting the chosen aspects. It can also not allow explorations other than those following the stated dependency chain. The focus of the hierarchical structure is the essence that transcends the parametric modelling from being a tool to being a digital model (CAD, formation, generation, and performance, performative). This is especially so when the hierarchical nature of the abstract structure forms the conceptual stage of a design.

In chapter 5.2, the performance criteria for the transformation of the Defence Line have been established. The selection and definition of the interrelations during the earlier structuring of the model are set, according to these performance criteria, which were established after the regional and urban analysis done for the Defence Line. The model focus is based on performance as listed in Table 2.

Table 2: correspondence between building performance assessment levels and performance focus in each stage

	Level 1 performances	Level 2 performances	Level 3 performances
regional design (1/50.000)		provide adequate space for required functions	
urban design (1/1.000)		provide connections between urban elements	conservation of the UNESCO Heritage site
building design (1/200)	structural performance illuminative performance		
production of scale models			compatibility with the surrounding

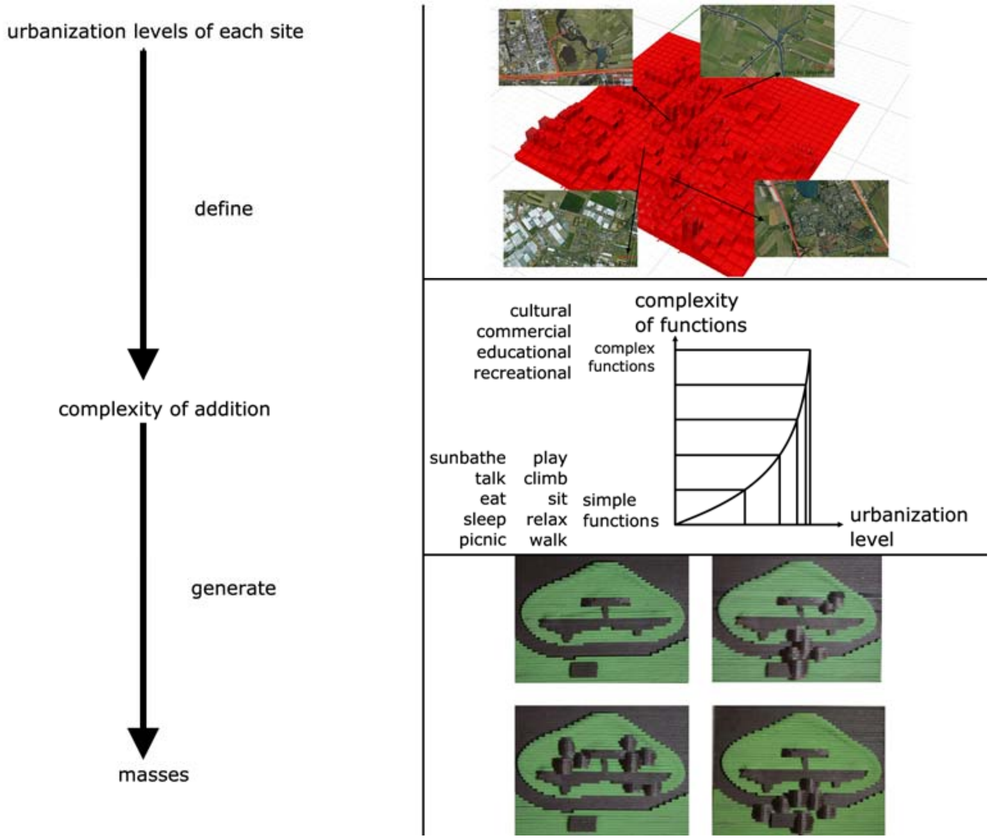


Figure 35: summary of the process for the first stage of model
a: computed urbanization levels
b: relationship between urbanization levels and complexity of functions
c: generated masses

6.1.1 Regional Design Stage

The first stage covers the parametric model used to calculate the urban levels for the Defence Line discussed in detail in chapter 5.2. The computed urbanization level for each site is used to understand the number of potential users, the scale of the transformation and the size of needed additions. The relationship between urbanization level of the site and complexity of functions shows an exponential relationship as illustrated in Figure 35 b. For instance, if a site has a transit point, then it provides connections to more transit points. Thus, the number of potential visitors to a site shows an exponential increase with the urbanization level.

The selection of a site in relation to urbanization level analysis model which is represented though the deformed height of grid cells (Figure 27) is the first input for the performative design model. This input is processed as the output of the definition of complexity of the addition and required area. The final step of the stage is the generation of masses according to computed area requirements, as illustrated in Figure 34c.

6.1.2 Urban Design Stage

The second stage of the performative model consists of two levels of independent parametric investigation: one is the definition of the relationship between the fort and the addition; the other is the connections between elements of the site and the urban environment. The fort and the addition can be related in three ways; across, front and back, as illustrated in Figure 36.

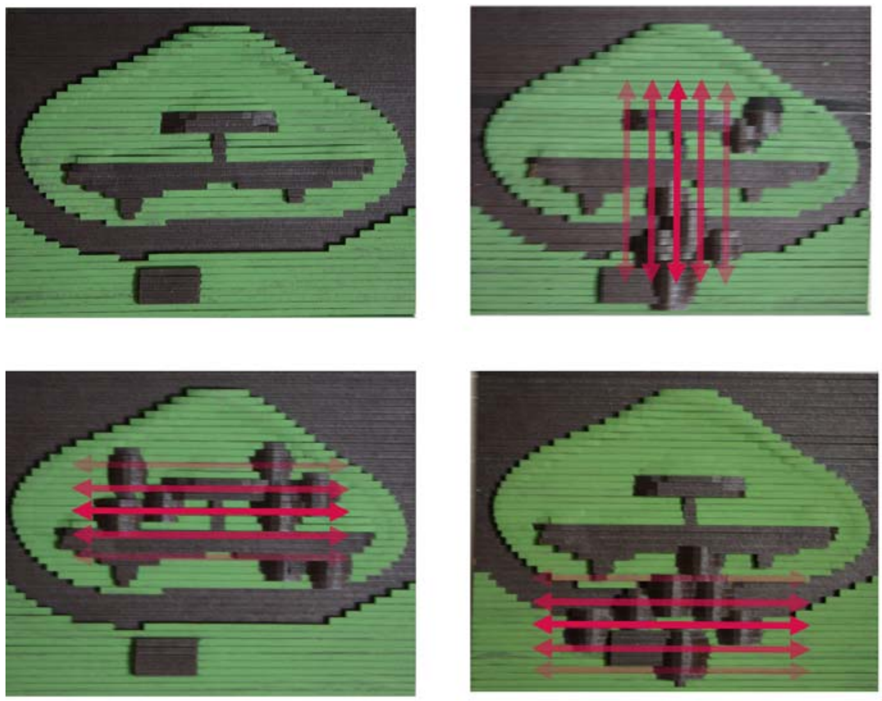


Figure 36: relationship between fort and addition, different configuration of masses according to desired relationships and connections between elements

Figure 37: satellite views of forts
a: transit points
b: urbanized areas

The elements of the site are the ring of water, the front fortress which is covered with sand, fortress, courtyard, bridge, shed, and defence dike as explained in detail in chapter 5. The elements of the urban environment are transit points (train stop, bus top, road, car park, marina...), urbanized areas (residential areas, industrial areas, greenhouses…), nature zones (water bodies, forests, grasslands and microclimates). Some of these urban elements are illustrated in satellite views of different forts in Figure 37. Elements of the site and urban nature are both variables for the connections.

The relationship between the fort and addition and connections between elements of the site and urban environment are parametrically independent. However, in real life they need to coincide with each other. For the success of the transformation the addition must provide the needed connections between elements and desired relationship to the fort. Definitions in levels 1 and 2 act as attractors for the masses. As seen in Figure 36, the masses generated in the first stage of the performative model are translated according to the definitions in the two levels of the model in this stage. Different configurations of the needed volumes are created as an output of this stage.

This stage of the performative model enables generation of designs having different relationships to the original structure. Dissimilar architectural points of views are created regarding the conservation of forts. The production of digital and physical models (in the final stage of the model) allows the quantitative and qualitative analyse of the different configurations. Due to this, the performative model promises success for the conservation of this UNESCO heritage site.

6.1.3 Building Design Stage

Two independent parametric models have been defined for the building level stage. First model is to compute catenary arches; and the second one is to compute sunlight angles according to time and date.

6.1.3.1 Computing Catenary Arches

A parametric model is structured for the definition of catenary arches based on their equation and structural properties described above in section 5.4.1. First step for the parameterization is to translate the interdependent variables (a, x and y) into architectural properties. In an arch, the parameters that define a space are span and height of the arch. Bearing the graph of catenary arch (Figure 29b) in mind, these parameters of an architectural arch corresponds to distance between maximum and minimum values in x axis and minimum value in the y axis. Therefore, the first input for the parametric model for a catenary arch is assigning “two points” for maximum and minimum values in x axis to control the position of supports. Then, the “pole position” controls the minimum value in the y axis, which is chain length. The input named as “steps” is the number of points that are computed according to the catenary equation.

The increase in the number of steps brings about more accurate results. The outcome of assigning different values for these attributes is shown in Figure 38.

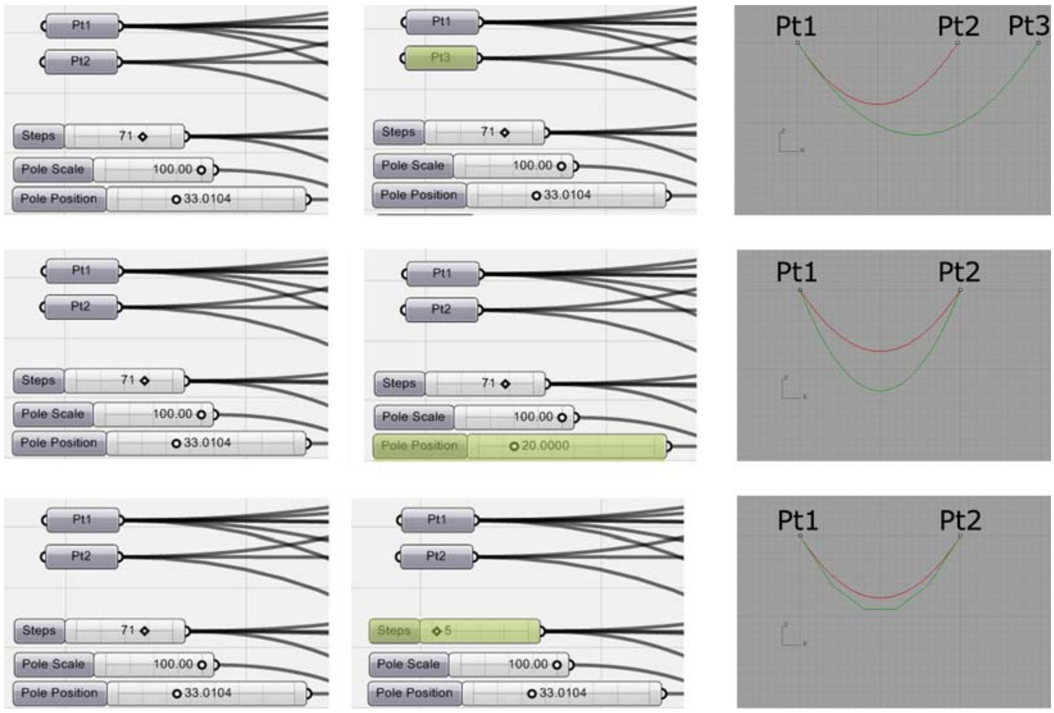


Figure 38: output of catenary definition
a: different points with same pole position and steps
b: different pole positions with same points and steps
a: different steps with same points and pole position

A lot of similar parametric models can be found online for the definition of catenary arches; however, none of these are adequate to define catenary arches for the performative design model. Deformed stripes consisting of series of catenary arches must create a hill like architecture as an extra layer to the existing topography. Therefore, this stage of the performative model must go beyond the computation of the form of a chain, which is supported by its two ends and acted on only by its own weight. The interdependent variables of a, x and y must be fed parametrically to achieve continuous deformed stripes from catenary arches as decided in the conceptual design of the transformations.

A collection of line segments are defined in this stage, as a base for the position of the supports of the catenary arches. In Figure 39 different collections of line segments are illustrated. The exact places of the support points are the intersections of line segments and generated masses. (These masses are generated in first stage of the performative model and translated in the second stage.) The heights of the arches are dependent on the height of the masses. The definition of support points and height of the arches are illustrated in Figure 40.

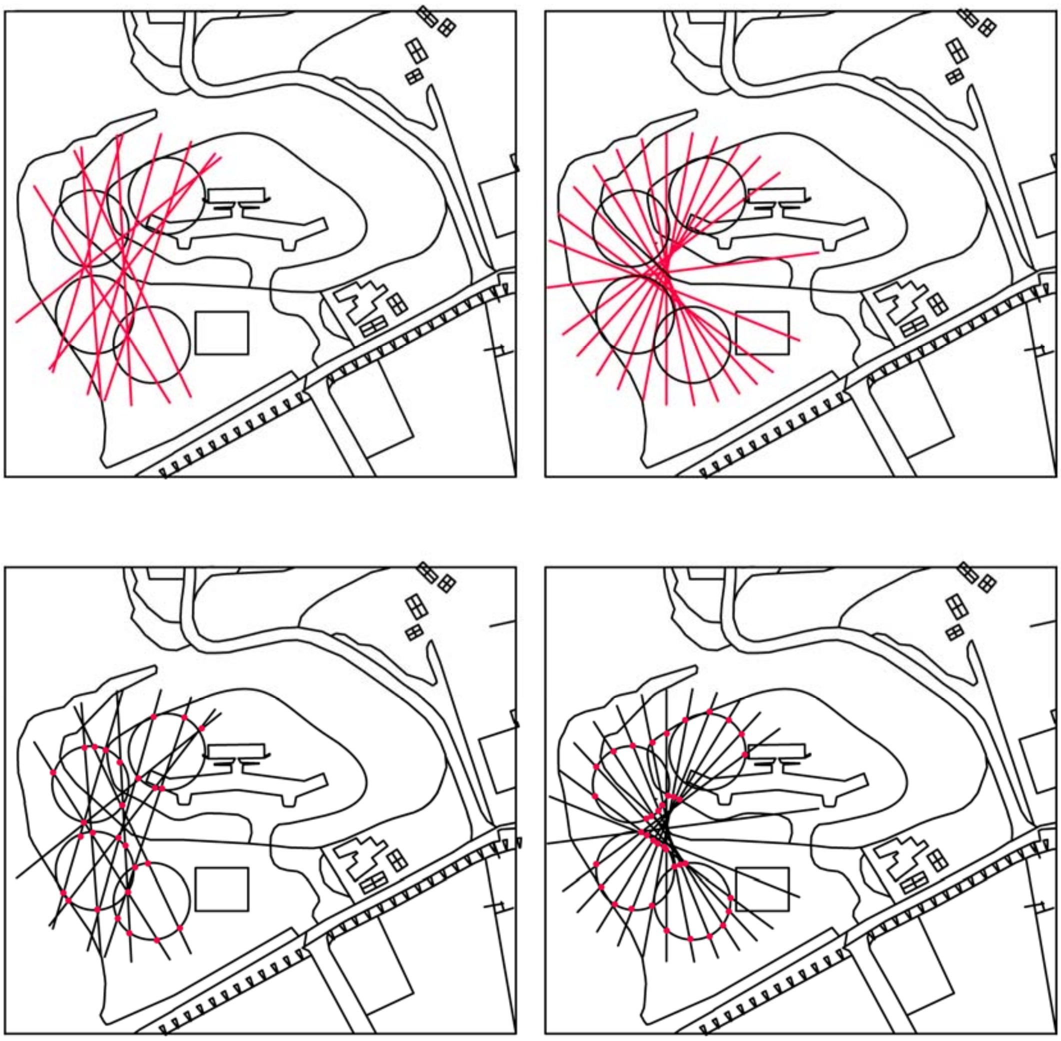


Figure 39: process for different collection of line segments
a: different collections of line segments
b: intersection points for the definition of supports for catenary arches

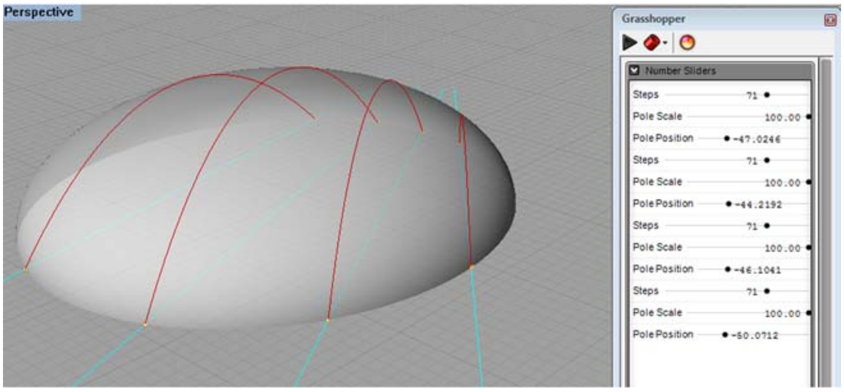


Figure 40: definition of support points and height of the arches

The only constraint for the catenary arches is the maximum span. The distance between positions of the supports must be shorter than 45 meters. The designer controls the line segments manually and intuitively to make the arches fit the constraint. In addition to this, choosing better defined spaces is also the fundamental criteria for the designer in the control of line segments.

6.1.3.2 Computing Sunlight Angles

For the third stage, the second model consists in computing sunlight angles. This parametric model is important for the generation of needed spaces of the greenhouse according to their sunlight needs. For this reason, a model is structured to calculate the sunlight angles according to changing time and location. Parameters related with time are year, month, day and hours; and parameters related with location are longitude, altitude and time zone of the location. Two other parameters (scale and north angle) are added to control the match between Rhino drawings of the site and the sunlight algorithm. An example of output of the model is illustrated in Figure 41.

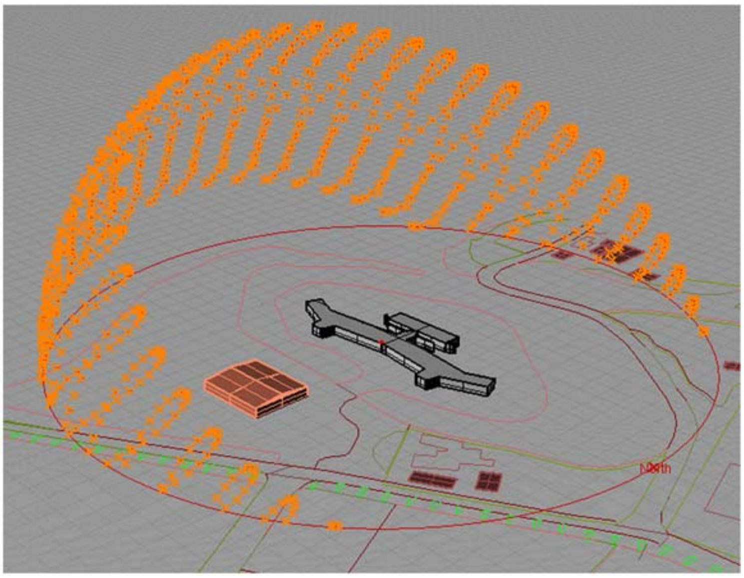


Figure 41: output of the model positioning of the sun through a year

The VB script used for the model is based on the program developed by the University of Oregon Solar Radiation Monitoring Laboratory (University of Oregon 2011). The Grasshopper® model used for computing sunlight angles are used in reference to the studies of the “ateliernGai” which is an experimental design and research studio in the department of Architecture at Rensselaer Polytechnic Institute (Atelier nGai 2011).

The computed sunlight angles are not used only for analysis. Along with the catenary arches, they are the generative factor of the form of the addition for the fortress. The output vectors of this model are matched with the categorization of plants according to their sunlight needs in chapter 5.4.2. The locations of matches define the voids of the form that lets sunlight inside, and the catenary arches define the solid parts of the form which works as a structural system.

In chapters 6.2 and 6.3 the results of different relationships these two models (catenary arches and sunlight angles) are discussed under the headings of “Instances Set One” and “Instances Set Two”.

6.1.4 Production of Scale Models Stage

Assigning fixed values for the attributes in the first three stages of the model results in a generated form for the addition to the selected site of Defence Line of Amsterdam. The final stage is the conversion of this 3d model to the 2d files for the CNC cutter. This parametric definition enables production of physical models from 1/1000 to 1/200 scale.

In each scale the presentation requires different level of detailing. Before conversion to 2d, some preparatory steps are necessary according to the scale of the model. In models of 1/500 scale and bigger, after the union of the stripes, the overlap in the intersections must be solved. In 1/200 scale models, the supports must be placed, and in addition to this the creation of the niches (Figure 42) on the site are necessary. This is due to ease of assembly of the stripes.

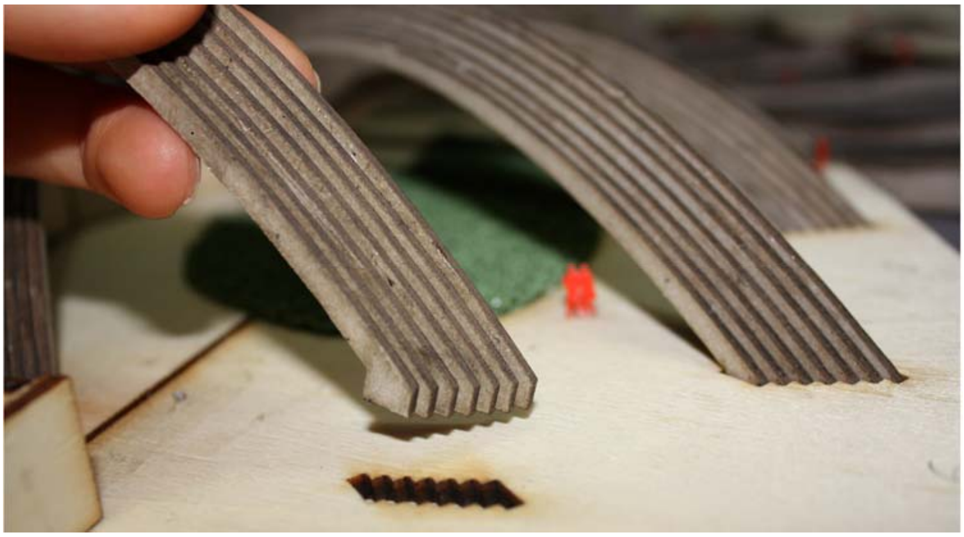


Figure 42: niches on the site to ease assembling

After these final modifications to the 3d model, the contouring of the form through 2d sections can be done. The basic parameters for contouring are scale, angle and spacing. “Scale” defines the desired scale of the physical model. “Angle” defines the rotation angle of the orthographic cut planes to the reference surface. “Spacing” defines the uniform distance between the sections. For a model with smaller scale, the rotation of the angle plane has a single value. For larger scales, where the representation of the stripes is more visible, the attributes for the parameter “angle” are multiple. The contouring for the each stripe must consist of the sections that are parallel to the stripe. Therefore, the rotation angle of the orthographic cut planes must be perpendicular to the stripes. In addition to these, the model also offers an automated layout to organize the generated sections for fabrication including labels. Some examples of the results are illustrated in Figure 43.

Production of scale models does not have to be the last stage of the performative model. 1/1000 scale is proper to visualize the results of previous stages as seen in Figures 36 and 43. On the other hand, 1/500 and especially 1/200 scales are proper for investigating compatibility with the surroundings and relationship with existing elements of the site. If the results are not favoured, the designer can go to the parameterization stage to change rules, the relationships between rules and parameters of the attributes. This topic will be discussed in detail through two examples (instances set one and instances set two) below.

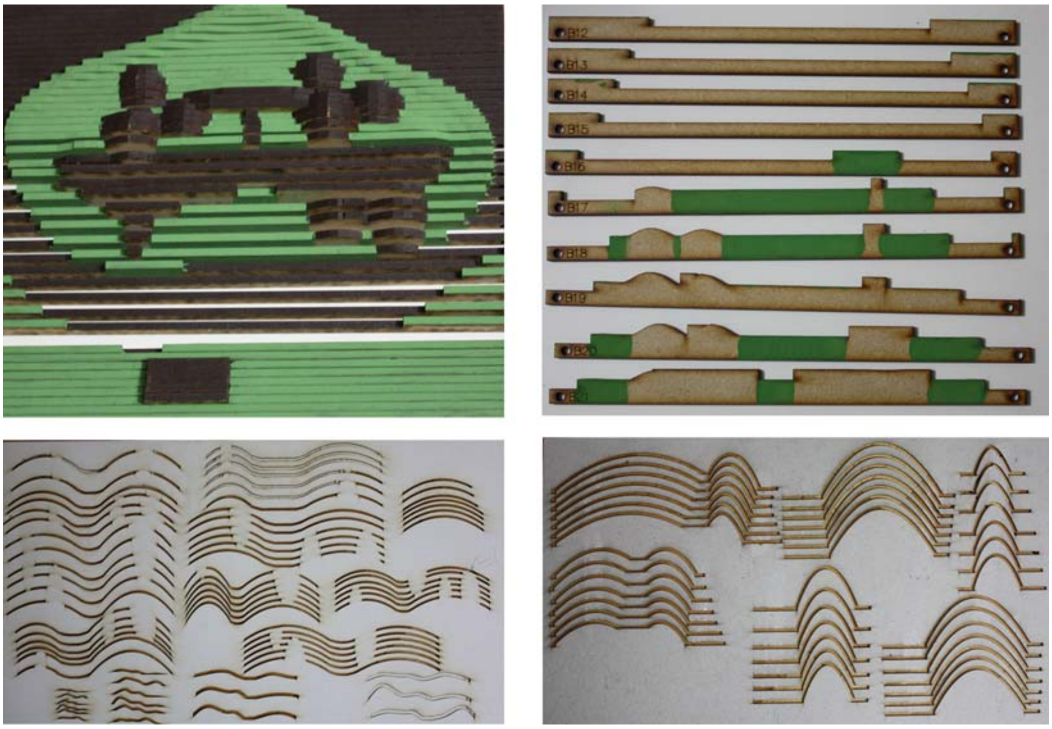


Figure 43: process for different collection of line segments
a: 1/1000 model
b: 1/500 and 1/200 model

6.2 "Instances Set One": Performative Model Elaborated Through the Transformation of the Fort near Penningsver using Preliminary Dependency Chain

The dependency chain of the performative model is described through parameterization and articulation. Figure 44 illustrates the preliminary dependency chain. Open ends of the chain, which act like inputs to the model, are independent variables.

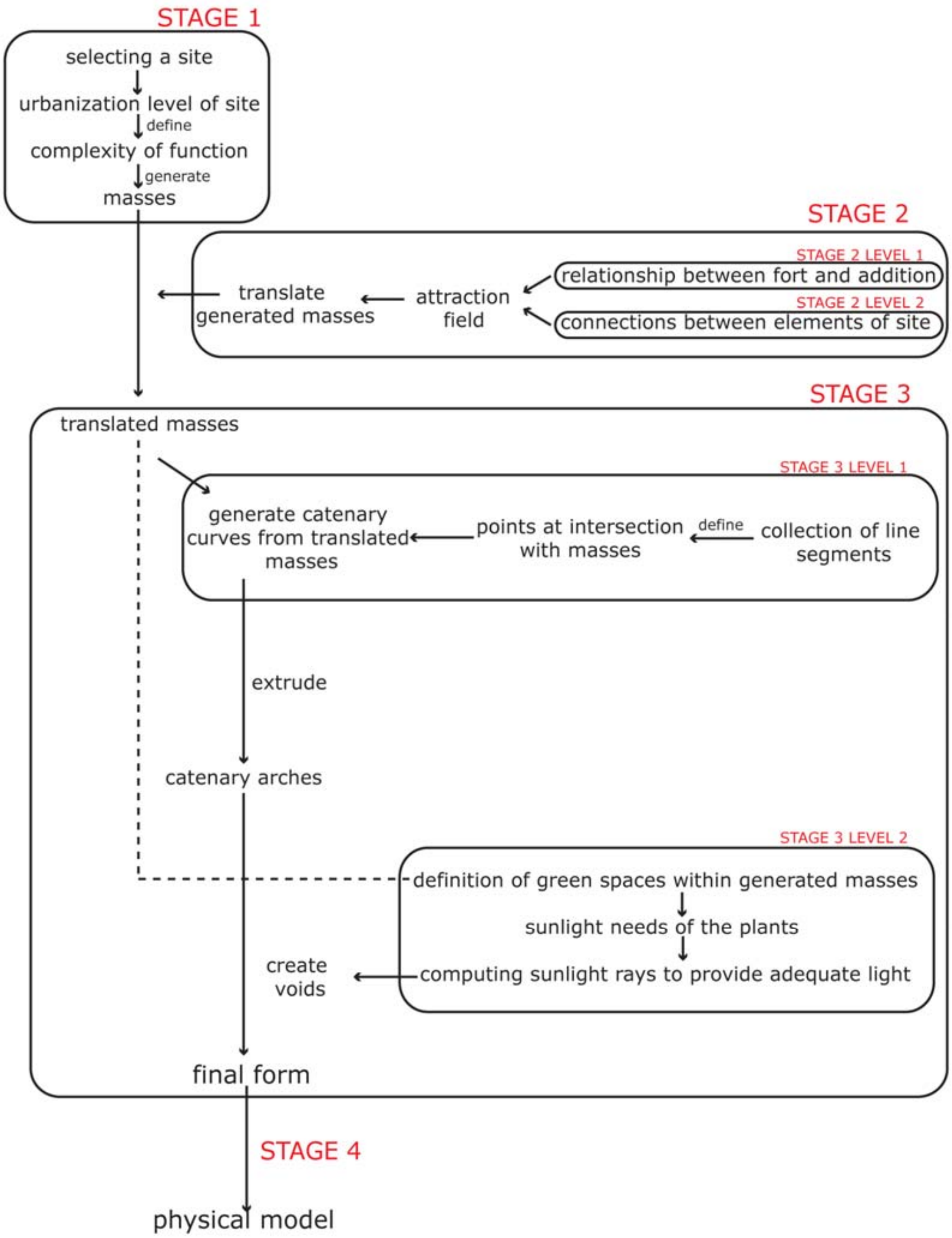


Figure 44: the preliminary dependency chain

In this phase the performative model is ready to generate the first outputs and to assess the performance of the outputs which will also indicate the success of the performative model. The outputs which are generated from this dependency chain are named "instances set one". An example output from this set, referred as instance one (i1), is studied in detail to illustrate how the dependency chain works.

Stage 1:

The first input for the model is the selection of a site. The fort near Penningsver, which are shown in satellite views in Figure 45, is chosen due to its high urbanization value; therefore the transformation of the fort requires addition to provide space for cultural, commercial, educational and recreational functions. As explained in Chapter 6.1 the conceptual idea for transformation is turning the Defence Line into a greenbelt around Amsterdam. Accordingly, the fort near Penningsver is turned into a botanical garden. While defining the program of functions, the primary input is the high urbanization value of the site. The diagrammatic summary of process for stage one is illustrated in Figure 45.

The fort near Penningsver is transformed into an attraction point as a botanical garden; moreover it is a transit point and provides connection to other forts in close vicinity by means of boat tours, biking and hiking trails. It is used by two groups of users: those that use the fort as a transfer area that connects the urban elements or within the site, and visitors who aim to do sight-seeing and spend time around the fort. Based on these factors, the program for the botanical garden is as listed in the Table 3. Figure 46 shows the bubble diagram of program elements and relationships between them.

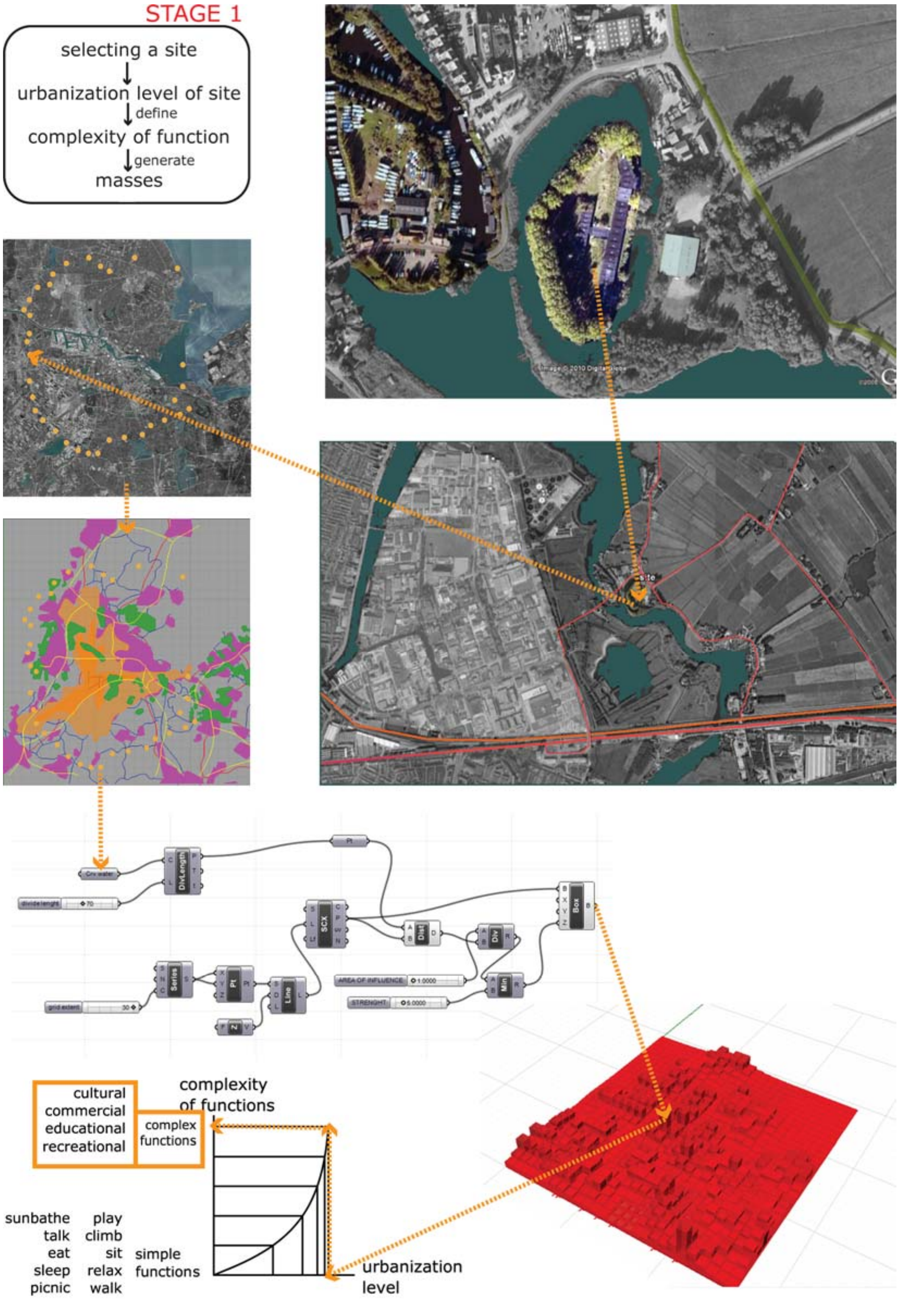


Figure 45: diagrammatic summary of process for stage one
-satellite view of for near Penningsver
-inputs for computation of urbanization levels
-urbanization level of site
-complexity of functions that corresponds the urbanization value of site

Table 3: program for botanical garden

	outdoor functions
transportation points	car and bike park dock for small boats marina
urban furniture	sit relax sunbathe sleep
walk	bridge connecting site to dike over road bridge connecting site to marina over water
play	children's' playground skate park cross cycle park

	indoor functions
entrance	info desk wc's and lockers botanical garden shop
café	kitchen service space food storage
educational	workshop rooms presentation rooms plantal growing demonstration rooms meeting rooms
compartmentalisation of nature as exhibition spaces	grassland forest water body microclimate
storage	service entrance loading/unloading receiving office botanical maintenance materials storage
rooms for administration and staff	

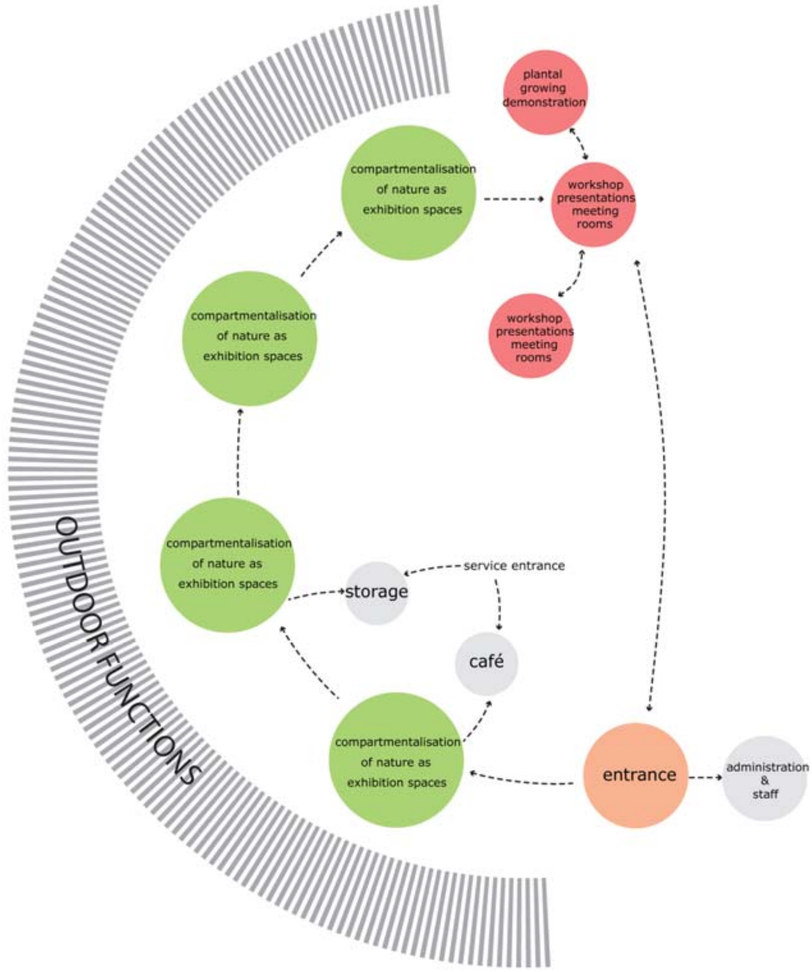


Figure 46: bubble diagram of program elements and relationships between them

Stage 2:

The relationship between the new building and the fort is initially planned as an indirect connection. The new building is intended to connect the marina to the car park. This configuration detached from the fort creates a lateral relationship with the fort in plan while connecting the dike to the marina. The masses that provide adequate space for these functions are translated according to the definition of the relationship between the fort and addition and connections between elements of the site and urban environment, as illustrated in Figure 47.

Stage 3:

The formation of the final form from the mass structure involves the procedures of stage 3, which are explained in detail in Chapter 6.1.3. The two levels of this stage, one for the structure and one for the voids, are defined as two independent parametric models in the dependency chain. In other words, the computation of catenary arches and formation of voids in the structure according to sunlight angle, are defined separately. Figure 48 illustrates the formation of catenary arches in relation to translated masses and a collection of line segments. Consecutively the voids are created to provide adequate sunlight for the compartments of the botanical garden, as also illustrated in Figure 49.

Stage 4: The last stage of the performative model enable the production on the 2d files for the CNC laser cutter to assemble a physical model with 1/500 scale as seen in Figure 48.

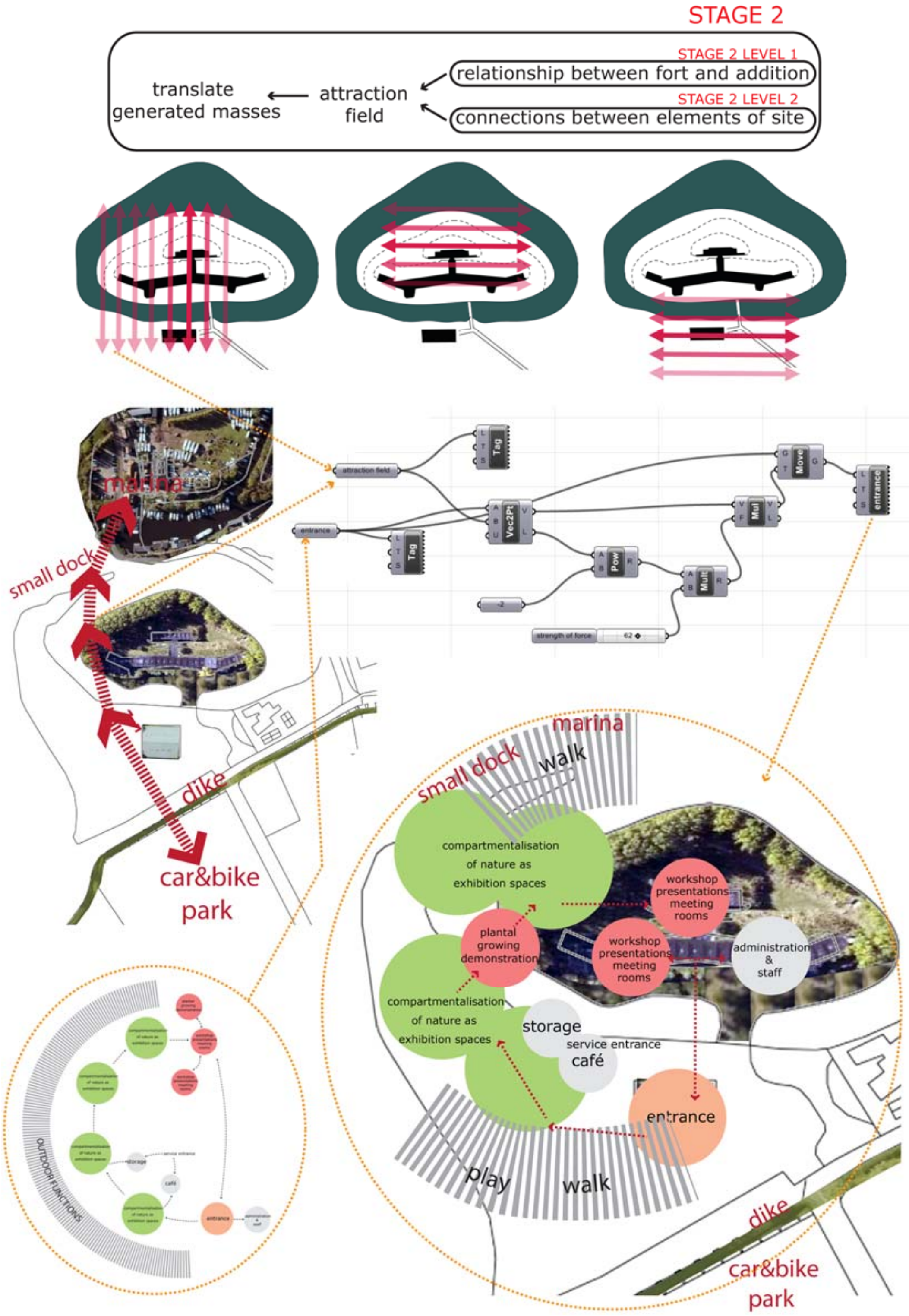


Figure 47 diagrammatic summary of process for stage two
-Level One: definition of the relationship between the fort and addition
-Level Two: connections between elements of the site and urban environment
-reconfiguration of masses according to attractors

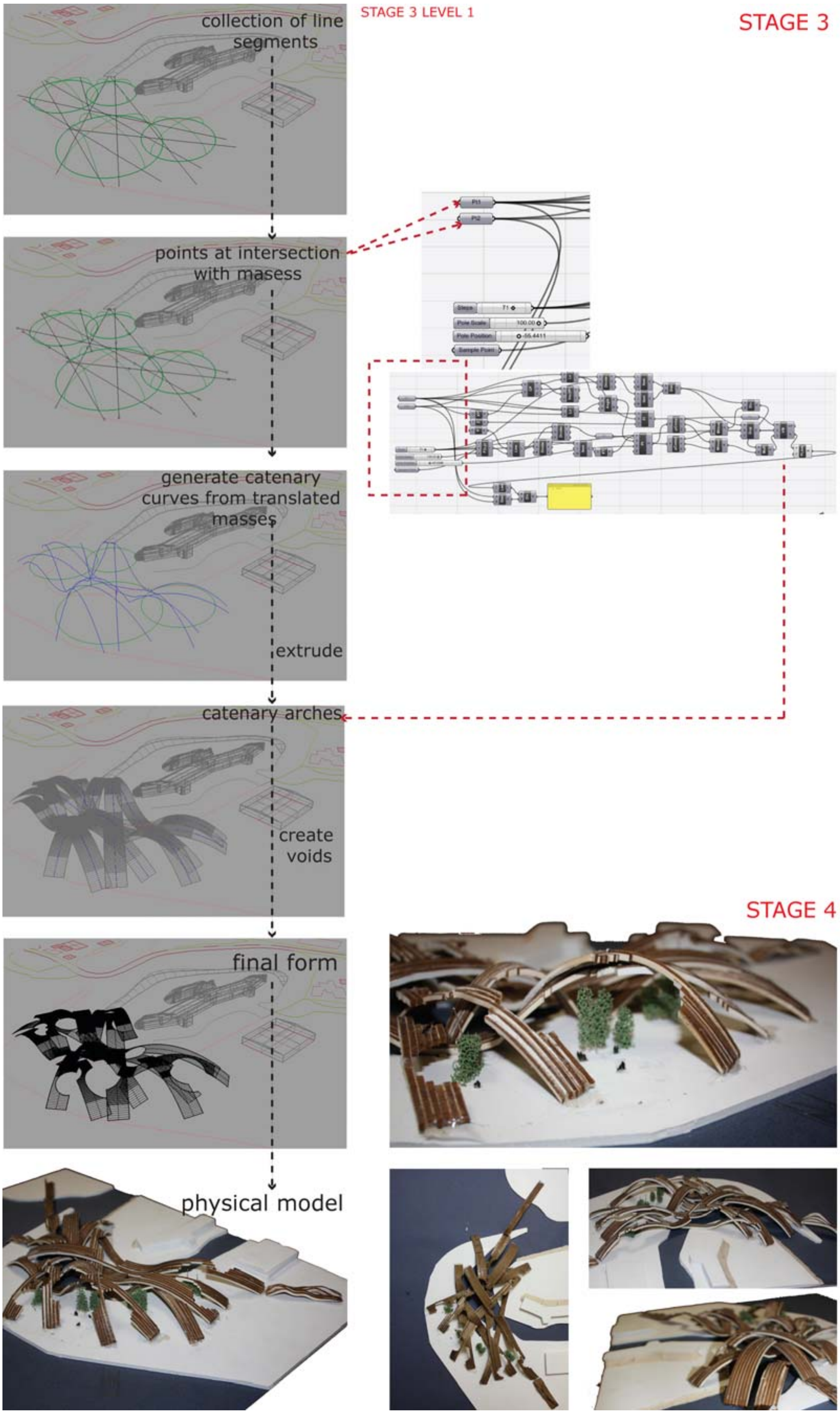


Figure 48: diagrammatic summary of process for level 1-stage three and physical model

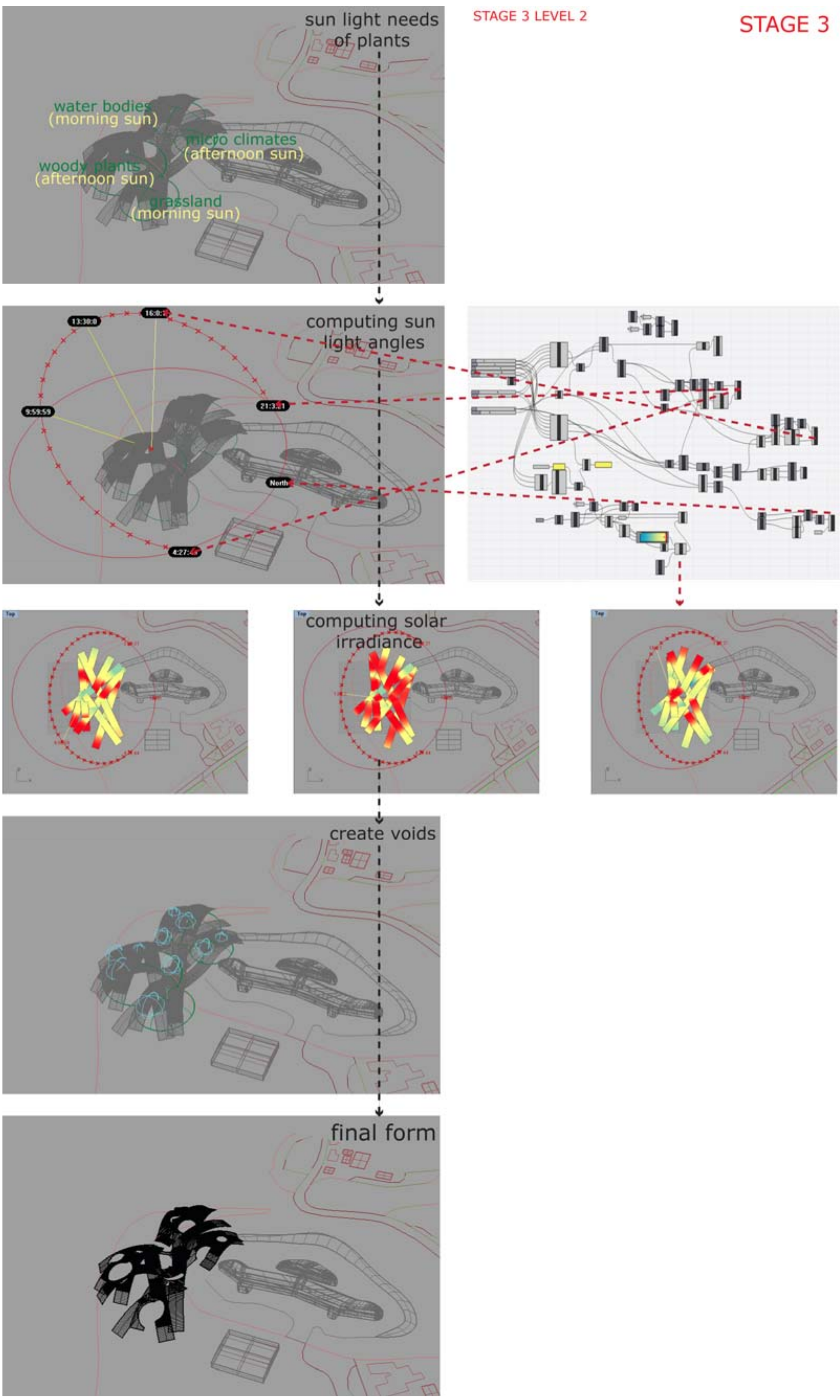


Figure 49: diagrammatic summary of process for level two stage three

Instance one is a preliminary design as an example of a process that results in a form that does not fulfill the performance criteria. It fails in revitalizing the fort as a new attraction point for users. The intention was to give minimum impact to the fort by designing a new fully detached building; therefore, the new building does not provide any direct connection to the fort. This attribute does not provide an advantage in the transformation of the fort; on the other hand it creates a disadvantage by not directing the users to experience the fort.

Independence of levels one and two in the third stage of the model results in non-satisfactory output. The voids computed according to solar nutrition of plants bring about a weakening of the arches. The catenary arches can no longer be an ideal form due to the holes for solar gain. The random collections of line segments for the catenary definitions results in non precise definition of interior spaces. Due to this the intersections of the arches are not geometrically well-defined.

The performance of instance one related with the conservation of the site and structural behaviour requires alterations in the second (urban design) and third (building design) stages of the performative model.

6.3 "Instances Set Two": Performative Model Elaborated Through the Transformation of the Fort near Penningsver using Improved Dependency Chain

The lacking points of instance one have been overcome with two very quick interventions to the performative model: a parameter change and a dependency change in the hierarchic structure of the model. The improved version of the dependency chain is illustrated in Figure 50. The outputs which are generated from this dependency chain are named generated instances set two. An example output from this set, referred to as instance two (i2), is studied in detail to illustrate how the dependency chain works.

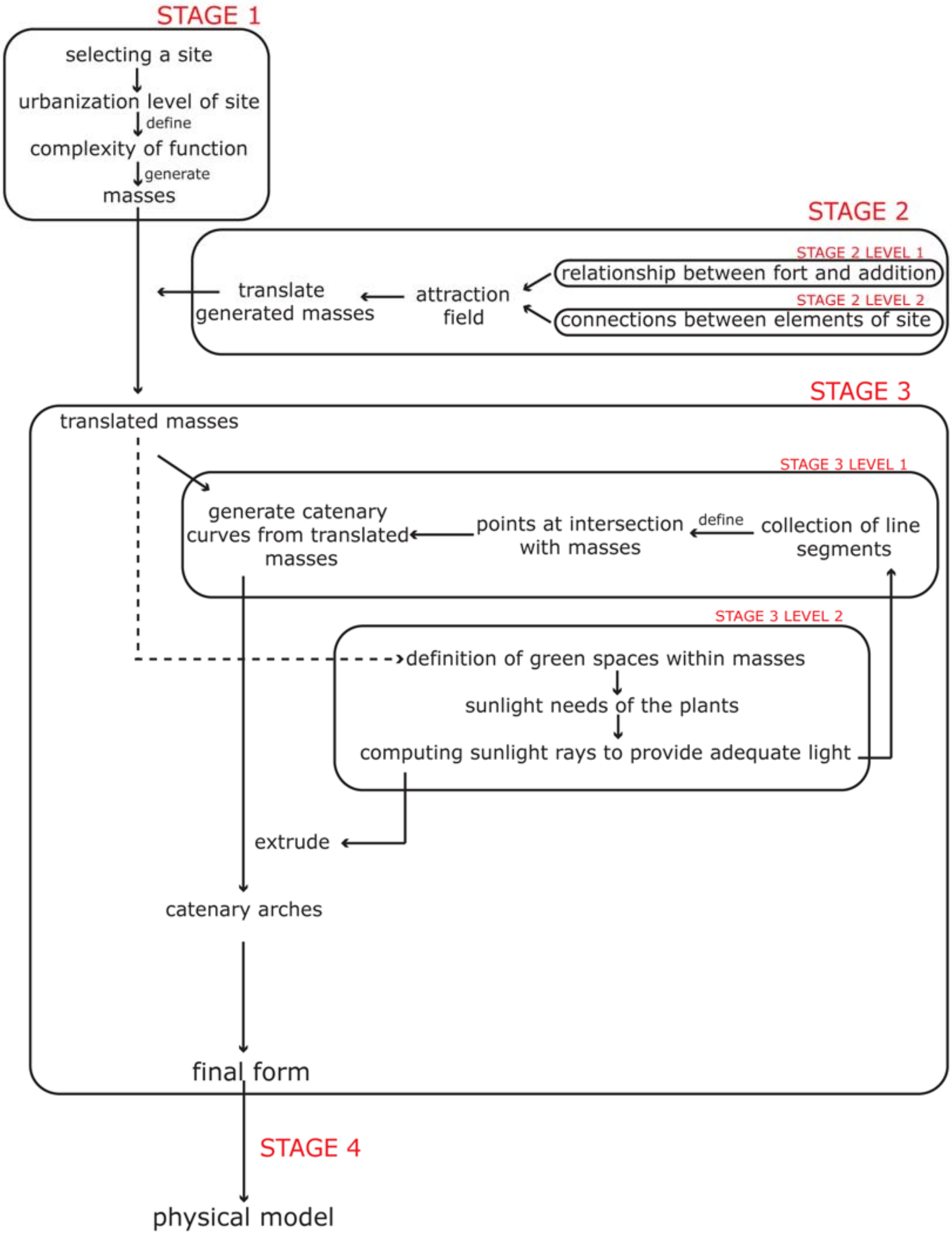


Figure 50: the improved dependency chain

Stage1:

Instance 2 like instance 1 covers the transformation of the Fort near Penningsver. Therefore the first stage of performative model is the same as for the previous dependency chain; which means urbanization level, complexity of functions, potential users, program for the functions, and generated masses are identical.

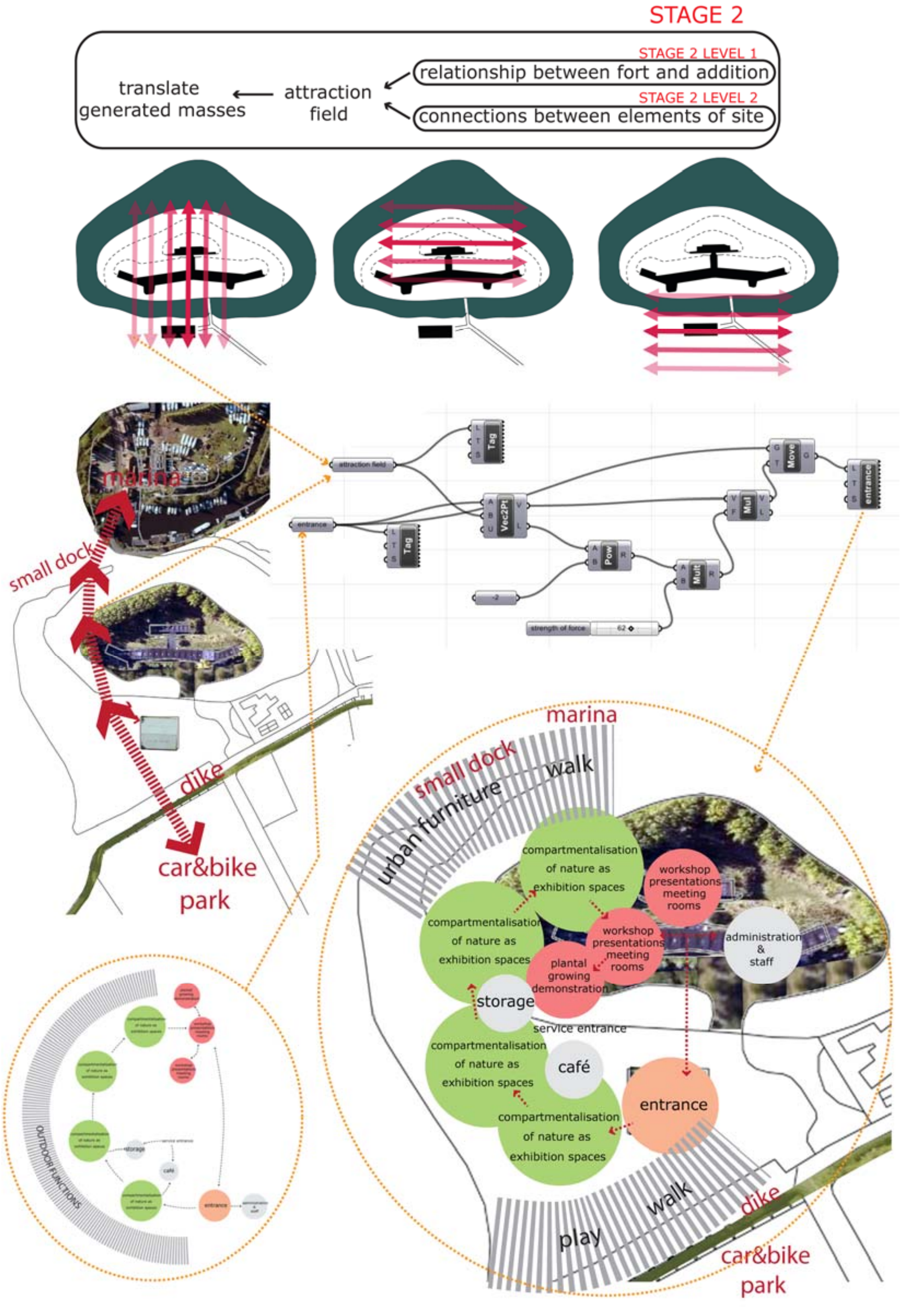


Figure 51: diagrammatic summary of process for stage two
-Level One: definition of the relationship between the fort and addition
-Level Two: connections between elements of the site and urban environment
-reconfiguration of masses according to attractors

Stage 2

The only change in the second stage is in the attribution of the parameter that controls the gradual relationship between the addition and the fort. In Grasshopper® software this alteration corresponds to a change in the attribution for the number slider that control lateral configuration. The desired connections between urban elements and elements of the site are the same in the second level of this stage. The diagrammatic summary of the process for stage two is illustrated in Figure 51.

Stage 3:

The main difference of the improved dependency chain is in the hierarchical structure of the two levels in the third stage of the design. The collection of line segment which define the support points for the catenary arches is not an independent value anymore. In plan, they are generated as perpendicular line segments to the computed sun rays, as illustrated in Figure 52. In section, the process of generating 3d arches from 2d catenary curves is not done with basic extrusions in y and z directions. The catenary curves are turned into 3d arches by extrusions parallel to the computed sun rays. The diagrammatic summary of process for stage three is illustrated in Figure 53 and 54.

These alterations in the hierarchic structure of performative model are achieved by defining new dependencies between the outputs of level 2 and inputs of level 1 in the third stage of design. In Grasshopper®, these dependency changes can be done very easily.

Stage 4:

This stage, aiming at the production of a physical model uses the same dependencies as instance one. However there are some parameter changes, such as scale. A smaller scale (1/200) is preferred in order to show more detail in the model. Assembling the model from CNC laser cut pieces is shown in Figure 55.

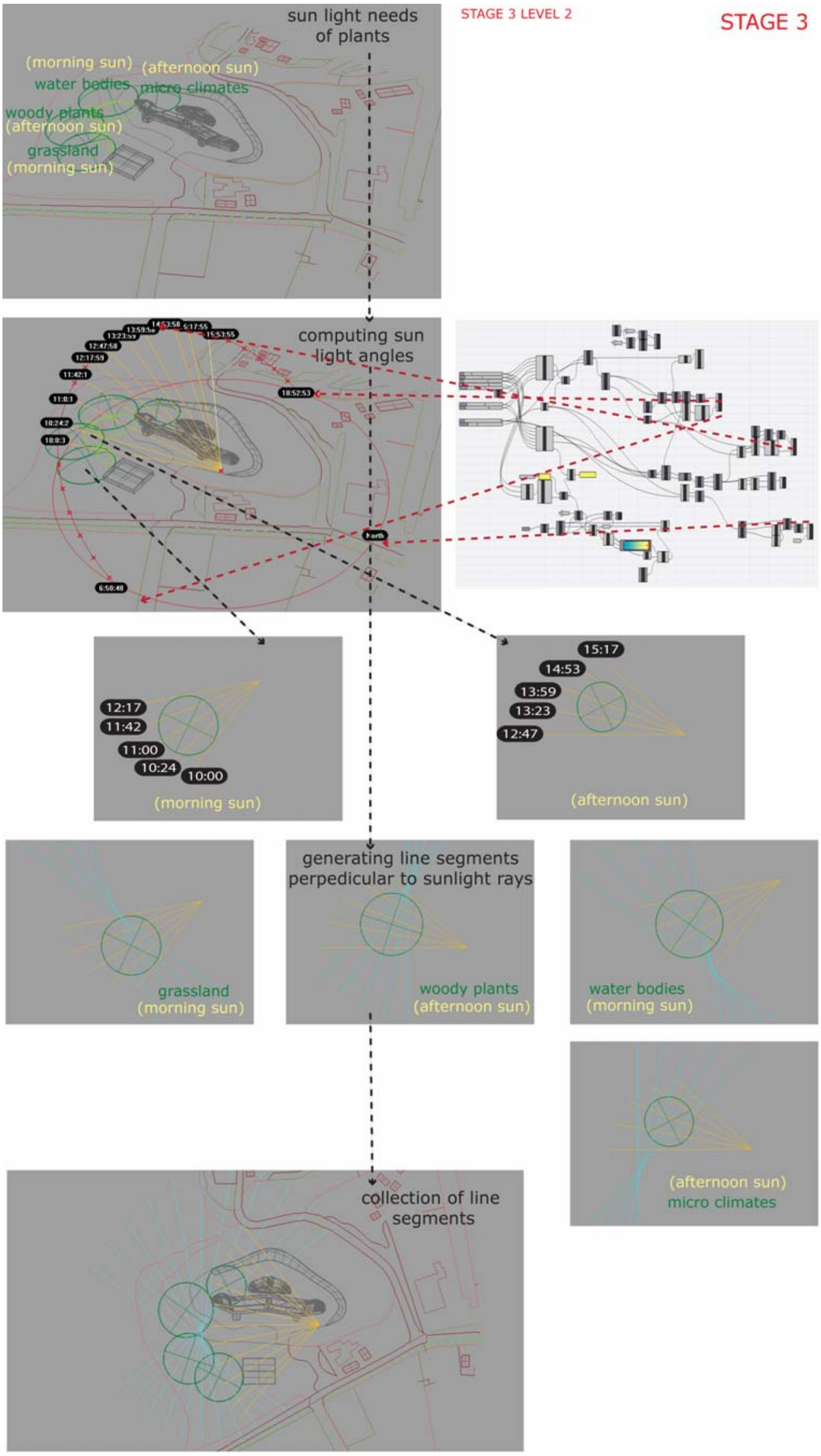


Figure 52: diagrammatic summary of process for level two stage three

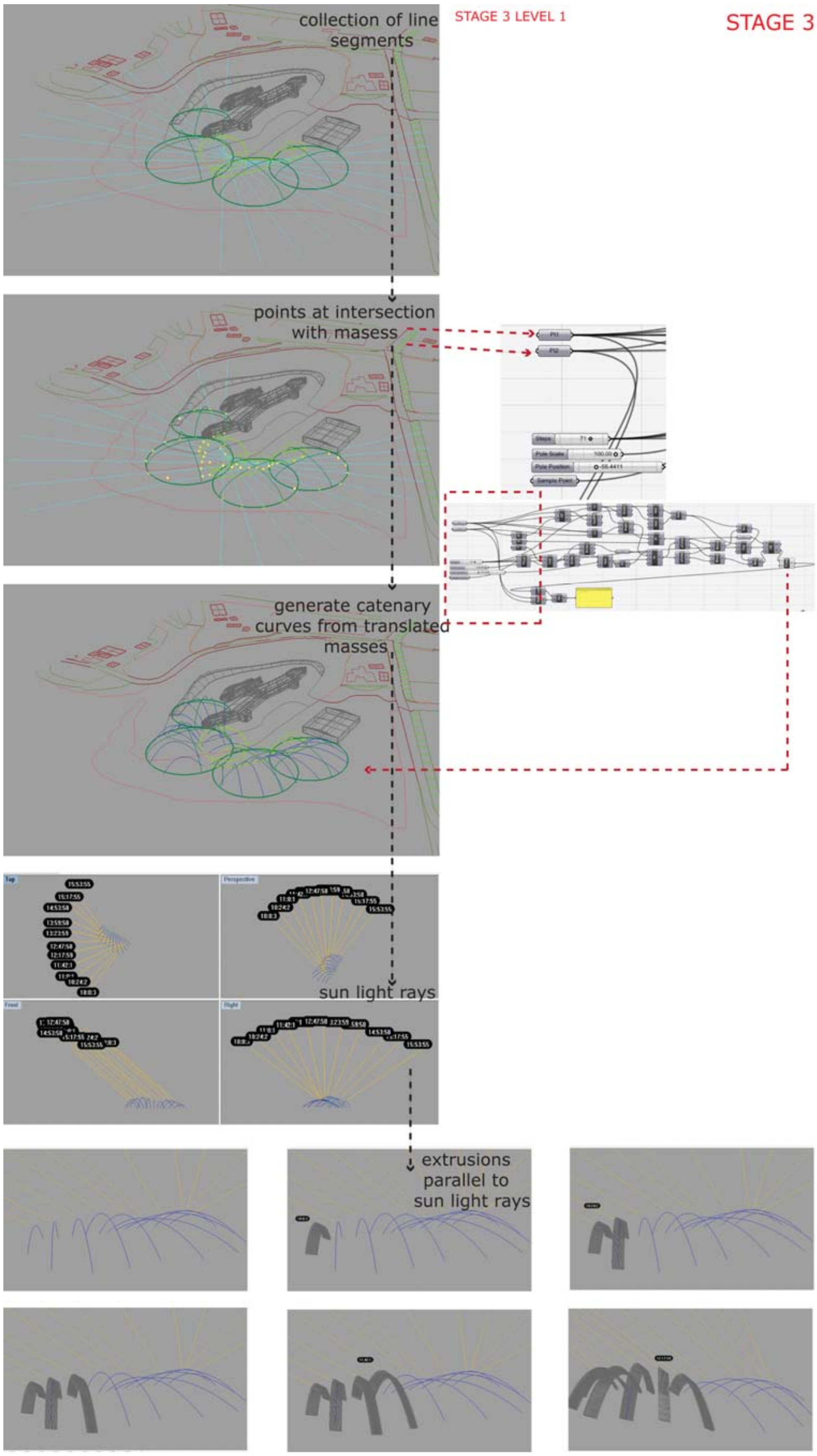


Figure 53: diagrammatic summary of process for level 1-stage three and physical model

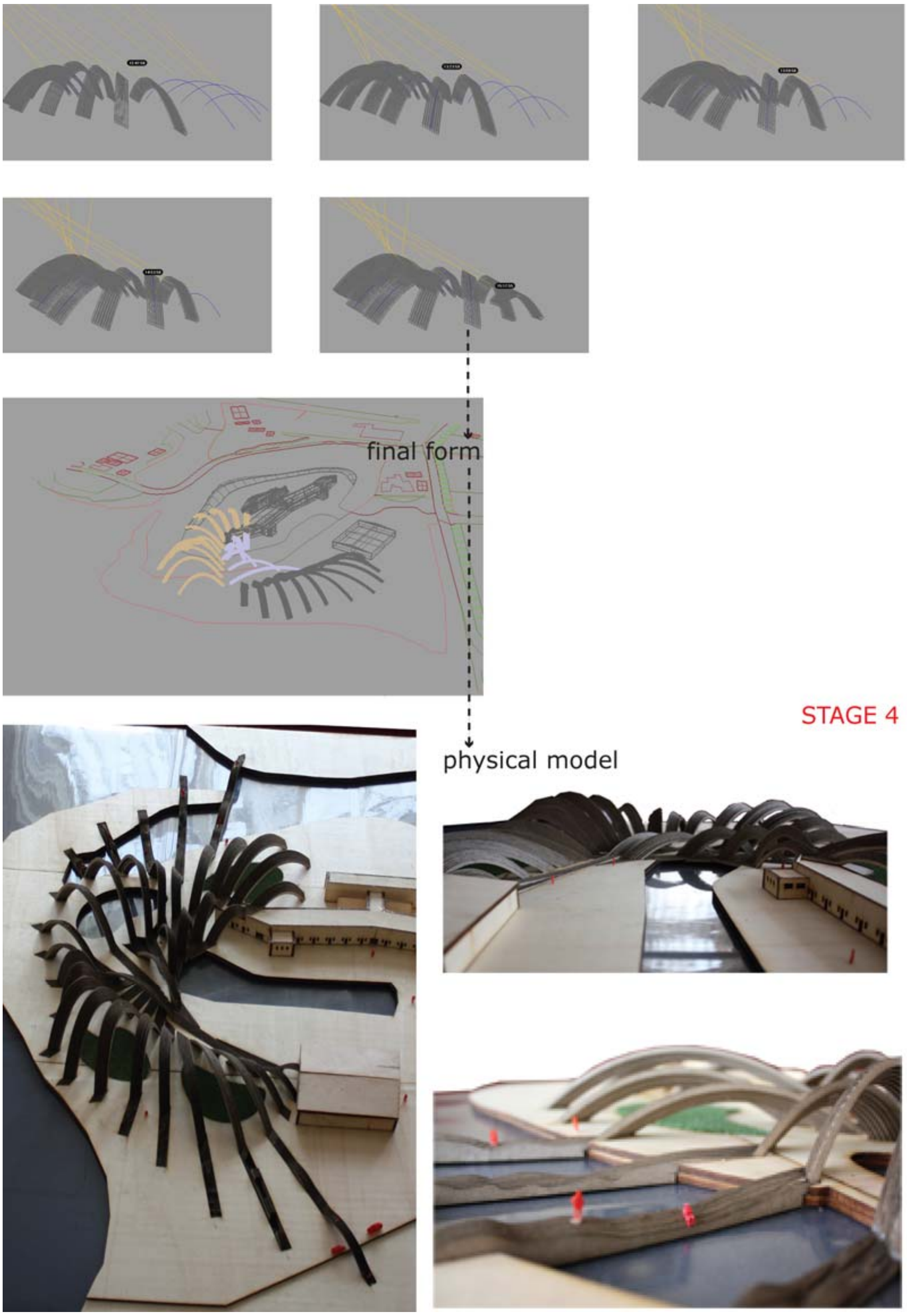


Figure 54: (continued) diagrammatic summary of process for level 1-stage three and physical model

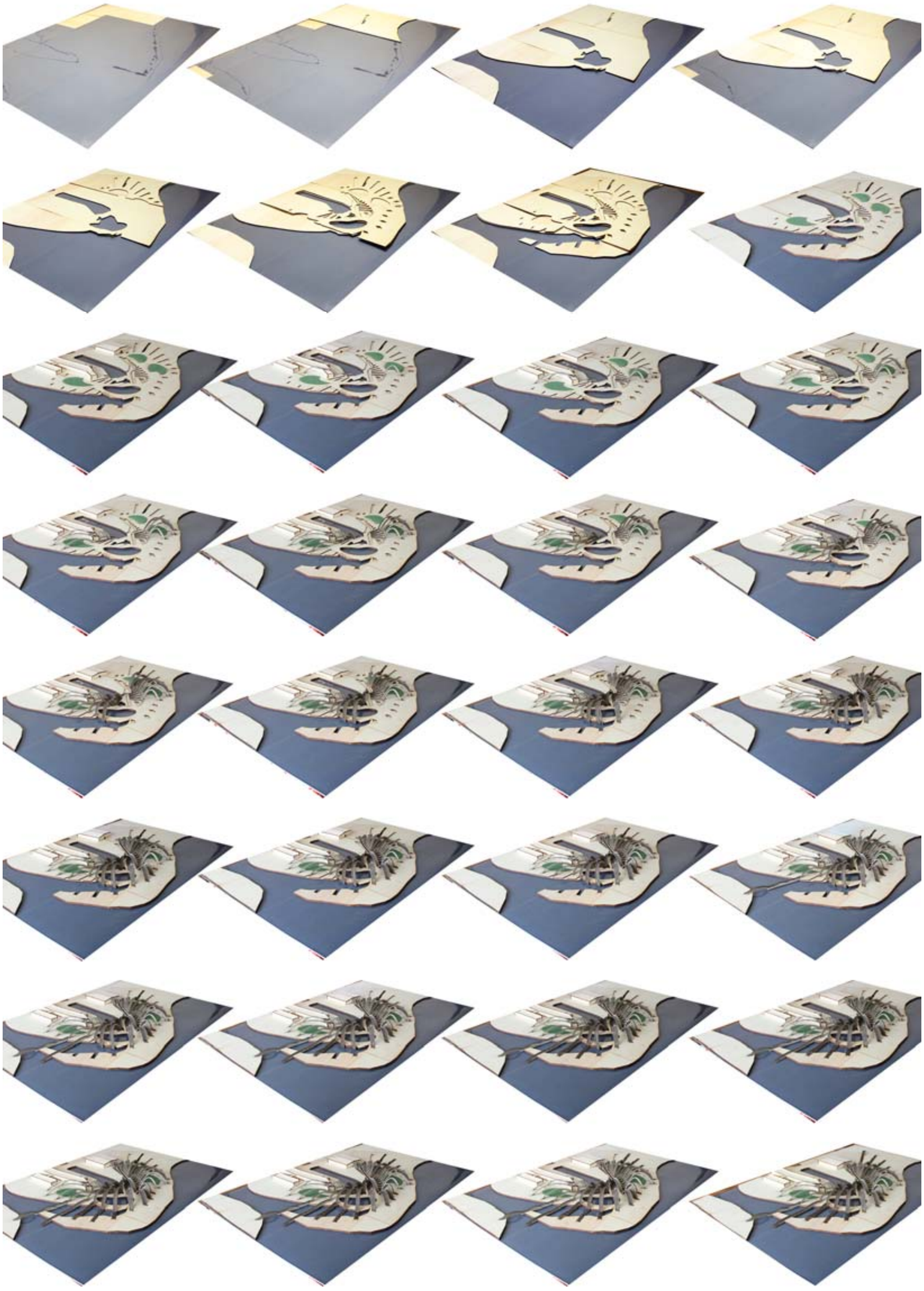


Figure 55: assembling of pieces of the physical model

CHAPTER 7

CONCLUSION

> Performative architecture is not a way of devising a set of practical solutions to a set of largely practical problems. It is a "meta-narrative" with universal aims that are dependent on particular performance-related aspects of each project. Determining the different performance aspects in a particular project and reconciling often conflicting performance goals in a creative and effective way are some of the key challenges in this approach to architecture. (Kolarevic 2005).

This definition of Kolarevic from the book "Performative Architecture Beyond Instrumentality" for performative architecture triggered the writing of this thesis, in order to prove that the developing technologies in the CAM/CAD can respond to the "social dimension of architecture, beyond general references to a shiny bendy new world." (Hagan 2008). Accordingly, within the scope of this thesis "performative architecture" is used as a paradigm of architecture which emphasizes the shift from building appearance to process of formation based on pre-determined performances. In consequence of the research (categorization of digital models, classifying different approaches towards performative architecture, and exemplification of those) conducted, the content of performative architecture is developed as described below.

Performative architecture defines the architectural object by how it performs (capability of affecting, transforming and doing). It uses digital generation and modification to search for alternatives where results are analyzed both qualitatively and quantitatively. Performative architecture describes the process through which culture, technology and architecture become interrelated to form a complex field of relations to produce new and powerful effects.

These definitions of performative architecture are used as a guideline for the transformation of the Defence Line of Amsterdam. They illustrate the emergent effects of performative architecture in the topics listed below:

- combining developing technologies with cultural heritage;
- using capabilities of affecting, transforming and doing to define additions to the forts (an element of the cultural heritage);
- disclosing functionality and reasoning of a building through the form;
- automatically generating different design alternatives for different sites;
- enabling quantitative and qualitative analysis through digital and physical models;
- producing creative and effective design solutions;
- producing new effects that transform culture.

Subsequently defining the outline for the transformation of the Defence Line of Amsterdam, the research done about digital tools showed that performative approach to design requires yet to be made digital tools that can provide dynamic process of formation/generation based on specific performative aspects of design. There are many digital analytical tools that can help designer asses certain performative aspects of their projects after an initial design is formed. None of those commercially available tools provide dynamic generative capabilities for conceptual explorations in architectural design. Consequently, instead of describing the architectural object as a conventional design process, a parametric definition for the transformation of Defence Line of Amsterdam is structured, called ‘performative design model’. This specific computational model is structured to provide the generative capabilities for particular performance-related aspects of the transformation.

Performative model is introduced in 4 stages (regional design, urban design, building design, and the production of scale models) which are parallel to the stages of a conventional design process; therefore it provides design support from conceptual stage until production of scale prototypes. The production of digital and physical models allows the quantitative and qualitative analyses of alternative instances.

Performative model is a network consisting of parametric models for those stages of design that have dependency relationships with each other. The designer is capable of controlling the parameters and the dependencies of the network. He can change the rules, the relationships between the rules and parameters of the attributes until he reaches a satisfactory output. Generally hierarchical nature of the parametric models has little flexibility in changes of dependency chain once a model has been created. On the other hand performative model offers great flexibility in the control of dependency relationships through the medium of Grasshopper®.

Performative model is convenient to create designs within a predefined language but with dissimilar architectural points of view regarding the conservation of forts. It enables generation of designs with different relationships with the original structure. Performative model has a rule based nature; nevertheless designer is not only tool maker, but also he is the decision maker through every stage of the model. This feature of the performative model makes possible the creation of different architectural concepts from the same tool.

The model is able to generate an infinite number of alternative design solutions, but this potential becomes useless if it is not associated with meaningful control, categorization and selection processes. Performative model is convenient within this scope since the designer is the decision maker in every stage of the design, where stages are defined as modules corresponding different performances related to design. An advantage of dividing a complex system into smaller modules lies in the ease of the intervention to the rules and parameters. For instance, the second stage of the model is composed of performance modules related with connections of elements and conservation of site, therefore alterations of parameters and relations within this stage correspond to generation of instances with dissimilar behaviours related with these performances. This feature of the performative model related with control and categorization of instances is used for generating and grouping processes of instances such as set one and two.

Besides all the advantages, the process modelling such complex relationships computationally is time consuming compared to a design process that uses conventional design methods. The model is encoded in Grasshopper® through some already existing commands that the software offers and some additional VbScript for specific purposes. In some steps using Rhino commands requires less time than writing scripts. Due to time limit for generating a design solution for graduation project in few steps Rhino commands are used manually during the formation of instance one and two. These few manually executed steps do not spoil the parametric nature of the performative model since they also follow computational logic and can be computable. For creation of two instances they save time, however to compute more outputs they must be translated into scripts. Only in this way performative model can reach its goal of generating different design alternatives.

The performative design model proposed in this study has uses beyond generating alternatives for one site. The transformation of the Defence Line of Amsterdam involves the transformation of 42 forts, which show similar characteristics but also some disparities. Due to the fact that the location of the forts is different, they require different transformations. The performative design model is structured to explore different design solution spaces for 42 different forts. Due to the wide range of possible use, the disadvantage of the time spent in implementing the model is offset.

Initially, performative model is structured specifically to represent the complexity of architectural design problem of transforming the Defence Line of Amsterdam. The final hierarchic structure with flexible relationships promises overall usage to represent other architectural problems. The model can be utilized for other design problems in two ways: using the whole model or using single modules/stages such as: computation of urbanization levels, defining relationships with site, generating attraction points for masses, formation, catenary arches, computing sunlight rays, generating 2d drawings form a three dimensional form. For instance the parametric model for computing urbanization levels for sites of each for is also beneficial for the site analysis for further design problems. This is due to variety of parameters and inputs that model offers.

Another possible use for the performative model is in the transformation of other historic artefact that shows resemblance to the Defence Line of Amsterdam. For instance in Portugal, along the coastline of Cascais there is a series of forts. These forts were built in the 14^{th} century for military proposes against the attacks from sea (Moreira, 1986). Cascais is in the maritime entrance of Lisbon; therefore the configuration of forts around the coastline of Cascais (as illustrated in the satellite view in Figure 57) is structured for the defence of Lisbon. Contemporarily these forts are no more used for military function; therefore they require transformation and conservation to host new functions. Some photos of the recent situation of the forts are illustrated in Figure 56. (Ícones de Portugal 2011). Beside having an original military function and being in relation with water, they also show resemblance to Dutch Defence Line with their relationship with train line and roads. Performative model structured for Dutch Defence Line is promising for its usability in the transformation of the forts along Cascais coastline.

Figure 56: photos of the forts from the Cascais coastline

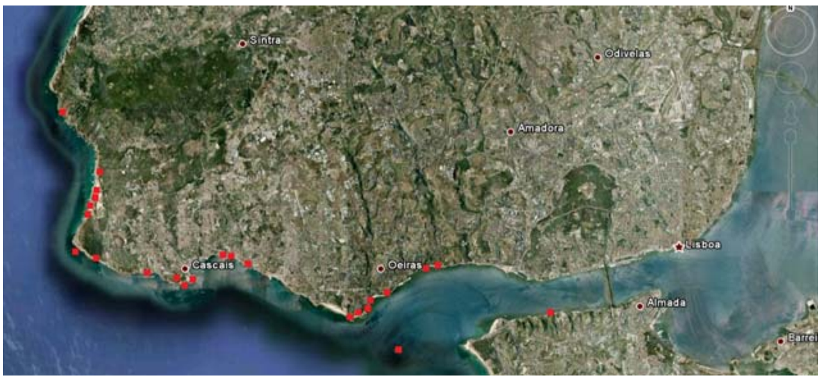


Figure 57: satellite view of the fort along the coast of Cascais

The performative model structured within the scope of this thesis is only dependent on particular performance-related aspects of the transformation of the Defence Line of Amsterdam. A model which aims to address a wider range of design problems must cover more categories of building performance; therefore as a further research we proposed to add new modules to the model to cover a wider range of performances.

REFERENCES

Bosma, K. (1994). “De stelling van Amsterdam; cultuurhistorie en landschapsarchitectuur”, *Rotterdam : Stichting Locus*, 1994.

Cross, N. and Maver, T. M. (1973). “Computer Aids for Design Participation”. *Architectural Design*. **53:** 274.

Edler, J. (2005). “Communicative Display Skin For Buildings: BIX At The Kunsthaus Graz.“ *Performative Architecture Beyond Instrumentality*. B. Kolarevic and A. M. Malkawi, Spon Press: 149-160.

Greg, L. (1999). “Animate Form”, *Princeton Architectural Press*.

Hagan, S. (2008). “Digitalia - Architecture and the Digital, the Environmental and the Avant-Garde”, *Routledge*.

Menges, A. (2007). “Computational Morphogenesis - Integral Form Generation and Materialization Processes”. *3rd Int’l ASCAAD Conference on Em‘body’ing Virtual Architecture*: 725-744.

Julian (1999). Scarre, Chris. ed. “The Seventy Wonders of the Ancient world The Great Monuments and How they were Built”. *Thames & Hudson*. pp. 185–186.

Kalay, Y. E. (1992). “*Evaluating and Predicting Design Performance*”. Y. E. Kalay, Wiley

Kalay, Y. E. (1999). "Performance-based design." *Automation in Construction* **8**: 395–409.

Kloft, H. (2005). “Non-standard structural Design for Non-Standard Architecture”. *Performative Architecture Beyond Instrumentality*. B. Kolarevic and A. M. Malkawi, Spon Press**:** 135-148.

Kolarevic, B. (2003). “Architecture in the Digital Age: Design and Manufacturing”. *S. Press*: 11-28.

Kolarevic, B. (2005). “Computing the Performative.” *Performative Architecture Beyond Instrumentality*. B. Kolarevic and A. M. Malkawi, Spon Press**:** 193-202.

Kolarevic, B. (2005). “Towards the Performative in Architecture.” *Performative Architecture Beyond Instrumentality*. B. Kolarevic and A. M. Malkawi, Spon Press**:** 203-213.

Leatherbarrow, D. (2005). “Architecture's Unscripted Performance.” *Performative Architecture Beyond Instrumentality*. B. Kolarevic and A. M. Malkawi, Spon Press**:** 5-19.

Mahdavi, A., Mathew, P. et al. (1997). "Bi-directional computational design support in the SEMPER environment." *Automation in Construction* 6: 353-373.

Malkawi, A. M. (2005). “Performance Simulation: Research and Tools.” *Performative Architecture Beyond Instrumentality*. B. Kolarevic and A. M. Malkawi, Spon Press**:** 86-95.

McClearly, P. (2005). “Performance (and Performers): In Search of Direction (and a Director).” *Performative Architecture Beyond Instrumentality*. B. Kolarevic and A. M. Malkawi, Spon Press**:** 215-224.

Menges, A., Hensel, M. (2008). “Inclusive Performance: Efficiency Versus Effectiveness - Towards a Morpho-Ecological Approach for Design.” *Architectural Design*. **78:** 54-63.

MOREIRA, R. “A arquitectura militar.” *História da Arte em Portugal - O Maneirismo* (v. 7). Lisboa: 1986.7

Oxman, R. (2006). "Theory and design in the first digital age." *Design Studies* **27**: 229-265.

Oxman, R. (2009). "Performative design: a performance-based model of digital architectural design." *Environment and Planning B: Planning and Design* **36**: 1026-1037.

Oxman, R., R. Hammer, et al. “Performative Design in Architecture Employment of Virtual Prototyping as a Simulation Environment in Design Generation.” *eCAADe 25***:** 227-234.

Pedreschi, R. (2008). “Form, Force and Structure: A Brief History.” *Architectural Design*. **78:** 12-19.

Preiser, W. F., Vischer J. C. (2005). “Assessing Building Performance”, *Elsevier*.

Turrin, M., A. Kilian, et al. (2009). "Digital Design Exploration of Structural Morphologies Integrating Adaptable Models - A design process based on parametric modeling." *PUM*: 800-814.

Sheaa, K., Aishb, R. et al. (2005). "Towards integrated performance-driven generative design tools." *Automation in Construction* 14: 253-264.

Vesters, P., Baas, H., et al. (2003). “De stelling van Amsterdam : harnas voor de hoofdstad / onder red”, *Utrecht : Matrijs*, 2003.

Atelier nGai (2011), “http://www.tedngai.net/experiments/incident-solar-current-time.html” Last accessed 10 January 2011

Future Systems (2011), “http://www.future-systems.com/architecture/architecture_19.html#” Last accessed 10 January 2011

Ícones de Portugal (2011), “http://mjfs.wordpress.com/category/fortalezas/” Last accessed 10 January 2011

Orambra (2010), “http://www.orambra.com/” Last accessed 10 January 2011

Rijksoverheid (2011), http://www.rijksoverheid.nl/onderwerpen/randstad/randstad-2040 Last accessed 10 January 2011

Stelling Amsterdam (2010), “http://www.stelling-amsterdam.nl/english/defenceline/index.html” Last accessed 10 January 2011

UNESCO/WHC (2011), “http://whc.unesco.org/en/list/759” Last accessed 10 January 2011

University of Oregon (2011), “http://solardat.uoregon.edu/SolarPositionCalculator.html” Last accessed 10 January 2011

World Resources Institute (2007), “http://earthtrends.wri.org/” Last accessed 10 January 2011