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TECHNICAL PLANNING TASKS AND PARTICIPANTS INVOLVED IN PLANNING ADAPTIVE BUILDINGS

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Abstract

Adaptive Buildings constitute an interdisciplinary approach for realizing the next generation of buildings in order to reduce the immense material requirements and energy demand in all phases of the life cycle. Based on a novel cooperation between the disciplines of architecture, civil and mechanical engineering, adaptive support structures and adaptive building envelopes are developed within a Collaborative Research Centre. In order to reduce the high complexity and achieve a goal-oriented procedure during the planning of such buildings, a holistic planning process is required. The experiences of the development and the application of methods in the field of design methods are therefore required and form part of the interdisciplinary project. The goal of this paper is to analyze current planning processes, existing adaptive elements and to derive the basic technical tasks of the planning process and the participants of the planning team of Adaptive Buildings, taking into consideration the life cycle of these buildings. The results were investigated with the support of architects and civil engineers.

Keywords: Multi- / Cross- / Trans-disciplinary processes, Sustainability, Design methods, Adaptive Buildings, Holistic planning process

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1 INTRODUCTION

Adaptive Buildings constitute an interdisciplinary approach to address the challenge posed by continuously increasing construction volumes and the existing problem of immense resource consumption in buildings. The energy demand of all life cycle phases of a building and the required building materials in particular are part of this resource consumption. Both constitute a large proportion of the resources required worldwide. For this reason, Adaptive Buildings represent a very intensive and thus novel cooperation between the building industry – in particular architects and civil engineers – and the mechanical engineering in the research stage. The research project is promoted by the German Research Foundation within the Collaborative Research Center 1244 called "Adaptive shells and structures for the built environment of tomorrow". The corporate objective is to develop new solutions within the described context. Based on the application of sensor-actuator systems, adaptive support structures and building envelopes or the related façade elements that enable the adaptiveness are able to interact with their environment (Sobek, 2007) to achieve new benchmarks in lightweight design, energy consumption and a high standard of living within the buildings. For adaptive structures, previous investigations which have already been presented demonstrate that more energy can be saved within this approach than that which is needed for the adaptiveness (Teuffel, 2004; Flaig et al., 2015). However, further investigations have shown that the approach of Adaptive Buildings leads to increased complexity caused by the technification and related disciplines when compared with conventional construction, which requires an interdisciplinary planning procedure (Honold et al., 2016). The development of a holistic and interdisciplinary planning process therefore forms part of the research project so as to achieve a structured and goal-orientated procedure with the recommendation of method applications to jointly plan and develop Adaptive Buildings.

2 PROBLEM STATEMENT AND GOALS

So far, different investigations led to several developments of adaptive elements for use in buildings or in the form of examples for so-called ultra-lightweight structures (Teuffel, 2004; Neuhäuser, 2014; Haase et al., 2011a; Haase et al., 2011b; Flaig et al., 2015; Knubben, 2014). Each element was tested in prototypes or full-scale models and fulfilled the respective requirements as well as related and desired advantages. In order to present a holistic overview of possible adaptive elements, Figure 1 shows different examples for the use of sensor-actuator systems in Adaptive Buildings. All examples in the visualization are selected results from appropriate literature sources and market research that are currently still in the research stage or already available for purchase. However, they can be assigned to the approaches of adaptive structures or adaptive façade elements and lead to a reduction in material or energy demand during the whole life cycle of buildings. Based on these previous investigations, the approach of Adaptive Buildings will be developed further within the Collaborative Research Center with 25 researchers working on the subordinate fields of Architecture, Civil and Mechanical Engineering. After focusing on individual and mutually independent adaptive elements or structures in previous studies, complete and larger habitable buildings such as multi-story buildings are the focus in the next steps – and also for the first time. On the basis of merging the existing and additional adaptive elements, the research project leads to a holistic building approach which represents a new scientific challenge brought about by the increasing complexity. However, the interdisciplinary approach is perceived as an opportunity, comparable with the association of the disciplines of Mechanical Engineering, Electrical Engineering and Informatics in the infancy of mechatronics some decades ago (Honold et al., 2016).

Due to the anticipated fact that the simultaneous application of adaptive elements delivers further advantages, yet nonetheless a great deal of interfaces and dependencies, appropriate coordination between the systems is required during the planning task. Compared with the conventional planning procedure, this issue therefore is one of several new and additional tasks which have to be considered during the planning process for Adaptive Buildings. As Adaptive Buildings are in permanent operation, they cannot be viewed as concluded systems, as it was the case for static buildings up to the present. For this reason, additional requirements and issues provide further tasks during the planning procedure. Thus all phases of the life cycle of an Adaptive Building have to be considered. However, the analysis of the entire life cycle is not a fixed constituent part of existing planning procedures and is only sometimes considered by special consulting services (Bergmann, 2013).

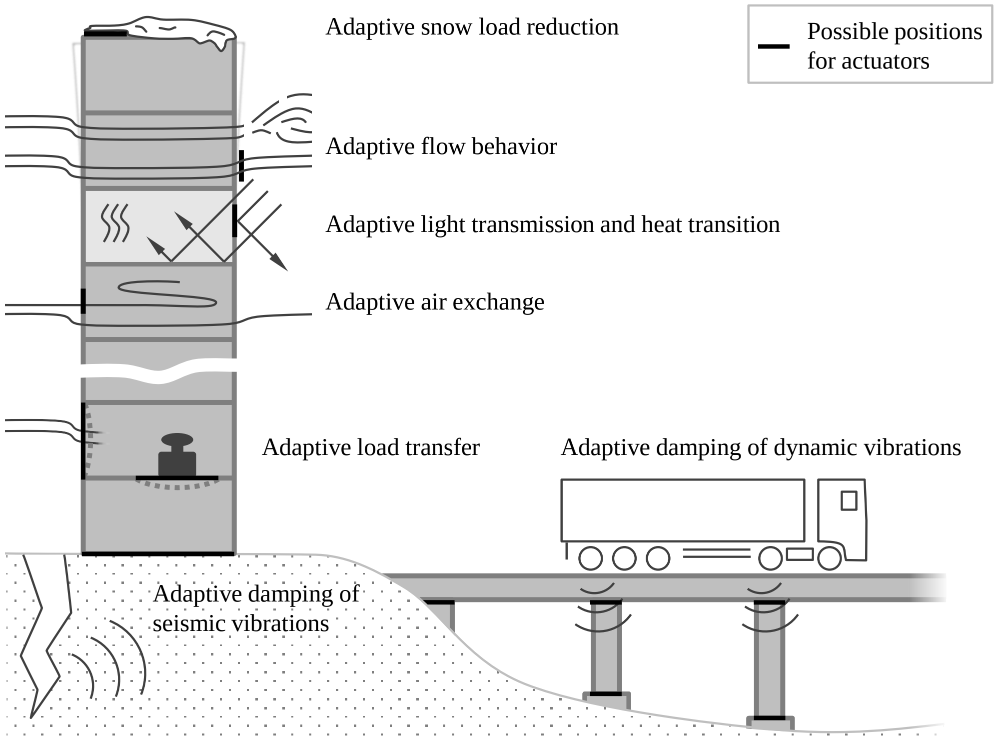


Figure 1. Possible positions of sensor-actuator systems in adaptive structures and building envelopes

The aforementioned complexity, interdisciplinary interfaces and issues – in addition to the described consideration of the whole life cycle – are aspects requiring a new or further developed planning process specifically conceived for Adaptive Buildings. Thus the required process is not an additional generic process in the collection of different existing procedure models, but is as specialized as possible for its target application. The overarching goal of the investigation is to research a planning process that supports the technical feasibility of the planning of Adaptive Buildings with the smallest possible adjustments to different use cases, such as different construction products or company-specific boundary conditions.

In summary, the adaptiveness of buildings presents several challenges, which can each be assigned to different disciplines. They are either already part of the planning procedure for buildings, such as architects or specialist planners, or will become part of it. But which basic technical tasks and related participants are these integral parts of the planning in general? This represents the main research question of this paper. The focus of this contribution is placed on the early stages due to its particular importance, as demonstrated in later sections.

In order to answer the stated research question, the goal of this paper is to analyze current planning processes, existing adaptive elements and to derive the basic technical tasks of the planning process and the participants of the planning team of Adaptive Buildings, taking into consideration the life cycle of these buildings. The results in form of a summary of technical planning tasks must be interpreted as an important basis for the further process development, for example to identify interdisciplinary interfaces and to solve technical challenges of Adaptive Buildings.

3 METHOD AND STRUCTURE

In order to structure this paper, the Design Research Methodology (DRM) according to Blessing and Chakrabarti (2009) is used. This methodology includes four major steps. Three of these four steps form part of this paper. The first step of the DRM, the "Research Clarification", addresses the clarification of the research aims. Within this paper, these are described in Sections 1 and 2. In the subsequent "Descriptive Study I", the state of the field is analyzed. The related results are summarized in Section 4 with the description of the current planning procedure of architects and civil engineers as a basis for the envisaged investigation. In order to enable a holistic view of the approach of Adaptive Buildings, the life cycle of buildings is presented in addition. The third step of the DRM is called the "Prescriptive Study". Here, the results of the research are developed. In this context, Section 5 contains the

presentation and analysis of four selected adaptive elements to derive the associated fields of planning tasks. As these tasks only refer to the development of elements and not of a whole building, they complement the existing tasks of the common building planning. The summary of these results, including existing, extended or new planning tasks, is listed in Section 6. In addition to that, a composition of possible participants of the planning team of Adaptive Buildings is shown. In order to verify the results of this paper, the content was presented to other researchers in the Collaborative Research Center and thereby analyzed in expert interviews. This step can be viewed as an important support evaluation to build upon the presented results of this paper in subsequent research steps.
The fourth and final step of the DRM is called "Descriptive Study II". In this step, the results are evaluated in order to comply with scientific requirements. However, the evaluation of the investigation in this paper has to be analyzed during the whole process development or during its application in particular, and will follow in future research steps. Thus, it does not form part of this paper. The paper concludes with a discussion of the results (Section 7), a conclusion with a brief summary and an outlook (Section 8). Figure 2 summarizes the content of this paper and assigns the related results to sub-areas of the development of the holistic planning process. However, these sub-areas have not yet been completely identified.

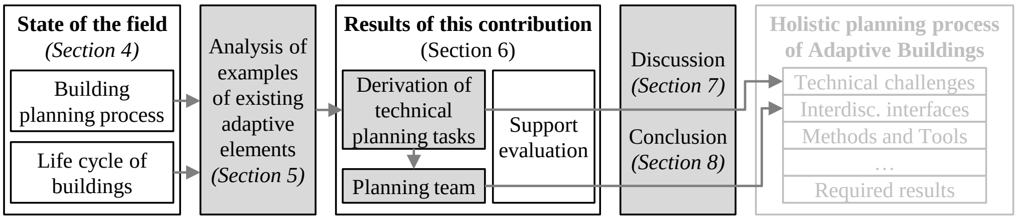


Figure 2. Content of the paper and its part in the process development

4 STATE OF THE FIELD

In this section, the state of the field is analyzed and described. These results form the basis for the subsequent investigations in this paper. The section is divided into two parts. Firstly, common processes and approaches are presented briefly in order to give an overview of the current situation of the building planning procedure – including the participants. In the second part, stages of the general building life cycle are summarized as a basis for the analysis of adaptive elements in a holistic view.

4.1 Procedure and approaches of the building planning process

In many countries, the procedure during the building planning process conducted by architects and engineers is related to an official scale of fees. For example, in Germany and China, the stated fees are compulsory (HOAI, 2013; Abele, 2010). However, in several countries such as the United States of America or the United Kingdom, the fees are not prescribed (AIA, 2007; Kulick, 2010). As the required holistic planning process is developed in Germany, the planning environment is further analyzed from the local perspective. The need for adjustments to different conditions has to be proven at an appropriate time during the development of the planning process for Adaptive Buildings.
The German Official Scale of Fees for Services by Architects and Engineers (HOAI, 2013) covers the entire period of time between the start of planning and the realization of the building. It is divided into nine service phases, which are visualized in Figure 3. In general, the service phases provide a sequential procedure that is generally comparable with the step-by-step development in the field of Mechanical Engineering or Product Development according to the VDI 2221 (1987) or Pahl et al. (2007) until the fifth service phase called "execution planning" (Honold et al., 2016). In industrial engineering, a task comparable to the fourth service phase in building, which is called "approval planning", does not exist. Moreover, the period during the production or realization also does not form part of the product development process (VDI 2221, 1987; Pahl et al., 2007). Apart from that, the building planning process starts with the identification of the needs and the requirements in the early phases and progresses with the development of various concepts and drafts.
The described services of the analyzed scale of fees include tasks concerning the architectural planning and design, in addition to the services of specialist planners, for example according to the support structure or the building technology, such as aspects of the supply technology. However, all descriptions are related to performances without naming the responsible discipline (HOAI, 2013).

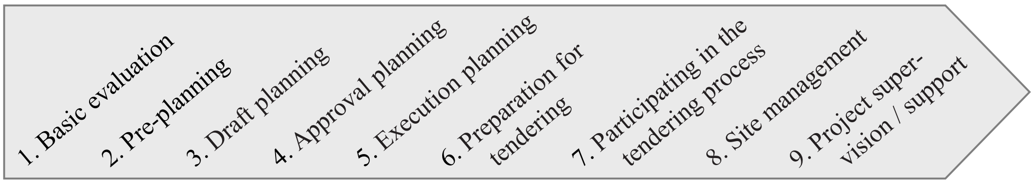


Figure 3. Service phases of the Official Scale of Fees for Services by Architects and Engineers in Germany (compare with HOAI § 43, 2013)

Bergmann (2013) analyzes the current planning process in detail, describes the need for action, suggests improvements and presents the participants in the planning process. It is explained that the current procedure is no longer suitable for complex and sustainable building tasks due to the development of the construction industry. Further approaches to the cooperation of the disciplines involved are suggested. Important reasons are missing precise definitions of responsibilities, insufficient consideration of multidisciplinary work, missing proposals of methods to apply, the lack of concentration on early phases and the fact that the life cycle analysis of the building to be planned must be assigned as an additional service. For example, the internationally familiar "construction team" approach aims to achieve closer networking between architects and craftsmen in order to save time and costs (Bergmann, 2013).

"Integrated Project Delivery" (IPD) is another example of a planning process and was presented by the American Institute of Architects (AIA, 2007). Contained therein, the early phases are rated as being more important and contractors, suppliers and facility managers are involved in the planning procedure in addition to the end users. IPD focuses on the early phases because the ability to influence cost and functional capabilities is much higher and the costs of related design changes are considerably lower (AIA, 2007; Bergmann, 2013).

Furthermore, "Building Information Modelling" (BIM) is a component of the Integrated Project Delivery approach. This tool delivers a "digital representation of physical and functional characteristics of a facility" (AIA, 2007) and offers increasing fields of application. During different stages of the respective life cycle of the building – and particularly while planning – planners and other stakeholders are able to share the contained information. BIM therefore supports cooperative and interdisciplinary development through the exchange of current information. (AIA, 2007)

In addition to the aforementioned architects, civil engineers and specialist planners, typical participants of these current planning procedures are generally constructors, foremen and craftsmen, major suppliers, utilities, quality assurance managers, financial institutions, lawyers, insurers, regulators, public services and – of course – the owners (Forbes and Ahmed, 2011). However, not all of them are involved in technical issues. Furthermore, the number of participants is unequal between different projects. That means, for example, that the composition of the planning team is influenced depending on the size of the planning task or the building type.

Although the planning approaches mentioned before address a common and interdisciplinary planning procedure to solve complex planning tasks, they are not suitable for developing Adaptive Buildings. The reasons are based on the fact that the approach of the adaptiveness and the related interdisciplinary participants do not form part of these. The conclusion of these results was already the requirement for a new or further developed planning process (compare with Honold, 2016).

4.2 Life cycle of buildings

This subsection presents an overview of the phases of the life cycle of buildings in accordance with the specifications of European standard DIN EN 15804 "Sustainability of construction works" (2012). This standard describes core rules for the product category of construction products. For the focus of this paper, the description of the life cycle stages of buildings contained therein is relevant and shown in Figure 4. Several associated aspects are assigned to each stage. In this context, the life cycle begins with production, including the raw material supply or the manufacture of construction components, for example, and ends with the deconstruction work, including disposal. In addition to Figure 4, issues of reuse and recycling are included in the standard DIN EN 15804 (2012).

The building planning process is situated between the occurrence of the need for a building and the second visualized stage of construction process. The overview of the stages and aspects provides a basis for analyzing adaptive elements in Section 5 and 6 with the goal of deriving planning tasks that have to be considered during the planning of Adaptive Buildings.

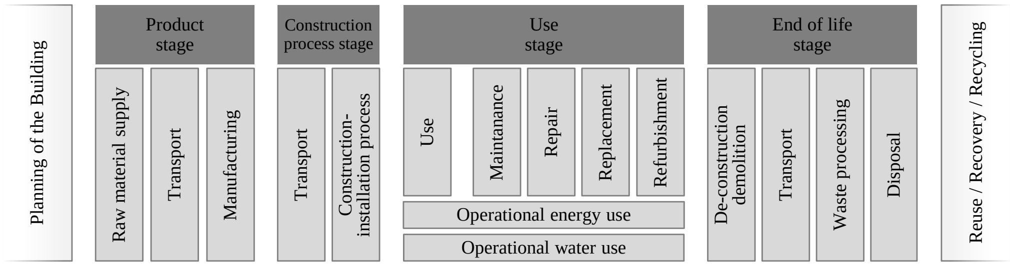


Figure 4. Life cycle stages of buildings (following DIN EN 15804, 2012)

5 ANALYSIS OF ADAPTIVE ELEMENTS AND DERIVATION OF PLANNING FIELDS

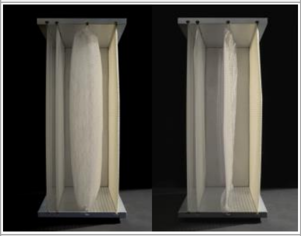
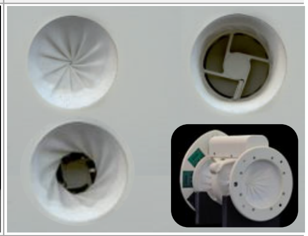
As previously mentioned, the planning of Adaptive Buildings requires additional development and planning tasks compared with the services of the participants currently involved in the building planning process. In order to identify these tasks, several adaptive elements which have already been researched and tested successfully are presented and analyzed in this section. In a first step, the fields of the required technical planning tasks are derived thereby. On this basis, the related tasks are summarized in the following section in consideration of the existing tasks of the common building planning process. Care was taken during the selection of the exemplary elements in order to consider adaptive elements for use in adaptive structures as well as in adaptive building envelopes or façades. In addition to this, each selected element was developed by a research institute which is part of the Collaborative Research Center. This fact is considered advantageous, so it was possible to assess the results of this paper with the support of experts in this field.

The first analyzed example, the Stuttgart SmartShell, is an adaptive structure. The second example, an adaptive glass façade element, is actually part of the building envelope, but the approach concerns an optimized load transfer. Consequently the glass façade element is also an example of an adaptive structure. The third and fourth adaptive element are examples for adaptive façades or envelopes. The latter allow adaptive heat transition or adaptive air exchange in closed façades. Each example is described in Table 1 more detailed. All four examples are concrete implementations of the possibilities by means of actuators in buildings shown in Figure 1.

For each analyzed adaptive element, the initial potential for improvement is mentioned as a problem description in Table 1. Afterwards, the approach of the respective optimization is explained briefly. In the last row, the aforementioned fields of technical planning tasks derived from the analysis of the scientific description of the development and testing of each example are listed. However, these fields are limited to technical aspects, as the associated tasks are important for developing the holistic planning process first of all. Planning goals which concern economic, legal or temporal aspects are already part of planning processes (compare with typical participants in Section 4.1) and have to be analyzed differently. As already mentioned, the focus of the research on the holistic planning process for Adaptive Buildings is placed on the basic feasibility and technical challenges in particular.

The derived planning fields are sorted in order to gain an opportunity to compare the results of all elements. Several tasks appear recurrently in some or all analyzed adaptive elements (compare with continuous indices). This concerns the drafts of the architecture that provides the holistic design of the building and of the adaptive element in the structure or the appealing integration of components. Moreover, tasks of the specialist planning, such as related to the load transfer or the building physics, were identified and have to be considered. Each sensor-actuator system requires specialized development with several actuators and measurement and control technology with related implementations in the building. In some cases, special high-performance materials are used and accordingly they need specialist experience for the selection. However, each analyzed adaptive element requires high reliability in order to ensure a very high safeguard against failure. Furthermore, the additional technical functions of the building necessitate the development of maintenance and repair concepts. It should be noted at this point that the approach of Adaptive Buildings provides permanent structural stability. However, the lifetime of the building will decrease in the event that the sensor-actuator systems fail. Whereas the control technology has to be developed and adapted for each individual building in future, the planning of Adaptive Buildings could resort to a design catalog of existing actuators in the case of general applications. Additional research investigations must be performed before an assured statement can be made referring to the extent to which designers have to develop actuators for each application individually or independently.

Table 1. Analysis of adaptive elements in order to derive fields of technical planning tasks

Adaptive structure Stuttgart SmartShell	**Adaptive glass façade element**	**Adaptive heat transition**	**Adaptive air exchange in closed façades**
			
(Neuhäuser, 2014)	(Flaig et al., 2015)	(Haase et al., 2011a)	(Knubben, 2014; Haase et al., 2011b)
Problem: External loads caused by wind, snow, payloads or seismic waves lead to rarely occurring peak stresses but require material-intensive dimensioning	Problem: Not homogenous and thus inefficient stress distribution in ropes of glass façades in addition to oscillations and strong deformations during wind loads	Problem: Different requirements to the heat transition of buildings during the course of a day or year, e.g. use of cold nights to cool down during hot summer days	Problem: Increasingly airtight indoor spaces lead to high air humidity and manual ventilation of rooms is inefficient or requires continuous discipline
Approach: Homogenization of stress peaks and oscillations in the shell structure by actuating three of four bearings with hydraulic actuators	Approach: Scissor actua-tors as struts tense up a double cable façade system to control the deformation and reduce oscillations and required cable diameters	Approach: A modular façade element with a compressible insulating layer achieves an energetic favorable and controllable heat transition between inside and outside	Approach: Decentralized and completely closing ventilation elements provide a fully automated air exchange as needed without huge central ventilation systems
Fields of technical planning tasks:			
• Architecture[1] (Ar)	• Architecture[1] (Ar)	• Architecture/design[1](Ar)	• Architecture/design[1](Ar)
• Form-finding of support structure[2] (SS) • Load transfer/statics[3](SS)	• Form-finding of support structure[2] (SS) • Load transfer/statics[3](SS)	• Ventilating and air-conditioning systems[10] (SP, BT)	• Ventilating and air-conditioning systems[10] (SP, BT)
• Bearing concept of support structure[4] (SS)	• Bearing concept of glass elements and cables[4](SS)	• Component integration[11] (Ar, SS)	• Component integration[11] (Ar, SS)
• Building material technology[5] (SP)	• Building material technology[5] (SP)	• Insulation material technology[5] (SP)	• Textile material technology[5] (SP)
• Hydraulic actuators and hydraulic system[6] (AT) • Measurement and control technology[7] (SD) • Reliability[8] (SP, AT, SD)	• Scissor actuators and pneumatic system[6] (AT) • Measurement and control technology[7] (SD) • Reliability[8] (SP, AT, SD)	• Actuator technology[6] (AT) • Measurement and control technology[7] (SD) • Reliability[8] (SP, AT, SD)	• Actuator technology[6] (AT) • Measurement and control technology[7] (SD) • Reliability[8] (SP, AT, SD)
• Maintenance[9] (FM)	• Maintenance[9] (FM)	• Maintenance[9] (FM)	• Maintenance[9] (FM)

Legend: Architecture, Actuator Technology, Building Technology, Facility Management, Specialist Planning (different), Support Structure, System Dynamic

The results outlined in Table 1 were presented to the architects, civil and mechanical engineers participating in the Adaptive Buildings research project. They were asked to assess the derived fields in order to complete them. The overview of Table 1 already includes the proposals and further additions as feedback for this preliminary validation. In a further step, several required specialist disciplines were assigned to the identified fields (see abbreviation in brackets). These links are based on the consideration of the experience of each discipline and on the related fields. The correlations exist in order to derive the planning team members required for Adaptive Buildings in Section 6.2.

6 SUMMARY OF TECHNICAL PLANNING TASKS AND COMPOSITION OF THE PLANNING TEAM FOR ADAPTIVE BUILDINGS

In Section 5, several adaptive elements were analyzed in order to derive additional fields of planning tasks during the planning of Adaptive Buildings. As the derived fields do not represent concrete tasks of planning whole buildings, the first subsection summarizes new technical planning tasks based on the existing tasks of the common building planning process. In order to gain an initial overview of the required disciplines, the second subsection presents one potential composition for a planning team which should perform the technical planning tasks.

6.1 Specific tasks of the holistic planning process

To get an overview of all significant technical tasks within the holistic planning process to be developed, the previous results of the analysis of the state of the field and the analysis in Section 5 must be complemented. A list thereby emerges which describes the specific tasks of the planning process for Adaptive Buildings. The result is shown in Table 2. Regarding the extent of all tasks, only the topics are referred to – with additional examples of subordinate issues. However, the resulting overview answers the stated question concerning the technical planning tasks.

Table 2. Summary of existing, extended or new technical planning tasks

	Which technical planning tasks have to be part of the holistic planning process of Adaptive Buildings?	Required disciplines	Correlation with adapt. elements
Examples of existing or extended planning tasks	Design of architecture, for example including appearance, floor plan, function chart, comfort, …	(Ar)	1, 5, 11
	Involvement of (still) applicable legal requirements and standards, for example aspects of the building permit like stability, fire protection, …	(Ar, BT, SP, SS)	1, 3, 5, 10, 11
	Structure planning (e.g. form finding and load transfer) and development of the building envelope	(Ar, SP, SS)	1, 2, 3, 4, 5, 11
	Planning of supply technology and building services	(Ar, BT, SP)	1, 10, 11
	Analysis of resource requirements and sustainability based on the results of a life cycle analysis, for example demand for building materials, lightweight design, energy consumption, emissions, recyclability, …	(Ar, AT, BT, SD, SP, SS)	1, 3, 5, 6, 10
New planning tasks caused by adaptiveness	Integration of sensor-actuator systems in support structures and building envelopes, development of individual operation and regulation concepts, as well as related modelling and simulations	(Ar, AT, BT, SD, SP, SS)	1, 2, 3, 4, 6, 7, 8, 9, 10, 11
	Consideration of building physics requirements, for example indoor climate, sound propagation or comfort, which will be changed by adaptiveness	(Ar, BT, SP)	1, 3, 5, 10, 11
	Ensuring safety and quality, for example fail-safe performance, longevity, as well as reliability of components, construction elements and systems	(AT, FM, SD, SP, SS)	3, 6, 7, 8, 9, 10, 11
	Development of a utilization and maintenance concept for adaptive operation, for example human-building interface, maintenance plan and intervals, replacement, …	(AT, BT, FM, SD, SP)	6, 7, 8, 9, 10

Legend: Architecture, Actuator Technology, Building Technology, Facility Management, Specialist Planning (different), Support Structure, System Dynamic

The first five tasks are based on existing planning procedures according to HOAI (2013), Bergmann (2013) and AIA (2007). The remaining tasks are new technical planning tasks according to the novel adaptiveness of the building. With regard to the analysis of existing planning procedures and the links between disciplines and the derived fields of partly new planning tasks in Table 1, required disciplines were assigned to each topic in Table 2. In addition to that, several correlations between the topics and the derived fields of planning tasks of the presented adaptive elements are stated in the last column of the table. The listed numbers conform to the indices of Table 1. These correlations result in the complementation of the tasks and demonstrate how the topics are related with the adaptiveness. In future work, each topic must be analyzed in detail in order to ascertain the completeness of subordinated tasks to the greatest extent. As a result of the adaptiveness, extensions or adjustments to the existing planning steps are either expected or already identified.

The composition of the topics was also presented to the aforementioned experts of the research project. The completeness was thereby confirmed as an overview of the relevant tasks needed to develop a complete Adaptive Building, considering the current research stage. It was underlined that the tasks listed are particularly important in the early stages of planning – during the identification and definition of the requirements for an individual building. The experts stated that the early determination of the adaptive elements to be considered would be absolutely necessary, as the modification effort would increase immensely in the event of change requests during the advanced planning stages. Therefore the topics serve as a checklist to consider different planning tasks early and completely.

6.2 Competition of planning team members

In order to establish a further basis for the planning process, an overview of the required specialists is also needed to introduce a possible planning environment. A distinction must be made while undertaking this investigation. Some of the involved research projects at the Collaborative Research Center supply studies, which for example deal with the development of specialized tools, and will probably be completed after a fixed period. The related disciplines will not become part of the planning team, but their concluded results will form part of the holistic planning process. On the other hand, several planning tasks have to be developed separately for each building. This relates to individual requirements like architectural aspects, the consideration of local boundary conditions and the associated drafts, calculations and simulations, for instance. The responsible architects, civil engineers and additional planners – as well as other stakeholders – have to be members of the planning team. Their tasks conform to the list in Section 6.1. The required disciplines – which are stated in the third column of Table 2 – must submit at least one member to the Adaptive Buildings planning team. One potential composition is visualized in Figure 5, in conformity with the approach of "Integrated Product Development" by Ehrlenspiel and Meerkamm (2013), with the goal of a constant exchange of participants, symbolically represented at a round table. The composition includes architects, planners of the support structure and specialists in the respective building technology as the most important specialists for existing planning procedures according to the German Official Scale of Fees in early planning phases. Specialists in the field of Actuation, comprising system dynamics and actuators for example, are also supplemented. In order to consider all phases of the life cycle, representatives from the facility management are also added. As a result of the positive experience of the "construction team", the customer or the owner also participates.

In the field of Mechanical Engineering, representatives from the production sector of the company or suppliers would form part of the team. However, discussions with the experts from the fields of Architecture and Civil Engineering have shown that contractors are not allowed to participate in early stages of the German planning procedure if appropriate tendering is required. This fact is explained by the aim of fair competition. A review must be conducted as to how far this legal requirement represents a restriction within the boundary conditions of the planning of Adaptive Buildings. Based on these assumptions, the composition must be viewed as an initial proposal for achieving advanced results and making adjustments with increasing experience in the next research steps.

Figure 5. Members of the interdisciplinary Adaptive Buildings planning team

7 DISCUSSION

As indicated in Figure 2, the identified planning tasks and the preliminary composition of the planning team are required results of the superordinate investigations for developing a holistic process in support of the planning of Adaptive Buildings. However, the research question on the tasks could not be answered by literature research due to the fact that research on the complex approach of adaptiveness in buildings is still in early stages. Existing adaptive elements are thus seen as suitable for deriving related planning tasks that have to be considered during the planning phase. The opportunity for exchange with experts has been utilized to ensure the validity of the described results. These experts are involved in the specified research project and experienced in developing adaptive structures and façade elements. In total, eleven researchers were involved in the results of Section 6.

With due consideration to existing planning procedures the goal is to persuade the current architects and planners not to have to adjust their procedures more than strictly necessary. The analyzed constituent planning tasks are set as a basis and will have to be adapted during further developments.

8 CONCLUSION AND OUTLOOK

This paper presents the analysis of several adaptive elements for application in buildings in order to derive an overview of basic tasks and related specialists of several disciplines that have to be considered while planning Adaptive Buildings. The results form part of initial research steps in order to develop this holistic planning process. Based on the analysis in this paper, each task can be investigated in detail in future work to determine which results require which methods, tools and other types of methodical support. Further goals are the identification of dependencies between all tasks and related results, as well as the interfaces between the responsible participants in the planning team. The identified technical planning tasks of the planning process for Adaptive Buildings largely comprise current planning tasks, the development and integration of actuators and control technologies as well as tasks concerning aspects of a long and fail-safe operation of the sensor-actuator systems.

The completeness of the derived tasks, their detailed specification and the validity of the presented approach of the competition of the planning team members will be ensured during future research work. The technical planning tasks listed and the composition of the planning team thus represent an initial approach for further investigations. An additional and – in particular – more detailed evaluation will be presented in a further scientific contribution. The evaluation will be conducted while planning and realizing an adaptive multi-story building. The start of the building's planning procedure is envisaged to take place in the coming months. The development of the holistic planning process will be continued at the same time.

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