

ALGORITHMS-AIDED DESIGN PROCESS IN INDUSTRIAL CONTEXT

CASE STUDY: CRUISE SHIP ENVIRONMENT

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ABSTRACT

The objectives of this work were to investigate the possibilities of implementing algorithms-aided design process in the cruise ship design environment and how this methodology would affect the appearance and the user experience of a cruise ship

Ship design and the appearance of ships today is defined somewhat strictly by the engineering tools. Traditional system-based ship design doesn't usually pursue the creation of novel concepts from the structural or architectural design perspective. Due the complexity and the size of the cruise ships the possibility to create completely new ship concepts is hindered, therefore manufacturers often settle on optimising and improving the existing designs. However, in order to succeed in the demanding markets, manufacturers and shipping companies must develop their ships and the cruise experience broadly and more comprehensively

This work is aiming to find ways for design thinking to have more emphasis in the ship field and research new methodologies to rethink the process of which it is being done today. This work is concentrating on parametric design methodologies because they give the benefit of bringing numerical planning together with visual geometry. This potentially makes the design process more agile and could turn the improvement process to an act of creating something completely new.

The research was done based on a literature review and interviews with professionals working in, or closely with, the ship industry. Some of the studied approaches were demonstrated by Rhino and Grasshopper models to verify the applicability of them in the ship design environment.

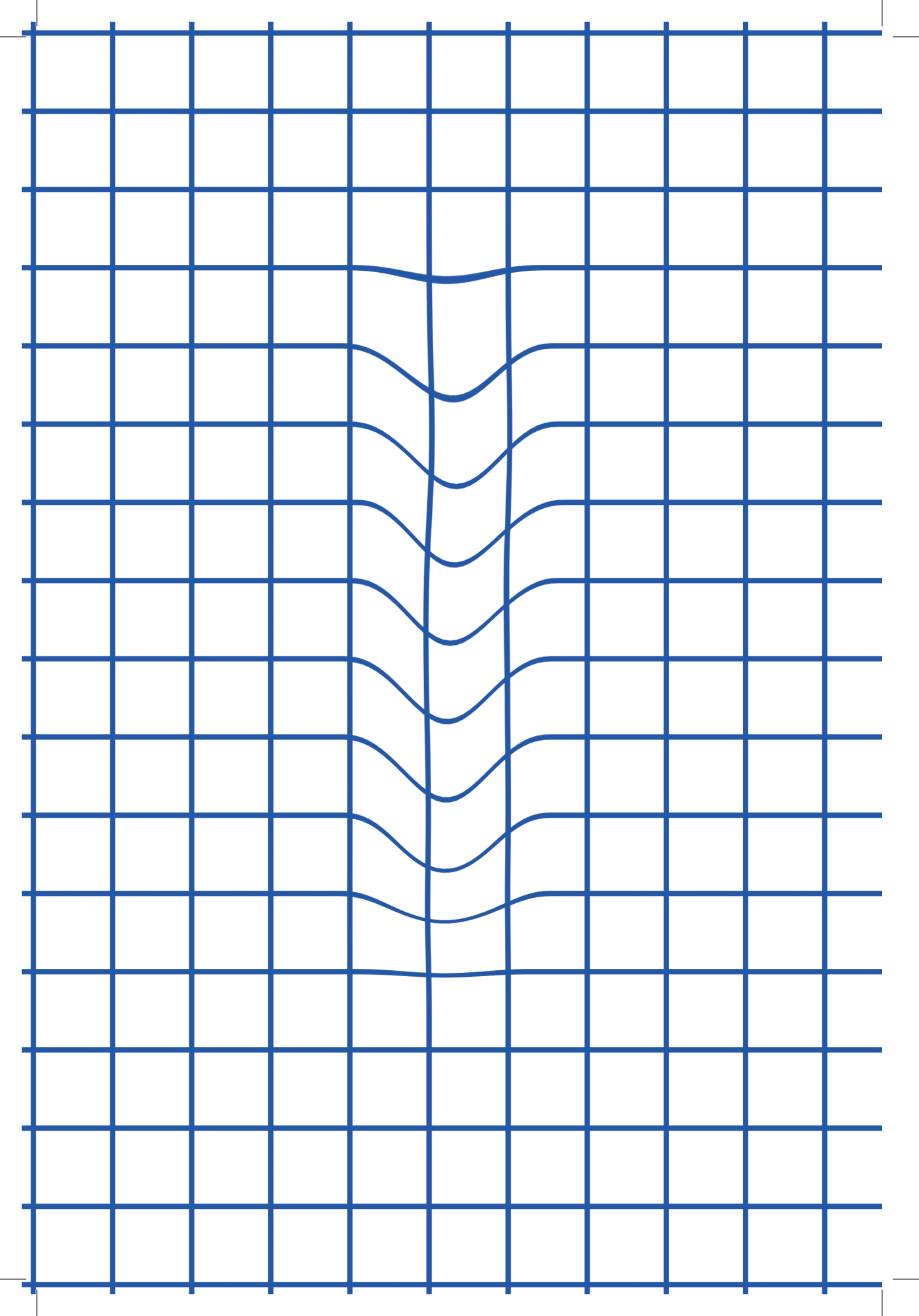
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1. INTRODUCTION



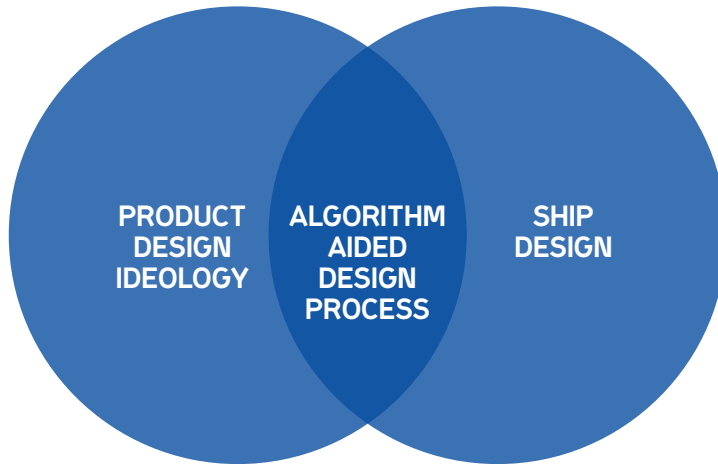
1.1.

ALGORITHMS-AIDED SHIP DESIGN

PICTURE 1
Typical rectangle
structure of a
cruise ship is visible
from the side view.
Detail of the “Royal
Princess”, launched
in August 2012
and delivered to
Princess Cruises in
spring 2013.

Ship design and the appearance of ships today are defined somewhat strictly by the engineering tools. Traditional system-based ship design doesn't usually pursue the creation of novel concepts from the structural or architectural design perspective. Due to the complexity and the size of the cruise ships the possibility to create completely new ship concepts is hindered, therefore manufacturers often settle on optimising and improving the existing designs (Aken, 2005). However, in order to succeed in the demanding markets, ship manufacturers and shipping companies must develop their ships and the cruise experience broadly and more comprehensively (Yao, 2013). The objective of this work was to find ways for design thinking to have more emphasis in the ship industry and to research new methodologies to rethink the process used today. This work is concentrating on parametric design methodologies because they give the benefit of bringing numerical planning together with visual geometry. This potentially makes the design process more flexible and could turn the improvement process to an act of creating something completely new.

The user experience of the ship can be improved through design thinking methods in the early stages of industrial design (Ahola, 2017). The technology and structure then comes at a later stage, complying with the design and engineering the most suitable structure to support the purpose. There is a great amount of rules



and regulations in ship building (Turan, 2012). The author doesn't consider that as an obstacle for using new design tools in this context. Instead, parametric tools could take care of the calculation tasks while the design and planning are done. This approach gives the designers and engineers instant feedback about changes in the structure when making design-based decisions. The idea is to change from calculation-based planning towards addressing visual and usability aspects of the ship.

The traditional ship planning process is iterative by nature where the cycles of the design phases have to be repeated many times before the final design is feasible. The technical issues related to the capacity of the ship are solved and the main characteristics of the ship are fixed during the first design phases. This leads, from the design point of view, to somewhat traditional solutions in the ship architecture (Picture 1). After the first iteration rounds are completed, it is hard to make radical changes to the layout. Consequently, the layout usually stays similar through the design process all the way to the final product. This doesn't leave room for actual customer centric design, as the designers' work is limited to filling the given spaces with decorative elements and interior design. (Interview 1.)

Concept development with many iteration cycles is time and money consuming. Contrary to traditional

FIGURE 1

The scope of the thesis is to apply AAD approach to find ways for design thinking typical for product design to have more impact on the cruise ship design.

process, the holistic parametric design of the ship could give possibility to make the process more flexible. The designers and engineers could work simultaneously separately with many different tasks and the system would take care of the compliance of the overlapping elements. The emerging new computer aided design (CAD) methodologies like algorithms-aided design (AAD) can potentially enable this integration in the design process.

This research is aiming to investigate these methodologies and the feasibility of their implementation in the cruise ship design environment. Research is done through contextual review of the cruise ship design and engineering, looking into emerging trends of engineering and ship design methodologies as well as parametric methodologies and implementation (Figure 1). The methodologies found from the research are demonstrated with examples of the potential usage of the methods.

RESEARCH QUESTIONS:

How parametric design methods can be implemented to the early stages of ship building decision making process?

How usage of parametric design tools would change the design and appearance of a cruise ship?

1.2

IT ALL COMES DOWN TO THE PROCESS

The topic for this thesis started to evolve when the author contacted Markus Ahola at the Aalto University and asked for position in the Cruise and Ferry Experience research program. The first idea was to study the appearance of the passenger ship and develop radical exterior design concepts - ideas for the passenger ship design of the future. The work started by analysing the reasons for all the passenger ships' today looking more or less the same from the design view point.

It was obvious from the beginning that the complexity and the scale of the modern passenger ship already pushes the engineering process work to its limits and this hinders the possibility for radical changes in the design. There are a lot of rules, regulations, building techniques, safety regulations all together with the strict budget that requires vast group of professionals from different fields to keep the strings in the shipyard's hands. However, the biggest observation in the initial research, was that the design and planning process of the ship hasn't changed remarkably in over 50 years (Interview 1, Mistree 1990). There are more components and technology in a bigger scale of a ship but the principles have stayed more or less the same. This leads to conventions where designs and solutions are reused from previous builds to be able to deal with the complexity of the project (Interview 1, Aken, 2005).

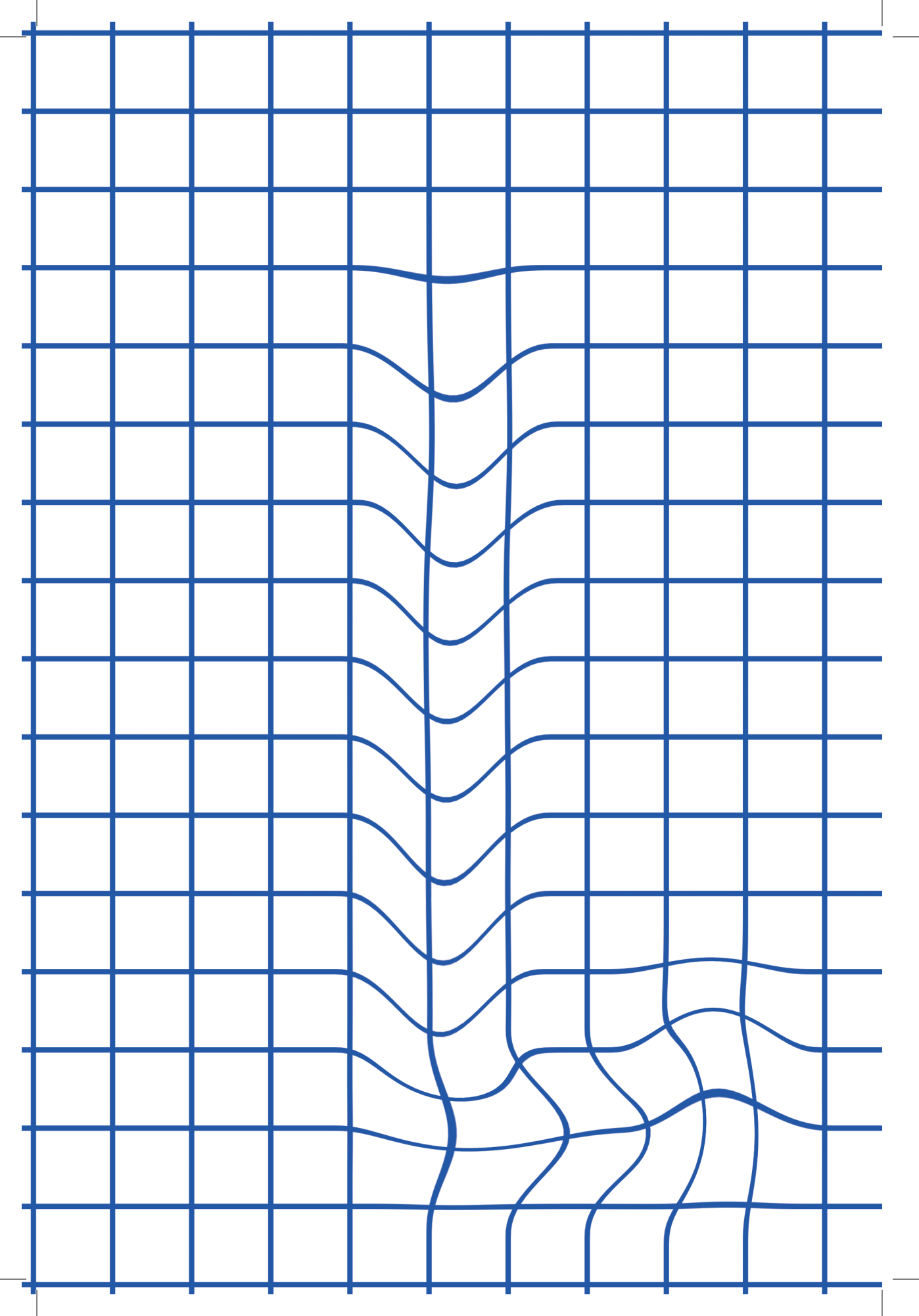
In order to make radical changes in the ship appearance or the design concept of cruise ship itself, one has to change the process quite significantly. This is why instead of doing specific ship design concepts the scope was redirected towards the design process - How to get the design done more efficiently and thus have a greater design impact to the whole ship as a final product?

As discussed, the ship planning and design process involves large amount of people and leads to a relatively complex design environment. The key to make the process more flexible lies on managing information between the stakeholders (Whitney, 1985). Today's computer technology and calculation power enables handling of large amount of information at the same time and making it available in real time to everybody involved to the process. Parametric design together with algorithm aided design can bring additional possibilities to the communication.

The idea to bring algorithms-aided design to this thesis originally came from nature. In the beginning of the research the idea was to look for a form language from completely different direction than conventional shipbuilding. As stated before, the form language in today's ships is highly dictated by the traditional manufacturing and engineering process. In nature, the structures of plants, animals and all living organisms are well defined over millions of years of evolution. All unnecessary material and weight is minimized to benefit the purpose in the most efficient way (without taking in consideration that organisms might be still constantly evolving towards even more suitable form). This evolution happens in the ecosystem that contains all the necessary building blocks but is also constrained by the physical and chemical restrictions. The shipbuilding as an ecosystem can be thought the same way. Ship has its clear purpose that it has to fit, it has certain "building blocks" available and it has the surrounding environment with the forces that it has to withstand. And in an optimal situation, this should be the only starting point to the ship design process - An empty paper without conventions.

From this utopia the author started to research possible ways to bring ship building closer to this "optimal

situation”. The form language of parametric designs that appeared during that research reminds the natural forms of nature and it was worth a closer look. The logic of creating forms was really similar to the nature idea where the rules are defined by the surroundings, physics and chemical reactions and forms are then created according to those rules. Once the parametric approach was chosen, the algorithms-aided approach came shortly after, when testing the first ideas of the parametric modelling. With algorithms the amount of managed data and intelligence of the model can be increased dramatically (Tedeschi, 2014). This allows the designer to rely on the program to manage the information that is related to the design issue. Consequently, the ship as an entity becomes a new medium - built of information - that can be formed freely according to its qualities. The same limitations and restrictions are built in the medium but when formed to the desired “shape” the algorithm keeps on track of all parameters simultaneously, managing the data beyond the human capabilities.



2. CONTEXTUAL REVIEW

2.1

BACKGROUND RESEARCH

2.1.1

DESIGN CONCEPT CREATION

Companies are using design successfully to increase the differentiation of their products from competitors. "Design thinking" has lately received raised attention among practitioners. Many consider design thinking to fundamentally change the way companies will strive to innovate. (Reiman, 2011) Design thinking is a human-centric methodology that combines the expertise from design, engineering, social sciences and business. "It blends an end-user focus with multidisciplinary collaboration and iterative improvement to produce innovative products, systems and services. Design thinking creates vibrant interactive environment that promotes learning through rapid conceptual prototyping" (Meinel, 2011). This chapter gives an overview of the design concept creation process based on design thinking ideology and defines the meaning of the "design" and "design concept" in this work. Different fields have their own definitions for design (Fasciato, 2002). "Design" in this work means a practice that is based on design thinking methodology. In order to understand the value that design thinking and design concept creation can add to the engineer based cruise ship design process, it is beneficial to look in to the process

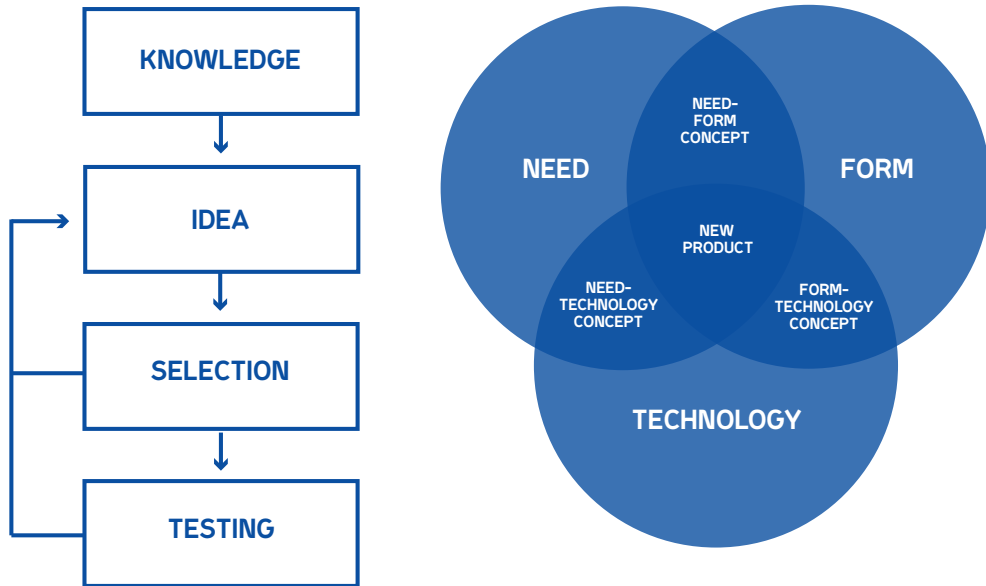


FIGURE 2
LEFT:
Typical steps of
design concept
creation according
to Kettunen (2001).

FIGURE 3
RIGHT:
Elements of the
design concept
and the relation
between the
elements according
to Kettunen(2001).

from industrial design point of view.

Based on the discussion about the current state of the industry (Interviews 1 and 4) it seems that the development in the cruise ship industry has been concentrating heavily on engineering innovation. The ships have become bigger and more efficient (both economically and energy wise) and that undoubtedly requires huge endeavours and achievements from the engineering. However, the concept of the cruise ship from the customer view point has remained unchanged for decades.

Industrial design and engineering processes are developing towards ever greater complexity. In cruise ship design this creates a need for theories in the process that are examining the processes in a more holistic way (see chapter 2.2.5) directing the people's problem solving capability to the real human related, abstract - conceptual problems. In the engineering disciplines the specialisation of the people is very specific and this puts them in a position in the processes where they have narrow scope on the issues they are dealing with (Pasman, 2010). What often happens in the engineer dominated industries and companies is that the

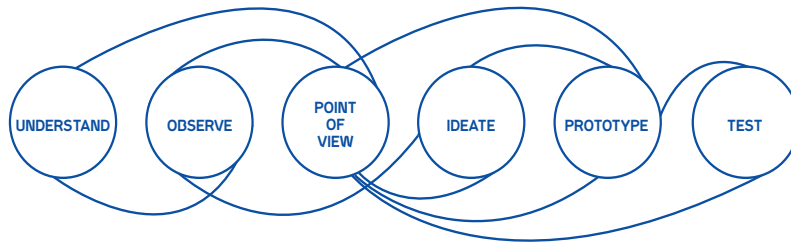


FIGURE 4
Design concept creation process is a highly iterative process. However, the iteration happens in conceptual level, before the idea is taken towards realization.

same isolating thinking characterizes the whole product development process (Brown, 2009). Philosopher Esa Saarinen talks about importance of “system intelligence” in the paper “Systems Intelligence: Connecting Engineering Thinking with Human Sensitivity”. In the design process if the problems are seen separately, fixing the problem out of the context doesn’t necessarily make the outcome as a “whole” any better. “The whole is more important than parts” (Saarinen, 2007).

Design concept is an approximate description of a new product (tangible or intangible). In industrial design the focus is on presenting the core idea of the product as a “whole”. Like an un-sharp picture of the final product, it shows the silhouette of the solution but the details in the picture are still somewhat fuzzy. (Kettunen, 2001) The definition of the word “concept” in industrial design is different from that in the ship engineering environment. In ship building, a “concept” is a well-defined description of the ship and it includes most of the information required for building a functional ship - the end product (Interview 1). In this work the word “concept” is used in the industrial design context and has the definition established in the design field.

Design concept covers the main features of the product: form, technology and the benefit it provides to the user. Concept development usually starts with mapping out the target group’s needs and desires. Based on those criteria the design brief is composed. The designer has to look into different sources of information to understand the context: competitors’ products, patents, literature and

professionals working in different fields. (Kettunen, 2001) There are numerous design research methods to collect data about the users and the surroundings affecting the design. These include interviews, mock-ups, behavioural studies, field research, form exploration and many others (Koskinen, 2011). However, this chapter concentrates on explaining the main characteristics of the concept creation and its positioning in the product development process.

The main objective in the concept development phase is to create alternative designs and ideas. More in depth, the objective in design as a strategic activity, is to produce all the artefacts present in the company aligned with one coherent message, and to reach common goals in a coherent process of value co-production (García, 2012). This typically means creation of a solid proposal and convince the other members of the process and manufacturing to commit to the design, already in the early stages of the design process (Figure. 2) (Kettunen, 2001) . The strategic dimension of design plays an important role in this work thus the “fully parametric” approach calls for the whole design and engineering environment to work seamlessly together in the design process. Therefore, to function properly in ship building environment, it requires large scale strategical changes in the design process.

When consensus in the product development team is reached and one concept is chosen for further development, the concept creation process ends. Even though the product is introduced to the markets, it stays on the concept level until it has been proven to be economically successful - when the product meets the requirements which are set for it from the economical perspective. Before that it is still under development, nevertheless it might be marketed at the same time (Figure 3). (Kettunen, 2001)

Kettunen identifies three elements of design concepts:

- **Form:**

Form means the physical form created for the product. When designing the physical object, say mobile phone, “form” means the physical object, software, operations, people and other aspects that are being involved when

making or receiving calls. If the design objective is a service “form” in this case means the operations of which the service is constructed.

- **Benefit:**
The product has value only if it can provide some of the benefits that the user desires or feels need for.
- **Technology:**
Technology provides the way of creating the form that enables the benefits and supports the purpose.

Innovation process can start from any of these three elements of the concept. What happens next may vary in different concept development processes:

1. User has a NEED, that the company acknowledges. Then TECHNOLOGY is brought in to create the FORM.
2. Company has a TECHNOLOGY that is suitable for the target group. The NEED of the target group is then discovered and satisfied with the FORM.
3. The company has a vision of the new FORM, which is implemented with the new TECHNOLOGY, and is then given to the users for evaluation, to see if they have any NEED for it.

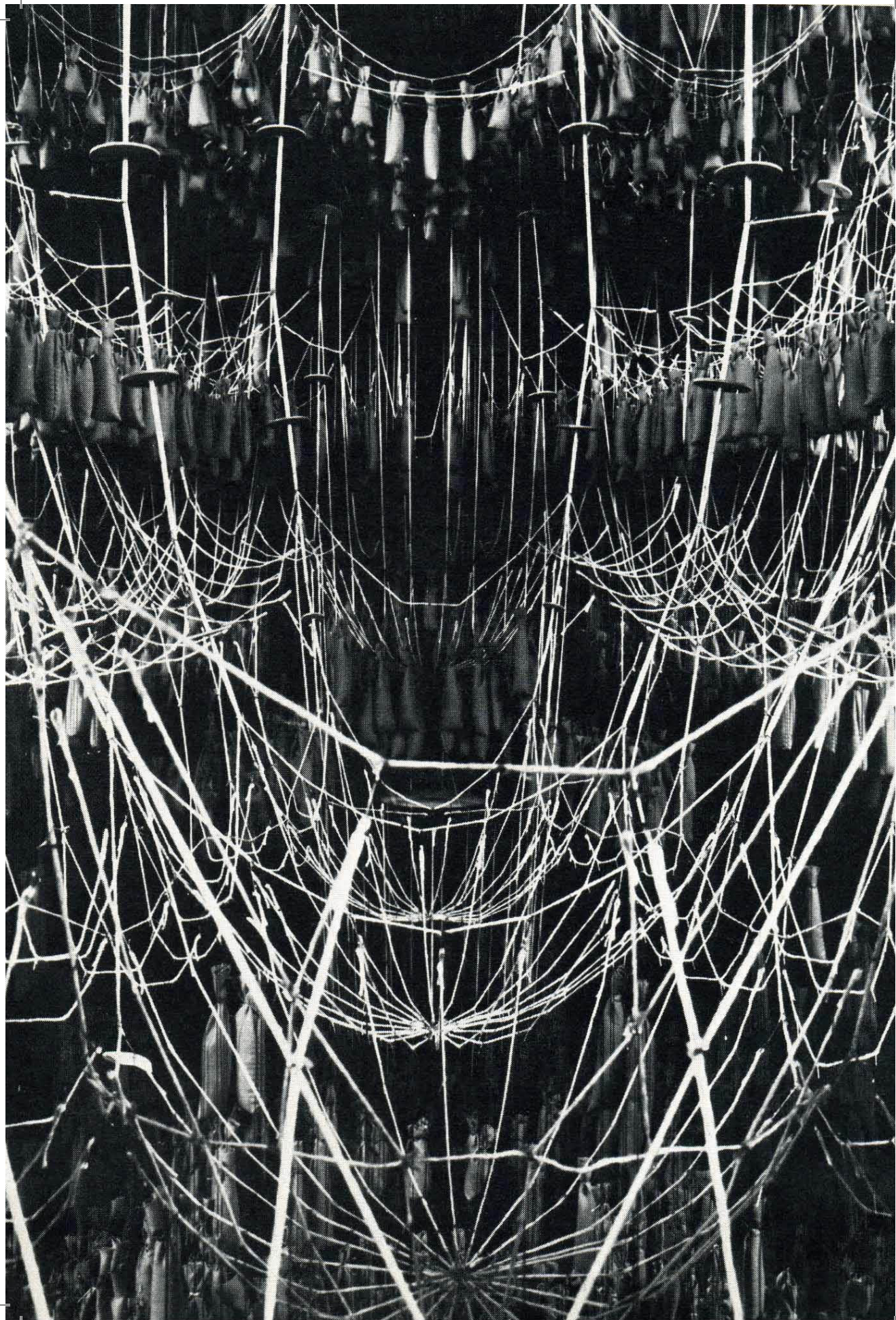
In the shipbuilding, the shipyard has traditionally a strong knowledge about the technology and the manufacturability, as they are today (Interview 1). It is fair to say that it is a technology driven design process, similar to the 2. approach shown above. However, the 1. approach seems to be more popular in today’s school of industrial design (Koskinen, 2011). It starts from the users’ needs and uses technology as a vessel to deliver the form most suitable for the user. User-centric approach is more likely to generate different results for the end product, when the technology and form have to adapt to the needs. This seems to be prevalent trend in most of the industries, especially in fields where the client is the end user. In the shipyard

business the client is often understood to be the shipping company whose client, then, is the end user. Ship yard's competitive advantage is emerging from the innovations that it can provide to the shipping company (Interview 1). These innovations are more and more required because of tightening standards and expectations of the end users (passengers). Advanced CAD implementations can provide a better information flow throughout the design process (Sener, 2002) and close the gap between the ship designers (including engineers) and cruise ship passengers - who the cruise ship is (mainly) designed for.

The industrial design process can be divided in three phases: product research, concept design, and product design. Of these, the concept design's creative process is the most interesting from the industrial design point of view. It has a major impact on the end product's usability, form and production cost. In that phase design thinking takes the power, innovations are done and product gets its form. (Kettunen, 2001) It is also often more cost efficient than the other phases in the product development - mistakes are cheaper to make, record and correct in the early phase than in the later development stages (Brown, 2009).

In a successful concept design process there are two phases: first, creating a lot of concepts, and then choosing the best one. In the creative phase of the concept design it is important to avoid premature criticism and generate as many proposals as possible. In the critical phase these proposals are evaluated and combined together until there is only one solid idea at the end (Kettunen, 2001). This is the optimal situation and usually it takes many iterations and interaction between the stakeholders to achieve this stage (Figure 4).

Design thinking is described by many authors to be an iterative process (e.g. Ahola, 1983, Brown, 2009, Gabrysiak, 2011). The more there is iteration, the better the outcome will be. However, the iteration is not as systematic and rigid as it is traditionally in the ship design. It happens in **conceptual** level dealing with evaluation of the ideas and solutions weighted heavily on the preliminary phases of the design. In ship design one iteration already includes well defined engineering solutions that make it impossible



PICTURE 2
A detail of Antoni Gaudí's physical form-finding model for "Colònia Güell" chapel. The inverted model is hanging upside down and can be edited by moving the sandbags on the strings forming the geometry of the ceiling.

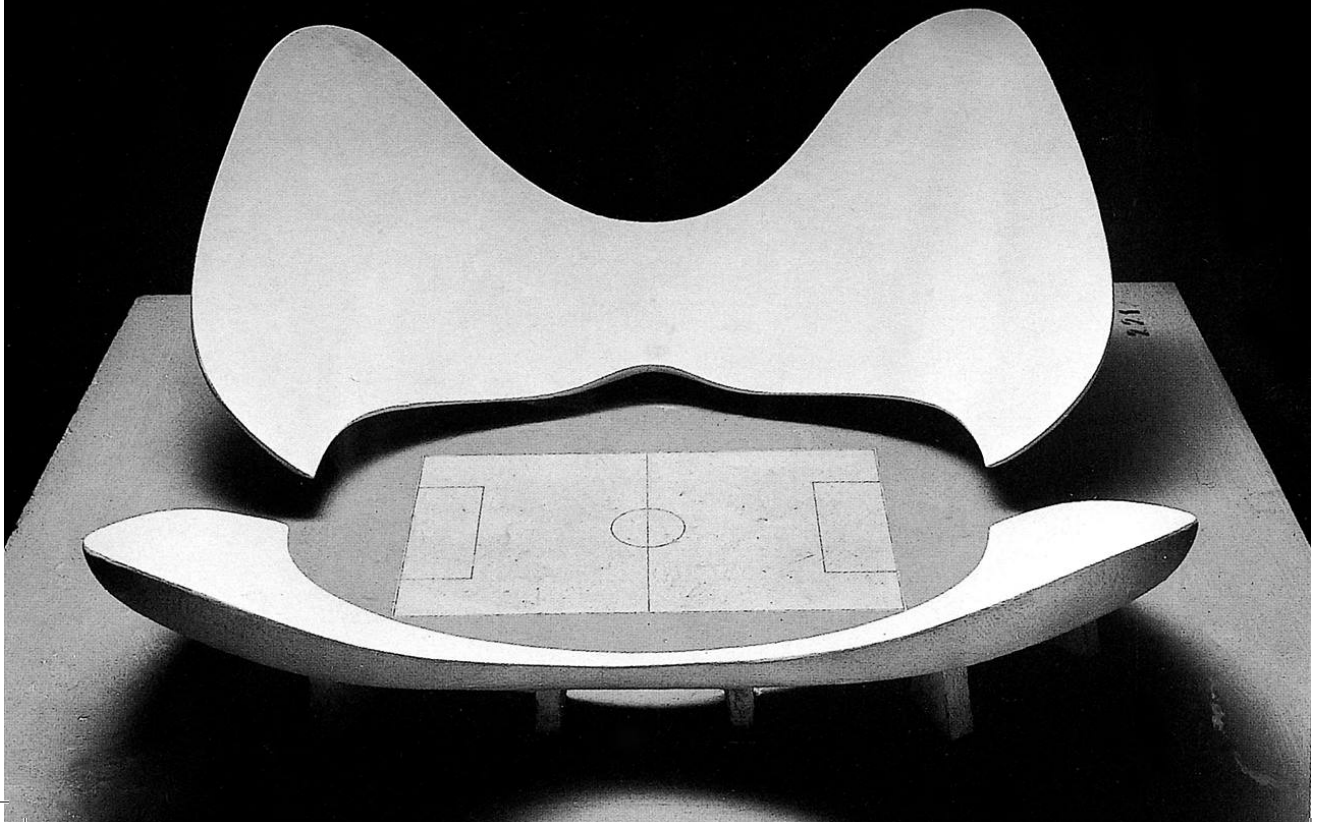
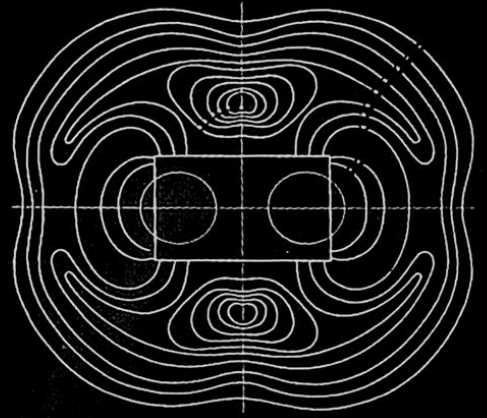
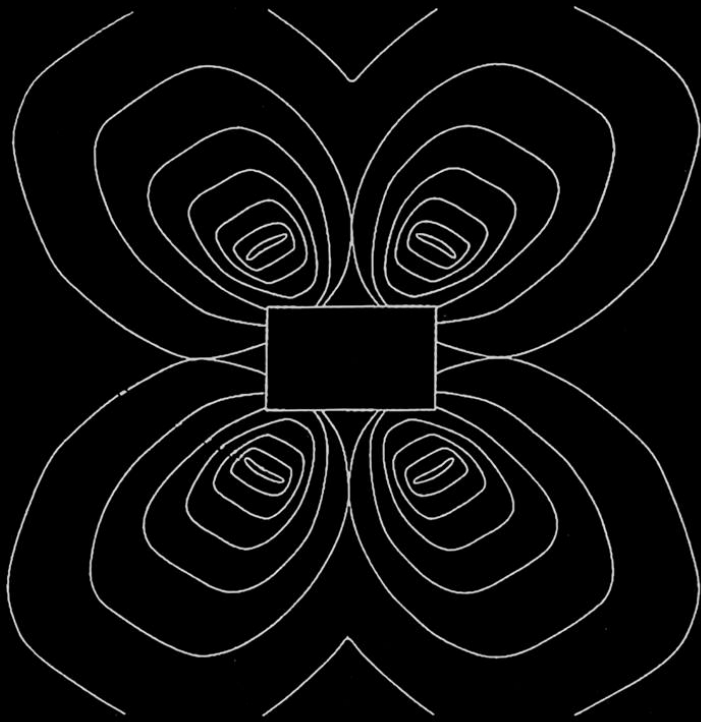
to change the **design concept** after one iteration (Interview 1) (See chapter 2.2.2).

Often in the traditional product development environments some of the "best" concepts need further investigation in a more physical form. This is costly and takes time and it is not always possible with large scale products like cruise ships. However, more and more alternative computer-aided methods from visualisation to virtual reality have emerged in recent years and formed a whole new field of Industrial design - "computer aided industrial design" (Yao, 2013), in which algorithms-aided design, used in this work, can be seen as one of the prospective methodologies. These new ways of designing can emphasize the concept phase in the ship design process by giving an opportunity to virtually prototype and iterate different solutions. All the stakeholders can be involved in the evaluation concurrently already from the beginning of the process, creating synthesis and more integrated design environment (Sener, 2002). The information and integration of the process is discussed further in chapter 2.3.1.

2.1.2 DEVELOPMENT OF COMPUTER-AIDED DESIGN

To understand the nature of computer aided design methodology, and the needs of the product design processes that have led to the development of such systems, it is relevant to look back to the history of the computer aided design (CAD) systems.

In his book "AAD Algorithms-aided Design: Parametric Strategies Using Grasshopper", Arturo Tedeschi describes the change from conventional drawing towards algorithms-aided approach in architectural planning. Even though the book is written from architecture point of view, the same



PICTURE 3
 Stadium design
 by Luigi Moretti
 introduced in the
 1960 Parametric
 Architecture
 exhibition at the
 Milan Triennial. The
 form of the stadium
 is optimised
 parametrically
 based on the view
 to the field.

principles apply in the industrial design process, which drives the change from analogue drawings to parametric computer aided design. In the architecture the catalysts have been the complexity of the structures and constraints of building processes. When products have become more and more complex, the same principles have been used in the product design and engineering design (Aken, 2004).

Traditionally the design work has been done on paper using two-dimensional drawing. Drawing is an additive process where complexity of the design is achieved with overlapping elements traced to the paper. Managing the internal consistency of the design and interaction of its elements is not supported by the medium/tool but is entrusted to the designer. (Tedeschi, 2014)

“drawing is not smart medium, but rather, a code based on standards and conventions “ (Tedeschi, 2014).

The logic of traditional drawing has two main limitations. Firstly, the cognitive mechanisms behind the creative process work by establishing interrelations unlike the additive logic of traditional drawing. Secondly, drawing excludes important physical aspects that in the real world drive the generation of forms. Forces (such as gravity) and constraints that affect and restrict deformations and displacements, cannot be managed by drawing. (Tedeschi, 2014)

Drawing has been the main tool through centuries, as architects have relied on typology, i.e. well proven, preconceived solutions and tectonic systems have been used. Typology has made it possible for designers to do form-making by refining variations within a specific set of forms and structural limitations. To overcome the limitations of drawing, form-finding started to emerge. (Tedeschi, 2014)

Form-finding attacked the conventional drawing in architecture in late 19th century. It aimed to investigate novel and optimised structures found through complex and associative relations between materials, shape and structures. Architect pioneers like Antoni Gaudí (1852-1926), Heinz Iser (1926-2009), Frei Otto (1925-), and Sergio Musmeci (1926-1981) have rejected typology and adopted self-formation process in nature as a way to organize buildings. Since the form could not descend from proven

solutions, traditional drawing could not be used as a tool to predict design outcomes. (Tedeschi, 2014)

For this reason, form-finding pioneers relied on physical models such as soap films which settled into minimal surfaces, and suspended fabric and stings which are bending following the laws of physics (Picture 2). In other words, the drawing as medium to investigate form was replaced with physical form-finding that relies on physics and analogue devices which demonstrated how dynamic forces could mould new self-optimized architectural forms (Tedeschi, 2014).

Over the last decades the increasing complexity of buildings has made form-finding an important strategy in determining the shape and form of indeterminate structures.

Structural optimization through physical modelling was based on only one parameter –gravity- but it marked a trajectory towards multi-parametric form-finding which aims to interact with heterogeneous data: geometry, dynamic forces, environment, and social data. (Tedeschi, 2014)

Parametric Architecture is one of the steps from additive towards associative logic. The definition Parametric Architecture was first used by the Italian architect Luigi Moretti in 1939. He was one of the first to understand the potentials of the computer applied to the design process. He developed parametric methods in architecture and his work was shown in an exhibition, in Milan, in 1960 where he presented public buildings such as football, swimming and tennis stadiums that had parametric data as a backbone for the design. (Bucci, 2002) For example, the form of the football stadium was optimized so that the view to the field would be optimal from all the seats in the stadium (Picture 3).(Tedeschi, 2014)

Another pioneer in computer aided design field was an American computer scientist Ivan Sutherland. During the 1960's he created the first interactive Computer-Aided Design (CAD) program called Sketchpad. He described it as “a man-machine graphical communication system”. It was the first program to apply interactivity to the interface that did not need any written language to set the geometry (Sito, 2013). It had a visual interface where the user could draw straight to the computer screen using a pen-like object.

Already in the early stages, the program had many functions that became commonly used in the CAD programs later on. You could draw, erase, and stretch the lines on the drawing, turn and move them and also rotate single lines or the whole wireframe. This was possible through algorithms that were set to communicate in relation to each other and at that time in a relatively innovative way. (Sito, 2013) This kind of associative capabilities were not possible to run with consumer computers of that day and it took several decades to achieve the similar functions in consumer programs.

The AutoCAD, launched in 1982, was one of the first commercially successful programs in computer aided drawing. It met the requirements of architects by speeding up the repetitive tasks and managing complex drawings with multiple layers. After all it still did not have capabilities of handling associative changes in the drawing. The big leap forward happened in 1987 when Pro/ENGINEER software was introduced. It was a tool for designing mechanical systems and gave the user a possibility to create three-dimensional parametric components with set input constraints given by the user. These constraints were controlling the shape of the model and could be changed in any stage of the work. Then the rest of the model adjusted to these changes. Pro/ENGINEER reduced the cost of making design changes and made 3D-modelling more flexible and easier to approach for the users. (Weisberg, 2006)

Since those days the CAD programs have become one of the most - if not the most -important tools for industrial designer (Yao, 2013). This has led to another interesting development when more advanced users and university researchers have started to improve and add functions to the modelling by manipulating the programs from inside. Many designers have started to use this programming additions and features to go around limitations of the software and to create unexplored solutions and forms to their design. Sophisticated programs can handle complexity in the structures and repetitive tasks beyond the human capabilities. These programs give the software instructions through programming language, based on which the computer can then create the 3D-model through step by step procedure: the algorithm. (Tedeschi, 2014)



PICTURE 4

In the flock, birds follow a simple set of rules and consequently form infinite amount of different shapes according to these parameters.

2.1.3**PARAMETRIC APPROACH IN DESIGN**

Patrick Schumacher, one of the pioneers of parametric design practice, defines “parametric design” as “a computer based design approach that treats the geometric properties of the design as variables”. Typically, it is a process based on algorithms that function in relation with each other forming geometries according to set of given values. If some of the values are changed during the process it affects the whole geometry accordingly. The input data can be fed to the program as a set of values and based on chosen algorithms the outcome behaves within the set guidelines. A classic example which demonstrates how simple rules can regulate really complex behaviour is flocking birds (Picture 4). It has been simulated with computer model that has only three rules: 1. “keep an equal distance from anyone around you”, 2. “don’t change speed too fast”, and 3. “avoid stationary objects”. With these rules the flock’s formation can be modeled quite accurately. (Poole, 2015) In design practice this means that it is possible to handle massive amounts of variables at the same time and work with complex multifaceted entities. (Schumacher, 2014)

Parametric planning has long traditions in the engineering 3D design where the geometries of objects can be edited parametrically during the planning process. The objects and the relations between the geometries are stored typically on a parametric “tree” where the values and relations between the objects can be stored and edited. When one parameter is changed on the tree it effects the whole geometry according to the set relations of the parameters. (Hietikko, 1996) To give a simplified example: if two parts in an assembly are bolted together with hundreds of bolts of certain size, and during the planning process the bolt size changes to bigger, all the bolts and respective bolt holes in the parts are scaled automatically to the right size. The parameter tree defines that the bolt size is relative to the respective hole size. Once the relations are set they effect

the geometry throughout the whole process. Consequently, altering the relations or values can be done at any point in the design without having to build the geometry all over again. This saves manual labour on 3D modeling and makes it easier and faster to make changes during the engineering process. This agility of the modeling tool gives opportunity to do multiple iterations of the same design and emphasize design decisions - also visual and user centric - that often drop out if sufficient resources are not available.

The definition of “parametric design” varies based on the context and deals with different kind of variables in different fields. In architecture and industrial design, where the objectives of the design are often more abstract, the definition of the “parameters” can be understood in a more ambiguous fashion. While in engineering practice the “parametric design” deals with mathematically defined numerical values, at the other end of the spectrum one could say “all design is at some level parametric” (Poole, 2015). Design has always its starting “parameters” that are in relation to each other and eventually, through certain procedures, determinate the outcome. In this work we use Merriam Webster’s simple and open ended definition of a parameter being “a rule or limit that controls what something is or how something should be done” (Merriam Webster, 2016). This definition encases any kind of information that controls the output of the process and leaves room for understanding the parameter in an abstract input. These inputs are controlled by a program that translates the information through algorithms to an output that is interpreted as an answer to an abstract problem like a specific human need. For example, the “perception of safety” could be one parameter that is monitored during the design process of a cruise ship. This is really an abstract parameter that is hard to give any specific value to. However, this rather a vague measure can be divided to smaller issues that can be studied and measured. The information of these parameters can be then combined and visualized to the designer as information that is something that people actually perceive from the design outcome. For example, natural light and lighting has a drastic effect to the customer’s perception of safety in a cruise ship (Ahola, 2016). The behavior of both light and the light sources in the

ship are known and can be measured. When combining that information with different measurable or known aspects like colors, openness and guidance, effecting on the perception of safety (Ahola, 2016), the parameter that is interpreted can be called “human safety perception in a cruise ship”.

Parametric design, or “Parametricism” as Schumacher calls this parametric design movement, is in a sense the “main category” of parametric methodologies where engineering, scientific, artistic, political, architectural and design approaches are all present (Poole, 2015). It seems that parametric design is the most commonly used term in industrial design language when talking about generative parametric practices. However, due to the term’s vagueness, we use “Algorithms-Aided Design” (AAD) in this work to underline the added intelligence and generative properties that can be achieved by designing advanced algorithms to control the parametric models.

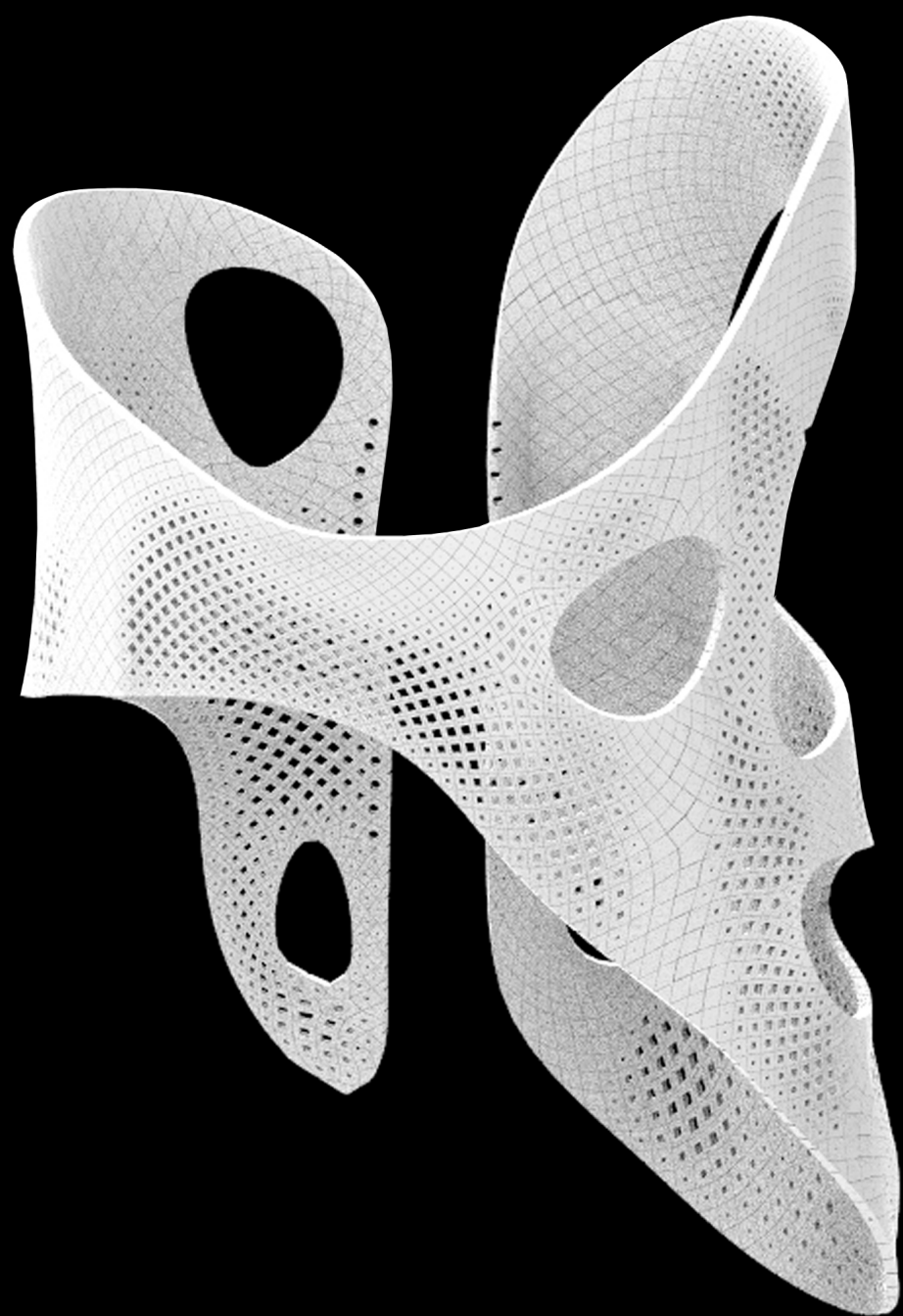
2.1.4

ALGORITHMS-AIDED DESIGN

As discussed earlier parametric design as we perceive it in this work requires advanced algorithms to handle complex entities of parameters. Thus it is clarifying to use the approach that Arthuro Tedeschi calls “algorithms-aided design”(AAD).

Algorithms are strongly associated with mathematics and computer sciences. However, they follow the human aptitude to split problem to, smaller, simple steps that can be easily performed. This “act of performing” tasks automatically is what we are interested in this work - generative outcomes that are visible to the human as a human problems are in real life. It is not the parameters that are “working” to achieve the outcome but the algorithms.

For example, recipe for cooking can be considered something similar to an algorithm: 0. Mix the ingredients, 1. Spread to pan, 2. Bake in the oven x time, 3. Remove from



PICTURE 5
The 3D printed brace designed to treat scoliosis, is a good example of a product designed with algorithms-aided design. It is generated to each patient individually offering light-weight and breathable design with perfect fit.

oven. And the outcome is aggregation of these steps - for example a cake. Algorithm can perform different kind of calculation, data processing and/or automated reasoning tasks. It is a step-by-step set of operations to be performed. Like well-defined list of instructions how certain task has to be done. They can be used to return a solution to a question or to perform a particular task (Figure 5). (Tedeschi, 2014)

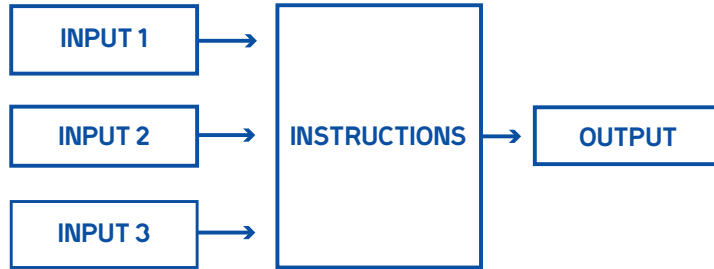
According to Tedeschi there are several important properties characteristic of algorithms concerning AAD:

- An algorithm is an unambiguous set of properly defined instructions.
- Algorithms depend on entered instructions.
- The result will be incorrect if the algorithm is not properly defined.
- An algorithm expects a defined set of input. Input can be different for type and quantity.
- The steps require quantitative information.
- Each input has a precondition, i.e. a requirement which must be met.

Algorithms-aided design is a CAD methodology and it is applied and used in computers that performs the processing according the set rules in the algorithms. Therefore, the application happens in a specific editor where the instructions- the scripting - are written.

Editors can be stand-alone applications or embedded in a software application. For example, stand-alone editors include C# and Python. Embedded editors are script editors provided by programs such as Rhinoceros and AutoCAD that allow users to write instructions to automate featured functions inside the program. (Tedeschi 2014) Grasshopper 3D, used in this work is embedded editor that uses the same principle but instead of text form input, it applies visual scripting (discussed further in chapter 3.2).

Different scripting methodologies have found their way to advanced CAD users also in architecture and design field. Algorithms-aided design is often used in form-finding and computer generated forms that consists complexity beyond human capabilities. The complexity can be in the form (structure or geometry) and/or in the information of the



model. “The output is not just a “digital sign” but it can be considered as and interactive digital model responding the variations in the in put by manipulating the entire system” (Tedeschi, 2014).

Good example of this kind of industrial design is 3D-printed brace designed to treat scoliosis, by bionic prosthetic manufacturer UNYQ, designed in collaboration with Studio Bitonti (Picture 5). The brace is a customisable and “breathable” brace that aims to be stylish and use fewer materials. It is light-weight using 75% less material than traditional alternatives, and can be worn for multiple hours a day. The design of the product started from algorithm - designing the program to design the desired result. (Burgess, 2016) The scoliosis appears different ways on different people as well as every one’s body is unique on its shape and size. However, the treatment has certain mechanics that can be modelled to the algorithm. The model combines the geometry of the patient’s body, the geometry of the align brace, and the highly complex medical information about the treatment. (Phan, 2011). As a result, or “output” we have elegant, customised align brace that is made to fit exactly to the patient’s needs. Not only it is more functional than traditional aligns, but it is one of the rare medical devices that have been unveiled at the fashion show at FashionNXT in Portland (Burgess, 2016).

FIGURE 5
The main principle
how algorithms
work, according
to Tedeschi (2014).
It analyzes well
defined inputs
according to set
rules and gives
output as a result.

2.2

DESIGN PROCESS ANALYSIS

2.2.1

THE SHIP DESIGN ENVIRONMENT

In the beginning of the 1960's airline traffic replaced regular sea-line service. Some of the major shipping companies sensed the change in the travelling culture on the sea and started to build ships for cruising purposes. In the 70's the modern cruising industry started to emerge and ships became ever bigger and more entertaining. The cruise ship became the destination. This led to competition in the markets where shipping companies wanted to attract customers and modern marketing strategies were taken in to use. This led to the development where the marketing strategies started to define what kind of ships were to be built. The marketing strategy has been commonly based on "economy of scale" thinking where the shipping company tries to maximize the amount of people and standardize the service to satisfy as wide a range of customers as possible. (Andersson, 1995) However, economy of scale has been in use for too long to offer much differentiation any more. All the major shipping companies have large cruise ships and the scale has reached its limits what comes to capacity of bridges and ports in the operating areas (Picture 6) (Interview 1.). This development forces the shipping companies to look for alternative ship **concepts**.

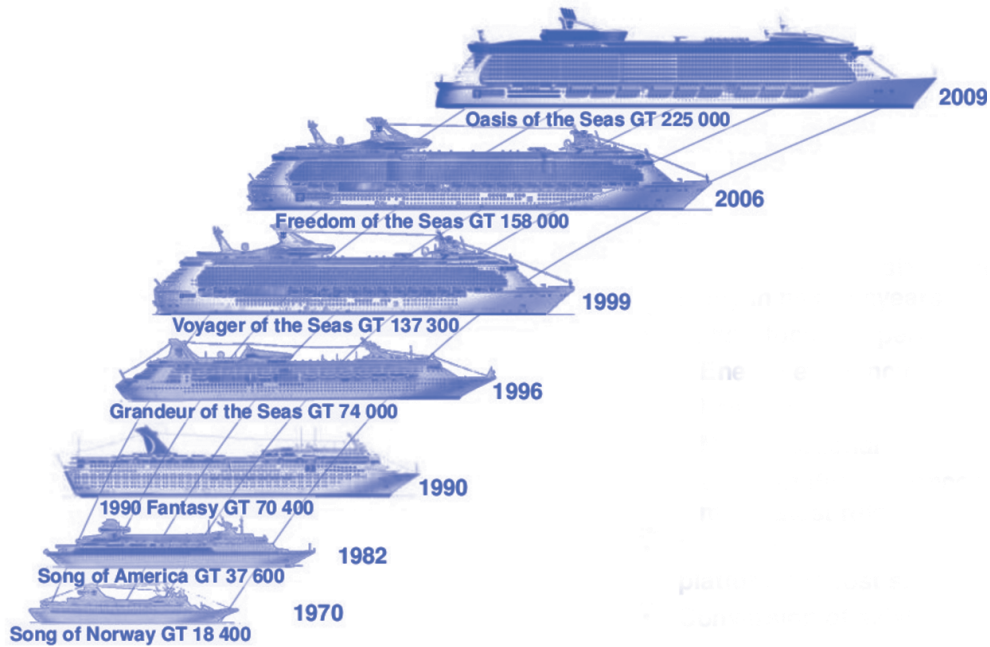
The design environment of the ship is interesting and also challenging from an industrial design point of view. Because of the scale of the product it is closer to an architectural object than a traditional industrial design product. The scale also requires a lot from the engineering to guarantee that the ship can be manufactured according to the requirements. And still the ship should work for the customers as an attraction and “destination” for their holidays.

According to Gale (2003) ship design takes place within a surrounding environment that can have a significant effect upon the process. Factors in this environment include:

- economic trends,
- current and pending government policies and regulations,
- the status of international regulations on matters such as pollution control,
- the breadth and depth of the vendor base for major equipment items,
- the management of the organization within which the design team works and to whom it reports,
- the prospective ship-owner—his foibles, preferences, modus operandi, etc.

Ship design is always a team effort. The team size depends on the size of the ship to be designed and can vary over the duration of the project. For a small, relatively straightforward ship design, the team size might start at one and ultimately increase to five or six. For a large, complex ship like a cruiser, the size of the design team might start at 25 to 50 and ultimately grow to many hundreds (Gale, 2003)

Every ship design must satisfy the requirements defined by the ship-owner. Ship-owner’s requirements set the boundaries and targets for the design and may contain constraints. Constraints apply to every ship design and the design process. Time and cost are nearly always constraints, applied to both the design itself and the delivered product: the ship. (Interview 1) Other examples of design process constraints might be the unavailability of sufficient skilled

**PICTURE 6**

The ship size has increased exponentially during the past decades. The size is reached its limits and the growth is expected to slow down because of the physical limitations of the operating areas.

design personnel or required computer software, hardware, or network capability. Physical constraints might be applied to the design itself for any one of three reasons: the need to build the ship in a specific shipyard and then get it to sea, the need to maintain the ship during its service life, and the need for the ship to visit specific ports. (Gale, 2003)

2.2.2 ITERATIVE PLANNING PROCESS

This chapter describes the current ship design process based on panel discussion (Interview 1) in the Meyer Turku shipyard and the paper Ship Design Process by Peter A. Gale (2003). The ship design process starts in the shipyard when the ship buyer asks for an offer from the shipyard.

At this point the buyer usually has already an idea of what kind of ship they are looking for. Based on their mapping of the requirements for their becoming ship, the shipyard and the buyer starts negotiation about the desired scale and features. At this point naval architects and designers use reference material from previous ships. A technical comparison is done with ships that have proven to be successful in similar circumstances. Also the references work as a discussion tool to find out what kind of user environment and experience the buyer is looking for. Some of this work is done already by the company that is looking for the ship offer. Usually the shipping company does marketing and trend analysis about the need and requirements for the new ship. When they come to the ship yard they usually have the ship concept brought already to a certain level. (Interview 1)

The main measurements of the ship are estimated according to the requirements. In this first phase the work is mainly based on previous experience and proven designs. Naval architects take into account the knowledge from previous designs and use the operational experience with ships built to those designs. (Gale, 2003)

The uniqueness of new designs may vary substantially. Some new designs are very similar to existing ships but with modest changes, like somewhat more or less propulsion power or payload. Other designs may differ from earlier ones in specific respects (for example, the propulsion plant type), but in all other respects they are not unique. In very rare and extreme cases the design is very different from anything considered before. This is an exciting challenge for ship design and also affects the early stages of the design process. (Interview 1, Gale 2003)

For designs similar to what have been done in the past, the design team will have a lot of data available for similar ships. This data can be used in early stage design and it helps to make quick and reasonably accurate estimates of the principal characteristics and costs of alternative concepts for the new design. (Gale, 2003)

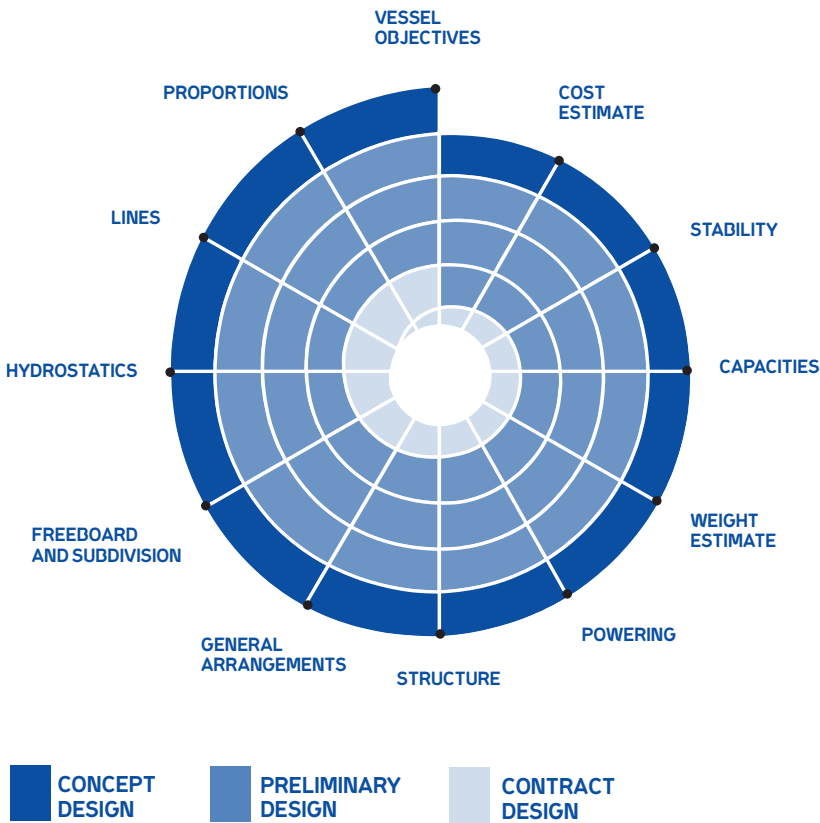
Ship design is an iterative process, especially in the early stages. The elementary design is produced and then analysed and modified. The modified result is re-analysed

and so on until all requirements are satisfied. Iteration is needed because so far ship design has proven to be too complex to be described by a set of equations, which can be solved directly. To get the process started, estimates and educated guesses are made as to main measurements, hull size, displacement, etc. and the initial figures are modified, as better information becomes available (Figure 6). (Gale, 2003).

The modifications are determined by numerical comparison. Numerical values describing the needs of the ship are compared to values of a comparison ship (or ships) to estimate the feasibility of the new design. The naval architect sees a diagram of the ship being designed and the respective diagram of the comparison ship(s) and can constantly compare how the new design relates to that. (Interview 1)

The ship gets its shape and the main structure. Next, the first rough version of the layout is drawn to visualize the different areas on the ship. At this point the technical elements - such as cables, air condition and water pipes - are not yet designed. In the offer calculation phase the layout design is kept as simple as possible to save time and keep it open for possible changes. Buyer is requesting changes until they are pleased with the layout. After that the iteration proceeds to placing the technical spaces in the design. (Interview 1)

According to P.A. Gale the planning configuration today is most likely happening in a 3-D computer model that all members of the design(engineers) team have access at the same time through a network, but the changes can only be updated with the approval of the team leader (Gale, 2003). However, it seems that still today some, and in some ship yards most, of the design work in the concept stage is done in 2-D environment in AutoCAD program. The layout is drawn manually inside the hull and spaces and cabins are tried to fit inside the areas dedicated for them. The engineers are aware of the rules and regulations and they try to make sure that the design follows these restrictions, while they are making the layout. The whole process is based on estimations of individuals who have solid knowledge about the shipbuilding as a whole. The



designers who are trained to understand better the functionality of the spaces and user experience usually come in the picture later on. This means that at this point the design is based on the technical problem solving - “trying to fit everything in”. The cabins are designed so that the number of different cabin types is minimized. Use of similar cabins makes the design work easier and more straightforward. Modularity also brings big savings to the ship builder. When the cabins are similar they can be designed once and then multiply according to the need of capacity. With traditional CAD programs, all the changes have to be done manually, and therefore the naval architects prefer uniform cabins to make the re-planning easier. (Interview 1)

FIGURE 6
Ship engineering / design process is traditionally seen as iterative cycle where all the steps are gone through over and over again until the in the “center” of the diagram the final ship design is feasible.

Because of the iterative nature of the design process, one single design process does not exist. Also, today's generic design process will evolve and undergo changes in the coming years. However, according to Gale (2003) certain elements are believed not to change significantly:

- The objectives of the design process
- The need for the designer and engineer to understand the ship-owner's requirements and, at the same time, to help the ship-owner to refine his requirements.
- The time and resource constraints imposed on the process
- The fact that both art and science are reflected in the process (albeit that the role of science is steadily growing at the expense of art)
- The fact that creativity and teamwork will always be cornerstones of the process.

2.2.3

CONCURRENT ENGINEERING

Concurrent engineering (CE) has been a major theme in the engineering research and practice in the past few decades (Wognum, 2013). It is the driving force in engineering discipline that have made, and still makes, it necessary to evaluate the cruise ship design process from the **engineering** point of view. However, the motives of CE, from the process development angle, are very similar to the intention in this work with applying the AAD approach.

Concurrent engineering emerged in 1980s to improve the competitiveness especially in the West to catch up with the advantage gained by Japanese companies like Toyota. The term has since been associated, in the engineering and product development, with the pursue towards cost and time reduction and quality improvement. It has gradually expanded from the manufacturing

design alignment towards incorporating the life cycle features and involvement of both customer and supplier. (Wognum, 2013) CE aims to integrate all the different requirements of the product that arise from marketing, financial, engineering, manufacturing, assembly, after-market, service upgrading and recycling (Whitney, 2004).

The fundamental of the concurrent engineering is to involve all the stakeholders from the beginning of the process and do the product development simultaneously, in interaction between the disciplines in a more integrated fashion (Mistree, 1990, Whitney 2004, Wognum 2013). It has also been called “simultaneous engineering” and described as **“a common sense approach to product development”** (Mistree, 1990). Over the years it has replaced the old-fashioned “over-the-wall” engineering where after one phase has been accomplished the “ball” is thrown over the “wall” to the next department to continue without thinking the consequences (Fukuda, 2013). Traditionally there has been less communication between the different stakeholders, even between the different departments of the company. CE on the other hand is always a group effort where all the specialists of different disciplines try to come up with a conclusion together before the next steps in the product design are taken.. Once the common goal is achieved all the departments and disciplines can work **simultaneously** towards that without having conflicts in the later phases (Figure 7). These stakeholders include the client and the client is also involved in the process from the early steps through-out the whole process. This way the clients wishes and preferences are heard in the stages where the changes still can be made.

Development towards CE has been present in the shipyards and research (Mistree, 1990, Bennet, 1996, Anumba, 2000, Milanovic, 2016), but it seems to be that, due to the complexity of the ship design process, ship design still has features of traditional engineering approach (Interview 1). CE process is well proven to be efficient and the author of this work sees that the mind-set that is present in the engineering community, what comes to CE, enables the AAD approach to enter the ship

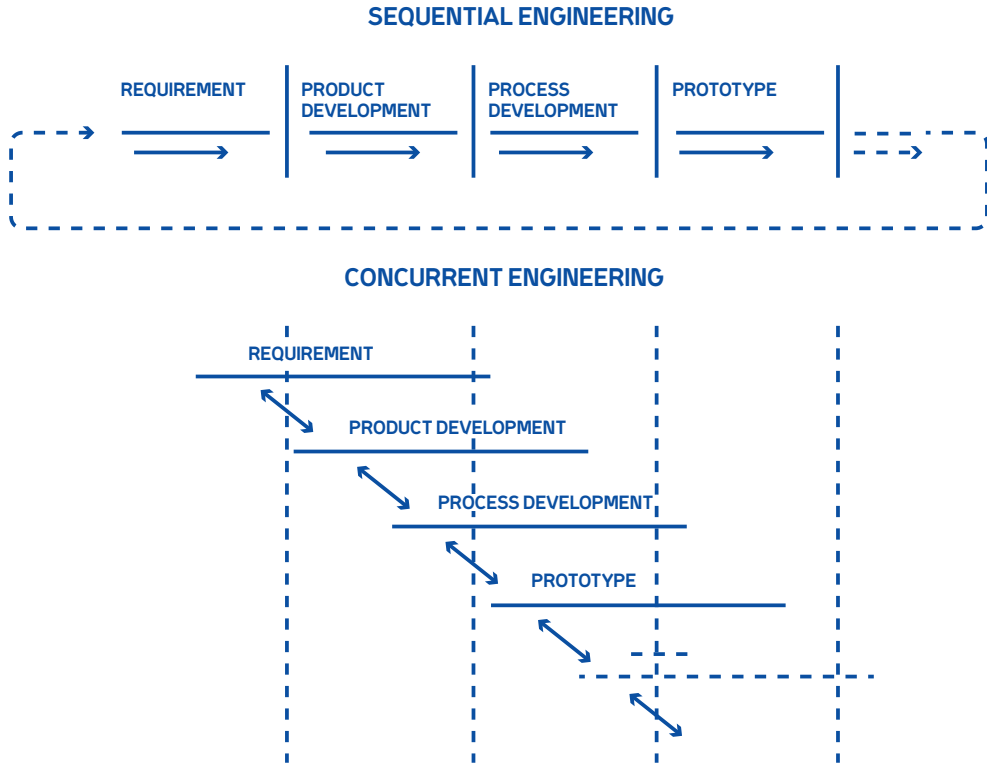


FIGURE 7
The difference between traditional, sequential engineering and concurrent engineering, according to Mistree, 1990.

design practice and also potentially works as a vehicle to implement the CE process better to the current ship design process. AAD and other computer aided methodologies could solve some of the problems current systems have with information handling. This is discussed further in the chapter 2.3.1 and 2.3.2. Also, the “decision-based design” and “building block” methodology, discussed in chapter 2.2.5, are built on top of the foundations of concurrent engineering. They are more concrete examples of the ways of implementing the ideology through computer-aided methodologies to the ship design process.

2.2.4

PARAMETRIC PRACTISE IN SHIP INDUSTRY

Advances in CAD software and computer technology since the 1960's have introduced new tools in the ship engineering design industry. These new media were first implemented in the shipbuilding by numerical control of steel plate flame cutting torch in part production. Shortly after, the CAD software was developed to simulate analogue drawing and more advanced 2D curves and geometries. In the years to follow, the 3D geometries were implemented and more advanced calculations and simulations became possible as a result of increased computer capacity. (Soulтанias, 2014) As the CAD design software developed like described in chapter 2.1.2 they were implemented to the shipbuilding industry. Parametric modelling has taken also its stand on the industry and taking its "first steps" to more advanced smarter methods like parametric modelling, numerical analysis, simulations and optimization. (Soulтанias, 2014)

Even though the parametric design methods are already used in the shipbuilding, the use is not as comprehensive as it could be. Usually in shipbuilding context it means numerical planning and it is quite different from what is today called "parametric design" in architecture and industrial design field. Usually the main objects in parametric planning are the ship hull and the technical measurements of the ship. These parameters are set according to strict structural guidelines that rely on the typology of the shipbuilding, following the principles that are well proven in certain conditions in which the ship is build. This means that in the early stages the ship hull and superstructure is scaled to the measures that are needed to fit the desired functions inside the ship (Interview 2).

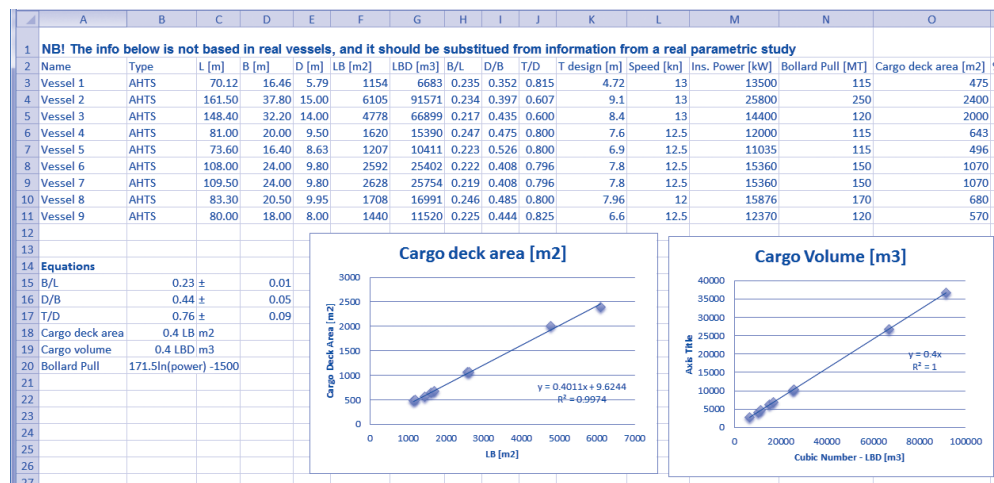
This kind of parametric design makes the early stages of shipbuilding much more efficient and reduces the workload of engineers. In practice, a commonly used

method is to set the parameters for different functions in the Microsoft Excel platform that updates the end result according to the set values. This gives, to the engineers the first idea about the measurements and the size of the ship. Usually, the values of a comparison ship are shown in the same diagram to help to estimate the feasibility of the design. The comparison ship or ships are similar type of ships that are already built and proven to be functional, from the technical perspective (Picture 7). (Interview 1) In principle this “Excel planning” is parametric design. However, the design changes are not interacting with the 2D drawings or 3D models, and certainly not following the principles of AAD by generating new designs according to the new values.

From design point of view this Excel based preliminary planning tends to lead to visually almost identical outcomes. Typically, the ship gets its crucial values from the Excel calculations and the hydro-dynamically, separately designed, hull is stretched to those proportions. Then the superstructure (hotel section) is added on the top of the hull and stability analysis is done to see if the combination works. If there are some changes needed after the stability test they are done manually in 2D environment and then changed back to 3D for the simulation. (Interview 1 and 2) This leads to time consuming iterative engineering cycle. The concurrent engineering approach can be enhanced with parametric and algorithms aided design process. CE within a holistic scope of the ship design, bypasses the original design spiral (Figure 6) and leads to a more integrated solution. This integrated approach has the ship model at its core and all the computational modules interact with it in many different layers (See chapter 2.2.5). (Soulтанias, 2014)

Ship design is one important field of optimization in engineering field. Over the past decades, optimization has been used in various ways in the ship design. Together with safety improvements optimization is clearly a big trend in shipbuilding today (Turan, 2012). New optimization methods are being developed and new fields of optimization are introduced. The complexity and the scale of the ship lead to the main limitation of the method.

2 CONTEXTUAL REVIEW



The complex structures make the calculation tasks usually really heavy and the calculation times can be several weeks or months. Therefore, optimization is not as widely used as it could be. The problem is the sufficiency of computer calculation power which is taking steps forward in fast pace. Also different strategies in the coding are being developed like evolutionary optimization, that reduces the calculation time effectively. (Turan, 2012)

In his thesis work Ilias Soultanias (2014) describes the different levels of implementation of parametric practices and what it concretely means in the ship engineering. These same principles apply when making **design decisions** in ship design context (Interview 2).

In the holistic approach of parametric modelling, the model and different computation modules interact through basic parameters. They are the values that define the model itself, its geometry and properties. The extent to which the parameters are used differentiates three major modelling concepts in modern CAD:

- Conventional design
- Partially-parametric design
- Fully-parametric design

PICTURE 7

In the preliminary ship design the reference ship's values can be seen in the Excel constantly and the effects of the design decisions can be evaluated.

Conventional design is about using the traditional design techniques. It includes no or little parametric functions. The designer has full control of the drawing by moving the essential points forming the lines and curves. This brings also great responsibility, as the designer has to deal with fairing, meeting constraints etc. Conventional approach is a rather a rigid method, where any changes to the original design are a time consuming task (Soultanias, 2014, Interview 1).

In **semi-parametric design**, CAD tools are able to build on existing shapes and modify a given hull form by controlling parameters that create variants. New hull forms can be produced by advanced transformations or distortion based on a given parent hull form. The method is qualified as “partially parametric”, as changes apply only partially to an existing parent geometry, which in the end keeps all the shape related information unchanged. It is favoured against conventional design, as it can provide the designer with some fast simple variants in the initial optimization procedure. (Soultanias, 2014)

In **fully-parametric design**, the model itself is generated out of relationships created by form parameters. This interaction enables creating ship hulls quickly and effectively, while many of the parameters are in many cases performance indicators, providing the designer with instant feedback. Moreover, the mathematically defined curves and surfaces yield excellent fairness by directly using the model parameters. Since all computations are highly integrated in the model, there is a wide range of variants, as soon as the model is set up. (Soultanias, 2014)

Choice of the design concept depends on the level of control required over the design. The wider deployment of CAD features emphasizes use of partial and full parametric modelling categories. Partially parametric models build on existing shapes and are exceptional for many short term applications. However, they are not compatible with more advanced and AAD procedures. To apply iterative, artificial intelligence or machine learning techniques to multi-objective optimization, a highly interconnected fully parametric model is needed. (Soultanias, 2014)

2.2.5

ALTERNATIVE SHIP DESIGN PROCESSES

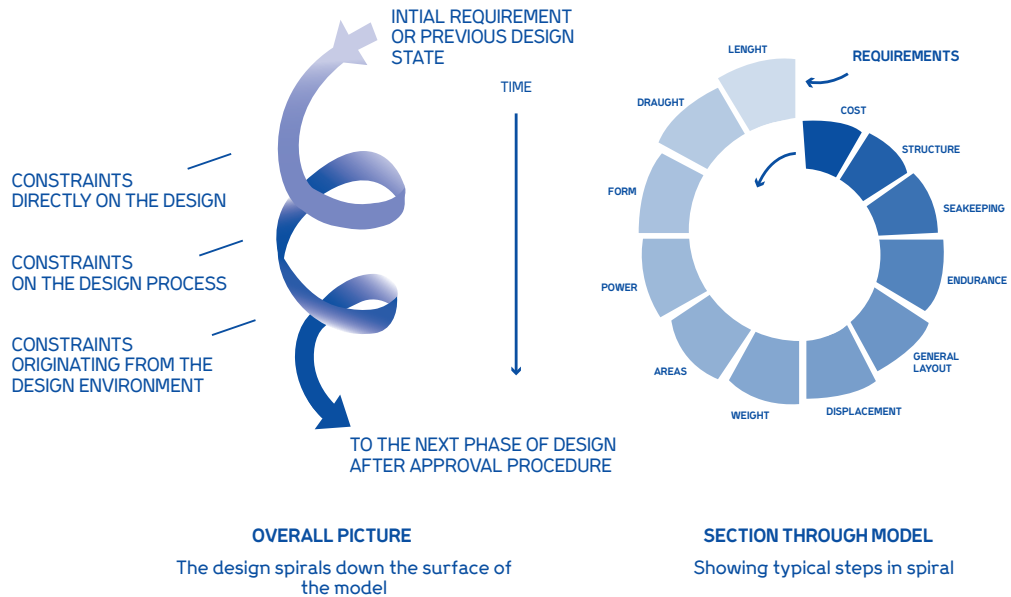
The traditional design cycle process of shipbuilding has been questioned in the engineering field in the past decades when the competition has been growing and the need for innovation has emerged. In the “Decision Based Design: A contemporary Paradigm for Design” (Mistree, 1990) the authors intend to introduce different ideology and approach to the ship design. It is written from the industry’s standpoint and the “design” is mainly engineering design, but it has a clear intention to bring more innovation and creativity to the process. Thus the ideologies presented in the decision based design can be applied when thinking, how to bring industrial design ideologies to the current ship planning process. Therefore, the “design” can be also seen as design process run by or involving significant amount of industrial designers.

The ideas presented in the paper were somewhat utopian at the time (early 1990’s) when they were presented, but has become more relevant in past few years due to the computer capacity growth. The calculation power of today’s computers can handle tasks and calculations fast enough to bring separate tasks together and design many overlapping elements at the same time. This helps the design team (designers and engineers) to see the product, in this case ship, as a unity. It proposes some features of the tools that can help bring the process towards more flexible interactive planning. (Mistree, 1990) The principles are still relevant although many of the practical parametric tools and interfaces discussed by Mistree are already been implemented in some software. However, in the process level the implementation of the ideas presented here are still not widely in use in ship industry. This kind of evolution is visible in the other fields and also slowly emerging in the ship design, and as some authors state (Mistree, 1990, Soultanias, 2014), is the most prominent

path of the evolution of the ship design.

The decision based design relies on the iterative design spiral (Figure 6) that has time dimension added to it. (Figure 8) This illustrates how the iteration is moving the solution towards the conclusion in different phases chronologically in more abstract level - similarly to the design concept creation (chapter 2.1.1). In decision based design, making decisions is the main role of the designer (or engineer). This role is a starting point for design methods in ship design that are based on paradigms that evolve from the perspective of designer's decisions. The tasks that can be assisted by the use of computers, optimization methods or specific analysis tools are not in the focus of humans. Decisions help in bringing an idea closer to reality. Thus decisions must use information from many sources (and disciplines) and have wide ranging consequences. (Mistree, 1990). Figure 9 shows Mistree's idea of the optimal process. Instead of iteration the "steps" are done simultaneously by computer putting the "designer" in the centre of the process to make decisions based on the created information (with help of "ring of interaction" made possible by a computer system). According to Mistree some of the aspects that are characteristic for decision-based design approach are:

- "The principal role of designer or engineer is to make decisions"
- "Design involves a series of decisions some of which may be made sequentially and others that must be made concurrently"
- "Design includes hierarchical decision making and the interaction between these decisions must be taken into account"
- "Design productivity can be increased through the use of analysis, visualisation and synthesis in complementary roles, and augmenting the recognised capability of computers in processing numerical information to include the processing of symbols (graphs, pictures, drawings, words) and reasoning (list processing in artificial intelligence)."



The decision based design ideology describes the idea of how the ship design process should work in order to produce novel ship concepts. However, in the beginning of the 1990's the computer power and the algorithms-aided design methods were not as developed as they are today. Decision-based approach is not giving precise practical description of the methodologies that should be applied to achieve the benefits of concurrent design. It seems that the development was not very constant until the beginning of the 2000's. During the past ten years the ULC university have done studies about "building block approach" (Picture 8). This is based on the simulation driven design methodology called Paramarine SURFCON. The building block approach is aiming to make the preliminary design of the ship more flexible. This approach also opens the possibility for more flexibility to implement human factors in the preliminary design stages. (Andrews, 2006) The "human factors", However, are rather technical in this methodology and related to the safety regulations, however, it is said that with building block method it would be possible to involve the **design thinking** and human needs to the process (Andrews,

FIGURE 8
The first step towards the decision based design was to add "time" to the traditional iterative design spiral. This helps to divide the tasks chronologically, in bigger more abstract steps. The iteration can be now done by a computer and the designer can concentrate on more abstract decisions.

2006).

The idea of the building block approach is that the elements of the systems can be moved around as “boxes”. (Picture 8) Certain parameters like stability and power requirement are the first things this method uses as a starting point. Human factors and naval architectural aspects are in the simulation at the same time and the program gives out different solutions to the same “problem”. The results can be evaluated based on different weights of the spaces and used by engineers to get the desired configuration.

In University College London (UCL) there is research going on to create a database of the systems that are crucial in the ship planning process. The data base consists of the information about the features of each system, physical weight and need of power. When these building blocks are combined to form a ship, the engineers can instantly see the displacement and the power consumption of the ship.

The ship could be designed so that the naval architectural features such as stability powering and resistance simulation is done constantly in real time. In addition, human factors can be added to the simulation. These human factors are simulations for different situations on the ship usually considering the evacuation of the passengers. This allows the designers and engineers to take into consideration the technical requirements and some human related issues at the same time. Author of this works sees here the potentiality to add even more “human factors” to the system taking into consideration also the normal situations and flow of people in the ship. As Andrews talks about his endeavours to “understand how designers design and how the design community might better achieve a more holistic and creative way of designing”. After all the hazard situations on the ship are rare and the main purpose of the ship is to give nice experience to the customers. This kind of values could be added to the simulations to evaluate the possible solutions also through the customer experience.

In optimisation tasks the problems are often multi-objective, meaning that the things that are being optimized are conflicting. If a vessel has to be stable it will be wider and thus less energy efficient because the hydro-dynamical

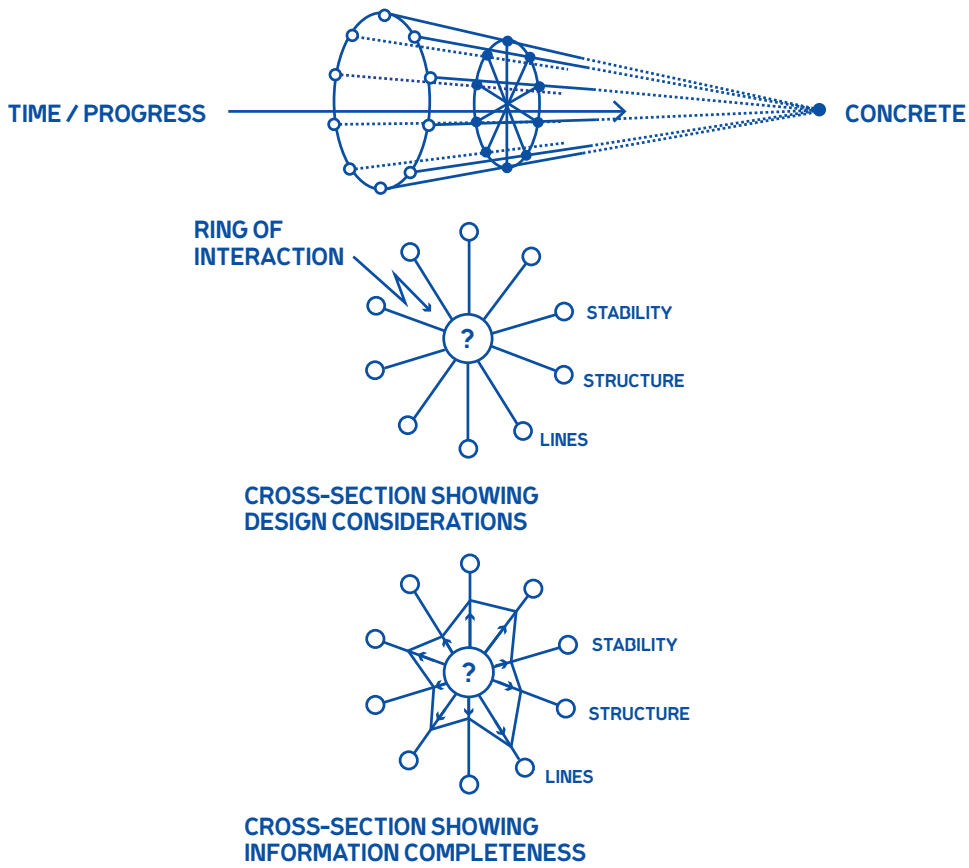


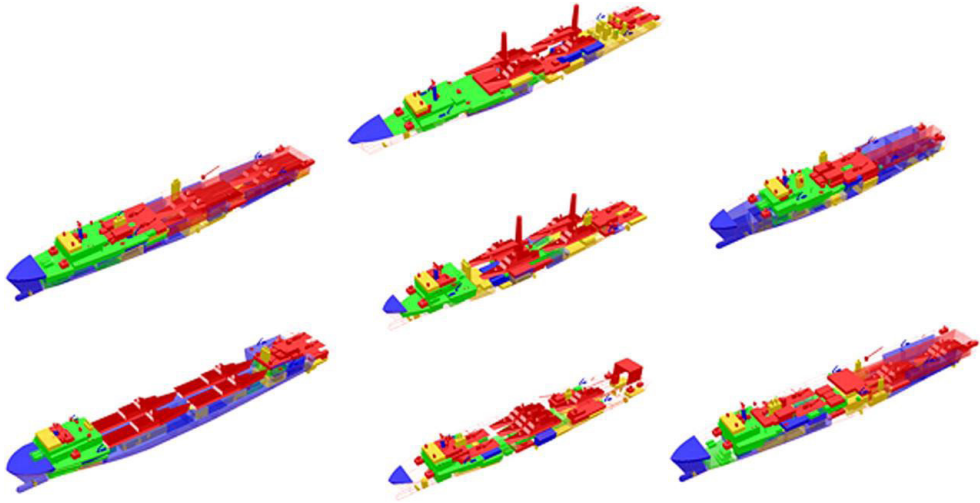
FIGURE 9

In the decision based design the engineers and designers are in the centre of the process getting the information simultaneously while it is generated in the process. Different solutions about e.g. stability and structure of the ship are getting closer to the center concurrently when the process gets closer towards the end.

properties decrease and need for power to drive the vessel increases. It is always a compromise and the ship engineer's job is to balance between these values. The public places in the ship are simulated to understand the efficiency of "packing". Engineering aspects and human factor aspects can be optimized at the same time. When the first arrangement is done and proven to be working from the engineering point of view, the blocks are divided to smaller blocks. These smaller subdivisions can be now organized more precisely and then divide them to even smaller combination of systems (blocks) until one block represents one individual system.

New International Marine Organization (IMO) standards require that the evacuation plans are done already in the early stages of the ship planning. This means that the first general arrangement pictures have to take these issues into consideration. (Interview 1) Building block method makes planning easier and the system "automatically" makes the arrangement to work in the evacuation situations, saving time in the early stages. In the computer simulations the human behaviours are modelled as a trajectories of people based on their role in the ship. People are behaving differently for example in evacuation situations. The passengers are one group that is going to the meeting points and to the exits while some of the crew members, responsible of the evacuation, are moving to opposite directions. (Interview 3)

It is also possible to do simulations about "normal" situations. This is used to optimize the efficiency of the logistics in the ship. Walking distances inside the ship can be optimized to be shorter by optimizing the arrangement so that logistically important spaces are close to each other and close to the loading areas, but at the same time not too far from the scenes where the supplies are needed in the ship. (Interview 1, 3) The people's movements can be presented as line segments in the program, and the optimization goal is to make the line segments as short as possible. This could be used more broadly to optimize the working environment in the ship, so that unnecessary walking could be optimized to the minimum. In these simulations also multiple scenarios can be tested at the



same time. (Interview 3)

The emergency situations are something that the ship has to be tested for. However, it is not the reason why they are built for. That is why it would be important to simulate and optimize for the normal operation as well. Normal operation and hazard situations can be simulated at the same time and find optimized solution based on the weights given to the different situations. For example, normal situation could have more weight in the optimisation, as long as the safety requirements are fulfilled in the emergency situation. Then the naval architect can evaluate the results and choose the outcome that is most suitable, not only from the safety but also the functionality point of view. (Interview 3)

PICTURE 8

The building block approach handles the functional entities or areas of the ship as "building blocks". It allows to create multiple preliminary plans of the ship effortlessly. Different functional areas are shown with different colours.

2.3

INFORMATION IN THE PROCESS

2.3.1

INFORMATION ENVIRONMENT

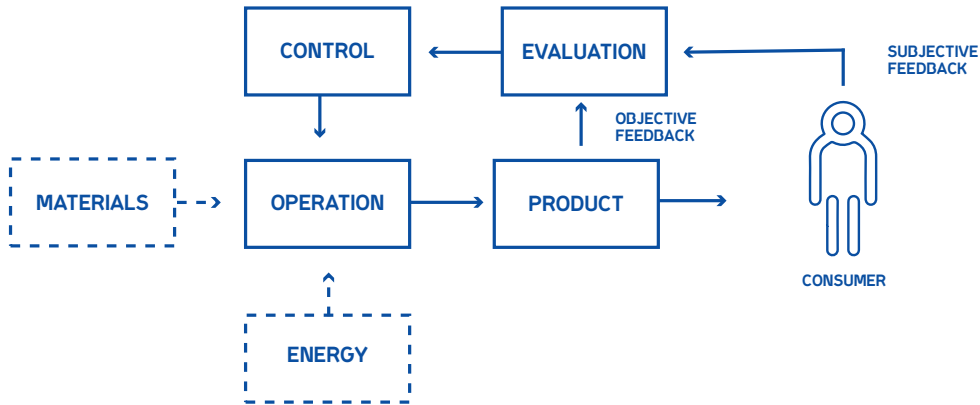
Cruise ship design process is a good example of a highly complex information environment. The ship as an entity is actually combination of information, materials and energy (Figure 10) (Whitney, 1985). Managing this massive amount of information is in the key role for successful and functional final product. Even when thinking of the other two: materials and energy, the information about them is what is relevant in the decision making process, whether it is design, engineering, marketing or economical decision making. The enormous amount of information is existing in the employees' knowledge, reports, regulations, manufacturers' specifications, part lists, drawings and 3D models - just to list down a few of the mediums of the sources. The biggest challenge is to bring the necessary information available for the designers (including engineers) in the right moment of the process.

The world economy is undergoing a profound revolution with information technology and computer networking technology. Today's "network economy" has dramatically changed the economy and the manufacturing environments. The customer demands have become more diverse and need for personalisation has led to the

market dynamic variability. Manufacturing enterprises are no longer isolated individual resources. They work as a member of a social system where they have to react to the increasing competition and product complexity. This has created pressure to change tactics of the manufacturing companies and establish a digitalized, flexible and agile networked manufacturing mode. (Yao, 2013)

Information equality is characteristic to the modern networked society. The “one and only truth” doesn’t come any more only from the centralised authorities (national tv, radio, news), but from vast network of information. This leads to vivid culture and exchange of ideas. The interaction in society creates new consumer desires, but the author believes that in enterprises, similar interaction could create new ideas about how to respond to the ever growing customer requirements. Similarly, to the “ring of interaction” of the “decision-based design” (chapter 2.2.5), the computer aided environment could collect the real-time information to the network. The information could be made available equally and simultaneously to everybody in the process instead of information dripping through the hierarchy filtered in every step and given in a “fixed” form to the subaltern levels (Fig 11). In the networked office the hierarchy still exists but the information contained in the interaction platform is accessible to everyone. This allows radical improvement in the problem solving ability of the company. (Whitney,1985)

Due to the complexity of ship design and building process the hierarchy and clear structure of the organization (interview1) are mandatory. However, it involves so many people that one department of the shipyard’s engineering and design sections can seem like a small size company itself. The information flow should follow the structure of the company so that it doesn’t get too integrated and cause information overload to individual worker. Different departments could still work separately solving problems in their smaller integrated information systems and just the most relevant information for the process as a whole would be shared between all members of the company tree.



2.3.2 VISUAL ANALYTICS

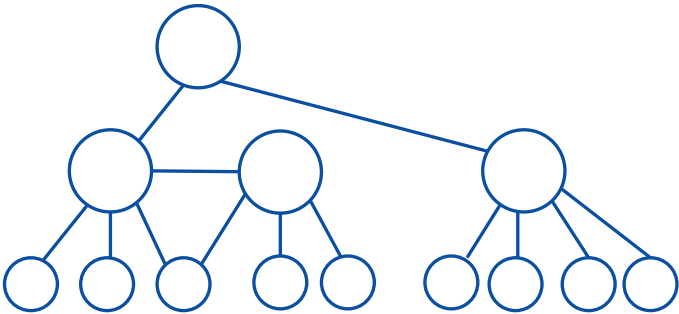
FIGURE 10
According to Whitney (1985) all the products can be thought of as a combination of energy, materials and information that are processed in the design process to be a product.

Visual analytics integrates new computational and theory-based tools with innovative interactive techniques and visual representations based on cognitive, design, and perceptual principles. This science of analytical reasoning is central to the analyst's task of applying human judgements to reach conclusions from a combination of evidence and assumptions. (Thomas, 2005)

One of the central motivations for visual analytics research is the so called information overload—implying the challenge for human users in understanding and making decisions in presence of too much information (Yang, 2003). Visual-interactive systems, integrated with automatic data analysis techniques, can help in making use of such large data sets (Thomas, 2005). Visual Analytics solutions not only need to cope with data volumes that are large on the nominal scale, but also with data that show high complexity.

Analysis is both an art and a science. The goal of analysis is to make judgements about an issue, or larger question. Analyses are often done on smaller questions relating to a larger issue. Analysts must often reach their judgements under significant time pressure and with

TRADITIONAL OFFICE



ELECTRONIC OFFICE

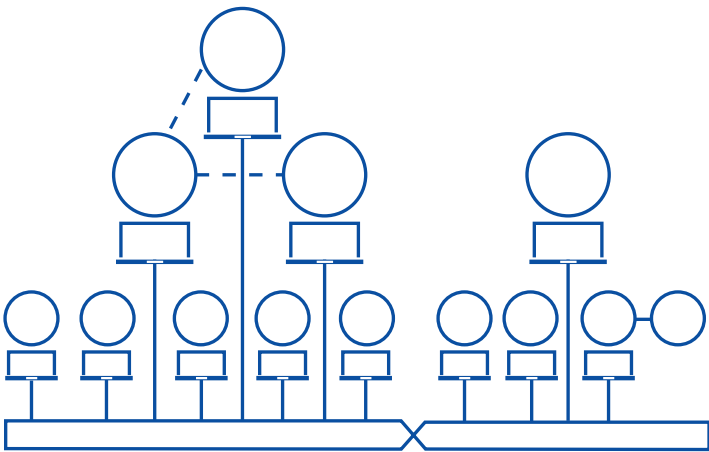


FIGURE 11
Comparison of traditional office and electronic office according to Whitney (1985). All the stakeholders involved in the design process are connected to a real time information system that reduces the hierarchy and enables a more agile design environment.

limited and conflicting information. Their judgements necessarily reflect their best understanding of a situation, complete with assumptions, supporting evidence, and uncertainties. Analytical outcomes are documented in the form of a product (Thomas, 2005)

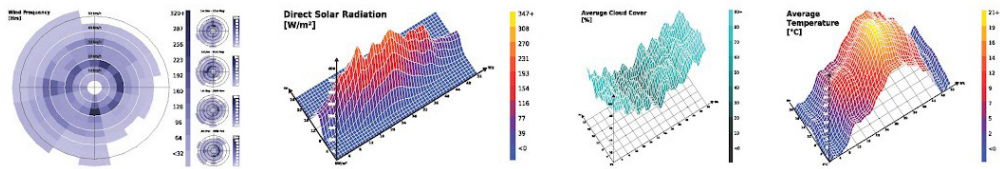
Visual analytics has transformed not only how we visualize complex and dynamic phenomena in the new information age, but also how we may optimize analytical reasoning and make sound decisions with incomplete and uncertain information (Keim, 2008). In ship design process

the information needs to be turned from the numerical preliminary plans to geometries that can be evaluated and adjusted efficiently, in the technical terms, but also from the design point of view (see chapter 2.2.4). In the design process, the implementation of visual analytics enables the designer to have information available based on the features of the geometry that he/she is creating - constantly and on the spot.

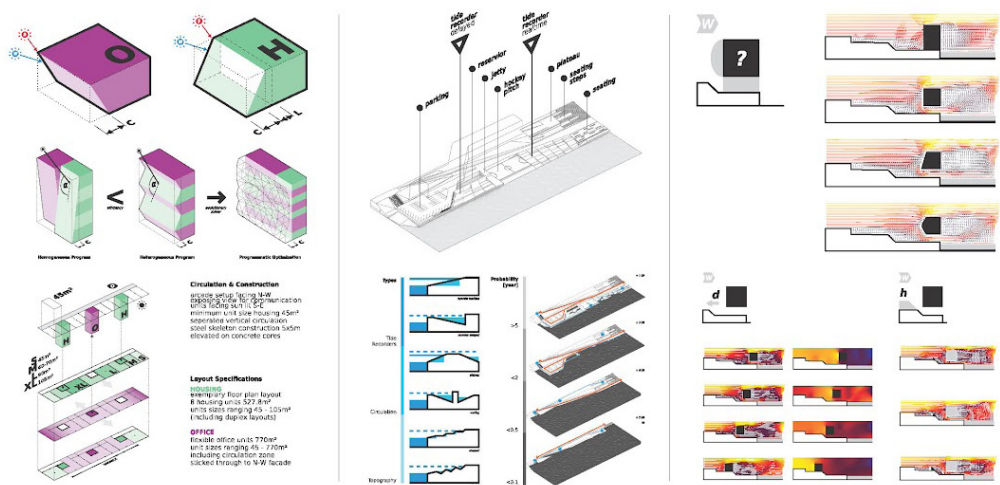
The idea is to extract descriptor from 3D models, which allow for meaningful comparison for the designer. This has been studied in architectural modeling to create methods to help architects query in 3D building models. The idea is to allow the users to quickly specify properties of interest in a building. (Landesberger, 2012) (Picture 9)

The author believes that in parametric design this query quality is, in a sense, built in to the methodology. The information can be picked up from the program and turned to meaningful values and formulas that give out specified information about the output data (for example 3D geometry). The information can be presented in many different ways. Typically, some selected features are monitored by a specific colour in the model. For example, colour gradient can follow curvature or continuity of a surface and change the surface colours in respective places, according to the values. Programs can also show areas or volumes of object and give different colours to areas while they change sizes when a change in the 3D geometry takes place. The “scale” of the gradient can be set so that it gives indication to the designer for example by turning a certain area red indicating that the area is getting too small. This is a strong and intuitive feedback (Landesberger, 2012) and designer can react to that while designing a complex system, before it causes difficulties.

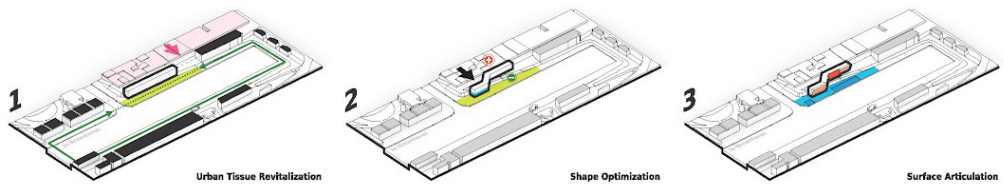
2 CONTEXTUAL REVIEW



PROBLEM DEFINITION & STATEMENT



PROCEDURAL TRANSFORMATION SCHEME



PICTURE 9

Visual analytics allow for meaningful comparison for the designer and allows to quickly specify properties of interest in a building.

2.4

CONCLUSION OF THE CONTEXTUAL REVIEW

The literature chosen to be reviewed in the contextual review, is stating that the motivation for new innovation is not only on the design field but also in the engineering community. The ship building industry, however, seems to be following a somewhat traditional designing process. This is mainly due to the high complexity of the product.

The ship building seems to live in a critical period now, where the physical size of the ship is reaching the cumulation point and the ship size cannot increase remarkably, at least not in the form it is built today. This pushes the shipbuilders to find new ways to compete in the demanding markets. To change the concept (see chapter 2.1.1) of the ship the methodology of the shipbuilding needs modernization and new approaches. It seems that the problems of the “economy of scale” mentality in shipbuilding has been acknowledged in the ship yards already in 1990’s but the evolution of the design process has not evolved in tandem with the scale and complexity of the cruise ships.

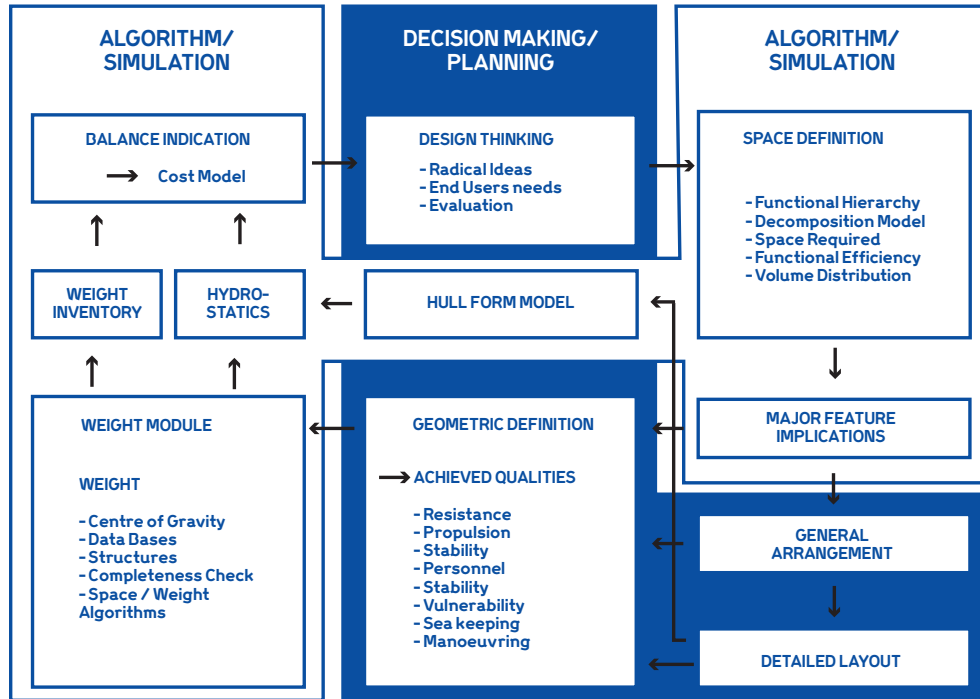
The ship design approaches found in the background research were all based on the engineering sciences. However, in the alternative ship design processes the approach has similarities to the design thinking based processes where the focus is not on “how to build it”, but more on “why we build it?” (chapter 2.1.1). In the optimal

situation, reasoning the abstract human-related issues should be in the focus of the designers and engineers. This is stated to be the key for innovation in both engineering (Andrews, 2006) and design (Brown, 2009) society.

Parametric approach can give more freedom to design decisions (Mistree, 1990). More agile ship design environment benefits both engineers and designers. The implementation of concurrent engineering should be emphasized to open up the iterative process so that the design thinking and decision based design could be integrated to the process - from the preliminary, to the final design. Parametric approaches like AAD together with other integrated CAD environments can make the design process more agile and the inputs of the individual designers and engineers visible in concurrent fashion.

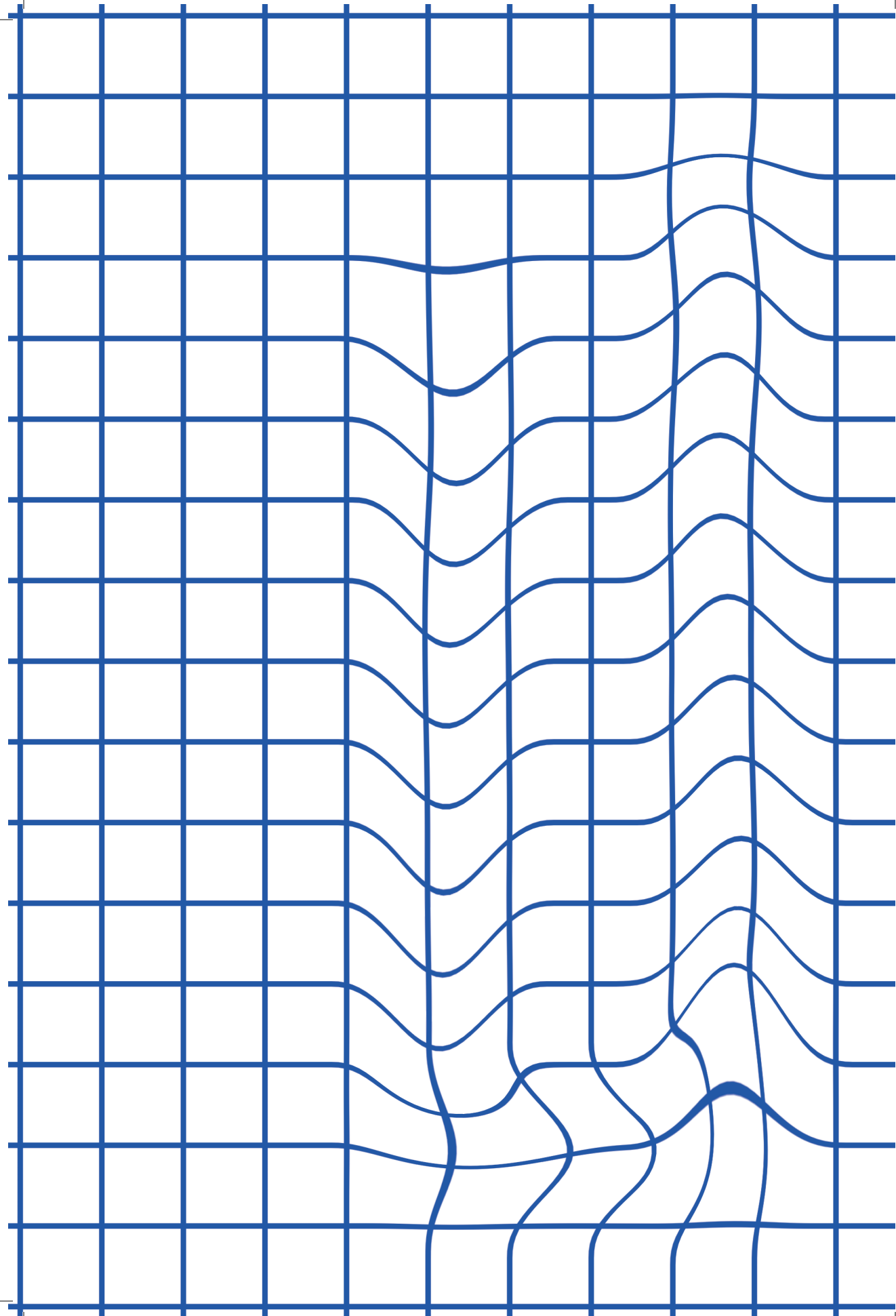
Handling the information is in an important role when designing complex entity like a cruise ship. In fully parametric system the information has to be available simultaneously to all the parties of the design process. Visual analytics can help handle this information in the design process and filter the most crucial data to the designer at a given time.

Implementation of the building block approach in the ship design process (Appendix 2) is similar than the implementation of the AAD could be. Thus the author of this work made his own interpretation of the design process based on the structure of the building block approach. The implementation of the AAD process is described in the figure 12. The design thinking was added to the process building block approach to represent the source of the “radical ideas” leading to innovations. Also the user needs where emphasized in the diagram. The other areas of the planning process follows the principles of the building block approach. All the stages or elements in the diagram are happening simultaneously. The elements on the white background are processed with computer and the elements on the blue are done by the designers and engineers. Thus the white elements are supporting actions for the design decisions happening in the core of the process.

**FIGURE 12**

The author's interpretation of how different tasks in the ship design process are related to each other and what is the positioning of design thinking and decision making in the process. Blue areas are the ones that are human related and need abstract human understanding.

The examples in the chapter 4 were chosen from this background to demonstrate the possibilities of using AAD in the ship design environment as comprehensively as possible.



3. METHODOLOGY



3.1

RESEARCH

OVERVIEW

PICTURE 10
The author's early experiment of a physical model inspired by Frei Otto. The shape is formed according to the physical properties of the sand and the size of the openings in the model creating a "voronoi" type pattern.

This work is positioned in between multiple areas of science, most important of which are ship engineering science and computer science. Both were relatively unknown for the author in the beginning of the thesis work. Thus first months of the work were used for understanding the context by reading, learning the programs, understanding the algorithms aided methodology and even creating analogue models (Picture 10) to understand the logic of algorithms. Due to several wide "unknown" fields of research, the literature review has an important role in this work. It aims at collecting the most relevant ideas from these fields and also pointing out the supporting theories from industrial design context. This phase worked as a basis for the author to understand better the needs on the ship industry and the context where and how the algorithm aided design process should be implemented. The literature review contains scientific papers, books and online articles.

To get the most updated information about the current situation in the industry, the author had a possibility to visit Meyer Turku Shipyard twice and interview engineers who are responsible of managing the engineering design processes. These interviews were done on January 2016 and March 2016. The first interview was a panel discussion of 3 hours and had 4 participants (Interview 1). The aim was to gain understanding of the big picture of the current planning process and map out areas where the ship yard sees the potential to develop computer aided methods.

The second interview was with Kari Sillanpää who was participating also the first interview (interview 2). This time the aim was to evaluate the author's ideas for case studies and define the case studies. One meeting was also organized in Elomatic engineering and consulting company March 2016 (Interview 3) where the topic was the "building block method" discussed in chapter 2.2.5. Another issue of discussion was application of Grasshopper algorithms in ship design environment. There were 3 participants in the discussion and it took 2 hours. Also one hour consultancy about industrial processes was done with Aalto University professor Eero Miettinen on March 2016 (Interview 4). All the interviews were voice recorded on the settings and summarised by author later based on the recordings.

The work was evaluated in steering group meetings of Cruise and Ferry Experience program every month during the author's 6 months thesis work period in Aalto University. The steering group members (For the list of participants: see "Appendix 1") were professionals from the cruise ship industry, shipbuilding and engineering professors as well as designers working closely with ship industry. In these meetings the author presented the progress of the thesis and got feedback about the ideas. Also it was an open forum for discussion and asking questions, define the research scope and learn about the expectations of the outcomes. The meetings were usually 2 hours, where 20-40 minutes each time were dedicated to the author's presentation and discussion of the work.

During the thesis writing the author was also working for 3 months at Meyer Turku shipyard. The work was not related directly to this thesis but gave important insides about the design process and planning work flow. It also gave the author a change to apply the knowledge learned during the thesis work and gave encouragement of the potentials of AAD in ship building.

3.2

USED PROGRAMS

As discussed earlier, the CAD systems that are used in the shipyards today are not supporting the algorithms-aided work flow. The target of this thesis is to evaluate AAD process, thus one of the important goals in the beginning was to find the most suitable software for this kind of prototyping. The author was not familiar with coding based 3D modeling so the program had to be as easy to approach as possible. Also the industry is quite conservative so the results should be feasible and the programs in use acknowledged widely in the industry.

Author had years of experience of using Rhinoceros 3D software (Rhino) which is a commonly used tool in the industrial design field. In the interviews in the Meyer shipyard it was found out that Rhino is also used in the shipyard (Interview 1). These reasons lead to choosing Rhino for primary 3D modeling software in this work. Rhino has not parametric or algorithmic capabilities built in but another well distinguished software plug-in – Grasshopper 3D – brings these functions available in the Rhino environment. Additionally, it is shown in similar cases that other software packages do not provide the necessary components for the creation of the workflow in as smooth and fluid a manner as Rhinoceros and Grasshopper (Lagios, 2010).

Rhinoceros 3D has become a popular tool for 3D modeling in many design and architecture schools and in selected practices, especially those with a focus on formal design considerations. Rhino is particularly popular with expressive London-based architects, such as Zaha Hadid, Buro Happold, HOK Sport and Foster + Partners (Day,



PICTURE 11
A detail of the
“Grand Macau
Hotel” by Zaha
Hadid Architects
in China. It is a
good example of
the possibilities
and form-finding
capabilities
of parametric
architecture.

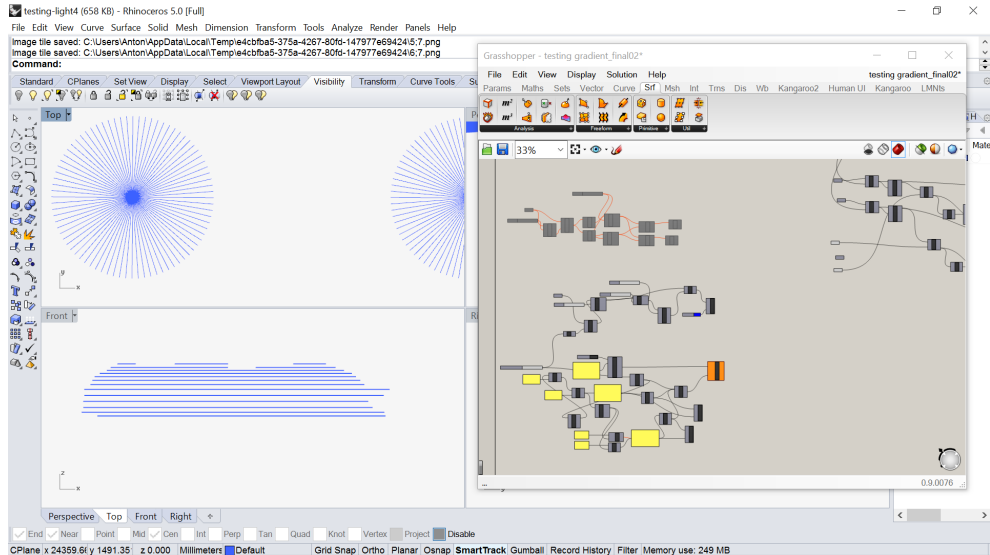
2009). Zaha Hadid Architects are known for pioneering with parametric approach in large scale architectural projects (Picture 11). Rhino is used in multiple design industries due to its accuracy and processing speed. It has gained popularity due to its low cost, ease of use and powerful feature set. It uses non-uniform rational B-splines (NURBS) to define the geometry. NURBS are mathematical representations that can accurately model any shape, surface or solid. Models created with NURBS can be used in any process from illustration and animation to manufacturing. (McNeel, 2015) The Grasshopper plug-in for Rhino is a graphical algorithm editor that allows designers with no previous scripting experience to quickly generate parametric forms. (Day, 2009)

Grasshopper is a visual programming language developed by David Rutten at Robert McNeel & Associates (Tedeschi, 2011). The first version of Grasshopper was released in September 2007 and it will become part of the standard tool set in Rhino 6.0 and onwards (Rutten, 2013). It runs on the Rhinoceros 3D CAD application platform as a plug-in.

The main interface for algorithm design in Grasshopper is the node-based editor. Programs are created by dragging components, “visual building blocks”, onto a canvas (Picture12). Data is passed from component to component via connecting wires which typically connect an output grip with an input grip (Picture 13). Data can either be defined locally as a constant, or it can be imported from the Rhino document or a file on the computer. Data is always stored in parameters, which can either be free-floating or attached to a component as input and outputs objects. Since Grasshopper is a plug-in for Rhino, the geometry created with the program is shown in the Rhino window. The interface of Grasshopper is relatively simple and opens on top of the Rhino window.

Grasshopper is primarily used to build generative algorithms, for applications such as generative art and architecture. Many of Grasshopper’s components create 3D geometry but programs may also contain other types of algorithms including numeric, textual, audio-visual and haptic applications.

3 METHODOLOGY



PICTURE 12

The Grasshopper window opens on top of the standard view of Rhinoceros interface.



PICTURE 13

Typical grasshopper element has input grips on the left side and the output on the right side. Each element contains part of the code and they are connected with “wires” to create the relations of the elements.

Grasshopper has hundreds of add-ons available. These add-ons are not included in the standard Grasshopper installation but can be downloaded for free from the Grasshopper community website. In this work “Kangaroo” physics engine developed by David Piker is one of the add-ons used in the prototype programs. “Kangaroo is a Live Physics engine for interactive simulation, optimization and form-finding directly within Grasshopper” (Piker, 2016). Another add-on used in this work is “Human UI” developed by NBBJ Architects. It is an interface paradigm for Grasshopper for creating professional looking Grasshopper applications with custom user interfaces using visual coding embedded to grasshopper code. (Heumann, 2016)

3.3

GENERATIVE MODELING

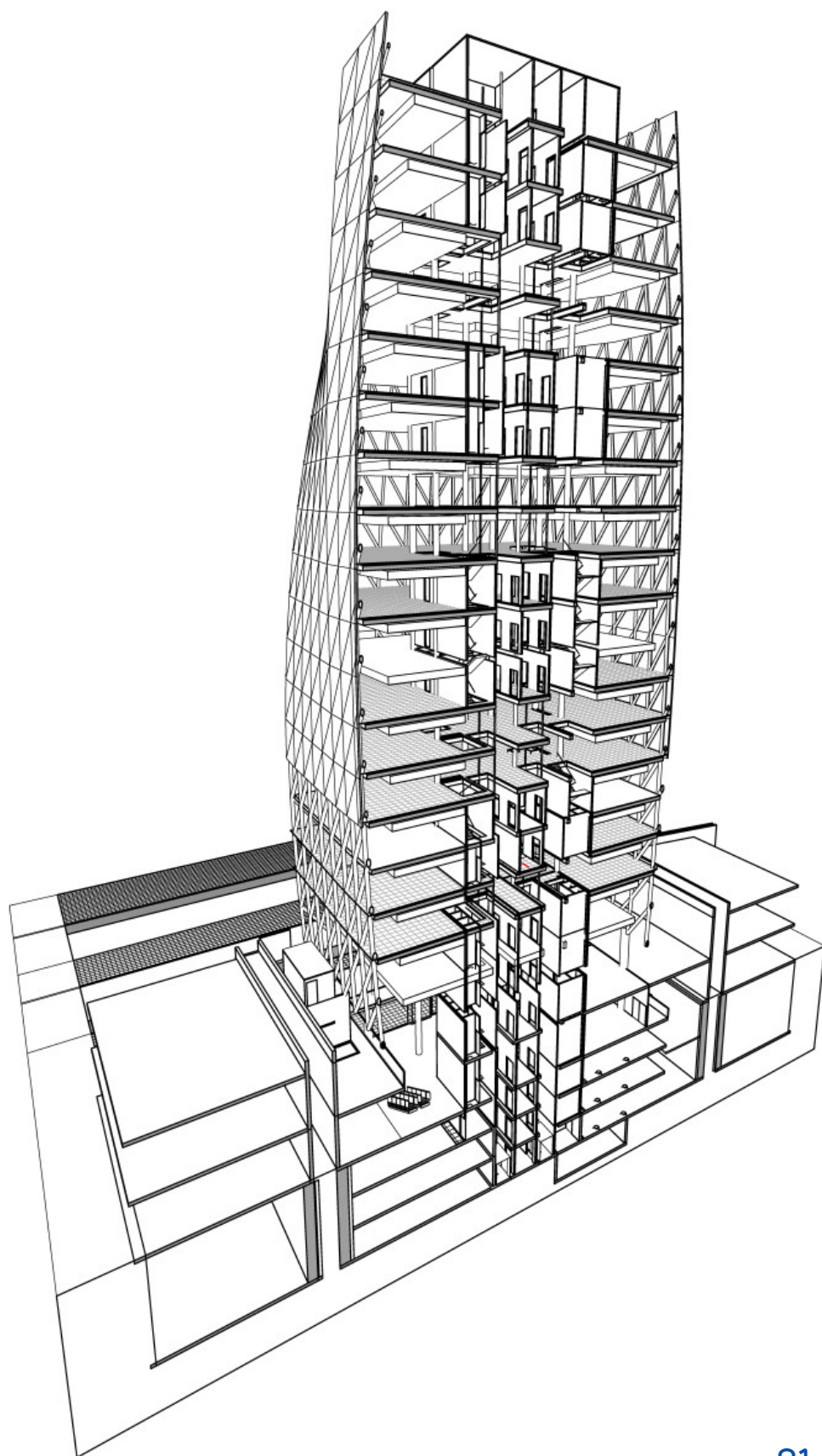
As discussed earlier in chapter 2.1.2 Generative modeling draws back to the analogue “machines” for form-finding. The idea is same as, for example, in the early Gaudi’s church planning setup (Picture 2). There the architect moved the sandbags attached to the strings and instantly saw the change happening in the model. The form was “generated” with the help of gravity and the connections of the strings. This enabled form-finding capabilities to very complex geometrical shapes. In algorithm aided design these forces and “connections” or relations are realized in the algorithm. The same real time modelling effect can be achieved with physics modeling plug-ins like Kangaroo. In the Grasshopper coding, the physical forces have familiar names like “springs” and “gravity” to describe the action in the 3D world. As a result, one can for example make functional model of Gaudi’s church in Rhino and use the same intuitive way to explore the shape and proportions. The advantage in Rhino however is that the “strings” are curves and it is possible to generate the surfaces and much more complexity to the structure and still maintain the same intuitiveness with editing. The result can be much more defined in a matter of seconds and turned to final geometry for manufacturing drawings.

The approach of this work to generative modeling has not so much to do with traditional form-finding but to handling the complex design constraints and freeing the designer to concentrate to the design decisions that are relevant for the end user. Patrick Schumacher calls this approach “rule- based design” (Schumacher, 2014). He

mainly describes it to be architectural implementation of parametric design methodology. However, similar network of constraints is present when designing complex industrial products like large scale cruise ships. “Rule-based” design as a word suggest to many critics that this method is restricting the creativity of the designer. Schumacher claims the opposite, “A new realm of creative exploration with its new design challenges is opened up and calling for the designer’s creative ingenuity. The more computational design tools free the designer from the drudgery of drafting and modeling, the more does the creative essence of the design process as process of invention and decision making comes to the fore” (Schumacher, 2014).

This ideology has emerged in recent years especially in architecture. The best examples of implementing algorithms-aided generative – rule based – design also come from the field of architecture. Oosterhuis-Lenard Architects designed the “Liwa Tower” in Abu Dhabi with similar methodology (Picture 14). The project started from the client’s demand to build a tower that has exactly 21604 square meters of interior space. At the same time the city of Abu Dhabi set a 3D footprint requirement for the new building. It had to fit inside those limitations in all 3 dimensions while delivering the desired square meters of space inside the building. To deal with these conflicting design objectives, the Oosterhuis-Lenard Architects designed a fully parametric model that monitors the restrictions while the design decisions were made and changes occurred from the input of the client or the city. The tactile element was created to the model to make the design process rapid and effective. The designer was able to push and pull the segments of the façade of the building, increasing the floor space of one floor while automatically decreasing it on another. Not only did the method prove to be successful in adding more freedom for the creative process of the design, but it also helped to create a schedule for the construction of the tower. All the elements of the tower were parametrically defined in the model and each individual element received its individual ID-number. This helped planning the construction of the building and saved a lot of time and money in the labor (Penman, 2016)

PICTURE 14
The “Liwa Tower” in Abu Dhabi is designed with algorithm that monitors all the restricting parameters of the building, allowing the designer to do form-finding freely.

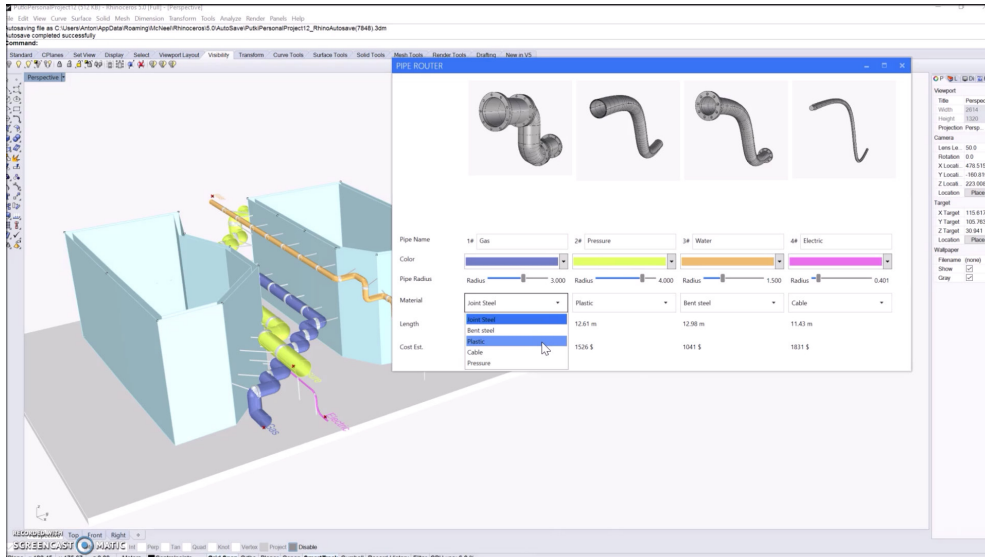


3.4

REAL-TIME VISUALISATION OF DATA

In this work the aim was to study the real-time visualisation of data with a few different approaches. First, to translate the starting point Excel table data, discussed in chapter 2.2.4, and visualise that in 3D geometries, volumes and areas. This allows the designer to understand the proportions of the needed spaces more clearly and also react to the possible changes of the space reservations in the preliminary planning phase. Another point of visualisation of data is to get real-time information of the designed spaces from the 3D model back to graphs and numbers to evaluate cost, weight, capacity and other aspects that are relevant to the designer's decision making process.

One of the major goals of this work was to make the design process more agile. One way to ease the process is to handle information so that it allows the designer to do decisions more intuitively. As described earlier in the chapter 2.3.1 the information flow from the client coming to the designer, and through the whole design process and back, is in a really important role in making the design process more flexible. The real time 3D modelling aided by algorithms is one part of making this information available. However, the idea is to keep it available but keep the irrelevant restricting data “away from the eyes” of the designer. This is done so that the design can be done from the end user's point of view - not from the regulation or



PICTURE 15
The Human UI
interface plug-in
for Grasshopper
translates the code
to a user-interface.

restriction point of view (Mistree, 1990). The design process of a cruise ship is a complex system and the end product is always a compromise. Usually it is a compromise between elements like customer experience, cost and measurements of the ship, as discussed in the chapters 2.2.1 and 2.2.2. In the circumstances it is really important for the designer to be aware of the effects of the design changes. The earlier in the process the better. Grasshopper can make complex calculations in real time based on the created geometry and provide instant numerical estimates of the current stage of the design.

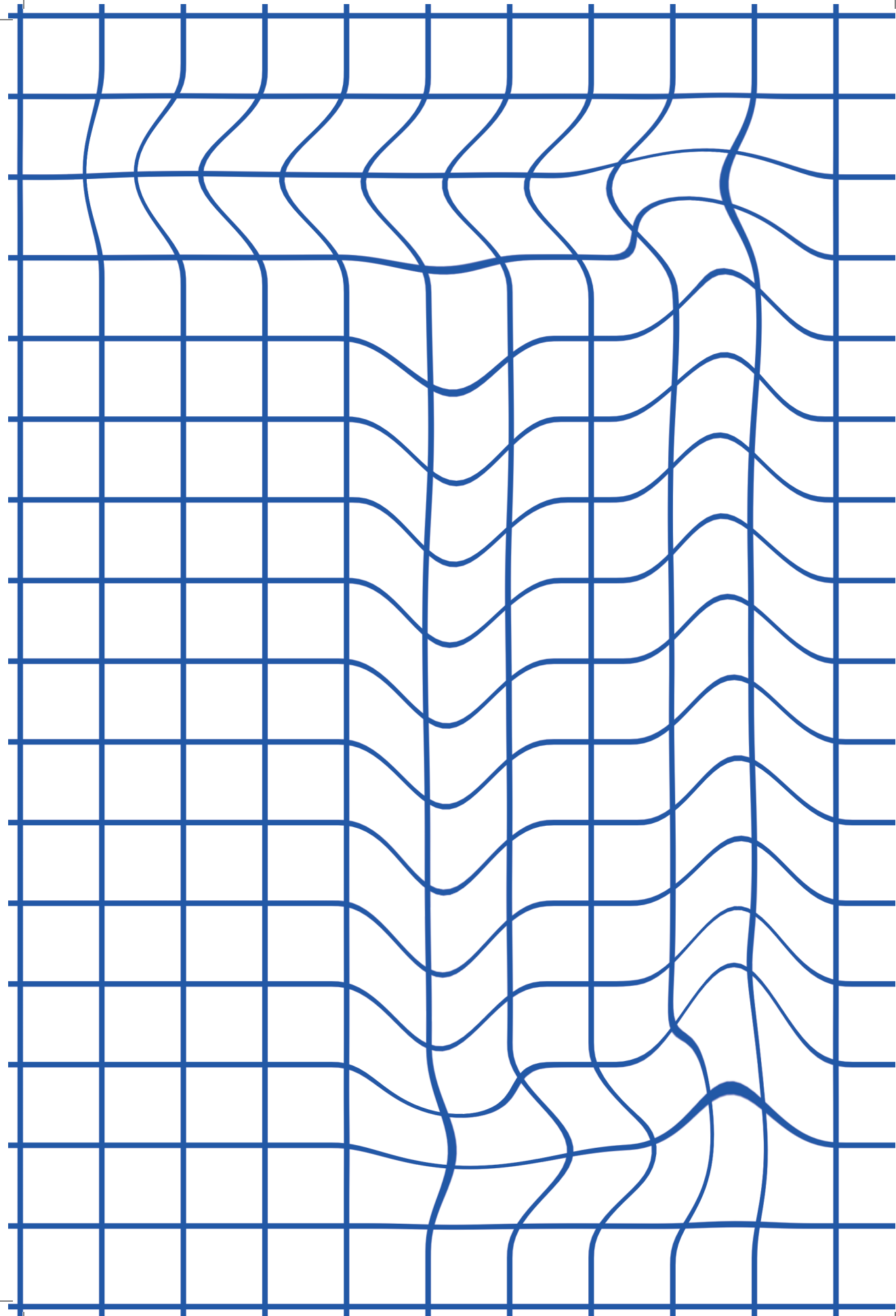
Grasshopper has a plug-in called Human UI. This plug-in adds user interface elements to the grasshopper code. The numerical information and result of the estimates, that are relevant for the designer in the design work, can be picked up from the code to an external user interface. This “user interface” is for the designer to make his/her workflow more efficient. Also, the designer who is using the algorithmic tool, built with Grasshopper, doesn't necessarily have to know grasshopper code to create the 3D models (Heumann, 2016).

The principles of Human UI coding work the same

way as normal grasshopper coding. However, instead of effecting to the geometry of the 3D model in Rhino, like Grasshopper normally does, it creates external control window(s) to Windows operating system (Picture 15). The coding blocks of the Human UI are placed in the main code to “translate” the most relevant parameter editors to create more convenient and easy-to-use control boards. This control board(s) contains sliders and switches that are chosen to be the most relevant for the desired design.

Human UI has also vast possibilities for creating graphical data visualisation. The same way one can dedicate one slider in the Human UI to represent the slider in the code, one can read and feed values through Human UI window. These values can be fed to different kind of graphical elements in the Human UI window. Elements like different style of pie charts, “Excel type”- of tables, pictures, geometries, or drop down menus are some of the main elements that can be used to build the user interface, just to mention a few. These set of functional elements can be named, organized and grouped in an intuitive to use fashion.

Decorative elements such as headers, images, colours and logos can be added and adjusted to fit the company brand image. This makes the “messy” Grasshopper code easier for the designer to work with, but also brings new possibilities of working with the client. Interface can be built so that it supports the design related meetings with the client. For example, to have different design solutions available in drop down menu or push of a button makes the feedback from client instant and therefore enables whole different interaction with the client (Heumann, 2016).



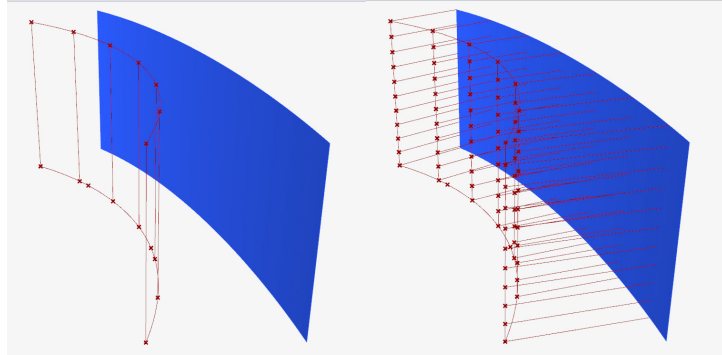
4. PROCESS IN PRACTICE

4.1

EXAMPLE 1: GENERATIVE BULKHEAD STRUCTURES

To demonstrate the use of generative modeling in ship design environment, the author made a program that generates different wall structures automatically. When the design work is done even the smallest architectural changes engage the knowledge of many people in the ship design process. This is the case in the current situation. The surrounding walls of the public spaces in the cruise ship include pipes for liquids and gases, air-conditioning ducts and machinery, electric cables and fire extinguisher systems. All of these have to be taken into consideration if design related changes are done during the ship design process. Moreover, the structures supporting the wall and the infrastructure have to adapt to these changes. If the walls need to be moved by the designer, for example, to make a corridor wider to increase the comfort of the cruise passenger, the change may be left undone in the current system because the change would cost too much in terms of time and money. The attempt with this Grasshopper based algorithmic model is to demonstrate how the automatically generated wall structure could work in the ship architecture.

In this chapter the set up for defining the algorithm

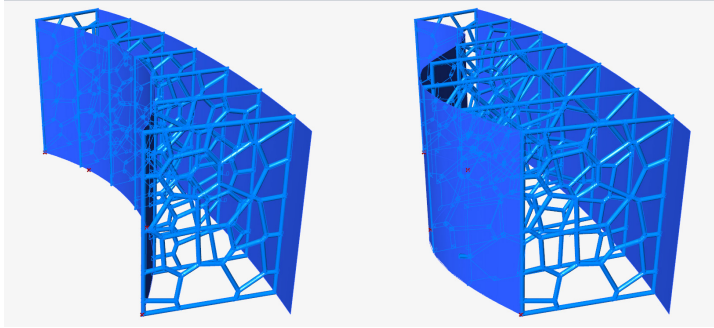


PICTURE 16
Wall geometry is created by defining the core structure for the bulkheads with curves and lines orientated with coordinate points.

is described “step by step” to show the workflow of/ in Grasshopper. The model is done by, first, setting the control-points for the wall to the wanted location of the wall to be created. The respective wall will go through these control-points. This can be done in 2D when the general arrangement of the ship is defined. In this example we use a small area for clarification. The control-points are then connected with the curve that defines the shape of the wall. It can be set as a poly-line curve for sharp corners, or an NURBS curve for curved surfaces. After this, the curve is copied and moved straight up to form the upper edge of the wall. The distance of the move can be set to follow the height of the deck where the wall is situated.

Next the supporting structure is defined. In this example we want them to be equally spread throughout the wall. Thus we define it by dividing the upper and lower curve to segments with equal length. The end-points of the upper curve segments are then connected with the corresponding points in the lower curve. This creates a network that can be lofted to form the geometry for the wall. The vertical curves that go from the upper edge to the lower edge can be now divided to get end points for the support geometry. These points are then projected to the hull geometry by finding the closest point from the hull. Now straight lines can be generated from the wall to the hull (Picture 16), and these lines can be lofted as bulkheads.

After that the cut outs for the infrastructure have to be made to the supports. This can be done in many ways



because the geometry to the cut-outs of the supports can be any shape. Usually they are rectangles with rounded edges. In this example the “voronoi” pattern is used. Voronoi is a mathematical pattern of which the formation the author was studying with the sand box “analogue model” (Picture 10). It creates rigid shapes that can be optimized to reduce the weight of the wall structure (However in this work the optimization is not done and voronoi structure works as a demonstrative element). The pattern is generated to the support and after some extrusions and more defined geometry the wall with the supporting structure is generated.

This definition is quite time consuming to make, but once it is done the changes on the shape and the position of the wall are generating a new geometry automatically. By adding more parameters to the model it is possible to automatize all the structures and infrastructure in the similar fashion. When the definition is done the actual designer’s work only begins. Now when the control-points of the wall are moved or edited to any direction, all the geometry follows according to the set rules, generating the whole structure in matter of seconds automatically. (Picture 17)

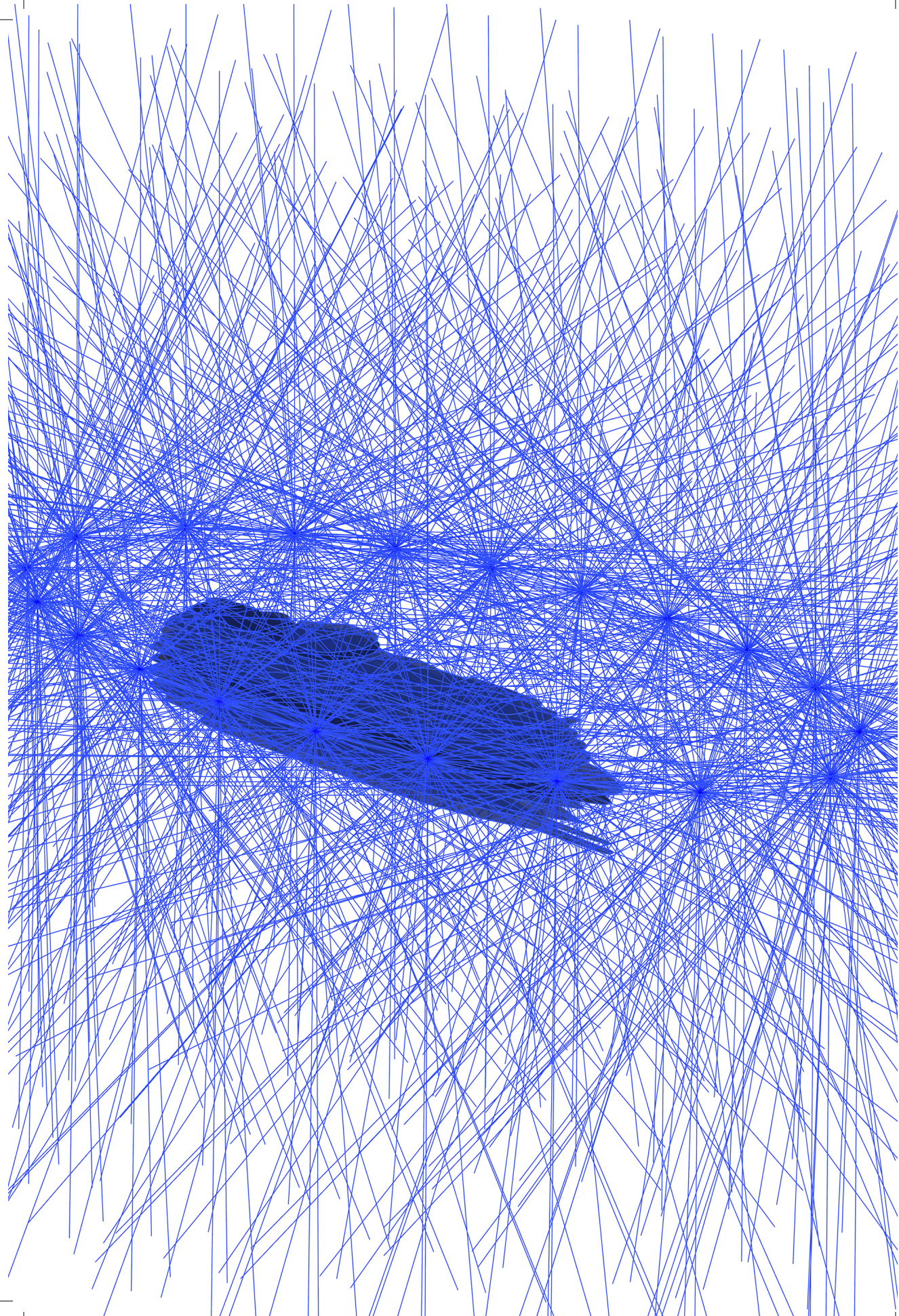
PICTURE 17
When the position of the wall’s control points are modified, the whole wall geometry is generated automatically by the program.

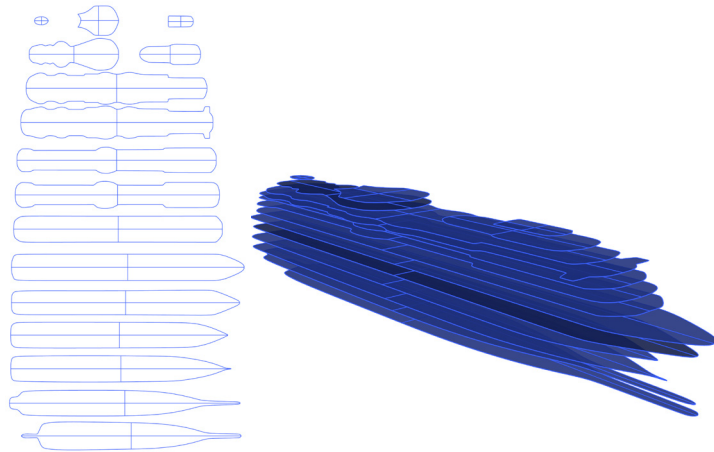
4.2

EXAMPLE 2: ARCHITECTURAL PLANNING WITH LIGHT

In chapter 2.3.2 visual analytics was mentioned to be helpful in the design process for the designer to easily assimilate information from the design plans, models or visualisations. This example demonstrates the use of visual analytics to visualize the appearance of light in the cruise ship interior. There are daylight simulations available for Grasshopper as ready made plug-ins (Lagios, 2010) but ship is a moving object and implementing these would not give useful information. Instead, in this model we use simple linear light that comes equally from all the directions towards the ship (Picture 18). Also the interior lights are set to the model as simple spot lights radiating equally to all directions.

The idea is to have a tool that enables the possibility to evaluate different areas and the amount of light available. Since Ahola (2016) stated that natural light and feeling of openness is one important factor (“or parameter”) that affects the passengers’ perception of safety. The areas where there is more natural and artificial light available are shown green in the model and the areas that are too dark, thus unpleasant to the user, are shown red. This gradient map helps the designer to keep track of the effect on customer satisfaction factors related to lighting while doing design



**PICTURE 18**

LEFT:

Ship geometry in the daylight system. The ring surrounding the ship can be moved up and down to simulate different times of the day. None of the lines are visible to the user of the application.

PICTURE 19

RIGHT:

The geometry presented to the program. It is simplified version that only models the surfaces that are affecting the travel of light.

decisions with the layout of the ship. When the walls are moved around, openings are done to the decks or the height of the decks are altered, the effects to the light can be seen instantly on the map. For example, lowering the deck height causes the sunlight to travel shorter distance inside the ship. At the same time, the spot lights in the ceiling are closer to the ground and the light is more intensive but travels shorter distance. Other similar parameters could be added to this kind of model, for example, sources of vibration or noise. Multiple gradient maps could be used simultaneously to measure the customer perception of the space already in the preliminary planning phase of the ship.

When the spaces and corridors are designed, the behaviour of light is hard to understand especially when working in 2D environment. The preliminary planning happens usually using 2D interface (Interview 1). The model in this example can also be used in 2D and the geometry it effects on 3D can be really simple, working on the background. The geometry is only there to “block” the light and cause the effect on the general layout drawing on 2D. (Picture 19)

There is a lot of science involved in measuring and modeling these phenomena. We are not aiming to make the presentation accurate at this time, in physics level, but demonstrate the use of visual presentation of the evaluation



process based on abstract parameters like light. Thus the simple direct light was chosen to be used as an example.

In this model the sources of lights are points in the geometry. The point represents the location of the light source and linear lines are pointed out from the point in a sphere-like formation. The amount of the linear lines is defining how intensive the light is. The floors of the ship model work as the “display” for the gradient map. When the line from the point intersects with the floor (or next decks floor, in this case ceiling) it gives the model a defined point on the floor surface. The model measures the distance between these points - the “rays of light” that reach the floor. When the distance gets bigger - meaning there are less points - the gradient map gets towards red. Similarly, when the distance decreases the gradient turns green (Picture 21). The daylight is modeled in similar way except that the light sources are surrounding the geometry at an even distance (Picture 20). Different light conditions in different times of the day can be simulated by moving this set of points up and down according to the angle of the “Sun”.

PICTURE 20
Screenshot from
Rhino showing
the light “beams”
traveling from the
daylight source to
the ship geometry.

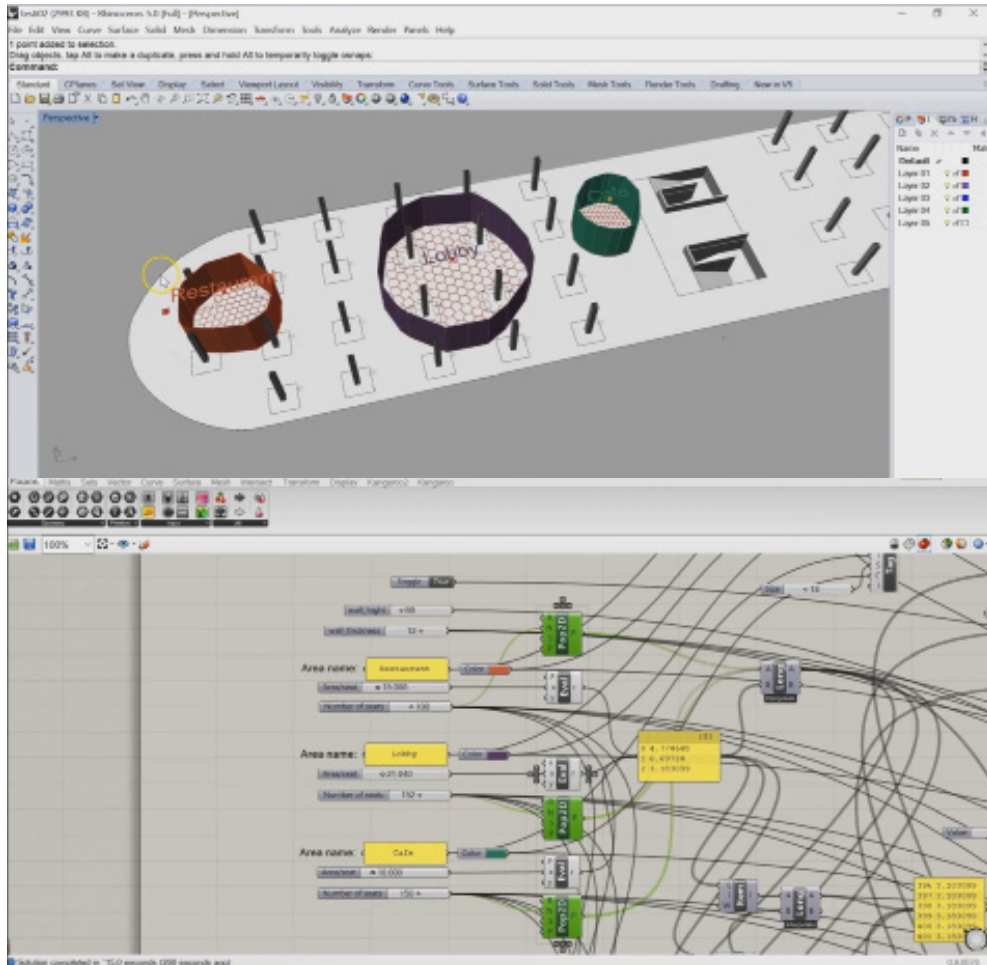
PICTURE 21
Gradient map
indicating the
ammount of light
in the general
arrangement.

4.3

EXAMPLE 3: REAL-TIME GENERAL ARRANGEMENT DESIGN

The idea for this approach started to evolve already in the beginning of the research. The initial idea from the beginning was to harness the algorithms to take care of the rules that are involved in the ship building and restricting the creative process in the preliminary design of the general arrangement. In the beginning the idea was to implement a couple of selected rules from the IMO guidelines.

Testing with the idea started with an algorithm that generates the general arrangement based on geometrical pre set parameters and uses evolutionary algorithm to solve the most optimal layout. The target of the optimization was to form certain number of rooms that are of different sizes. For this, the weighted optimization was done. Different rooms had different “weights” in the algorithm and that defined the target size of each room. The corridors were set so that they cannot become narrower than the regulations demand. The evolutionary algorithm does hundreds or thousands of different



PICTURE 22

The parameters that are affecting to the geometry are set to the code and can be altered at any phase of the process.

variations of the same layout and systematically moves towards the optimal solution. After each change on the geometry that the algorithm generates it compares the result to the target and leaves out the results that are not bringing the values closer to the target.

As found out in the later contextual research, for example, the building block methodology is highly based on solving space optimization related issues in the preliminary phase of ship design, by parametric methods and simulation. The simulation with evolutionary

5					AREA	REL. AREA	HEIGHT	VOLUME
21	1113	Balcony EA	16.5 m ²	328 pcs	5,412 m ²		0.00 m	, m ³
22	1114	Balcony EAX	24.6 m ²	8 pcs	,197 m ²		0.00 m	, m ³
23	1115	Outside E	15.2 m ²	202 pcs	3,070 m ²		0.00 m	, m ³
24	1115	Atrium G	15.8 m ²	165 pcs	2,607 m ²		0.00 m	, m ³
25	1116	Outside EX	24.9 m ²	6 pcs	,149 m ²		0.00 m	, m ³
26	1116	Family H Outside	24.6 m ²	10 pcs	,246 m ²		0.00 m	, m ³
27	1116	Large Outside DA	17.8 m ²	22 pcs	,392 m ²		0.00 m	, m ³
28	1116	Atrium Family H	24.6 m ²	4 pcs	, 98 m ²		0.00 m	, m ³
29	1116	Atrium GX	23.6 m ²	3 pcs	, 71 m ²		0.00 m	, m ³
30	1117	Inside F	15.0 m ²	546 pcs	8,190 m ²		0.00 m	, m ³
31	1118	Inside Disabled FX	23.4 m ²	13 pcs	,304 m ²		0.00 m	, m ³
32	1118	Family H Inside	24.6 m ²	2 pcs	, 49 m ²		0.00 m	, m ³
33	1119	Corridors	31.5% addition		9,938 m ²		11.73 m	116,622 m ³
34								
35	112	Passenger public facil.		7932 seats	30,052 m ²	8.27 m ² /pass	2.54 m	128,140 m ²
36								
37	1121	Restaurants & Café's	2.1 m ²	3321 seats	6,987 m ²	1.92 m ² /pass	3.96 m	27,671 m ³
38	1121a	1121a Main Dining Rooms	1.9 m ²	2105 seats	4,102 m ²	1.13 m ² /pass	4.18 m	17,143 m ³
39	1121b	1121b Windjammer & Jade	2.7 m ²	774 seats	2,065 m ²	0.57 m ² /pass	3.72 m	7,681 m ³
40	1121c	1121c Pizzeria Sorrentos	1.7 m ²	90 seats	,156 m ²		3.30 m	,516 m ³
41	1121d	1121d Cafe Promenade	1.6 m ²	74 seats	,116 m ²		3.30 m	,384 m ³

algorithm didn't seem agile enough a method to do form-finding of the spaces for the human desires. The optimization has a starting point and it generates optimized solution to the numerical target. However, when talking about human factors the author believes that not all of them can be described as numerical values. The designer's creativity and sense of human related issues are needed and can not be replaced with algorithm. Once these design decisions are done the optimization could work, for example, to adjust the final design to fit the industrial standards.

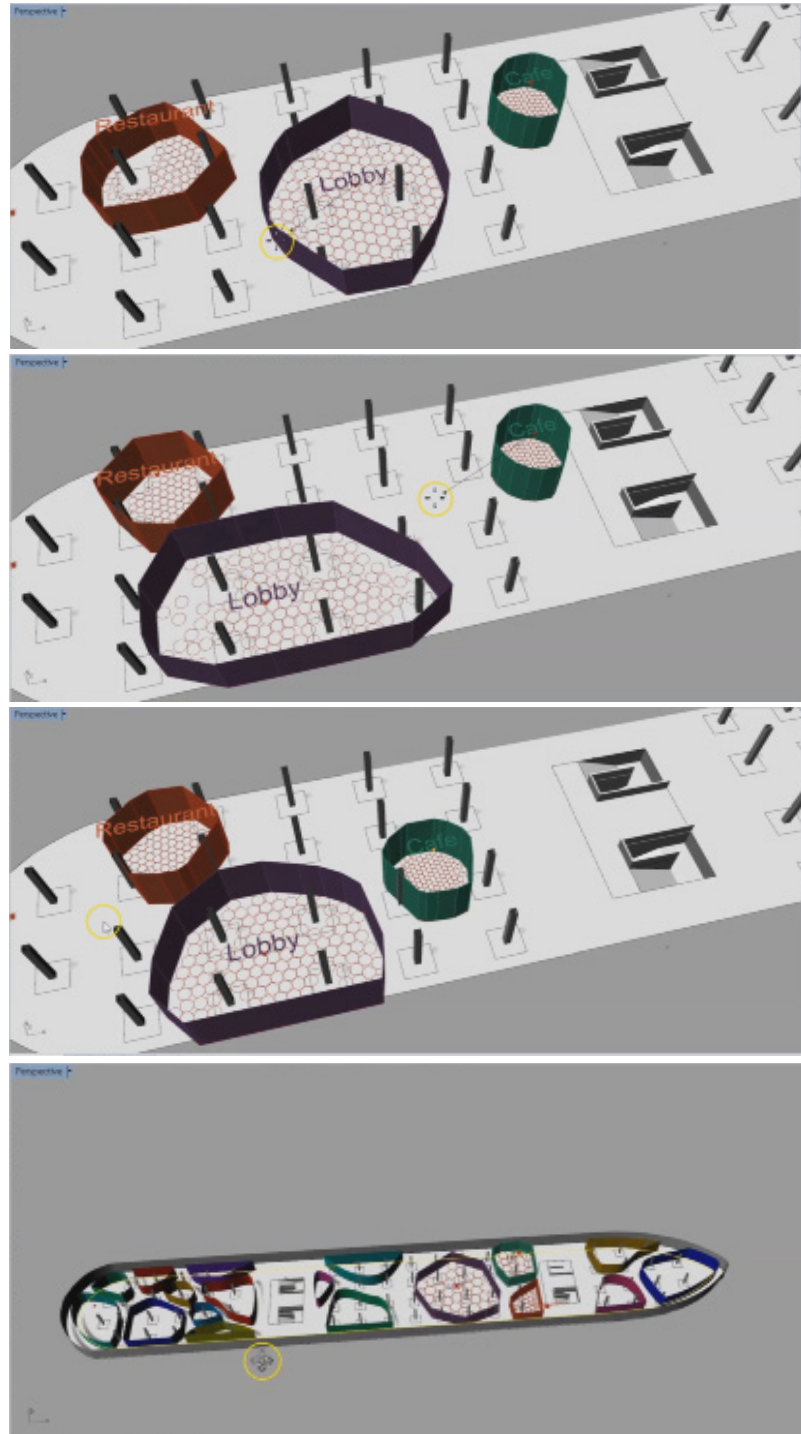
In this work the target moved from optimization of the layout more towards to the workflow of the designer. And translating the preliminary numerical design from Excel to geometries that are easy to perceive. In the design workflow the limitations should stay in the background and the decisions should be based on design thinking where the user's needs should be in the centre of the decision making. Thus the program was done from scratch so that the different areas can be moved freely around the ship and the program generates the optimal space for the requirements. At the same time it ensures that the corridors around the areas are formed so that the regulations are met. This program keeps the minimum width of the corridor according to set parameters and also

PICTURE 23

The preliminary phase in the ship design starts with numerical calculations about capacity of the ship.

PICTURE 24

The dedicated areas can be dragged around the layout plan and the program monitors the size of the area and the corridors between the areas.



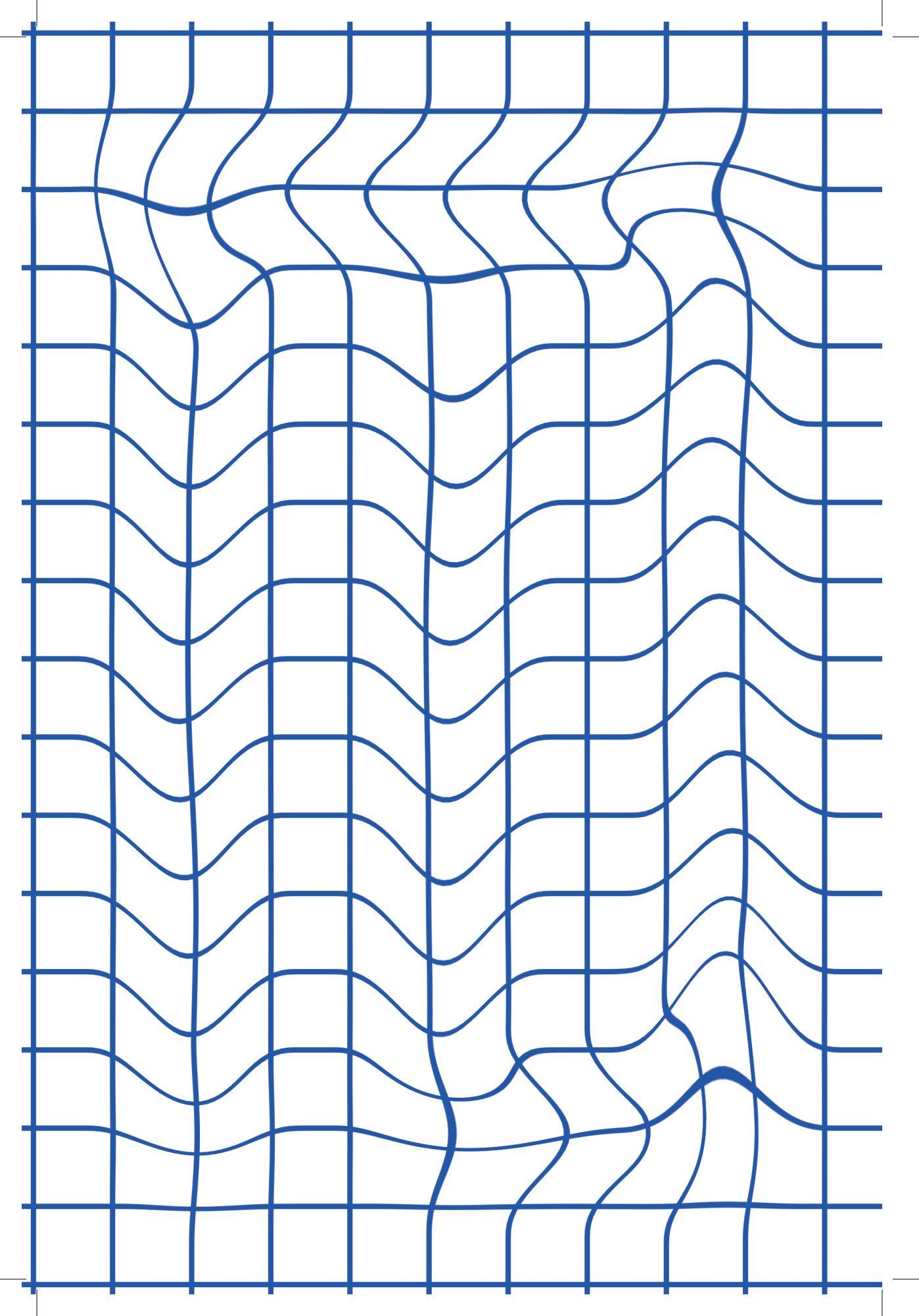
the geometry is formed so that it doesn't form dead ends on the corridor layout.

The main advantage of the program shown in Picture 22 is that it allows the Excel values in use to be changed directly in the code as they are and it forms geometrical volumes from those numbers. These volumes can be then divided to different areas and organized and modeled to create the general lay out. Also at any point it is possible to alter the numerical values and move back and forth with the 2D and 3D worlds.

When the requirements from the shipping company are recieved by the shipyard, they are set to Excel platform. The capacity of the ship is discussed with the shipping company and shipyard and as the result the number of passengers is defined. Depending on the level of service on board the Excel gives out the first numbers to start with the preliminary design of the general arrangement. These numbers include the space reservations for the cabins of different types, restaurants, cafeterias, theatres and other entertainment required for the cruise ship. It also gives the estimates of how many crew members are needed on the ship to operate and how much space is needed to facilitate the crew. These values are space requirements given in square meters. (Picture 23) For example, needed place for restaurant is 1000sqm and each customer needs 2,5sqm of that space.

In the model these values for space reservations are turned into geometry. To simplify and keep the program running effortlessly the space reservations are turned to circles with corresponding area. Thus, following the previous example, the area of one circle - one "seat" - is now 2,5sqm. Because the "restaurant" is formed from tens or hundreds of seats, these circles have to have a rule that keeps them together. For this purpose, the Kangaroo physics engine is used. The circles are interconnected to each other with force that pulls them together. When the spaces are modified this force keeps the restaurant as small as possible, still maintaining the required space reservation for the restaurant. This same rule applies to all the other spaces in the public area. The circles are "pulled" to the surface representing the floor of one

deck. Some areas like air-conditioning rooms or other technical areas should remain unaffected by the changes in the public spaces. The areas which the changes are not “allowed” to influence are cut out of the floor geometry (the geometry that sets the boundaries for the circles to move). In this example the algorithms were set so that the space reservation circles are avoiding the beam structure of the ship and the staircases that go through the whole ship (Picture 24).



5. DISCUSSION

5.1

DISCUSSION

The objectives of this work were to investigate the possibilities of implementing algorithms-aided design process in the cruise ship design environment and how this methodology would affect the appearance and the user experience of a cruise ship. The research was done based on a literature review and interviews with professionals working in, or closely with, the ship industry. Some of the studied approaches were demonstrated by Rhino and Grasshopper models to verify the applicability of them in the ship design environment.

The interviews and the steering-group meetings gave the author valuable information about the current state of the industry and the emerging trends in the ship engineering. The three months working period in Meyer Turku shipyard during the thesis work gave the author new ideas and trust to the plausibility of the parametric approaches in ship design. Those insides together with the professional knowledge gained during the industrial design studies, gave the author a good understanding of what is required to be able to change the design methodology and culture of the shipbuilding to become more end user centric.

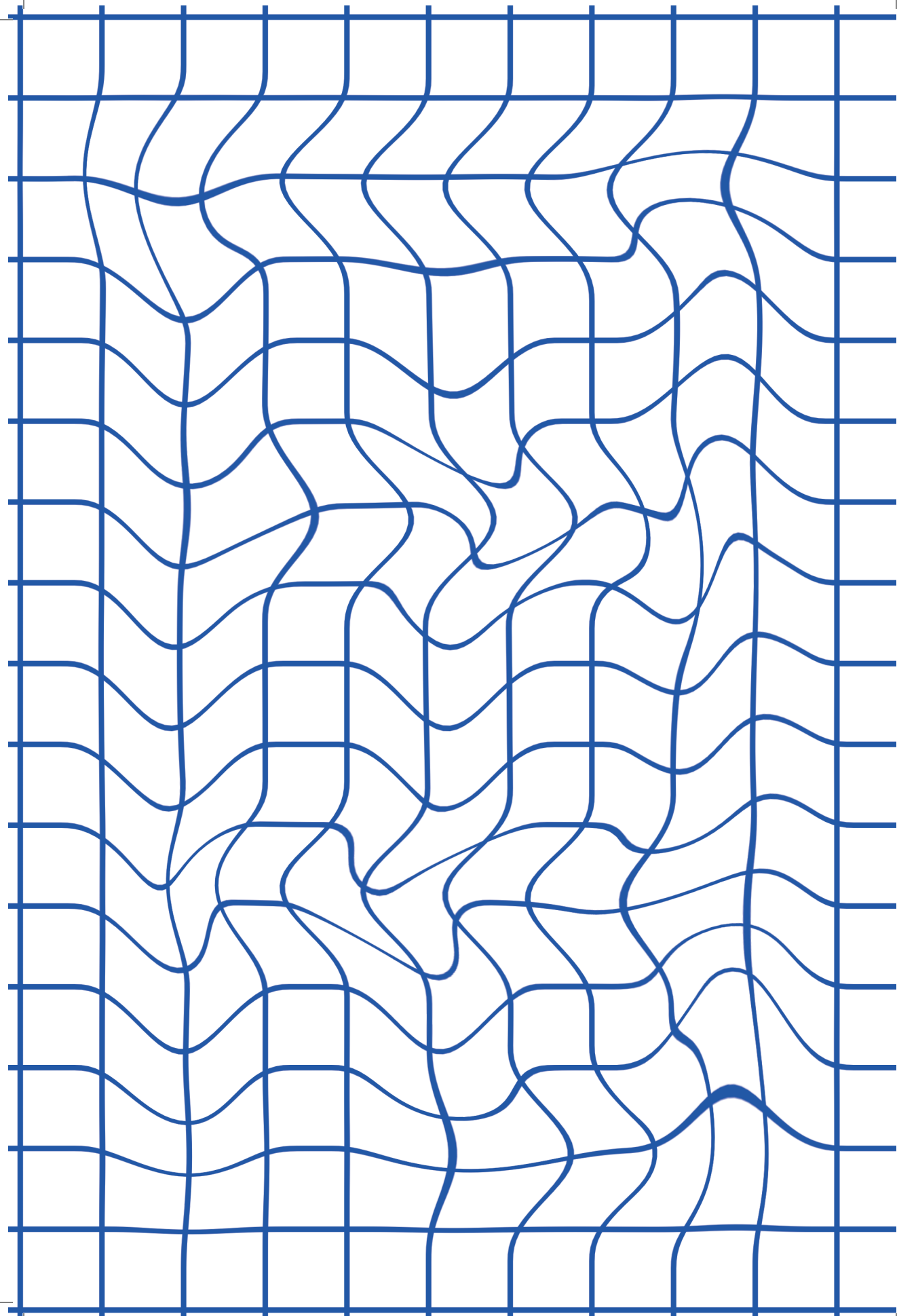
It goes without saying that the goal of this work was not to find one revolutionary way to change the whole shipbuilding industry, but to create knowledge - fragments of information - that would support this path in the future by further research.

Outlining of this work was challenging from the beginning, because many of the major research objectives haven't been unambiguously defined. Parametric design,

algorithms-aided design, and design thinking are all really broad topics and the terms can be understood differently in different fields and even inside the disciplines themselves. Also, even though the ship design processes are more precisely described in the literature, the practices differ in every shipyard. Thus, this work is, due to time constraints, only aiming to describe the most essential ideas of each ideology and methodology. Many of the different interpretations and theories had to be left out of this work.

More research should be done on the more precise implementation of the AAD. The examples in this work are done with Rhino and Grasshopper. These tools were chosen because of their ease of use and because they were the most suitable for prototyping the workflow. However, in the ship design environment there is a variety of software in use, some of which could have similar features taken into use by advanced scripting and software development. The use of AAD could only be properly evaluated when integrated to the existing shipyard environment. The success and level of impact to the appearance of the ship can be seen only when the whole design system is turned from traditional to parametric integrated design process. This is something that cannot be done by one person, and certainly not in a short period of time. It would require endeavours of the whole shipyard for many years.

However, as a result of this work we can say that we now know that the AAD seems to be a promising methodology for the ship design to make the process more agile methodology for making the ship design process more integrated. When implemented in a holistic level it can support the pursuit towards concurrent engineering and emphasize the design thinking in the process. The author hopes that this work would augment the discussion about alternative emerging design methodologies and ideologies in the ship industry.



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INTERVIEWS:

(Interview 1)

Panel discussion done and at Meyer Turku shipyard in January 2016. Turku, Finland.

Kari Sillanpää, Head of Research & Design at Meyer Turku

Sami Mäkinen, Naval Architecture Design at Meyer Turku

Esa Helenius, Technical Team Leader at Interior Design at Meyer Turku

Ilari Graf, Project Engineer at Meyer Turku

(interview 2)

Interview done and at Meyer Turku shipyard in March 2016. Turku, Finland.

Kari Sillanpää, Head of Research & Design at Meyer Turku

(Interview 3)

Panel discussion held and in Elomatic oy in March 1016. Helsinki, Finland.

Antti Pösö, Project Engineer at Elomatic

Olli Leino, Product Manager at Elomatic

Markus Jokinen, Thesis worker at Elomatic

(Interview 4)

Interview done at Aalto University, School of Art Design and Architecture in March 2016. Helsinki, Finland.

Eero Miettinen, Professor at Aalto University

REFERENCES

PICTURES:

Picture 1.

Detail of photography from a blog post at: Livorno Daily Photo. All rights reserved by: VP & Trillian. Original at: https://livornodailyphoto.blogspot.fi/2013_09_01_archive.html.

Picture 2.

Published in “Complex Geometry in Architecture” at <http://www.phd.gmelin.li/>. Copyright: Sebastian Gmelin, 2012.

Picture 3.

Collage of two images published in : Bucci, Federico and Marco Mulazzani. 2002. “Luigi Moretti: Works and Writings”, Princeton Architectural Press, New York.

Picture 4.

Color of the photo edited by author. Original photo published in: “The Last Word On Nothing”, <http://www.lastwordonnothing.com/2016/04/29/redux-murmuration-the-poetry-of-the-morning-walk/#more-11034>. Copyright: Christie Aschwanden, 2016.

Picture 5.

Edited by author. Original published in: “This 3D-printed brace built by an algorithm could help treat scoliosis”, WIRED Magazine, WIRED.co.uk, October 2016. Condé Nast, UK, Photo credit: Studio Bitonti/Jason Perry. <http://www.wired.co.uk/article/studio-bitonti-algorithm-intel-cast>.

Picture 6.

Colors edited by author. Original published at: <http://www.slideshare.net/CNMG/eero-mkinen>. Copyright: Eero Mäkinen, STX Finland.

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Picture 11.

Published in: The Architects Newspaper at <https://archpaper.com/2014/04/the-grand-macau-hotel-zaha-hadid-behind-new-addition-to-chinese-casino-resort/>. Courtesy Zaha Hadid Architects.

Picture 14.

Ooster Huis Architects 2016 <http://www.oosterhuis.nl/?tag=liwa>

REFERENCES

APPENDIX 1.

List of “Cruise and Ferry Experience Program’s” Steering Group Members:

Ahola Markus,
Design Researcher,
Coordinator of the program,
at Aalto University.

Jarno Soinila,
Head of Main Department,
Design & Engineering,
at Meyer Turku Oy.

Janne Andersson,
Head of Architectural Design,
at Meyer Turku.

Kari Sillanpää,
Head of Research & Design,
at Meyer Turku Oy.

Juhani Pitkänen,
Director Newbuilding,
at Royal Caribbean Cruises.

Markus Aarnio,
Chairman of the Board,
at Foreship Ltd.
Mervi Pitkänen,
Director,
at Machine Technology Centre Turku Ltd.

Kujala Pentti,
Professor of Marine Technology,
Aalto University,
Kevin Otto,
Adjunct Professor,
at Aalto University.

Markku Tinnilä,
Docent at School of Business,
at Aalto University.

Jasmin Jelovica,
University Lecturer,
at Aalto University.

