MSc Program
Engineering Management

Challenges of Implementing a System - Oriented Model in the Architectural Design Process

A Master's Thesis submitted for the degree of
"Master of Science"

supervised by
architect DI Dr.techn. Thomas HRABAL, MSc

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Thursday, 31 March 2016

Affidavit

I, **Aurélie Dell**, hereby declare

1. that I am the sole author of the present Master's Thesis, "Challenges of Implementing a System-Oriented Model in the Architectural Design Process", 64 pages, bound, and that I have not used any source or tool other than those referenced or any other illicit aid or tool, and
2. that I have not prior to this date submitted this Master's Thesis as an examination paper in any form in Austria or abroad.

Vienna, 31/03/2016

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Abstract

The aim of this master thesis consists in recognizing the challenges of putting the architectural design process into a system-oriented model.

While project management has become a useful in order to assure the successful progression of a project, it is very difficult to apply the same strategies than for a production project, for example, in a design domain; in architecture. While the success of a project in a scientific domain can easily be measured, it is not evident to assess the quality of a design. An analogy is established between the architectural design process and a system-oriented model, which transforms given inputs into outputs.

In the first part of this master thesis the architectural design process – or system–architecture – is analysed and two different concepts are presented: the linear architectural design process and the integrated design process. The two processes are considering the architectural design as starting with the first sketch and ending with the built construction. Not only the processes will be presented but also the available tools, like BIM, which facilitate the implementation of a system-architecture.

In the second part, the drawbacks, challenges and advantages of the previous described concepts of organising the architectural design process and using the tools (software and platforms) are analysed.

The conclusion does not give the optimum solution how a strategic concept can be established in order to improve the organisation of an architectural process. The conclusion rather shows the origins of the difficulties and pinpoints an important issue: Architecture is always developed by humans for humans.

Key Words: system-oriented model, system-architecture, linear architectural design process, integrated design, design management

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Chapter 1 – Introduction

1.1 Context of the topic

With the implementation of the project management discipline in many domains, a new method to prepare, execute and measure projects appeared. The 'Iron Triangle', defining time, cost and quality as the key factors for a successful project, is one of the most important measurement criteria used in project management.[1]

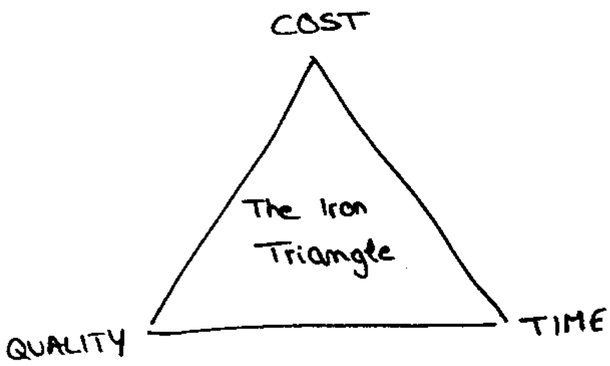

Figure 1: The Iron Triangle

This triangle represents the main goal of project management: reaching the scope of the project in time, respecting the budget and the requirements on quality.

Project management can be defined as follows:
"*Project management is the application of processes, methods, knowledge, skills and experience to achieve the project objectives*."[2]

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[1] Mofizul Islam Awwal, "Importance of Strategic Aspect in Project Management: A Literature Critique," *International Journal of Supply Chain Management* 3, no. 4 (December 31, 2014): 96–99.
[2] "What Is Project Management?," *Association for Project Management*, accessed March 30, 2016, https://www.apm.org.uk/WhatIsPM#WhatisPM.

Project management deals with the entire process of running a project; from the beginning to the end. The main phases of the project can be defined as follows[3]:

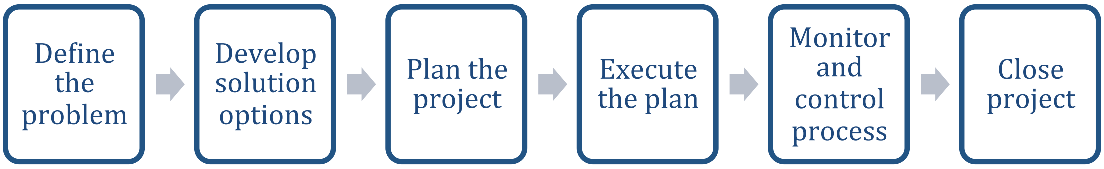

Figure 2: The Steps of Project Management

As already mentioned in the 'Iron Triangle' above, the success of a project does not only depend on the time and cost, but also on quality. In order to achieve this quality, the objectives and goals of the project have to be clearly defined. The SMART[4] acronym helps to outline the objectives, which should be:

S	specific
M	measurable
A	achievable
R	relevant
T	time-bound

Since project management can be applied in every discipline, it is very useful in construction management. However, the aim of this master thesis is not to focus only on the construction part of the architectural design but to consider the entire project: from the first sketch to the final construction.

[3] James P. Lewis, *Fundamentals of Project Management*, 3rd edition (New York: AMACOM, 2006), 15.
[4] "SMART Criteria," *Wikipedia, the Free Encyclopedia*, March 29, 2016, https://en.wikipedia.org/w/index.php?title=SMART_criteria&oldid=712456429.

1.1.1 Definitions

This short overview of project management leads to the core of this master thesis: '"Challenges of implementing a system-oriented model in the architectural design process". As already mentioned in the previous section, the aim of this paper consists in analysing the adaptability and the ability of implementing a 'project management' approach for the entire architectural design process. Two terms have to be defined before proceeding with this master thesis: 'Architectural design process' and 'system-oriented model'.

Architectural design process: According to the Oxford Dictionary, the process is defined as "*a series of actions or steps taken in order to achieve a particular end*".
Thus for this master thesis, the action of designing and building a construction project is defined by a sequence of phases which are leading from the first idea (or the first drawing) to the final (built) construction.

System-oriented model: The Oxford dictionary defines system as "*a set of things working together as parts of a mechanism or an interconnecting network; a complex whole*". In engineering, the system can be understood as a process, which transforms inputs into outputs.

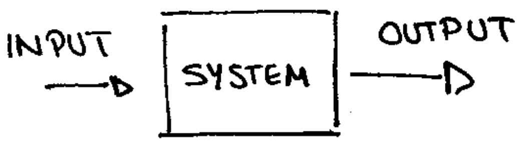

Figure 3: The System-Oriented Model

Thus this paper studies the feasibility of considering as well as the need in understanding the architectural design process – a creative procedure – as a system with defined inputs, in respect of given constraints, in order to obtain the desired result; the built design.

1.2 Research Goal

Due to the increasing complexity of the architectural design process the step from ‘traditional’ design ‘system-architecture’[5] becomes unavoidable and essential in order to realise successful construction projects[6].

The mission of the architect therefore can no longer be reduced to the creative (designing) part but a new function is attributed to the architect who becomes the manager of the construction project. Today, many new actors appeared in the construction market: project managers, global constructors, real estate companies and so on. As these economical actors are gaining more and more power in the construction world, the architect has to fight against losing his position and has to redefine his place in our society.

In contrary to his equivalent - the civil engineer – the architect has a much harder work to do in order to defend his position as he firstly deals on the creative part of the project, which has not always a scientific reason. During this master thesis, the challenges of considering a creative process as a sequence of scientific actions, as well as the available tools, which are used to realise this move from ‘simple designing’ to a ‘design process’, will be studied.

Hypothesis: *“Is it possible to implement a system-oriented model in the architectural design process?”*

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[5] ‘System-Architecture’ will be considered as a synonym for the ‘architectural design process’ in this master thesis.

[6] In this master thesis, the expression ‘construction project’ shall be understood as the whole process, comprising planning and constructing.

1.3 Study framework – Limits of the study

As already mentioned, many actors are dealing with the construction as an industry – a market which is not taking into account the architectural value or only uses the architectural design as a marketing vehicle.

One challenge of considering architecture as a process is probably due to the fact that it is difficult to measure the success of a design. How can you say that one design is better than another? Which parameters can be used to say by how much one designer is better than the other? While the performance of design can be measured by analysing determined features, the subjective judgement or perception also plays a role in the consideration of the success of the design.[7]

In order to measure the creative process and its result, the design should satisfy given requirements. However at a certain point, for larger design situations, as the design of buildings, the evaluation of the success of the design before having completed the building is very complex.

This difficulty of measuring the design or the value of architecture is one important issue of this master thesis.

[7] Bryan Lawson, *How Designers Think: The Design Process Demystified*, 4 Rev ed. (Oxford; Burlington, MA: Routledge, 2005), 63.

1.4 Structure of the Thesis

As a first step, the actual situation of the architectural process will be described. What is the actual understanding of architecture? Which factors are boosting the system-architecture or this need in considering architecture as a design process?

The research part will be divided into two categories: the architectural design process and the tools. A deeper definition of the architectural design process will be given, describing the different phases of the process. This "definition" is necessary for the reorganisation of the (already) available tools in order to obtain the best possible sequence of the design project; from the idea (*the raw materials*) to the construction (*the finished product*). The most important tools (software, platforms, concepts) allowing to facilitate the implementation of a system-architecture, will be presented

After having described the process and explained the 'ingredients' of the architectural design process, the results will be analysed. In this part of the master thesis the drawbacks, advantages and challenges of the previous explained concepts and tools will be discussed.

The conclusion of the master thesis will not give a recipe for the best implementation of the system-architecture but as suggested by its title ('challenges') will resume the outcomes of the results and pinpoint the origins of the problems and how they will evolve in the future.

Chapter 2 – State-of-the-Art

Architecture plays a significant role in daily life: for the planner, but also for the perceiver. Architecture is everywhere and nobody can completely escape from its (conscious or unconscious) influence. Architecture becomes also more and more important on political agendas. As the interest in architecture increases, more responsibilities are attributed to the whole design process. Architecture is no longer just a building or design product, but gets socio-economic and environmental responsibilities. In this chapter some factors or events, which explain the origin of these interests in the design process, will be presented as well as a few case studies, which give examples of possible synergies allowing to deal with the complexity of the architectural design process and to increase the effectiveness of the project.

2.1 The Factors Influencing the Architectural Design Process

2.1.1 Socio – Economic Aspects

As for any other project, the success of the building project depends on the balance between time, cost and quality. This balance has to be obtained for the whole architectural design process: from the first sketch to the final construction.[8]

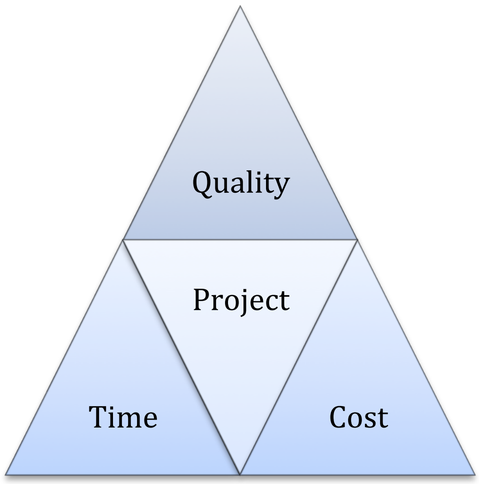

Figure 4: The Time Cost Quality-Triangle

Latest after the economic crisis in 2008, more importance is paid to the budget and the time schedule of the building project. The question if this increase in interest, in costs and time is done to the detriment of the design is exceeding the borders of this master thesis. In this paper the architectural design process will be discussed, assuming that the architectural value of the project will not suffer under the implementation of new factors or concepts. Thus the work of the architect is not limited to the design itself, but also comprises the project management in order to respond to the client's needs within the timeline and budget.

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[8] "Time, Quality and Cost," *Creating Excellent Buildings*, accessed March 28, 2016, http://webarchive.nationalarchives.gov.uk/20110118095356/http://www.cabe.org.uk/buildings/time-quality-cost.

The architect has an economic responsibility and therefore has to assure a certain transparency in order to show the evolution of the project all along the process. Nevertheless the architect has also a social responsibility, as his design will be constructed for humans: the construction has to ensure the well-being of his clients, to fulfil its social function and also to respect the environment in which the building is located.

The economic crises of 2008 as well as the global challenges resulting from the climate change lead to a change in the meaning of architecture. The on-going political, socio-cultural and economic development influences the being of architecture. All over the world the construction of new artefacts, playing a huge economic role, can be observed.[9]

As an example of "modern artefacts" the *Elbe Philharmonic Hall by Herzog & de Meuron, Hamburg,* the *Swiss Re Tower by Foster, London*, or the *Guggenheim Museum by Frank Gehry, Bilbao*, can be cited.

As mentioned above, the architectural design is influenced by the political and economic situation, in which the construction is ordered, designed and understood. The aesthetic of the design as well as meaning of the architecture are the key elements in thus political-economic context. Architecture cannot be considered as a simple work of art, but has to play a cultural role. Not only the owner but also norms, local requirements and available technologies are influencing the design process.[10]

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[9] Lucy Kimbell, "Rethinking Design Thinking: Part I," *Design and Culture* 3, no. 3 (November 1, 2011): 285–306.

[10] P. Jones, "Putting Architecture in Its Social Place: A Cultural Political Economy of Architecture," *Urban Studies* 46, no. 12 (November 1, 2009): 2519–36.

2.1.2. Environmental Aspects

Due to the fact that it is now widely accepted that the climate change is a consequence of the combustion of fossil fuels and the emission of greenhouse gases (GHG), a dramatic improvement in the energy performance of Europe's buildings is required.[11]

The building sector (services and households) is the most important energy consumer in Europe, accounting for more than 40% of the total energy consumption. This percentage pinpoints the positive impact of changing the energy performance of buildings on the general sustainability efforts.

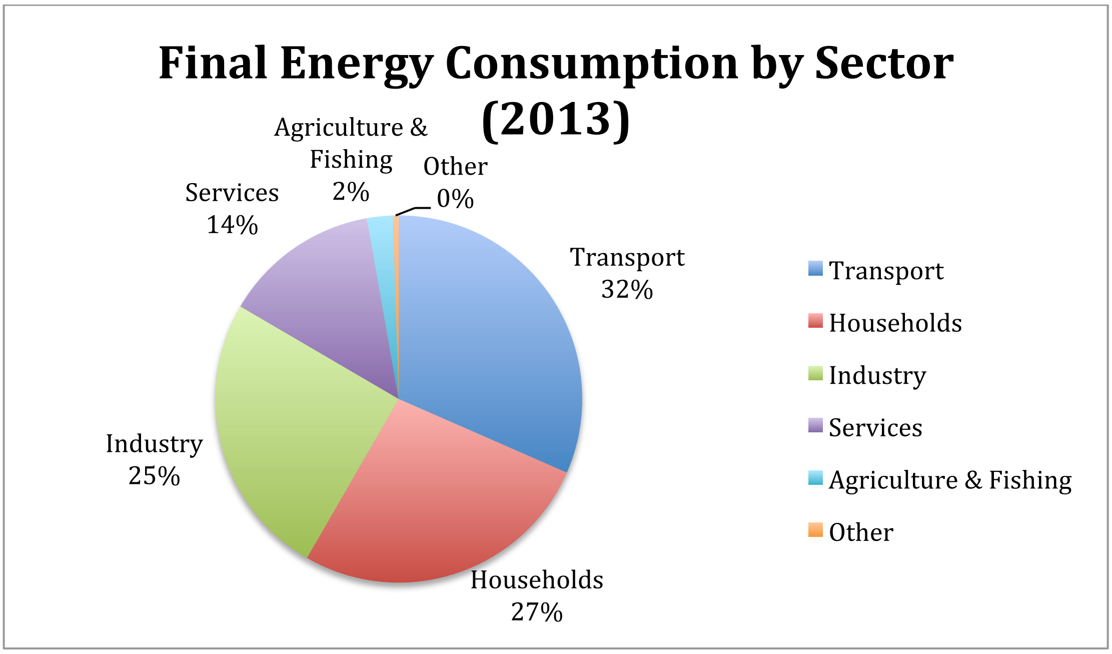

Figure 5: Final Energy Consumption by Sector (2013), Europe[12]

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[11] Atanasiu et al., "Europe's Buildings under the Microscope" (BPIE, 2011).
[12] "Energy Statistical Pocketbook - Energy - European Commission," *Energy*, accessed March 28, 2016, https://ec.europa.eu/energy/en/statistics/energy-statistical-pocketbook.

The need in system architecture is increased with the emergence of the performance-driven design. The projects are becoming more and more complex as they have to fulfil many requirements. The goal of performance-driven design is to develop ecological and economical performances of buildings without passing over the aesthetics and the functions of the design. The popularity of energy efficient buildings and sustainability tools like LEED or BREEAM strengthen the concept of performance-driven architectural design.[13]

> **LEED:** *"Leadership in Energy and Environmental Design (LEED) is basically a third-party certification program. It is a nationally accepted organization for design, operation and construction of high performance green buildings. This ensures the buildings are environmentally compatible, provide a healthy work environment and are profitable."*[14]

> **BREEAM:** *"BREEAM is the world's leading sustainability assessment method for masterplanning projects, infrastructure and buildings. It addresses a number of lifecycle stages such as New Construction, Refurbishment and In-Use."*[15]

The goal of these tools is to assess the buildings by analysing their social, energetic, environmental and economic performances. The building earns credits for the different criteria and the total number of obtained credits provides information on the sustainable value of the project.

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[13] Xing Shi and Wenjie Yang, "Performance-Driven Architectural Design and Optimization Technique from a Perspective of Architects," *Automation in Construction* 32 (July 2013): 125–35.
[14] "Leed.net," *Promoting LEED Certification and Green Building Technologies*, accessed March 29, 2016, http://www.leed.net.
[15] "BREEAM," accessed March 29, 2016, http://www.breeam.com/.

Nevertheless the construction sector should not be reduced only to its impact on the final energy consumption. The building sector can be seen as a key factor of Europe's economic growth and its employment sector. Many partners are part of the construction process. The building value chain shows the involvement of the different actors and how complex the system is as many functions and services have to be coordinated during the process and they are interconnected. This means that every decision may influence another choice. Architects, engineers, contractors and suppliers have to work together; in the interest of the client and the design while respecting all the requirements and norms.

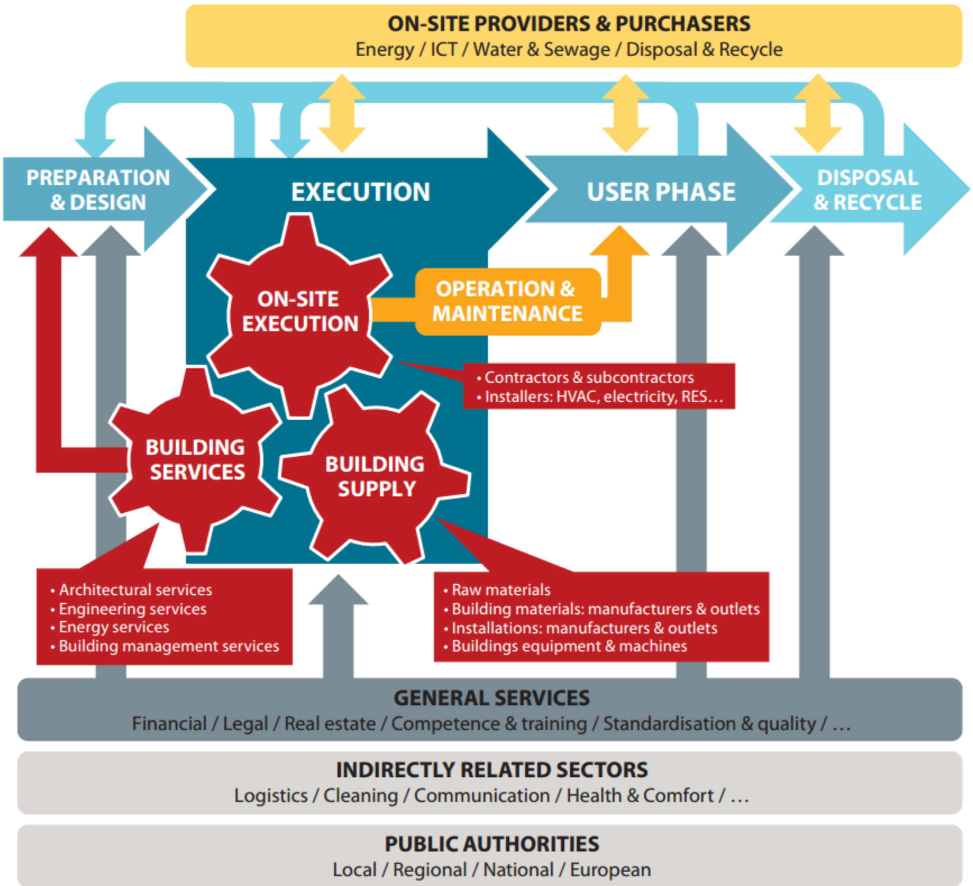

Figure 6: The Building Value Chain[16]

[16] Maarten De Groote and Marianne Lefever, "Driving Transformational Change in the Construction Value Chain" (BPIE, 2016).

This high level of interaction during the architectural design process promotes a change in the perception of the design: the building is no longer seen as a single object (or product) but the functional end-use of the building is considered. This change in the reason of architecture explains the move from the traditional design to a system architecture dealing with the whole design process. The building processes are becoming more and more complex and require a strong interaction and collaboration between the actors.

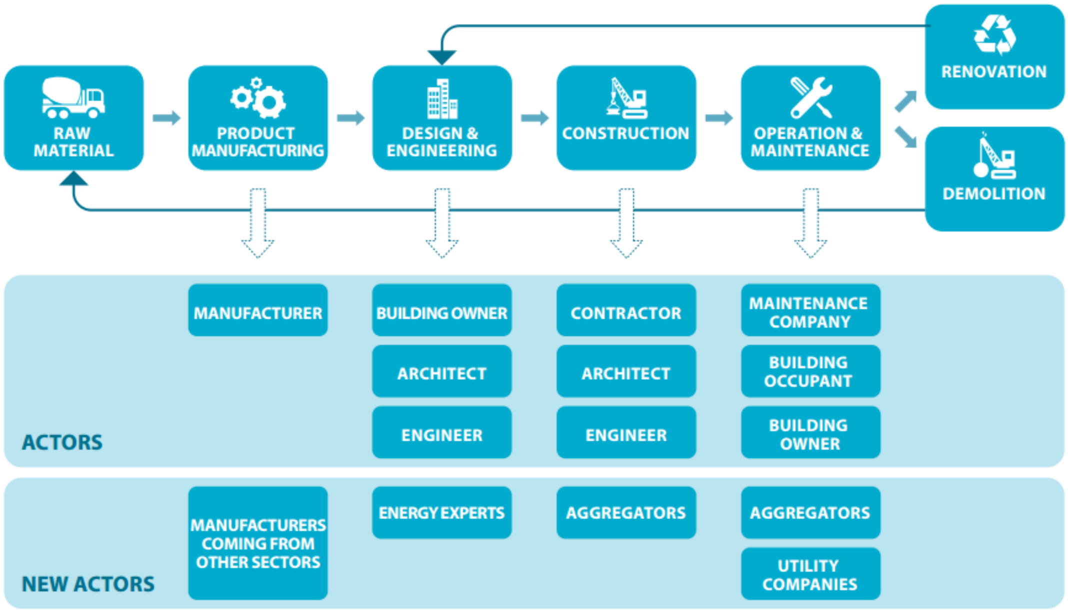

Figure 7: Innovation in the Construction Value Chain[17]

Megatrends such as energy availability are affecting the building value chain (cf. table above). New actors are joining the construction project team. The system architecture becomes the only chance to deal with the increasing complexity of the architectural design process.[18]

[17] Ibid.
[18] Ibid.

2.2 Case Studies

After having pinpointed the origins leading to a system-architecture, some examples of collaborations or tools moving from traditional design to architectural design process will be presented in this section.

2.2.1 Worksheet – Collaboration between Architects and Engineers

In this worksheet established by the "*Ordre des Architectes et Ingénieurs Conseils*" (Association architects and consulting engineers) of Luxembourg, a project guideline is given to the architects and engineers. This guideline suggests a method of how the architectural design process can be understood and how the collaboration between architects and engineers should take place. In this worksheet, the design process is divided into 3 major categories:

1. **Project Conception**
    - Preliminary design
    - Detailed design
    - Authorisation and approval documents
2. **Project Development**
    - Final design
    - Tender documents
3. **Project Realisation**
    - Construction management and delivery of the project
    - Final record

The needed inputs and the required outputs of this system dealing with the collaboration between architects and engineers are analysed for every single step of the design process.

The following table shows, as an example, the inputs and outputs (right column) of the preliminary design phase. The phase is subdivided into general issues, planning, plans and documents, and costs. For these subcategories, as well the tasks concerning the architect, as the tasks concerning the engineers are described.

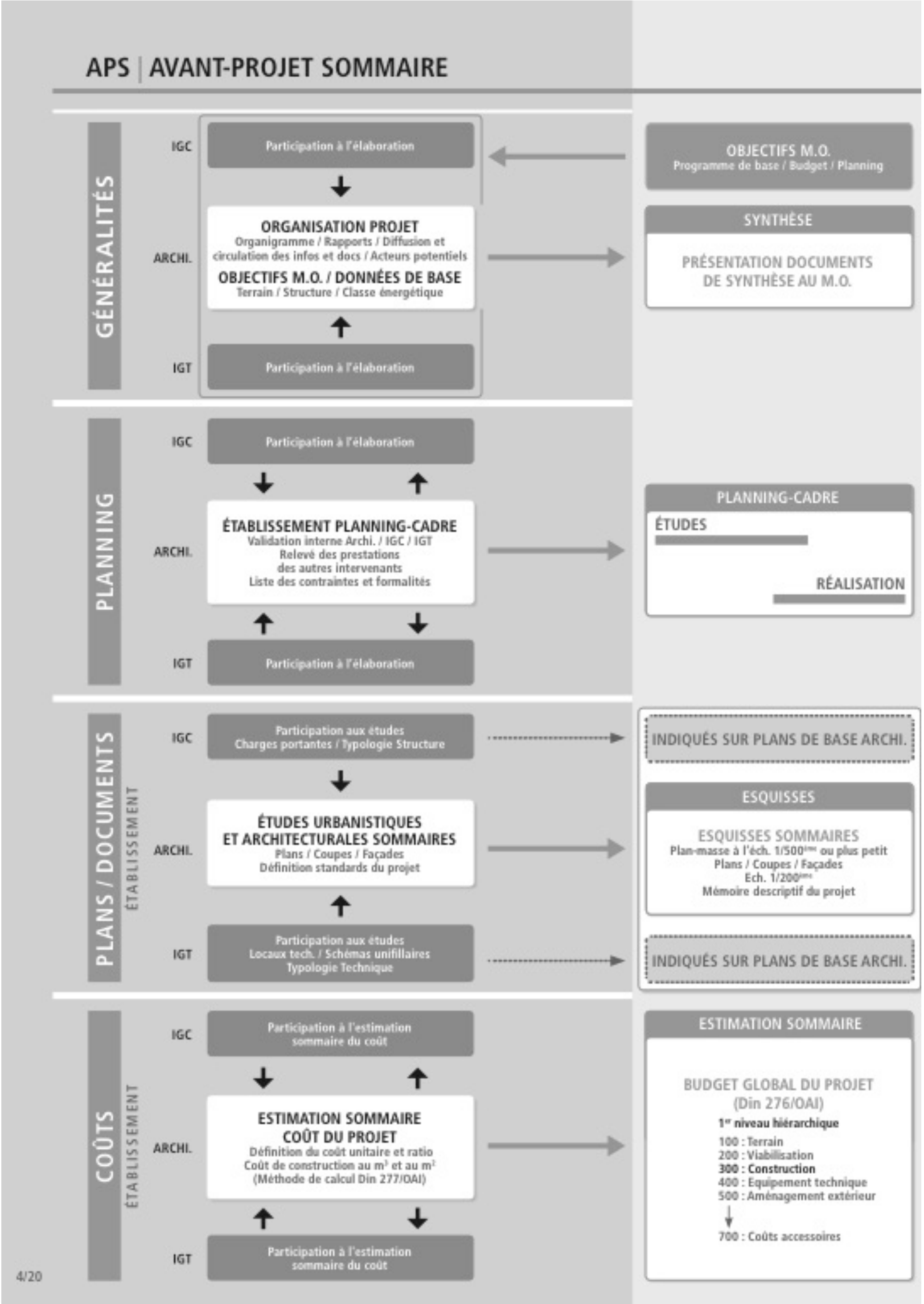

Figure 8: The Preliminary Design Phase (Source: OAI)[19]

Supplementary checklists are provided for the different sections in order to control the different documents and works, which have to be done.

[19] OAI, "Fiche de Travail Générale - Collaboration Architectes/Ingénieurs" (Luxembourg, January 2013).

2.2.2 PMTools[20]

PMTools (short for Project Management Tools) is a web-based page, which offers specific tools for project management in construction in order to optimize the design process and to create transparency.

These tools are set up for all the actors involved in the design process: owners, real estate companies, architects, engineers, contractors and sub-contractors. The goal of the platform is to give those actors tools and management methods, which help them to implement a standardized development of their processes in order to be competitive in the construction world.

PMTools offer various services (software tools, workshops and professional books) in order to provide a high knowledge based on a system-oriented model and to support strategic and structured project processes.

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[20] "PMTools," *PMTools*, accessed March 29, 2016, http://www.pmtools.eu/index.php/pmtools-stellt-sich-vor.

Chapter 3 - Methodology

This master thesis studies the challenges of implementing a system-oriented model in the architectural design process.

As a first step, the system, as well as the understanding of the architectural design process have to be determined. These definitions are based on scientific lecture and personal experience in conceiving the architectural design process.

As a second step, a deeper analysis of the current trends and methods will help to identify the drawbacks, challenges and advantages of these systems. However not only the architectural system itself but also the available tools (in our high-technology oriented world) are presented and studied.

The conclusion will not give a unique and final solution but identify the efforts, which have already been done, the potential for improvement as well as the future tendencies of organising the architectural design as a system-oriented model.

Chapter 4 – Description of the Research Problem

4.1 System-Architecture

"An architect is a generalist, not a specialist-the conductor of a symphony, not a virtuoso who plays every instrument perfectly. As a practitioner, an architect coordinates a team of professionals that include structural and mechanical engineers, interior designers, building-code consultants, landscape architects, specifications writers, contractors, and specialists from other disciplines. Typically, the interests of some team members will compete with the interests of others. An architect must know enough about each discipline to negotiate and synthesize competing demands while honouring the needs of the client and the integrity of the entire project."[21]

The above-mentioned quote already defines the main role and responsibility of the architect: the architect has to manage a team – which consists of designers, civil engineers, building services engineers and others - and to bring the project from the very first idea (the first sketch) to the constructed project. This process has to be done respecting various parameters and constraints such as economic, environmental, social or esthetical factors.

Architecture is no longer seen as a single object or artefact, but the entire work from the very beginning until the end of the project is defined as design process. This change in the understanding of architecture is due to the emergence of **performance-driven architectural design**. The extremely fast development of the technologies as well as the powerful idea of sustainability – playing an important role in the building sector - creates a huge change in the responsibility of architecture which is translated into the architectural design phase. While conventional architectural methodology focuses only on space and form, performance-driven architectural design adds holistic parameters - such

[21] Matthew Frederick, *101 Things I Learned in Architecture School*, 3rd Edition (Cambridge, Mass: The MIT Press, 2007), 21.

as ecological and environmental performances – to the basic factors of architecture. In literature, the term *holistic* is often used to explain the idea that all the choices and elements of a project are interconnected and that every decision brings consequences, which influence another parameter. The appearance of performance-driven architectural design can be understood as a consequence due to the concepts of sustainable design and green building. In order to be able to respond to the new needs, high-tech architectural solutions have to be developed.[22]

Together with the idea of performance-driven architecture, other concepts of architectural design are appearing and will be discussed in this chapter: the **system architecture** and the **design process**. In order to reach a performance-driven architecture, the design has to be seen as a process or complex system composed of different sub-systems – depending on the goals of every single architectural design project – which are linked together. The design process can be defined as follows: "A design process generates a description of a design object which satisfies a given set of design requirements and fulfils a given set of design process objectives". [23]

[22] Shi and Yang, "Performance-Driven Architectural Design and Optimization Technique from a Perspective of Architects."

[23] Michela Turrin, Peter von Buelow, and Rudi Stouffs, "Design Explorations of Performance Driven Geometry in Architectural Design Using Parametric Modeling and Genetic Algorithms," *Advanced Engineering Informatics*, Special Section: Advances and Challenges in Computing in Civil and Building Engineering, 25, no. 4 (October 2011): 656–75.

4.2 The Architectural Design Process

There are different ways to define the architectural design process and many definitions of the different stages or phases of the design project can be found in literature, but all of them describe the same idea. Therefore, even if there can be variations in the terminology, the process of the architectural design project always begins with an idea and ends up with the reception of the final (constructed) work.

In architectural design - contrary to product design - every single project ("product") is unique and developed according to various factors (qualitative or quantitative criteria) and regulations. As the consumer demands are increasing, the system architecture becomes the only method to be able to respond to all the criteria. As said before, the architecture is not only based on the basic criteria as space, form or function, but also has to integrate social, economic and environmental answers in the design solution. Nevertheless a project giving answers to all the mentioned requirements is not automatically architecture. Good architecture integrates all these factors and puts a supplementary artistic, cultural layer on top of it. In order to give the best possible solution, a high technical knowledge is needed in many fields going from structural design to HVAC[24] and much more. The architect cannot be a specialist in all these domains and has to work in a team of experts and to manage this team during the entire design process.

Indeed, the system is not only fed by external factors and demands, but also has to be fulfilled in a defined time frame respecting a given budget. The architect has to ensure the good development of the project in respect with cost and time management. Concerning the experts and specialists from the different domains, partnerships are created in order to be able to develop the best possible design solution in the whole system design. This process is also known as **integrated design process** and can be defined as "the simultaneous and

[24] HVAC : Heating Ventilation Air Conditioning

interdisciplinary interaction of the creative input of all those involved in the design process"[25].

By working this way, a structural element or a HVAC-technology could be for example integrated directly in the design and become a valuable part of the design concept itself. While this separation of the functions has the advantage that specialists are working on their domain of the project, the team manager (the architect) has to work on the global level of the project and to make sure that the whole design is optimized and not only the sub-systems. In order to be able to work in an efficient team, also human-factors have to be considered and the boundaries of the system (budget, time-frame, client demands, and so on.) have to be accepted and understood by the whole team. This does not mean that the boundaries are fixed forever at the beginning of the project. They are flexible and can vary over the process of the project, but only in accordance with all the team members.[26]

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[25] Core Competence Integrated Design," *ATP Architects Engineers*, accessed March 7, 2016, http://www.atp.ag/integrated-design/services/integrated-design/.

[26] Fiona Charnley, Mark Lemon, and Steve Evans, "Exploring the Process of Whole System Design," *Design Studies* 32, no. 2 (March 2011): 156–79.

4.2.1 The Linear Architectural Design Process

Is architecture an art or not? Opinions differ on this question and it seems to be nearly impossible to give an appropriate definition of the design process. According to the American Architect Richard Meier, winner of the Pritzker Architecture Prize in 1984, “architecture is the greatest of the arts”.[27] Others, like Zaha Hadid’s partner Patrik Schumacher, claim that architecture should not be confused with art, as architecture deals with the “form” of the built environment and not with its content.[28] Who has the power to decide which premise is right? Or maybe both theories have their veracity?

This fundamental question is leading to the challenges of implementing a system-oriented model in the architectural design process; the issue of this master thesis. Considering architecture as an art, would there be any advantage in considering the design process as a system? The answer should be yes. Implementing a system-architecture does not (necessarily) mean nipping in the bud any creativity of the designer/architect. The architect does not develop an “object” but has – independent on the question if architecture or not – responsibilities; responsibilities towards the client, the user, the society, the environment and many more. Therefore the idea is to give a framework to the creative. The challenges in structuring the design process consist in adding a value to the project without restricting the creativity of the architect or the power of the design. Again, for some, developing a system in which “architect” and “structure” are combined might sound paradoxical. Indeed, the term “structure” is associated to engineering and therefore to science. If architecture is an art, how can it be a science as well? This question could lead to a long – probably never ending discussion – which is out of the topic of this master thesis. The aim of this paper consists in analysing the architectural design process as a system by discussing the resulting difficulties, advantages and disadvantages.

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[27] Richard Meier, “Is Architecture Art?,” *Big Think*, February 4, 2008, http://bigthink.com/videos/is-architecture-art.

[28] “Why Architecture Isn’t Art (And Shouldn’t Be),” *ArchDaily*, March 8, 2016, http://www.archdaily.com/783412/why-architecture-isnt-art-and-shouldnt-be.

To sustain the idea of system architecture, the design process will be divided into 5 main stages:

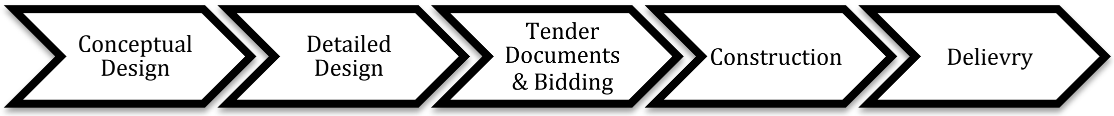

Figure 9: The 5 Phases of the Linear Architectural Process

Phase 1: Conceptual Design

Phase 2: Detailed Design

Phase 3: Tender Documents & Bidding

Phase 4: Construction

Phase 5: Delivery

Despite the linearity of the process, some steps may overlap, as there is not always a necessary condition that a new phase can only start if the previous step has been completed. Nevertheless there are some logical factors, which determine the order of the process. Therefore the tender documents (phase 3) can, for example, not be done if the detailed design plans are not finished yet (phase 2). On the other hand, single works of the different contractors can be already delivered even if the construction phase of the project is not yet completely finished. A detailed analysis of the different steps will help to understand the complexity of the design process. Some phases need an approval before the next phase can start. It is important in the design process to point out these necessary approvals. A distinction is made between internal approvals (architectural practice, conception team, client) and external approvals (authorities).

4.2.1.1 Phase 1 – The Conceptual Design

While starting the conceptual design, all the different actors implicated in the process of the project should be identified. This listing should, besides containing the coordinates and contact data of the actors, point out their role in the process, their responsibilities and the link between the different actors. The list has to be completed and adapted during the different project phases.

The conceptual design phase is the beginning and also the crucial part of every project. During this phase, the project will be developed with all its personal characteristics. The visual aspect (shape, size, geometry, and orientation) of the design is defined, the functions are set up, the systems and strategies (structural system of the construction, HVAC) are chosen, the energy performance is calculated and also the costs can be estimated. This is the crucial and decisive phase of the project: decisive because all the characteristics of the final project are defined and crucial, since the architect has to make sure that all the criteria and parameters are integrated in the design.

On the blog "First in Architecture"[29] - blog intended for architectural students and professionals in order to give them tips for various architecture related subjects - the author defines the architectural concepts as the "designers way of responding to the design situation presented to them" and describes the process as follows:

1. Define the problem
2. Collect information
3. Brainstorm and analyse
4. Develop solutions
5. Present your ideas
6. Improve design

[29] Emma, "How To Develop Architectural Concepts," *First In Architecture*, accessed March 12, 2016, http://www.firstinarchitecture.co.uk/how-to-develop-architectural-concepts/.

As said before, all the parameters of the final project are defined in this phase. However it is important to emphasize that this is absolutely no random process. Every choice made by the designers is the result of a detailed analysis of the problem, which cannot always be explained in a transparent manner to all the actors. The architect and therefore the design is subject to many requirements and constraints. The architect does not design a project and sells it after completion, in contrary to an artist for example, but gets the order by a client before starting the project.[30] This means that the architect has to design a project which pleases the client and respects the requirements (functions) and the budget. However the mission of the architect is much more important than just drawing plans of what is asked or wanted by the client. The architect, as every other profession, is a specialist in his domain. Therefore his "job" or duty is to identify the needs of the client and especially the future users of the building and to develop the best possible design.

Unfortunately the designer does not only have to integrate the requirements and constraints of the clients and users, but is also committed to norms and regulations (e.g. in Austria the EN Eurocodes[31], ÖNORM[32] and OIB[33] have to be respected for the design of buildings and civil engineering works) and construction laws. These norms and regulations determine, inter alia, the minimal passage widths, the required dimensions for barrier-free constructions, but also the sizes of the structural construction works and will therefore have a large impact on the shape and aspect of the building. While these norms are general and have to be applied everywhere (in a region, a country or even a continent) the project is also liable to local rules related to the geographical situation and environment. Every territory is part of a specific construction

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30 This sentence is only true under « general » conditions. Indeed there are cases of architects, which undertake a real estate company work but these exceptions are out of the scope of this master thesis. On the other hand, to be complete, there are also artists (e.g. painters or sculptors), which create an artwork ordered by a client.

31 "The EN Eurocodes," *EUROCODES Building the Future*, accessed March 12, 2016, http://eurocodes.jrc.ec.europa.eu/home.php.

32 "ÖNORM," *Austrian Standards*, accessed March 12, 2016, https://www.austrian-standards.at/en/infopedia-topic-center/infopedia-articles/oenorm/.

33 "OIB-Richtlinien," *Österreichisches Institut Für Bautechnik*, accessed March 12, 2016, http://www.oib.or.at/de/oib-richtlinien.

zone, which determines for example the maximal height of a building and minimal distance between the construction and the neighbour.

This overview or the architectural concept phase pinpoints the complexity of the design. One major challenge of this first step of the design process might be the fact, that the architect has to consider all these needs, requirements and norms in the development of the design and this only on a non-physical phase of the project. All the information has to be integrated in the plans.

The conceptual design phase is completed by the first milestone of the design process: **the building permit**. The architect has to hand in all the relevant data of the project to the authorities, which decide – on the basis of the plans and documents – if the proposed design meets all the laws and norms before handing out the building permit – the permission to construct the building. The documents needed for the demand of this building permit comprise the architectural plans (at a scale 1:100 generally), the energy performance certificate and the pre-structural calculations from the structural engineers.

4.2.1.2 Phase 2 – The Detailed Design

The detailed design phase comprises the process of developing the approved conceptual design.[34] In theory, the detailed design phase should start when the conceptual design is approved by the authorities; when the conceptual design phase is finished. In practice these two phases often overlap in order to save time. As soon as the concept of the design is defined, the architectural teams can start with the detailed plans. If the architect starts the detailed design phase previous to having obtained the construction permit, he accepts the risk to make modifications if asked by the authorities.

What is detailed design? Detailed design, as the name says, is expressed by detailed plans or construction drawings and all the needed information should be on the plans. The plans have to be that detailed that theoretically somebody else - without knowing the project - should be able to construct the building only on behalf of the plans. The scale of the detailed plans is increased, compared to the conceptual design plans, in order to show the information graphically.

The construction drawings therefore have much more information than just the design itself (walls, openings, dimensions, and so on.). Also the HVAC systems and components have to be indicated in the plans (e.g. the position of the radiators or technical devices). The structural system of the building is also represented graphically; supporting walls can for example be distinguished from non-supporting walls by colours and hatches. The detailed plans are represented in a larger scale (usually scale 1:50) as well as the details showing he most important composition and connections of the structure.

[34] "Detailed Design Stage in Building Design," *Designing Buildings*, accessed March 12, 2016, http://www.designingbuildings.co.uk/wiki/Detailed_design_stage_in_building_design.

4.2.1.3 Phase 3 – Tender Documents and Bidding

The third phase of the architectural design process can only start when the detailed design phase is completed. As the detailed design phase and the tender documents phase are very often, due to the reduced time schedule, overlapping, the following conditions have to be respected. All the detailed plans concerning the named tender have to be completed and an interface list defines which elements are concerned by the different tenders. In comparison to the first and second phase, which is mainly represented by plans and drawings, the "tender documents and bidding"-phase, text documents are completing the graphical documents.

The tender documents contain all the information of the project in one single document (text and graphics). All kind of works, which are necessary for the construction are enumerated in this written document. Every work has its own position number and detailed description (e.g. material, size, special requirements, and so on.). The goal of the tender documents is to have a complete description of the project, in a written form, which is needed to calculate the final costs of the project as the contractors give their price (bid) for the specific works on the information contained in these documents. Prior to launching the bidding, the architect and the engineer have to check the costs. To do this, the calculated costs on the basis of the tender documents must be in accordance with the specific estimated budget of the conceptual phase.

Depending on the size and the kind (public or private) of the project, the bidding can be "open" or "select". In an open bidding, every qualified contractor can give his price, while in a select bid, a certain number of pre-selected contractors are invited to bid.[35]

[35] "Design–bid–build," *Wikipedia, the Free Encyclopedia*, accessed March 13, 2016, https://en.wikipedia.org/w/index.php?title=Design%E2%80%93bid%E2%80%93build&oldid=673822715.

The contractors establish their bid based on the tender documents. As all the works (structural works, dry-wall constructions, doors and windows, roof works, HVAC, finishes, landscaping and so on) of the construction are separated and organised in different positions with detailed descriptions, the bidder indicates the price per unit and per position for every position. Also the prices for the execution of the works, the transport and the labours are part of the tender documents. At the end all the position prices are summed up in order to give the total costs. The architect has the choice of, either working with many contractors (or analysing the bids for the different works), or working with a general contractor. In the case of the work being attributed to a general contractor, this last one chooses the sub-contractors (this choice is also based on their bids) and submits a global price to the architect.

The contractor and sub-contractors have a given time frame to establish their bids and to submit the price. During this bidding phase, they have the possibility to ask for further information if there is some ambiguity in the documents. After having received all the bids, respectively when the deadline of the bidding phase has passed, the architect reviews all the bids in order to be able to decide, together with the owner, who gets the contract.

As the total costs of the project are established and evaluated during the "tender documents and bidding"-phase, it is very important that the "detailed design" phase has been done extremely precise and meticulous but also foresighted. Only if the quality of the detailed design plans is very high, the tender documents can contain all the needed positions and the right quantities. This way extra costs can be minimised.

4.2.1.4 Phase 4 - The Construction

Following the logic of the linear architectural design process, the construction phase can only begin when the "conceptual design"-phase and the "detailed design"-phase are finished. Having obtained the building permit, which indicates the end of the conceptual design phase, is an obligatory condition to be allowed to start the construction phase.

While these first two phases must be accomplished, the "tender documents and bidding"-phase might still run. Theoretically on the construction site, the basements can be executed even if, for example, the tender documents for the finishes are not yet submitted. This parallel working of the two phases causes negative and positive consequences: on the one hand, the costs and the planning cannot be totally foreseen and on the other hand time can be saved.

During the whole construction phase, the architect has the responsibility to manage the time schedule and the costs, but also to make sure that the project is built according to the approved construction plans. While the contractors and sub-contractors have their own responsibility to execute the works as they should, the architect has to establish a planning and consider margins in order to be able to deal with unforeseen events. Unforeseen events, which cause delay in the construction process, can have various origins:

- Human factors: e.g. illness of workers
- Weather conditions: e.g. snow, rain, minus temperatures
- Technical problems: e.g. unforeseeable obstacles in the construction area, delays in material delivery
- Modifications asked by the client
- And many more

4.2.1.5 Phase 5 – The Delivery

During the delivery phase, the client accepts the works done by the different contractors. The architectural team therefore assists him. It may happen that, in this phase, the client will not accept, or only with restrictions, the work of the contractor. To avoid this, the architect should implicate the client in the decisions (e.g. approval of the different materials) made during the construction phase.

Of course, the entire project can only be delivered when the construction phase is completed. Nevertheless this last step of the architectural design process can already start when the construction phase is still on-going. As soon as the works of a contractor is finished, this part of the construction can already be approved by the architect.

4.2.2 The Integrated Design Process

The analysis of the different steps of the architectural design process stresses out the complexity of this process despite the linearity of the problem. As said before, the project always has to follow certain logic meaning that, for example, the construction phase cannot begin if the plans and the concept are not yet defined completely. On the other hand, this linearity in the order of the process does not decrease the complexity. Many decisions of one phase have an influence on another step, or are the result of previous choices.

The concept of **Integrated Design** (already mentioned in the first paragraph of this section) goes a step further than the linear architectural design process and expresses the necessity of involving all the actors of the project already at the very beginning of the process. The structure of the process (in this master thesis, the 5 phases of the architectural design process) remains the same (conceptual design → delivery) but all the actors, which might influence the project at one moment, are already involved at the starting point of the project. In other words, the design is no longer developed only by the architect but, together with the partners of the different domains, the project is the result of the work of a team.

According to the ATP design philosophy[36], integrated design is the only way to reach the design goals of realising projects where the classic criteria (form, function, cost and time management) of a design are achieved in a resource-efficient way. ATP explains this need of resource-efficient projects as an answer to the three forms of sustainability:

1. Economic sustainability
2. Ecological sustainability
3. Sociological sustainability

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[36] "Core Competence Integrated Design."

As mentioned above, the main idea of integrated design - or **Integrated Project Delivery** (IPD) as a result – is, that the project is the work of a collaboration of partners (architect, owner, users, engineers, contractors and more).

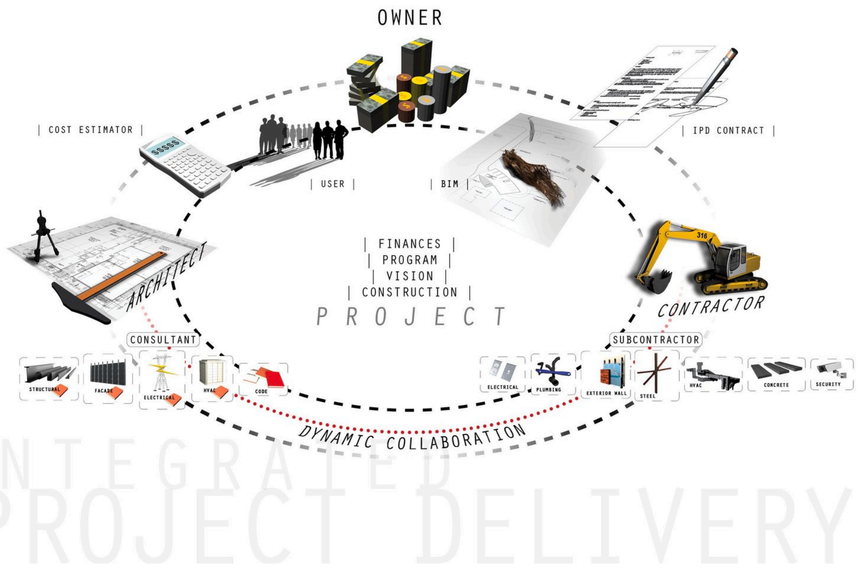

Figure 10: The Integrated Project Delivery Methodology[37]

In opposition to the “traditional” design process, the integrated design methodology can remove the hierarchies of the project. The interdisciplinary project team members, often located in the same office for the duration of the project, share ideas and work together in order to develop the best possible solution.[38]

While the Integrated Design concept has the power to deal with complex design problems, special interfaces are needed to allow the communication between the different parties. Indeed, the actors have to work out one common model in order to assure the efficiency of this methodology. The idea of operating on a shared model is that every partner can directly react to changes made by a second one.

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[37] “Integrated Project Delivery Methodology,” *ArchDaily*, August 2, 2011, http://www.archdaily.com/153953/integrated-project-delivery-methodology/.
[38] Ibid.

As an example: if the architect wants to modify something related to the volume of the design, the structural engineer can see directly if this change has an impact on the structural concept of the design.

Even if at a first look this sounds well, some fundamental difficulties have to be pointed out:

- How to show the changes done by an actor and how to define who is concerned?
- During a project the resources used by the different actors accuse a great variation. It could happen, that at certain moments, a specific actor is no more active in the project

The most common interface, which offers a shared platform to the parties, is the **Building Information Modeling** (BIM) tool. In the next section BIM as well as some other tools promoting an integrated design approach will be presented.

4.3 The Tools

4.3.1 Building Information Modeling – BIM

"Building Information Modeling (BIM) is an intelligent 3D model-based process that equips architecture, engineering and construction professionals with the insight and tools to more efficiently plan, design, construct, and manage buildings and infrastructure."[39]

Thus BIM – which is probably the best known application of the integrated design process – is not a new concept, but a tool or a process allowing considering and evaluating all the parameters influencing a design over the period of the project. The BIM tool does not only contain 2D- or 3D-models but also data. All these functions are interconnected.

The BIM methodology is based on analysis and feedback during the design process providing an application interface, which allows the simultaneous work on two distinct domains: design and analysis. During the development of the project, all the choices made by one actor are analysed in order to decide if yes or no this idea will be implemented in the project, respectively will become part of the project. This participation of the actors, as well as the analysis-feedback method, are realised by means of digital (non-destructive) models. The effects of the properties of the design (e.g. HVAC, structural design, architecture) are simulated on the digital model. The consequences of the choices are studied and the feedback is the key element in order to take the final decision based on the analysis of the alternatives. Nevertheless BIM does not only allow developing an effective and sustainable architectural concept, but also gives feedback on the cost and planning.[40]

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[39] "What Is BIM | Building Information Modeling | Autodesk," accessed March 15, 2016, http://www.autodesk.com/solutions/bim/overview.

[40] Paola Sanguinetti et al., "General System Architecture for BIM: An Integrated Approach for Design and Analysis," *Advanced Engineering Informatics*, Knowledge based engineering to support complex product design, 26, no. 2 (April 2012): 317–33.

4.3.2 Parametric Design

As already mentioned, the concept of integrated design is explored on digital models. While BIM, presented in the previous section, allows combining design and analysis, parametric design has the power to exercise the alternatives on a digital model.

Parametric design can be defined as the “non-destructive modeling of objects in 3D-space”. These parameter-driven models allow a quick and easy adaptation.[41]

The most famous tools and software for parametric design are probably the CAD-software ‘Rhinoceros’ combined with plugins as ‘Grasshopper’.

> **Grasshopper:** *“For designers who are exploring new shapes using generative algorithms,* ***Grasshopper®*** *is a graphical algorithm editor tightly integrated with Rhino’s 3-D modeling tools. Unlike RhinoScript, Grasshopper requires no knowledge of programming or scripting, but still allows designers to build form generators from the simple to the awe-inspiring.”*[42]

The plugins allow controlling the design with algorithm by means of user-friendly interfaces. Every line or element of the Rhinoceros-drawing (2D- or 3D-model) is attributed to a parameter in the Grasshopper plugin. This way, a direct and visual link between code and design is created.

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[41] Niel De Temmerman, Pieter Herthogs, and Lara Alegria Mira, *Parametric Design of Transformable Structures* (Brussels, 2012).
[42] “Grasshopper,” accessed March 31, 2016, http://www.grasshopper3d.com/.

The following print screens illustrate the interface between Rhinoceros and Grasshopper. An organic pavilion has been designed in Rhinoceros before adding parametric functionalities using Grasshopper. The final result shows a pavilion with parametric functionalities: the thickness of the pavilion can be changed, the pavilion can be rotated, mirrored and even displaced.

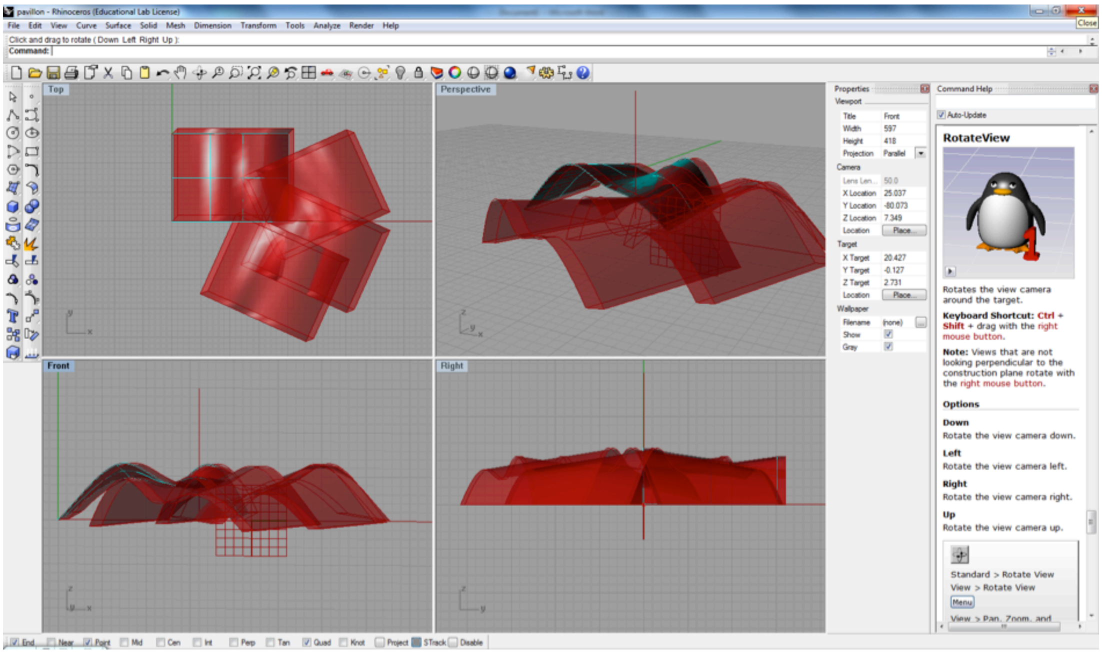

Figure 11: Pavilion in Rhinoceros

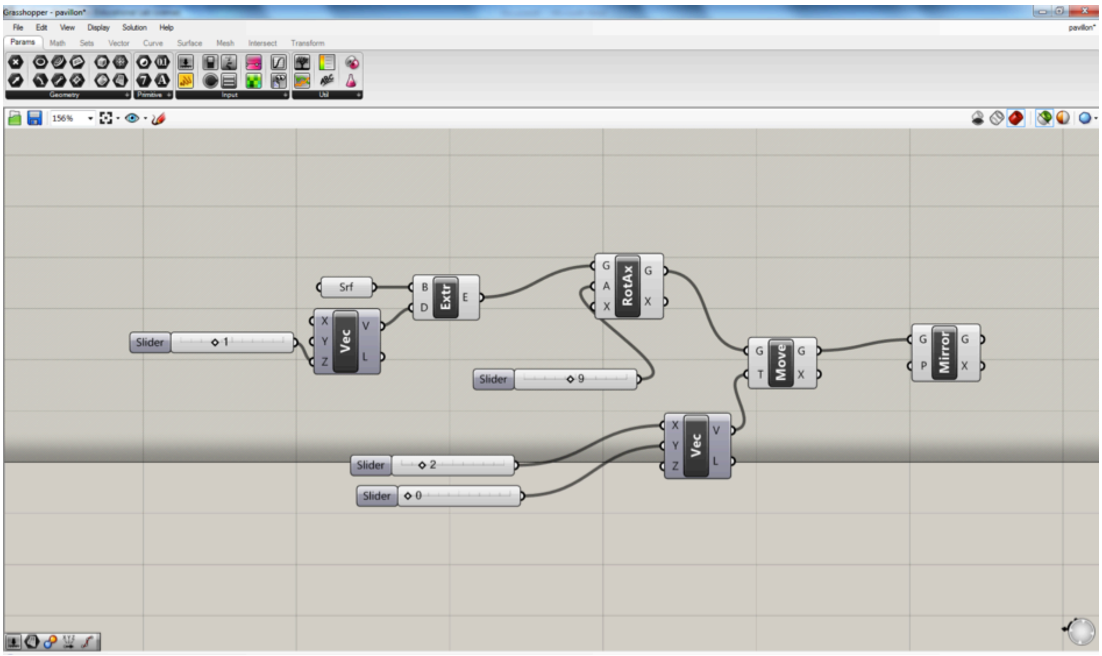

Figure 12: The Same Pavilion in Grasshopper

4.3.3 Simulation Software

While Parametric Design is used to model functionalities based on the geometry of the design, there are many other simulation tools on the market. These simulation tools are particular interesting for the calculation of the energy performance of the buildings or for structural engineering. Some of them will be presented in the following sections.

4.3.3.1 Energy Performance Tools

'EnergyPlus' is a tool or platform that is used as a plugin for the 3D modelling software 'SketchUp'. The design is modelled in SketchUp linked to EnergyPlus in order to study the energy performance of the building.

> **EnergyPlus :** *"EnergyPlus™ is a whole building energy simulation program that engineers, architects, and researchers use to model both energy consumption—for heating, cooling, ventilation, lighting and plug and process loads—and water use in buildings."*[43]

Many modifications can be, as well in SketchUp, as in EnergyPlus. While the changes in SketchUp are limited to the geometry and orientation of the building, the EnergyPlus tool allows modifications on the performances of the different elements of the building (e.g. doors and windows) and also adding special devices and systems for the HVAC, changing the thickness and materials of the external envelope (walls, slabs and roofs), adding PV-panels, blinds, and much more. The program then simulates the energy performance of the building according to the selected parameters. The simulation can be done for a time period, a specific date, another location of the building and so on. It is very important to choose the orientation and geographic location of the building as climate and the sun exposure have a huge impact on the energy performance of the building.

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[43] "EnergyPlus," accessed March 31, 2016, https://energyplus.net.

The following pictures show an example of SketchUp working together with EnergyPlus. In this simulation, the possible improvements on an existing house regarding its energy efficiency are studied.

Obj1	Obj2	Obj3	Obj4	Obj5	Obj6	Obj7	Obj8	Obj9	Obj10	Obj11
Groundfloor Existant	Exterior Wall Existar	Cellar Existant	Roof Existant	Groundfloor Cellar	West Wall Annex	South Wall Annex	East Wall Annex	Cellar Annex	Roof Annex	Groundfloor Annex
12cm Concrete	Roughcast	Limestone	20cm insulation	16cm Concrete	15cm insulation	15cm insulation	15cm insulation	30cm Concrete	10cm foamglass	6cm foamglass
8cm insulation	15cm insulation	Coating			30cm Ytong	24cm Ytong	10cm foamglass		13cm foamglass	15cm Reinforced C
	Limestone				Coating	Coating	20cm Reinforced C		15cm Reinforced C	Insulation Heraklit
	Coating									

Figure 13: EnergyPlus Input of the Envelope of the House

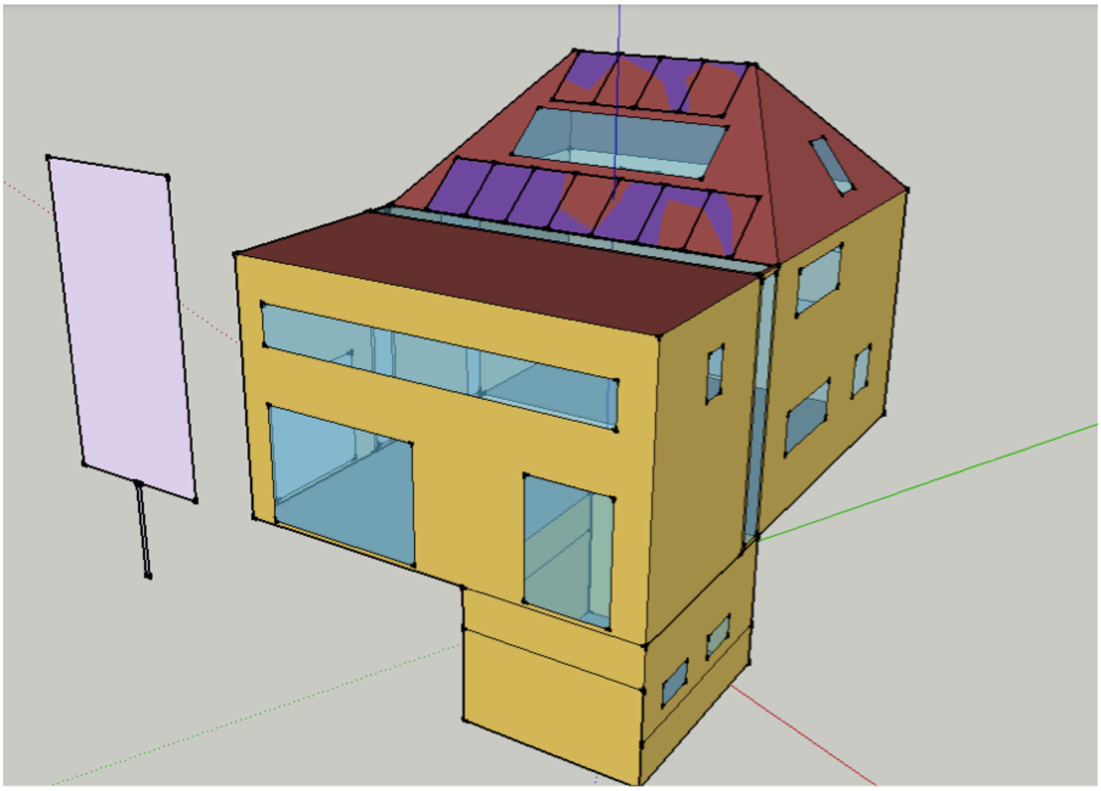

Figure 14: The Same House in SketchUp

4.3.3.2 Structural Engineering – Finite Elements Tools

Simulation software is especially interesting in structural engineering. The structural system of a construction is very important and crucial part of the design. The simulations allow to model a structure and to study its feasibility and impact before actually having to build it. Simulation software (e.g. 'SCIA' or 'Abaqus') are working as suggested by the finite elements method. This means, that the structure is divided into a multitude of elements and the impact of the forces (external and internal) is calculated on every single element of this structure.

SCIA: *"SCIA Engineer is an integrated, multi-material structural analysis and design software for all kinds of projects."*[44]

Abaqus: *"Abaqus FEA is a software suite for finite element analysis and computer-aided engineering."*[45]

The following figures show the calculations for the stresses of a roof structure computed in SCIA. In this case, the model has been drawn in Rhinoceros before being imported in SCIA.

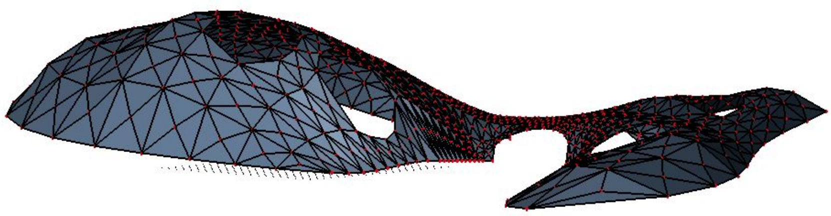

Figure 15: 3D-Model imported in SCIA

[44] "SCIA Engineer," accessed March 31, 2016, https://www.scia.net/en/software/product-selection/scia-engineer.

[45] "Abaqus," *Wikipedia, the Free Encyclopedia*, March 25, 2016, https://en.wikipedia.org/w/index.php?title=Abaqus&oldid=711888366.

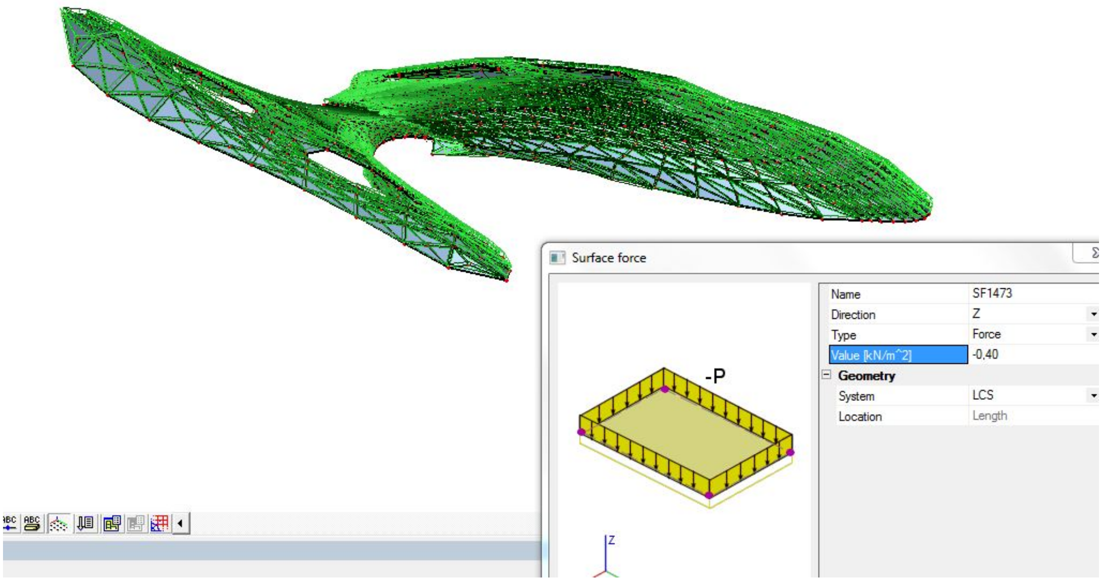

Figure 16: Imposed Loads in SCIA

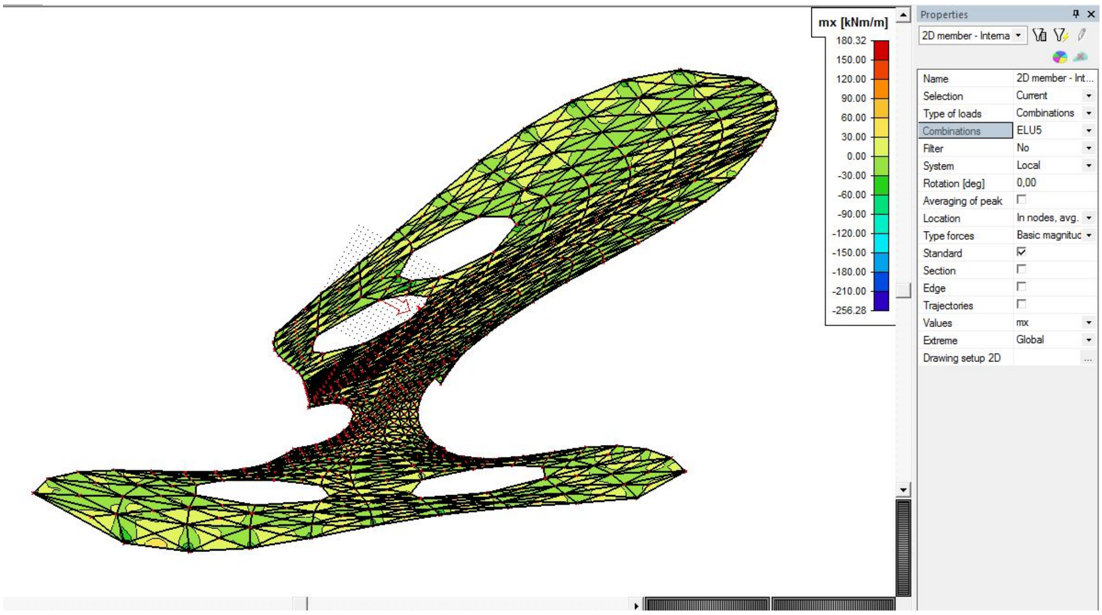

Figure 17: Calculations in SCIA

4.4 Project Management

Whatever the choice for the design process method, the project management remains one of the key components in order to lead off a project successfully. Project management means bringing the project from a beginning to an end and fulfilling the goals: achieving and respecting time, cost and quality.

The project management is needed for the entire process, which means including the design phases as well as the construction phases. The most difficult phase regarding project management is certainly the construction phase. During the construction phase many different contractors are involved in the project, but also external factors have an impact on the construction.

Dynamic instruments are used in project management and can be summarised as follows[46]:

- planning for time control
- conformity to specifications for quality control
- accident statistics for safety and health control
- cost control for budget management

In order to accomplish a successful project, risk management has to be integrated into the design process. The project is therefore divided into different tasks in order to analyse the related risks and to keep the project under control. If the risks are identified before they actually happen, solutions can be foreseen and integrated in the project management.

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[46] Yves Rammer, "R.A.M.P. - Risk Analysis and Management for Projects" (Université Libre de Bruxelles, n.d.).

Also in project management, tools are helping the designers to organise and control the project. The best-known software for project management is probably 'Microsoft Project' (MS Project).

Microsoft Project: *"Microsoft Project is a project management software program, developed and sold by Microsoft, that is designed to assist a project manager in developing a plan, assigning resources to tasks, tracking progress, managing the budget, and analysing workloads."*

The following picture shows an example of the planning for a fictive project including all the steps of the project realised in Microsoft Project. The output (Gant diagram) shows visually that some phases of the project can overlap.

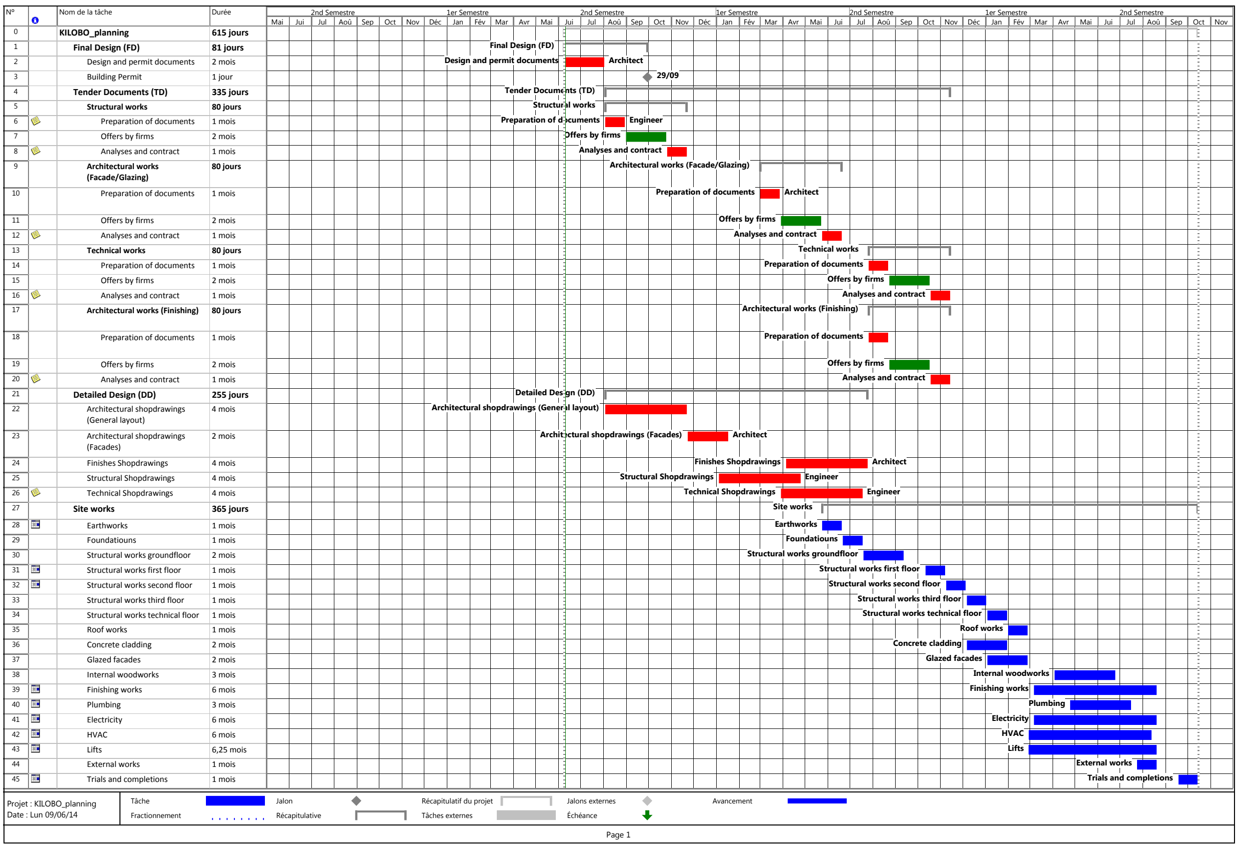

Figure 18: Project Management Diagram

Chapter 5 – Results

5.1 The Architectural Design Process

In the previous chapter, the architectural design process was presented by two different concepts: the linear design process and the integrated design. Both concepts comprehend the same elements of the architectural system but the (internal and external) organisation of the process differs. In the following section, the drawbacks, challenges and advantages of a system-architecture will be discussed by analysing the results of these two concepts.

5.1.1 The Role of the Architect

Regardless the chosen concept of the process (linear or integrated design), a change in the role of the architect – compared to his function in the traditional design – can be observed. The architect is no more only responsible for the design itself but a function of project manager is assigned to him. Due to (more and more) severe project and design requirements, many specialists in various fields are involved in the design process. The architect becomes the coordinator of a team of specialist. Indeed he cannot do everything by himself but has to manage the work of the involved actors in order to assure a successful progress of the project. The role of the architect is comparable to the function of the conductor of an orchestra, who also has to make sure that his team, the musicians in this case, play well together in order to obtain a great result.

5.1.2 The Hierarchies of the Process

Many actors are involved in the design process and the success of the project depends on the work of the entire team. This result can only be achieved if the strategy of the project is clear, understood and accepted by all the team members. Every actor has his own responsibilities (to perform his work as foreseen) but who is responsible at the end of the project? The architect or could it be someone else? If design should have an importance in the project, the architect must be responsible for the project. Besides the management of the team and the respect of all the constraints, the architect has in mind an architectural expression for the project. This vision can only become reality when the architect remains the leader of his project. The architect has to manage all the measurable elements of the project without weakening the architecture itself.

As already mentioned in the description of the linear architectural design process, the different phases of the process can overlap. However this overlapping is leading to new issues. If one phase begins before the previous step is approved, on the one hand the "speed" of the process is increased but on the other hand the project is exposed to a risk of interruption or dysfunction. The project manager therefore always has to assure a risk management in parallel to the project management. Not only should the impacts of one phase be known at every time of the process but also the dependencies between the phases.

Still considering the linear process: how should the hierarchies of the different steps be determined? At the end of the first step of the architectural design project – the conceptual design phase – the project is defined by graphical documents, planning and budget. All the following phases of the project have to be realized in accordance with these primary parameters, which are defined during the first stage of the project. Regarding the hierarchies of the process, the planning and the budget are certainly rated by the client at a higher level than the graphical documents. This is due to scientific background of the calculations in contrary to the drawings. It is much more evident to understand and to comprehend the calculations than design itself. One of the major difficulties therefore consists in explaining which part of the graphical documents is fixed from the beginning and which part will be detailed in later phases. Of course the differences in the level of detail of the different phases have an impact on these hierarchies of the design. During the process, the project becomes increasingly more detailed and new parameters have to be fixed, which could not even be observed in early stages of the project.

Another very important issue is that the decisions – once fixed – should not be changed anymore. As an example: the design team decides to change the position of the door whereas the engineer has based his calculations on the initial hole for the door. At the end of a phase, decisions have to be taken and kept for the rest of the project in order to assure the efficiency and effectiveness of the process.

The hierarchies are not less important for the model of the integrated design process. As in this concept, all the actors of the project are involved since the very beginning, what does that mean for the client. Does he have to take all the decisions in a very early stage as the contractors are already integrated in the process from "zero hour"? One big advantage of the integrated design for the project team is that design errors can be avoided by this early cooperation with the contractors. As an example: the technical devices can take a huge space on the roofs of buildings; the integrated design concept allows the architect to "integrate" the needed system in the design.

Still concerning the hierarchies of the project, a crucial part of the integrated design consists in deciding when which contractor should be involved in the process. Depending on the work the contractor has to do, the laps of time needed for the preparation of his work, before on site works, can vary a lot. For instance carpentry work needs a far longer preparation than painting. The parameters and criteria of the project have to be fixed in the beginning with the main partners before involving all the different actors.

As in the integrated design process, all the partners are working simultaneously on the project, a common working platform has to be created: the shared model. As already mentioned in the previous chapter, nowadays thanks to very powerful software the projects can be simulated during the design phase and all the impacts (e.g. structure, HVAC) can be studied on that computer model. According to the concept of the integrated design process, all the team members are therefore working on one common model. However if this model "belongs" to everyone, what about the responsibilities? Nobody will feel personally responsible if there is a problem. Would it not be better if everybody would have his own model and would share it only when the task has been accepted in order to avoid a disorder?

The BIM-tool is a very important tool for the integrated design process. While the BIM platform simplifies the collaboration between the partners, new problems may occur. The process becomes much more transparent thanks to BIM but is this high transparency good for the exchange with the owner? This does not mean that the architect (or project team) should hide information from the client but how can the project evolve if the owner is questioning every single step of the process? Or in other words, can a process, which might not be understood by the client, really be transparent? Again, the hierarchies in the process have to be clear and well decided in order to give a transparency to the project, which is understandable for all the actors; client and contractors.

Irrespective of the chosen concept, at the beginning of the project the milestones of he planning should be fixed in accordance with all the actors. This planning should not only be established for the construction phase but for the entire design process. The planning gives the possibility to the actors to be prepared. If they do not respect the time limits the entire process might be disturbed. The challenge of the "process management" consists in making sure that the actor is ready on time.

5.1.3 The Human Factors

As already mentioned before, the project can only be successful if the team works well. The human factors play an important role in the performance of the project. But not only the interpersonal relations have to be good. The architect has to be aware that unforeseen events can occur at any moment. Due to illness, dismissals or even bankruptcy of a contractor, the process can be delayed or interrupted. The architect has to be aware of the consequences of these scenarios and keep in mind possible risks when establishing the project planning.

While the project leader can choose the team in order to have a good cooperation the relationship between the architect and the owner is much more complicated. The owner does not necessarily understand the language of the architect. How can the architectural concept developed in the mind of the architect be transparent for the client? There is a risk of misunderstanding. During the conceptual phase the architect takes already many decisions (e.g. spatial relations, finishes of rooms), which are not yet visible for the owner while the architect is convinced that these choices have been accepted. Does the client understand all the graphical elements? The drawing of a stair means much more to the architect than only a functional element relating the different levels of a building. Is it used all day or only in case of escape? Should it be understood as a meeting point for people? What expression should it have? How should it be materialized? These conceptual ideas are difficult to explain at a very early stage of the design process and nevertheless they mainly fixed at that moment. The flexibility for later change is rather limited.

On the one hand the client might have difficulties to understand the decisions of the architect. On the other hand, for the architect it is not easy neither to explain all his choices taken during the conceptual design phase. Perhaps he does not even want to explain everything to the client. The reason of some elements might be understandable for the client only at a later phase of the process.

5.2 The Advantages and Limits of the Tools

Many software, used in the design sector, appeared, thanks to the development of the technology, easier for the design teams. Due to the complexity of the design process, which is increasing because of the constraints, norms and regulations that have to be respected, it becomes very difficult to do everything by hand. The simulation software allow the user to study any impact on a computer based model before processing to the real construction process. These tools are used as well by the designers (architects) as by the engineers. The speed of the processes is increased. Working on computer-based models avoids loosing time when a part of the design is changed as the impacts can directly be recalculated.

In the previous chapter the most common tools have been presented. In this section, their advantages and limits will be discussed.

The BIM tool is used especially in the integrated design concept as it gives a platform to the project team, which allows the actor to work simultaneously on one common model. This model gives them the opportunity to explore many design and conceptual alternatives. However if every contractor is studying his system on the model in order to find the best – according to him – solution, who has the power and the courage to take a final decision. Taking decisions at some point is important as the project has to proceed and the actors cannot "play" eternally on the model. Moreover the choices of one actor may influence the possible solutions of another partner. Also in the integrated design process where all the actors are operating together on the project, somebody has to take decisions. This is a matter of hierarchies as discussed earlier.

Rhinoceros combined with plugins like Grasshopper enables the optimisation of the performance of a building parallel to the shape and space. The designers can deal with complex systems, which was not possible at that level in the traditional design process. Every element of the model is linked to an algorithm, which controls the design optimization. While this tool is very powerful, the performance is depending on the knowledge of the user. Indeed the user is still operating "manually" on the model. While the tool is very good in giving results, the performance still depends on the skills of the manipulator in the concerned field.[47]

In parametric design, the conceptual phase becomes an iterative process as the user generates, transforms and manipulates the model in order to become the best results. This phenomenon leads to the question of the origin of the design: is it a creative part or is there a scientific nature behind the conceptual design process? The architect has a list of certain criteria to fulfil in the design and manipulates the model in order to obtain a suitable solution. As said in the above paragraph, the desired performance can be obtained by operating on space and shape. However if this form-finding procedure is based on an iterative process, how valuable remains the function of the designer?

The strength of parametric design is that not only the geometries are represented but also their relationships. However the complexity requires a participation of the actors at an early stage of the process in order to exploit the capacities of the tool at a maximum.[48]

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[47] Shi and Yang, "Performance-Driven Architectural Design and Optimization Technique from a Perspective of Architects."
[48] Turrin, von Buelow, and Stouffs, "Design Explorations of Performance Driven Geometry in Architectural Design Using Parametric Modeling and Genetic Algorithms."

The simulations tools used especially by the engineers for the structural part of the design are based on the finite elements method. This means that a structure is divided in a huge number of elements and the final result is based on studies of forces on every single element composing the structure. Programs like SCIA or Abaqus study the performance of the structural system of model. The goal of the software does not consist in finding the structural system for a particular design but in doing the calculations for a given structure developed by the engineer. The operator has to implement the structure and to define the parameters (e.g. materials, external forces, safety factors) manually. The tool therefore does not perform a task instead of a human but presents a help to the user. The results are much more precise compared to calculations done by hand as the program is able to perform the computations on a number of elements, which is not imaginable without computer. Therefore – even if the calculations are done by the software – the users still have to have the necessary skills in order to be able to evaluate the results and, if they are not satisfactory, to develop a new structural concept.

Chapter 6 – Conclusions

In this master thesis, two ways of organising the architectural process (the linear architectural process and the integrated design process) have been presented. It is difficult to say if one is better than the other. Indeed, both of them have their advantages and their limits. The danger of the linear system could be to miss the links and impacts between the different phases of the project while the advantage consists in the clear structure of this process organisation due to its linearity. On the contrary, concerning the integrated design process, the interconnections of the different steps are visible already at the very beginning of the project as the actors, coming from the different domains, are developing the project together. In this concept, the difficulty might consist in the decisions necessary for the evolution of the project. If everybody is involved, which actor has the power and the courage to decide? Perhaps it should be the designer; the architect. But is he able to take all the decisions, as he has not the knowledge of every discipline?

As explained in the results, establishing a clear structure and acceptance of the hierarchies in the project-team, as well as defining the responsibilities and duties of the actors, are very important in order to realise a successful project.

While I decided to study these two definitions of the architectural design process, this does not mean that there could not be a third or fourth method to organise the process. Maybe the understandings of the design process have to be combined in order to obtain a definition? The on-going evolution and improvement of the technologies will probably predict the future direction of the architectural process. During the presentation of the tools, one could notice that there are software for a specific topic (e.g. EnergyPlus for calculating the energy performance of a building) as well as platforms (e.g. BIM) available in the market, which enable and facilitate the collaboration between the different actors.

One issue, which should be discussed, is the question if these tools and the increase in the use of technology in the design process do not present a danger regarding the concept itself? Of course, thanks to the tools, complex problems can be solved but are we not risking of going too much into detail already during the design phase and losing the global view of the architectural concept? If every single problem (especially in the integrated design phase) is discussed at the very beginning (e.g. HVAC system) is there still enough space for creativity?

Indeed, because if this increasing use of automation, we might create a gap between our mind and our hand, which is replaced by the mouse. Does the human being still keep the power or does the machine take over the design process? Design can be understood as the result of a creative process. How could an automated process replace the creativity of a human being? How could it be reduced to an algorithm? This partly automated process could be observed in the parametric design technology. The design phase becomes an iterative process and the desired result is obtained by trial and error. In order to be able to recognize when the result has been obtained, we might notice that a parametric approach works only when the problem is well understood.[49]

Indeed, the design process should not become an optimisation process. And how could we encode aesthetic constraints?[50]

We already noticed in the results that there is a need in transparency. The client invests in a project and he has the right to know where his money is going. As he expects a certain result (or design) from the architect, he should have the possibility to follow the evolution of the project.

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[49] Michael Kilkelly, "Are Computers Bad for Architecture?," *ArchDaily*, accessed March 6, 2016, http://www.archdaily.com/618422/are-computers-bad-for-architecture/.
[50] Jonathan Byrne et al., "Combining Structural Analysis and Multi-Objective Criteria for Evolutionary Architectural Design," in *Applications of Evolutionary Computation*, ed. Cecilia Di Chio et al., Lecture Notes in Computer Science 6625 (Springer Berlin Heidelberg, 2011), 204–13.

The BIM platform promotes this transparency. Unfortunately this transparency is not always in favour of the architect and therefore neither of the client. A priori, the architect knows his work (being a specialist in his domain) and should be in a position to advise the client and to help him to develop together a project in respect with budget and needs. However there might be a risk that the client is questioning even the smallest decision of the architect. In this case, there is no space left for the architect, which would allow him to work on the improvement of the project. This does not mean that the architect should hide information from the owner, but maybe the information exchange between them does not take place on the same level as between the professional actors of the project.

Nevertheless, we should not neglect the importance of the relationship between the architect and the owner. If this relationship does not work well, how could the project be successful? The architect has to find an interface or a communication language to connect with his client. As the architect is an expert in his domain, he cannot expect that the client has the same level of knowledge in that discipline. Does the client understand the plans? The owner – the client who orders the project – has to make many decisions all over the process. But does he have enough knowledge to do so? Is he aware of the consequences of his choices? How can the architect make sure, that the client sees the same project in mind as the designer and the built construction will satisfy him?

The quality of the design is obtained by respecting the uses and wishes of the client and doing a good architecture (as already mentioned in the introduction 'good architecture' is rather subjective as there are no tools to measure the success of a design). Therefore 'good architecture' means much more than just respecting the client's desires and following the norms and rules.

It is very important to pinpoint the impact of the human interferences and relationships regarding the challenges of implementing a system-architecture. In the beginning of the master thesis, the iron triangle has been presented. According to that idea the success of a project is determined by cost, time and quality.

While the move to a system-oriented model in the architectural design process is quite easy concerning the cost and time part, it presents a huge challenge concerning the quality of the architecture.
This can be understood by the fact that the time and cost criteria are dealing on numbers, which can be calculated, proved and easily understood. Powerful tools like MSProject facilitate the task of project managing. As for any project in any other domain, a risk analysis has to be performed in parallel to avoid unforeseen events, respectively to be able and ready, if needed, to deal with them. The implementation of a system-architecture concerning the quality of the project remains a challenge as the quality of architecture cannot be measured. In other domains, like in automation, this quality level is reached by quality control. Performing a quality control in architecture might be even less feasible than measuring the success of the design as every project is unique.

To conclude, we can say that the need in organising the architectural design process according to a system-oriented model can be explained by the increasing complexity of the projects of today. The big challenges of finding a suitable method consist in the fact, that the creative process cannot be, neither completely automated, neither completely assessed, as the design remains a subjective perception. Architecture is developed or thought by humans for humans.

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