Application of Parametric Modeling in the Early Design Phase for an Interdisciplinary Design Approach for Adaptive Buildings

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Abstract

The integration of adaptive elements to buildings might reduce significant amounts of material and energy. Load-bearing structures are extremely oversized for the predominant period of use. If it is possible to dampen the stress peaks, significant quantities of building materials could be saved.

As a result, the overarching objective is to enable material savings through the deployment of energy when required and to anticipate such an approach in early design through computational processes. For adaptivity, almost all design and form-finding methods embedded in the planning process require completely new exploration and development.

A building with adaptive qualities has no constant properties. Therefore, such structures can't be designed with the usual design methods. The related knowledge and components from mechanical and aerospace engineering need to be transferred, adapted, and redeveloped, since the building industry lacks the experience of adaptive qualities.

Furthermore, this means an increase in the number of disciplines participating in the planning process.

This Paper presents insight in the ongoing process of building a twelve story tower with adaptive qualities by an interdisciplinary research team from the fields of architecture, mechanical engineering, civil engineering, aerospace engineering, textile engineering, social science and computer science.

For this task, parametric modeling was used in the early design phase to investigate the advantages and limitations of this method in terms of adaptive behavior. The findings will be the foundation for a computational design approach in early design for adaptive buildings with the integration of knowledge from the different research fields in the future.

Keywords: **Computational Design, Adaptive Buildings, Early Design, Material Savings, Interdisciplinary, Parametric Modeling, Building Information Modeling**

Introduction

Globally, the building industry consumes 40% of our global resources, produces about 50% of the entire waste, and is responsible for 40% of energy consumption and emissions [1]. Furthermore, 2 billion people need new apartments, workplaces, and infrastructures within the next 16 years because of the rapid growth of the world population [2]. The creation of such a big construction volume with conventional approaches is impossible without tremendous consequences for our planet. Therefore, a new approach is vital.

For the future, the described problems require building more with less material, waste, energy consumption, and emission. The integration of adaptive elements inside a building can reduce significant amounts of material and energy. Nowadays all load-bearing structures are designed for peak loads, which usually occur in very rare cases. As a result, they are extremely oversized for the predominant period of use. If it is possible to dampen the stress peaks by manipulating the stress conditions in the load-bearing construction, significant quantities of building materials could be saved. Adaptivity allows a façade or a supporting structure to assume a variety of different states. This is the major difference to the current building design, which assumes one state for any possible scenario. This raises the question of how we design and represent these multiple conditions. Since the building industry never worked with adaptive qualities before, the related knowledge and components from other disciplines like mechanical and aerospace engineering need to be transferred, adapted, and redeveloped.

The Collaborative Research Center (SFB) 1244 "Adaptive Building Skins and Structures for the Built Environment of Tomorrow", funded by the German Research Foundation (DFG), focuses on the basic principles, as well as the potential and the impact of integrating adaptive elements in load-bearing structures, facades and interior work of buildings.

Here, the term "adaptive" is used in the context of precise modification of the geometry, adjustment of material characteristics and the properties of construction elements over time. The aim is to minimize the amount of required material and minimize embodied energy. The interdisciplinary research team consist of scientists on the topic of architecture, mechanical engineering, civil engineering, aerospace engineering, textile engineering, social science and computer science.

As a first milestone, a 36-metre-high tower with an adaptive load-bearing structure will be built for specific research into the topic of adaptivity [Figure 1]. At a later point in time, the demonstrator tower will also be equipped with different adaptive façade systems, which are still in development. The demonstrator serves as a proof-of-concept and gives the researches the ability to contribute and analyse the process of creating such a tall adaptable building.

The main part of the authors work was to assists and observes the design, planning and construction process of the demonstrator. For this task parametric models were created with

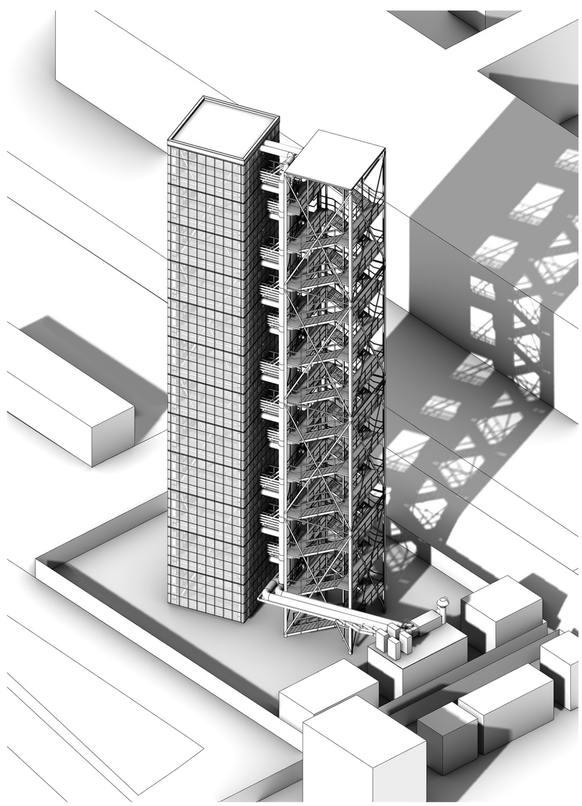

Figure 1. Twelve-story demonstrator tower

the Building Information Modeling Software "Autodesk Revit" and relevant information was shared with other research fields to guarantee an interdisciplinary design approach from the start. The gathered information of the building process will provide the framework for novel computational methods for a digital planning environment to help architects anticipate adaptive qualities in early design in a later stage. The findings from the planning of the demonstrator can be used to specifically identify the restrictive aspects of linear, conventional planning and to define and concretize requirements more precisely for the investigation of computational processes.
Also the design model of the demonstrator will be used in the future as a benchmark for an adaptive design model which is to be developed.

Current State

The established architectural planning process is hierarchical. A first draft developed by the architect can only be successively refined, constructively developed, and realized in the later phases in cooperation with experts like structural engineers.
The formulation of the task is initially vague and is only defined over time by the generation and evaluation of variation in the early design phase. For this reason, no optimization is possible right from the start.
Today, stationary and static planning is carried out. Each element of a building can be described precisely and has only one state for each occurring situation. For example, façade insulation has a set heat transfer coefficient, which remains identical regardless of external weather conditions and is unable to adapt.
The linearity and hierarchy of the existing process make it more difficult to integrate adaptivity into the necessary planning, structural, structural-physical, mechanic, and mechatronic considerations in the early design decisions. But these early design decisions account for 80% of a building's energy and material consumption [3]. On the other hand, this phase is only compensated with 24% of the commission fee according to the German Regulations for Architects and Engineers [4]. As a result, many architects lose the opportunity to examine far-reaching decisions and their implications in depth at this phase and postpone conflicts to later phases in the planning process at which a higher compensation is paid. But at this later stage it is not possible to explorer the solutions space for better individuals anymore, because the design phase has already been completed and a final design has been selected.
Building Information Modeling is a method which attempts to break the linearity of the planning process and enables collaborative work on 3D models, avoidance of collisions, quantity and mass determination, coordination of processes on construction sites, etc. BIM is an approach for merging and enriching the planning and construction process with information. But the method lacks considerable influence on the early design phase. Therefore, BIM is usually applied after the conceptual design process, when there aren't many changes to be expected. Almost two-thirds of the UK BIM user think, that BIM won't help to reduce greenhouse gas emissions in the built environment by 50% [5]. Although there is research in the field of using BIM in the early design phase, nobody is approaching an interdisciplinary design approach for adaptive buildings. In contrast to existing information models, an extended information model should be able to map and quantify the different states of the structure and systems with dynamic and instationary properties, as well as their temporal change due to adaptivity.
The existing methods and approaches of architectural planning can therefore only be conditionally applied to adaptive structures, because they cannot fulfil the fundamentally interdisciplinary character right from the start. The essential requirement for the development of new methods and procedures for adaptive architecture is to enable integrative planning right from the beginning.

Adaptive Envelope Systems and Adaptive Structures form a linked system of sensors and actuators with a variety of interdependencies. In order to better investigate these interactions, the architect needs digital support to assist him in exploring the solution space. This process has to recognize or point out characteristics and thus create new solutions which the human being alone can hardly foresee.

Observations of the design and planning process

The task was to analyze the capabilities of current state-of-the-art Design and Planning software in the Building industry regarding the advantages and limitations for adaptivity on a real showcase. “Autodesk Revit” is the market leader for BIM Software with a usage rate in the UK of 41%, followed by “Graphisoft ArchiCAD” with 15% [5]. Therefor “Autodesk Revit” was used for parametric Modeling of the demonstrator building. The parametric models were created on the foundation of vertical and horizontal Gridlines with dependencies to each other. On top of these guides, family members were attached and could adapt to changes of the gridlines.
As in the Beginning, this approach of parametric modeling seemed the most logic. The Topology of the Building was set. A ten stories tower with a height of 36 Meters had no space allocation plan and therefore very little requirements concerning the architectural design.
The main task seemed to be massing, detail drawing and scheduling to support the construction planning. Later the BIM Model should be transferred to become a control model of the adaptive elements.
Over time, more Inputs and Outputs were added to the Model [Figure 2]. Some of these requirements are specific for adaptive design and helped the interdisciplinary approach of the planning process. The BIM Model was used as central hub for all information.
A small footprint of the building would help the oscillation behavior for the testing scenario of the damping actuators of the structure. For this reason, the access had to move to a separate tower standing nearby, with stairwell, an elevator and bridges connecting the demonstrator.

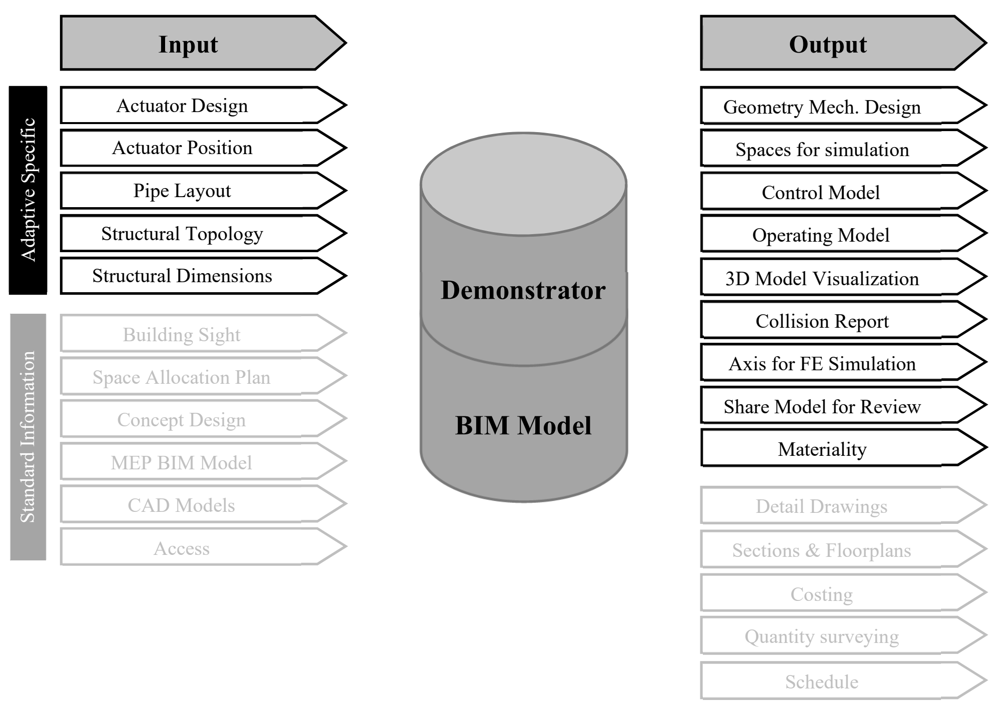

Figure 2. Inputs and Outputs of the BIM Model

This resulted in a conflict of the structural and the architectural design, because the bridges had to avoid the structural diagonal branching in order to access the demonstrator.
The principles for the adaptive structure were developed in a parallel process by civil and mechanical engineers. Over time, the tower had to become slender to increase the oscillating behavior. This was easily achieved by changing the parameter of the Center-to-Center distance. Over the course of one year the distance changed from 6000 millimeters, to 5300 Millimeters and 4300 Millimeters. Massing and drawings were updated on the fly without the need change multiple plans by hand. The process for the actuator integration [Figure 3.] was included into the linear and hierarchical planning process, because of the limited timespan to build the demonstrator. Also it was not the main goal to test novel planning methods in this phase and risk the fixed date for the completion of the building. Still this process leads to some interesting findings: Left side of the diagram shows similarities to the normal planning process, while the most adaptive activities happen on the right side. The concept design lacks adaptive qualities at the start. Therefor some feedback loops had to made, which the architect didn't like, because it meant more work which wouldn't be reimbursed.

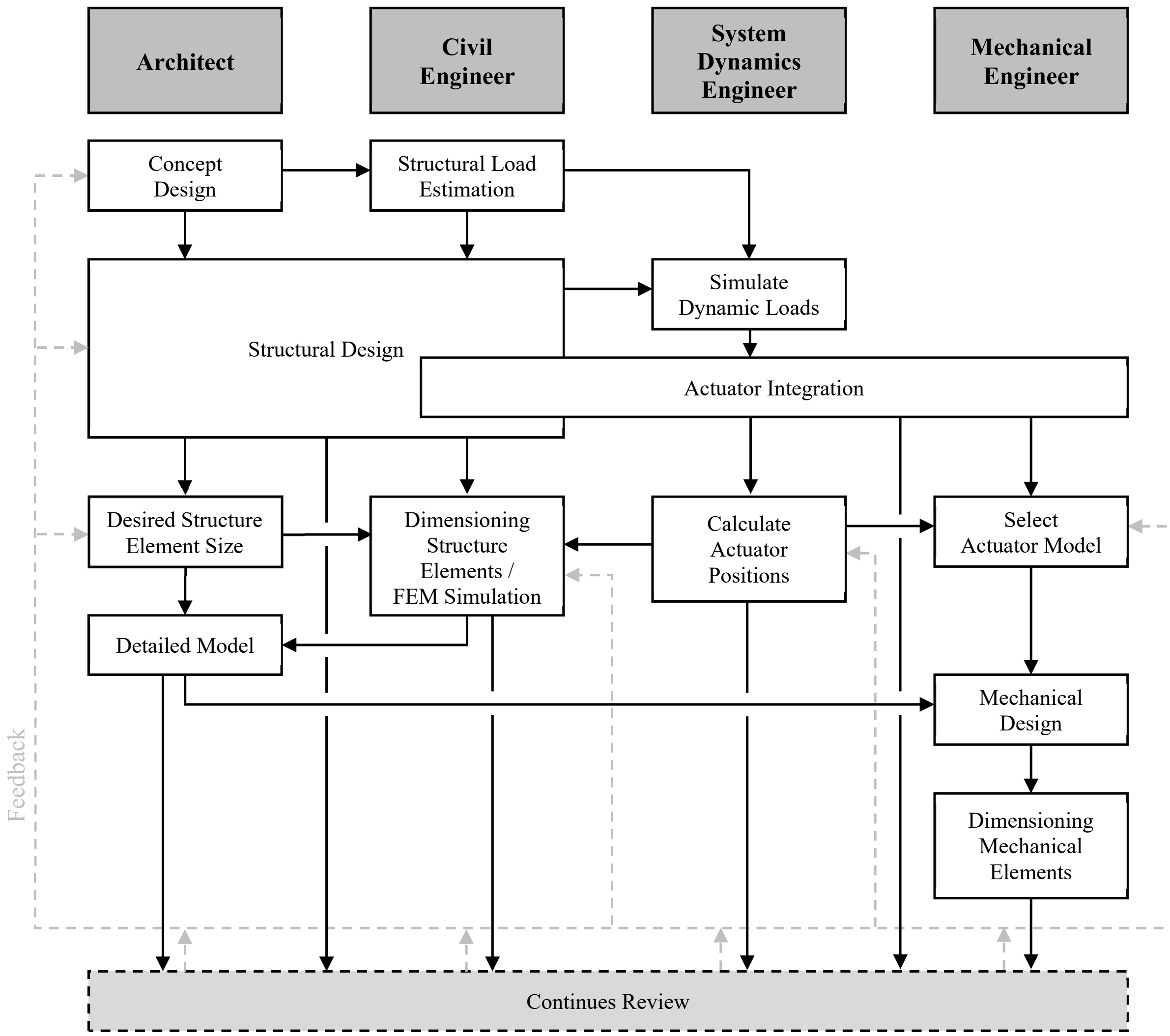

Figure 3. Design Process for the adaptive Structure

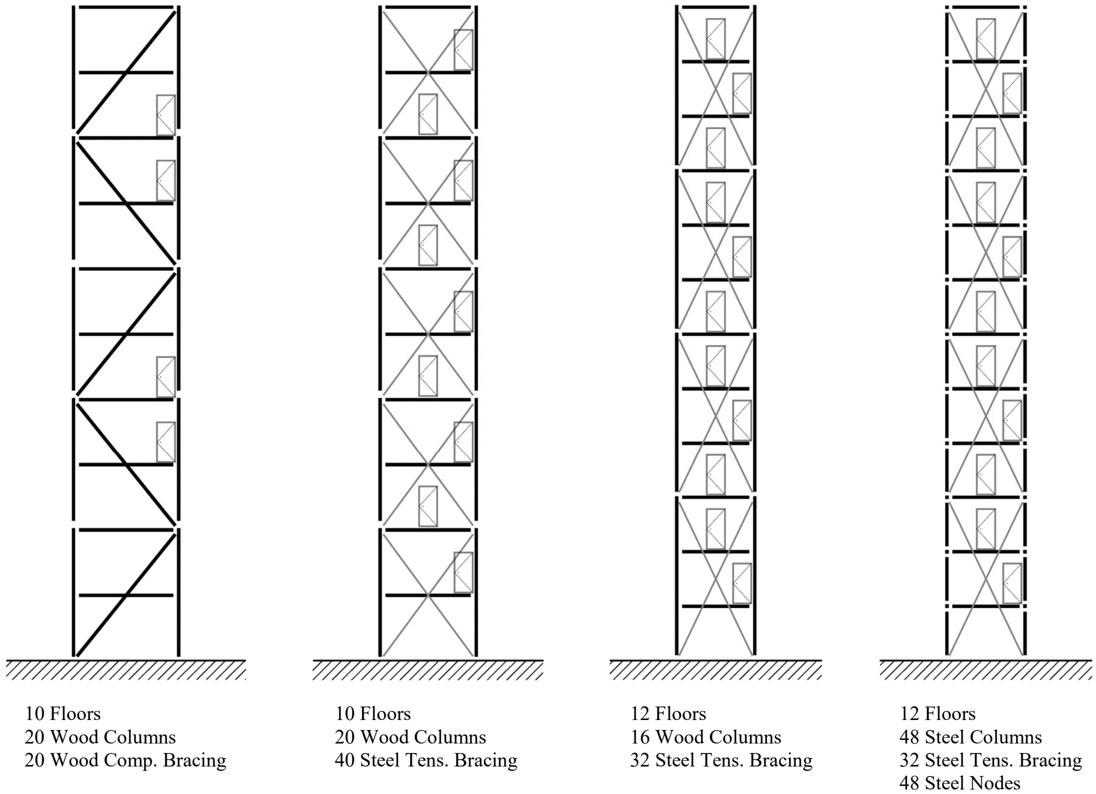

Figure 4. Changes of the Structural Topology in the Design Process

Fundamental topology modifications in the structure make parametric modeling difficult [Figure 4. & 5.]. Most of the time the parametric model can't adapt to topology changes and a new parametric model needs to be created, because the changes couldn't be foreseen, while creating the parametric model. Due to continuous improvements in the calculation of the actuator placement, changes in the adaptive structure topology had to be made more frequently. The first design envisaged a wooden structure. But a wooden column with an actuator could not be developed in the short time. So it was decided to use only a steel structure for the time being.

This also results in the idea of having maximum flexibility in changing the structure topology even after the building was finished. Therefore, the idea came up that every column or diagonal could integrate an actuator. Also every element of the structure can be replaced by a different design e.g. concrete or wood columns after the construction is finished. This is because there may be improved actuator placement models in the future, which might need further investigation.

So an attempt was made to change to Generative Parametric Modeling with the ability to solve the previous mentioned problems. This process is currently under investigation. However, implementing such an approach under the recognized conditions takes a considerable amount of time and still cannot guarantee to cover all upcoming scenarios of changes in the topology. But in the early design phase it is important to have no limitations in the creation and evaluation of many variations without spending too much time creating complex solutions. As mentioned before, the time in this phase is restricted and not sufficiently compensated.

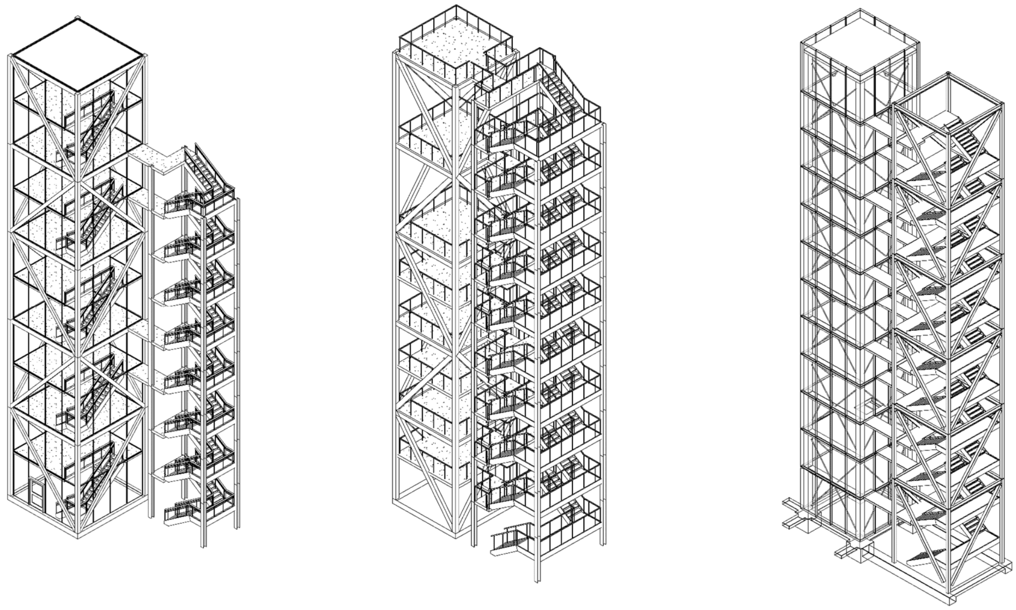

Figure 5. From Left to right: Evolution of the Building

Conclusions and Outlook

Parametric BIM modeling is capable of assisting in the early design process of adaptive buildings of an interdisciplinary team. Still it lacks the ability to describe dynamics and instationary properties of adaptive elements and is therefore limited in exploring the solution space in the early design phase. Hence, a holistic description of adaptive qualities in an extended building information model must be developed. Because of the necessity to change the structural topology during the exploration of the design space, further development of parametric models with regard to topological flexibility and variability is required. A graph-based approach for parametric modeling could be one feasible solution. Other longtime goals are the Development of computational processes and tools for the exploration and variation reduction in the early design phase, with the principles of adaptive buildings and the Integration of processes and methods into a digital design environment which enables feedback and optimization on the principle of simulation and analysis with the involved disciplines.

Acknowledgments

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