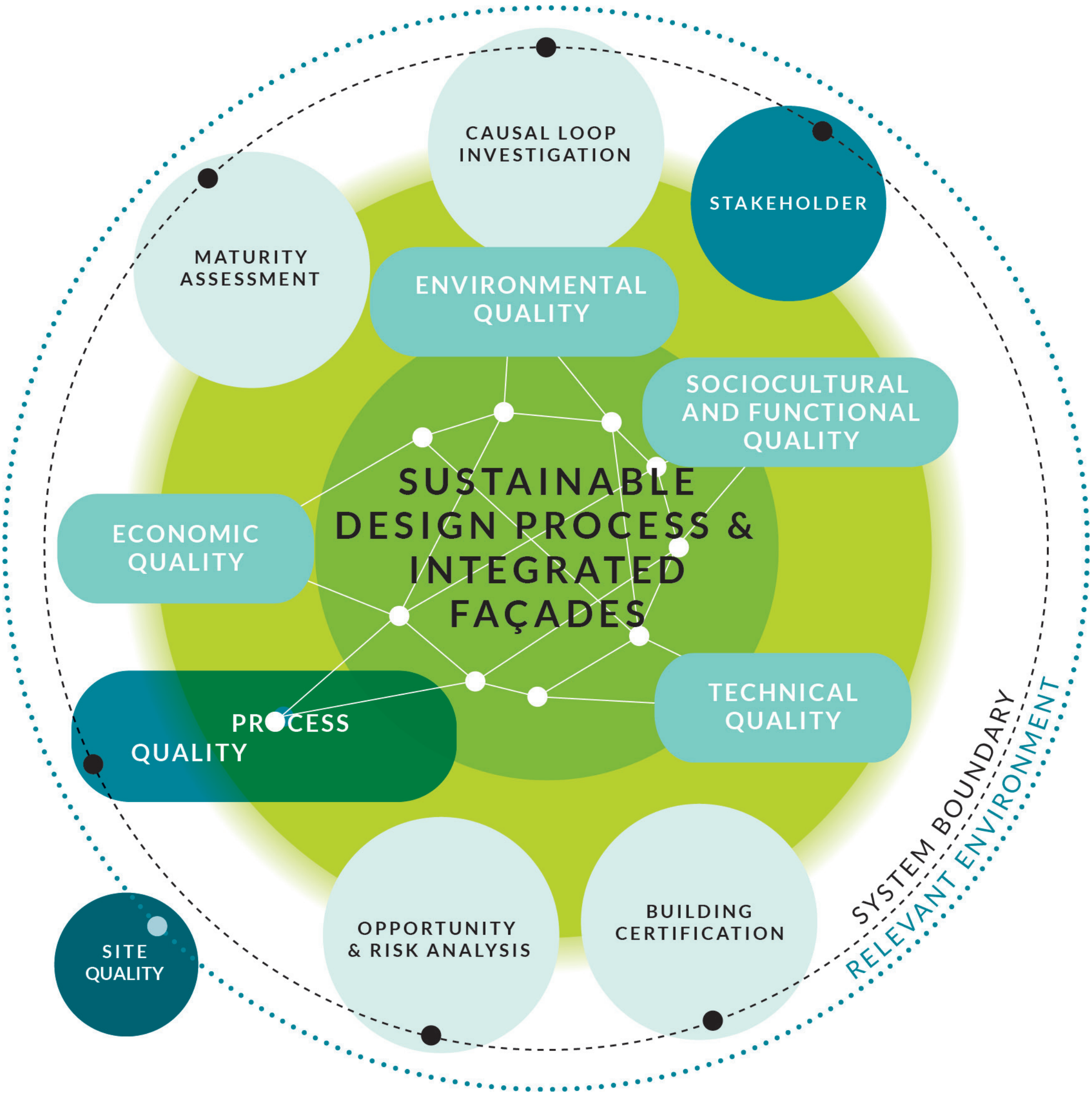

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SUSTAINABLE DESIGN PROCESS & INTEGRATED FAÇADES

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CONTENT

INTRODUCTION

Sustainable construction and the associated aspiration to consider construction activities in a holistic way (environmental, economic and socio-cultural sustainability) is rapidly developing into a mega trend.

The research project UNAB offered the possibility to bundle the technological production and environmental competences available in Styria and to develop a new Styrian regional strength in the resource and energy-intensive construction sector. The implementation took place within the scope of an inter-faculty and interdisciplinary collaboration in the TU Graz together with industrial project partners in two parallel and complementary research approaches.

The interaction between the two research approaches was designed to produce results that offer building contractors, planners and project managers a basis upon which the holistic view of multi-factorial requirements in the planning project phase can be structured and traceably processed.

The first approach targets the systemic perspective of sustainability requirements in the planning and project management process. The current practice in planning is the consideration of sustainability aspects mainly via a focus on individual object qualities such as improvement of energy efficiency, or the reduction of environmental impacts and life cycle costs. However, the European evaluation concept for the rating of building sustainability stipulates the consideration of a wide spectrum of environmental, economic and social, as well as technical and functional building characteristics, preferably early in the construction project's planning phase. Suitable instruments are therefore required that enable the operationalization of sustainability requirements and permit an early assessment of the predicted sustainability characteristics a building will achieve. Knowledge of the systemic interdependencies of critical sustainability requirements depending on the stakeholder's preferred goals will permit the planning and control of real estate characteristics from a holistic point of view.

The second approach targets the constructive implementation in the building envelope. The main focus is on the materials that unite diverse cross-section designs, easy dismantling (assuming appropriate joining technology) and durability (with correct choice of materials) with maximum recyclability. The design of the façade as a self-supporting, highly efficient load-bearing structure with new methods of forming and joining technology from the mechanical engineering sector, together with the integration of building systems into the building envelope, present a range of challenges regarding the constructive, static, physical and system aspects of design. These can only be solved via very close interdisciplinary collaboration between the participating expert areas. So-called “integral façades” influence a number of social and functional, technical, economic and environmental criteria regarding the sustainability rating of a building and are thus eminently suitable to make major improvements to the sustainability of a building. This book describes the progressive implementation of the integrated design and assessment approach within the framework of the research project UNAB.

Editors,

December 2018

01

REQUIREMENTS PROFILE FOR SUSTAINABLE FAÇADES

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Contemporary planning practice often only considers aspects of sustainability at very late stages of planning and sometimes also to an insufficient degree. The increasing pressures of time and cost occurring simultaneously with growing complexity, for example the building envelope assuming additional functions, are placing continuously challenging demands on planning and project controlling. The current situation is exacerbated by a (continuing) lack of planning instruments that would make the management of these planning tasks possible at all.

Therefore, methods are necessary that on the one hand permit a holistic and systemic approach for the consideration of currently valid limitations of scope in the defined requirements in early planning phases, and on the other, simultaneously identify suitable areas of improvement to optimise the planning process.

Comprehensive knowledge and consideration of the appropriate and current laws, regulations, guidelines and policies on a European and regional level **[1-41]** are critical in order to be able to develop a suitable requirement profile while considering the holistic sustainability aspects for the façade building component, based on the currently relevant strategies and intentions. Closer inspection of the European construction product directive shows that the requirements listed in the directive are directed less towards the products themselves than towards the building. The quantification of the systemic effects of a construction product or a building construct for the fulfilment of multi-criteria requirements is therefore of critical importance for a sustainable building.

The currently required performance declaration replacing the previous conformity declaration regarding the declaration of a manufacturer's construction product **[42,43]** results in planners being fully responsible for the selection of construction products **[44,45]**. This means that both the test for fitness for use (fulfilment of the CE declaration of performance for the corresponding application of the construction product) and for usefulness (suitability of the construction product for the corresponding application) lies within the domain of the planner.

As a consequence, the planning of sustainable façades must involve the analysis of the valid conditions for planning, tendering and awarding regarding the (legal) implementation possibilities of sustainability aspects for the specific case.

With regard to quality assurance of the implemented sustainability measures, suitable instruments are required that enable the comparison and evaluation of different planning alternatives to guarantee specific sustainability targets, not least because of the possible interaction of criteria.

Over the past three decades, a variety of very different building certification systems that evaluate the sustainability of buildings have established themselves on the European and national markets. However, the allocation and/or weighting of their sustainability aspects is done in very different ways.

The implementation of a building, and as a consequence the construction of its façade in accordance with valid national or regional constructional and technical requirements based on the goals of the decision maker, requires appropriate processes for development, planning, tendering, awarding and building. Process management is overed within the workscope of the project management. The entire construction sector is facing a paradigm shift due to the current additional and wide-ranging framework, in addition to legal and technical requirements, for planning, construction and operation of sustainable buildings.

In order to implement the additional requirements for sustainable buildings named above therefore requires adapted (sustainability) processes in addition to the current and necessary processes for the implementation of a building, even if this explicit evaluation of process quality is not (yet) a part of the CEN/TC 350 standard[1].

The current requirement for a holistic and systemic perspective and the associated interactions among sustainability aspects makes it difficult for planners and project controllers to choose the correct strategy that considers sustainability aspects, above all in early project stages.

The evaluation of holistic, life-cycle oriented effort in planning alternatives and the monitoring of the main processes to ensure achievement of specific goals is complex and not implementable due to the limited budgets and time resources found in practice in conventional planning and project controlling processes.

HOLISTIC EVALUATION OF BUILDINGS

Whereas the focus within the scope of the "Green Building Challenge" (GBC) was on aspects of environmental sustainability, the focus today is on so-called "Blue Buildings" that comprehensively describe the sustainability of buildings. The method of building certification **[1]** is basically aimed at an improvement of the system "building-user-environment" by considering selected sustainability aspects. Over the past few decades, there have been numerous activities aimed at developing building certification systems **[45]**. The "oldest" existing certification system is BREEAM[2] in the United Kingdom, upon which the certification systems LEED[3] (USA), HQE[4] (France) CASBEE[5] (Japan) and Green Star[6] (Australia) are based. The scope of evaluation is being successively extended towards a holistic perspective.

The European concept for the evaluation of the sustainability of buildings **[7–9]**, **[37,38,40]** considers both the "classic" three columns of sustainability (environmental, economic and social), and the technical and functional qualities of the building. So-called certification systems belonging to the "second generation" for example are the DGNB[7] (abbreviation for German Sustainable Building Council) building certification system. Austria currently has three national building certification systems available: The ÖGNI[8] certification system (abbreviation for Austrian Sustainable Building Council), klima:aktiv[9] and the ÖGNB[10] (abbreviation for Austrian Sustainable Building Council) certification systems.

Contemporary literature **[46]** even attempts to first prove how a corresponding certification increases the market value of a building. It can also be often observed that a consumer's purchase decision is influenced by diverse "tests", certification associated with classifications (e.g. energy class, fuel consumption l/km etc). The impression **[47]** is that the market expectation for certification results for a complex purchase object "building" is higher than the fundamental evaluation method **[48]** and its supportive scientific theory can guarantee.

A holistic set of criteria (a criteria set is understood to be the sum of the individual criteria, that describe the building characteristic) that represents all functionality and technical requirements together with market needs and wishes could reduce the gap between market expectation and method performance.

In order to take the functional requirements into account and enable a meaningful comparison between different buildings, the evaluation is performed in so-called "schemes" (e.g. existing use-profiles for office and industrial buildings, educational buildings, healthcare and laboratory buildings, etc).

A comparison of the evaluation results from different building evaluation systems is associated with a comparatively high amount of effort due to diverging goals and different weighting of their evaluation categories. Therefore the trend in research is also towards the development of a unified, European certification system. Individual supporting organisations of the above-mentioned evaluation systems are beginning to evaluate entire districts in order to be able to improve the consideration of building user interaction and also the interaction with the environment. For example, the DGNB scheme "urban district" is available in Germany and certification according to the "2000 Watt Area Evaluation System" is possible in Switzerland.

A considerable advantage of building certification lies in the quantification of sustainability aspects based on previously defined targets. In order to fulfil the target preferences of the decision maker as well as possible, it would make sense to implement these certification systems, preferably in the early planning process. To achieve this, various evaluation systems have the possibility of so-called "pre-assessments".

1. THE ÖGNI/DGNB BUILDING ASSESSMENT SYSTEM

The German Sustainable Building Council (DGNB) has developed a certification system in cooperation with the former german federal ministry for traffic, construction and urban development[11] that is based on the European evaluation concept CEN/TC 350. The Austrian Sustainable Building Council (ÖGNI) was established in 2009 and has adapted the existing certification system based on a cooperation with the DGNB to the conditions prevailing in Austria (e.g.

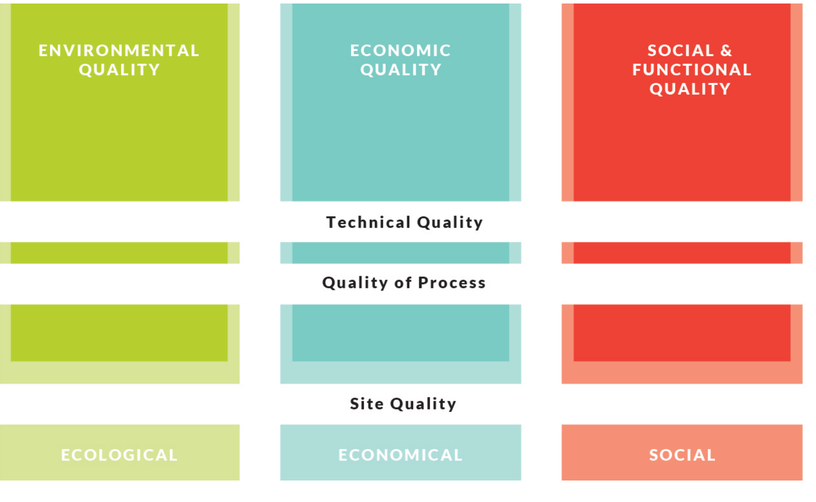

FIGURE 1-1: MAIN CRITERIA GROUPS IN THE ÖGNI/DGNB CERTIFICATION SYSTEM[12]

legal and normative framework, technical regulations, calculation rules, etc)

The ÖGNI/DGNB evaluation system consists of six evaluation categories (so-called main criteria groups) that judge the sustainability of a building in different weightings (see **FIGURE 1-1**). The allocation of the evaluation criteria is done in the individual evaluation categories that are also weighted differently.

The evaluation of the achieved characteristic in a criterion is differentiated in the ÖGNI/DGNB between a limit value, a reference value and a target value. The limit value describes the minimum requirement (e.g. conforming to legal regulations), the reference value describes the individual characteristic for an average existing building and the target value describes the highest certification level (from the perspective of the certification system) for the desired sustainability characteristic of a building. Certain evaluation criteria are defined as knock-out criteria. Non-fulfilment of these criteria results in non-certification.

For example the fulfilment of the following minimum requirements is a prerequisite for the certifiability of new buildings:

- Minimum requirement for indoor air quality must be fulfilled
- Minimum requirement for accessibility characteristic (design for all) must be fulfilled
- All legal requirements for fire safety and sound insulation must be fulfilled

A building can be awarded with a pre-certificate (in the planning phase) or a certificate (for the completed building). The overall degree of fulfilment to achieve a certain award level is linked to the minimum fulfilment requirements for each main criteria group.

This process guarantees that only a balanced consideration of all sustainability categories leads to a sustainable building. In order to be able to take awarding sustainable buildings with just "one-sided" optimisation of one evaluation category into account, the evaluation system provides exactly this threshold value in the form of so-called "minimum degrees of fulfilment".

The measures applied by the decision maker during the optimisation of an evaluation criteria, both from a building and from a process perspective, need to be considered regarding any possible interactions with other main criteria groups to fulfil the previously listed associated requirements early on in the planning process.

The ÖGNI/DGNB certification system, with its structured and transparent layout, enables a wide-ranging evaluation of the sustainability of the completed object. At this point in time, no further changes can be made to the project and only the status quo of the sustainability aspects of the building can be determined. In order to optimise a project in the direction of sustainability, the setting of an early course for target achievement is mandatory. A high rating in the process quality main criteria group is a major criterion in ÖGNI/DGNB for a sustainable building. The evaluation of process quality is done in ÖGNI/DGNB in parallel to the other main criteria groups that describes the object characteristics. However, a detailed and final description of the required processes for each criterion cannot be determined in the certification system. Knowledge of the effects of the most important sustainability processes, depending on the targets, their interaction and influence on the final building quality, is critical to determine whether sustainability aspects are implemented in a building project, or not. It is expedient to embed the evaluation instrument in a holistic optimisation tool, not least because of the time required to carry out such evaluations in early planning stages, the high number of interactions among criteria and mainly insufficient documentation (above all for complex building objects).

2. TOP - DOWN APPROACH

In order to show the relevance of the previously described building certification requirements to the building component "façade", a matrix will be used based on the building certification system ÖGNI/DGNB. Using a "top-down" approach, the criteria used for building certification system will be broken down to the component level. To do this, those criteria that are relevant to façades or those criteria where the façade has an influence on the sustainability evaluation on a building level are identified using the criteria catalogue from the ÖGNI/DGNB building evaluation system. The analysis shows that the building component "façade" influences a total of 28 out of 42 criteria[13]. A rough estimate of the façade's degree of influence (i.e. low/medium/high) on each evaluation criteria was also performed.

The matrix suggests measures and needs based on building level requirements that appear to be fundamentally important from a sustainability perspective early in the development of façades. Additional requirements can be noted extra in the matrix over the course of the development of the constructive approach. Furthermore, it should be identified whether any criteria are already considered in current, conventional façade planning and design phases.

HOLISTIC PLANNING PROCESS

Integral planning requires that all project participants collaborate in an early planning phase. Methods are needed that permit possible trade-offs to be evaluated for simultaneous and inter-disciplinary planning processes that are able to visualise the systemic relationships of sustainability criteria and make a preliminary estimate of their effects on the total sustainability of a building. Associated with this is the need to analyse suitable system analysis methods with the aim of developing a new process and to evaluate suitable software tools to display the cause-effect relationships between sustainability criteria. A situational analysis of the current planning, tendering and awarding conditions can identify possible starting points for the implementation of sustainability aspects in early project phases.

SITUATIONAL ANALYSIS FOR PLANNING AND AWARDING PROCESSES (STATUS QUO)

The construction industry is one of the most resource and energy intensive industries. 50% of the total resources and 40% of energy is consumed by the construction sector in the European Union **[28,49,50,59]**. These numbers clearly show the potential for a "sustainable building" and the possible contribution that can be made to future energy policies. Suitable processes are critical for the implementation of this, and they will need to be supplemented regarding target achievement.

It is therefore necessary to closely observe suitable contractors of large construction projects regarding the effectiveness of sustainability construction implementation. A special role will therefore be given to contracting authorities. The total volume of public contracts within the EU is approximately 2,400 billion €, or approximately 14% of the EU's[14] gross domestic product (GDP). In Austria, the gross domestic product is approximately 18-20%. Conditions are necessary for the sustainable management and operation of this. The European Union has been driving environmentally friendly procurement (Green Public Procurement, GPP) for some time. This also includes a transition to a life-cycle oriented view of construction projects. A critical tool for the implementation of sustainability requirements is provided by the previously described building certification systems (e.g. DGNB, ÖGNI, ÖGNB, etc).

It is useful to view the sequence of a building project in more detail in order to obtain a fundamental analysis of the situation from the

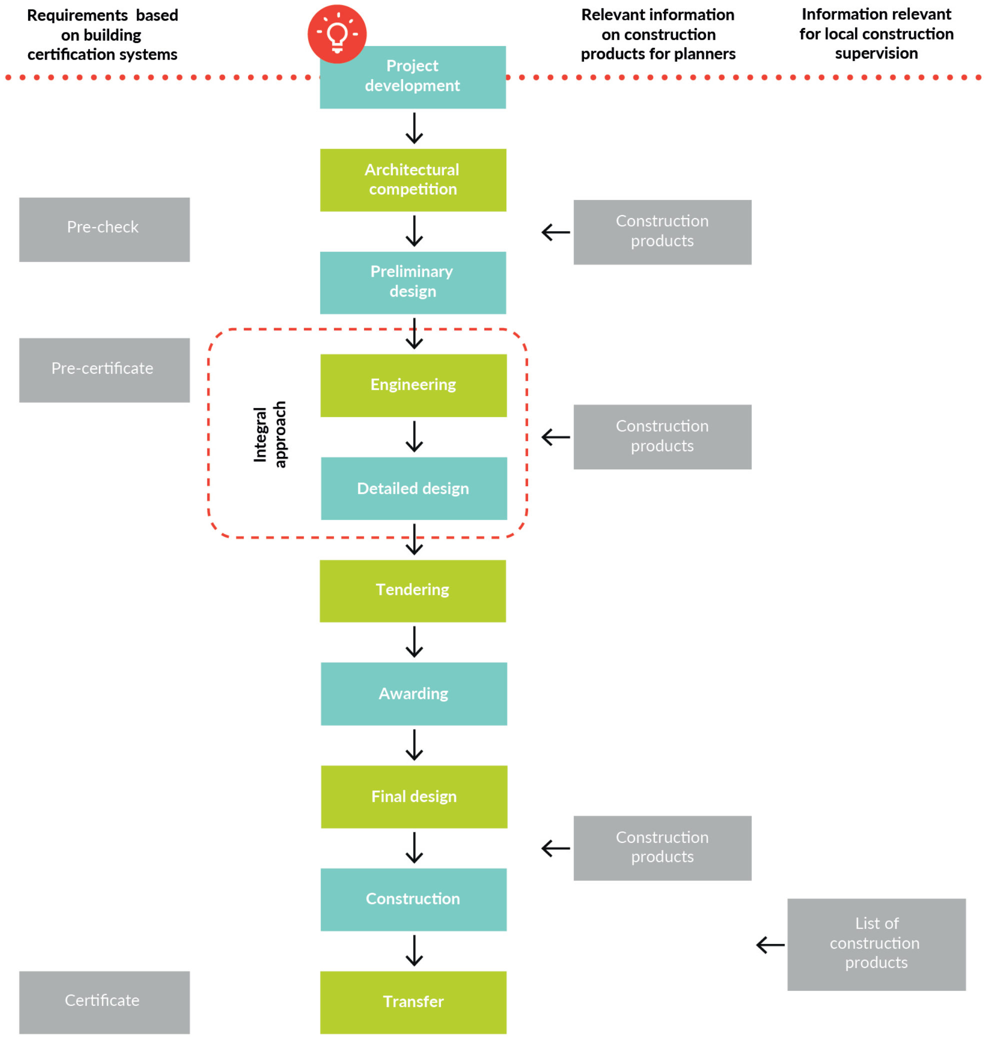

FIGURE 1-2: PROJECT STAGES AND STARTING POINTS FOR THE IMPLEMENTATION OF SUSTAINABILITY ASPECTS[15]

perspective of the planning and awarding process. **FIGURE 1-2** shows the project stages starting with the project development, via the architect competition, tender and award, execution and handover. If the decision is made for a system, then the pre-certificate during object planning represents the sustainability characteristic. This is documented and subsequently made transparent and traceable. Once production is complete, the certificate is awarded and serves as documentation and award for the "sustainable" building performance.

In this context, a major role is played by building products that are selected by the contractor or the planner according to environmentally related criteria. Information regarding the building products in the scope of the project is shown in **FIGURE 1-2**.

A selection of building material takes place, beginning with the architect's drafts. It is therefore an advantage to be informed of the requirements placed on a component and the corresponding material characteristics.

These considerations are subsequently detailed in the planning and specified for the tender. This is an interactive process and requires appropriate coordination so that desired characteristics are clarified and considered in the drafts and in the planning permission.

Doing so requires above all that the framework provided by the Austrian Federal Public Procurement Law **[5]** are observed from a public contractor point of view. The quality assurance and documentation of the products used play a major role, also for the local building inspection, since they are responsible for the monitoring of the construction project execution and handling of the development. This requires that the product characteristics specified in the planning and tender are correspondingly documented and also that indicators are defined that can be used to check implementation and hence provide quality assurance.

With regard to the future implementation of sustainability aspects, the current regulations covering the tender and award process need to be looked at more closely. Corresponding starting points must also be identified to meet the increasing demands of sustainable construction. The focus is on the definition of specific award criteria. These need to be looked at in more detail and possible sustainable criteria need to be defined and evaluated appropriately. Surveys of expert opinion were conducted to help identify these starting points.

The path towards a future "sustainable" quality of a building can be paved based upon the survey of requirements planning and competitive concepts in which the user behavior has been considered. The success and measurability of the desired targets is defined as a critical part by the specifications in the tender and awarding stages. Particular emphasis in this phase needs to be placed on the life-cycle concept to be considered, since an extension in two time horizons occurs due to a life-cycle oriented approach: on construction targets and on the subsequent process targets **[6]**.

Currently these criteria, which are relevant to the tender, are mainly evaluated qualitatively in certification systems using the evaluation criteria. This means that increasing levels of requirement detail increase sustainable performance. There are many starting points regarding this. Beginning with the preliminary note stage, general requirements for health and the environment could be formulated in parallel to technical aspects such as durability or ease of cleaning. An increasing level of target detail increases the number of points awarded and the evaluation of the criteria is visibly better. The maximum requirement when evaluating the criterion is achieved when the individual performance positions are fulfilled according to the corresponding requirements. These could be recommended criteria such as the eco-quality stamp "Blue Angel"[16] or similar. Knock-out criteria, for example, could be specific contents such as certain materials (e.g. tropical timber).

A further focus of project execution is in the area of public contracting and the associated regulations in the federal procurement law. The principles contained therein, in particular concerning free and fair competition with equal treatment for all competitors and suppliers, are decisive for the consideration of sustainability aspects in the tendering and awarding of construction work. The tension between environmental compatibility and the ban on discrimination of individual suppliers poses a challenge for subsequent project execution. The environmental aspects mentioned in the Austrian federal procurement law have to be written into the scope of work. The standardised work description provided by the federal ministry for science, research and economy in the 3rd updated edition from May 2013 **[51]** is relevant for structural engineering work.

This standardised scope of work permits the corresponding standard positions to be implemented with little effort. Sample criteria with particular focus on environmental aspects are partially included. The contractor is obligated to adhere to the product declaration list. The environmental products are collected in the internet platform baubook[17], which provides environmental criteria for product evaluations. This free product database provides detailed information on technology, health and environment regarding the tendering of building products.

Based on the valid regulations covering the awarding of contracts for work, starting points are available in the federal procurement law and also in the ÖNORM A 2050. These make it possible to define environmental characteristics as requirements for buildings regarding sustainable construction. Particular care must be taken when suggesting approaches to develop recommendations for the concrete application of sustainability requirements in subsequent project stages so that they are non-discriminatory and formulated in an appropriate manner, that they enable competition and are not evaluated more than once during the awarding process. To be in line with European sustainability concepts, economic as well as environmental factors should be considered.

Both builders and building users, whether public or private, are increasingly interested not only in the cost of construction but also in running costs (costs for heating, cooling, maintenance and cleaning). In order to obtain comparable numbers, a standardised calculation of life-cycle costs (LCC) is necessary. With respect to the individual economic methods, mainly static procedures are used in early project stages. Dynamic procedures are also mainly found in the evaluation criteria of different certification systems if life cycle cost calculations are to be done.

The LCC perspective is basically a cost accounting method used to evaluate cost flows according to their amount and the point in time they were incurred. Dynamic procedures are also capable of logging incomings thanks to their suitability for long-term observation. Payment flows can be made comparable using discounting with the calculation interest rate. This enables stage-specific identification and analysis of life-cycle costs.

Particularly in early project phases, an important foundation is laid for successful project management. Critical tools here are instruments for the systematic consideration of sustainability aspects, for example in the form of planning competitions.[18]

Regarding future aspirations to integrate sustainability aspects in early project stages, this requires much stronger consideration in architectural competitions. It should be noted that corresponding criteria are already include in the awarding, which can be evaluated later on in the procedure. This requires the appropriate selection of a competition jury with competences that support the procedure. The prerequisite for this is comprehensive requirements planning where the builder thoroughly discusses his needs and the requirements for later use is considered in the form of a room and functional program (e.g. room book). However, this would cost a certain extra effort, which would be necessary to be able to execute a life cycle oriented planning in a needs and user oriented manner.

Life cycle oriented planning requires an increasingly integral approach. It consists of the adaptation of the processes, the finding of a solution in the sense of life cycle orientation, and enabling and supporting energetically optimised, yet still architecturally pleasing designs. Early project stages are given greater importance in this respect, see **FIGURE 1-3**, which shows the ability to influence the total costs.

The focus is on the critical procurement variants (individual contracts up to complete general contractor contracts) and their contribution to a sustainably optimised project execution. The construction industry is characterised by increasing pressure on costs and time, together with growing complexity regarding the requirements placed on a building (e.g. building technologies, etc). This requires stronger networking of the participants, which should take on the form of integrated project management. Current practice in the industry shows that this approach is not always taken. A corresponding skill-spanning optimisation of the building systems via close cooperation of planners, users and several supplier companies is necessary at an early stage. Quality, time, costs, quantities, fault susceptibility and process qualities represent the main and mutually influencing decision variables of the design.

STAKEHOLDER MANAGEMENT

The best possible fulfilment of decision maker targets is critically important for the acceptance of a building and hence for its long-term and sustainable use. The following results of two expert surveys will be presented regarding the target definition for multi-criteria decision problems and the identification between technical and functional goals, and process qualities.

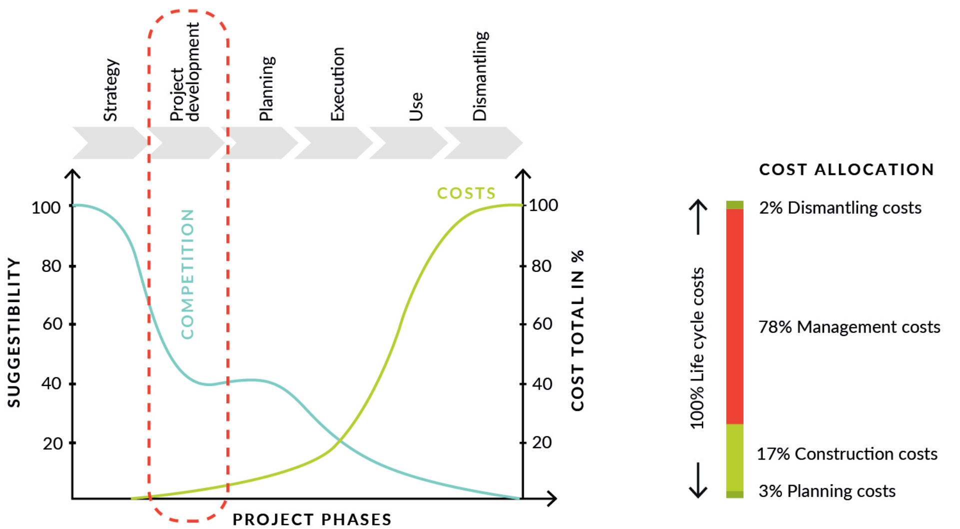

FIGURE 1-3: SUGGESTIBILITY TO INFLUENCE TOTAL COSTS[19]

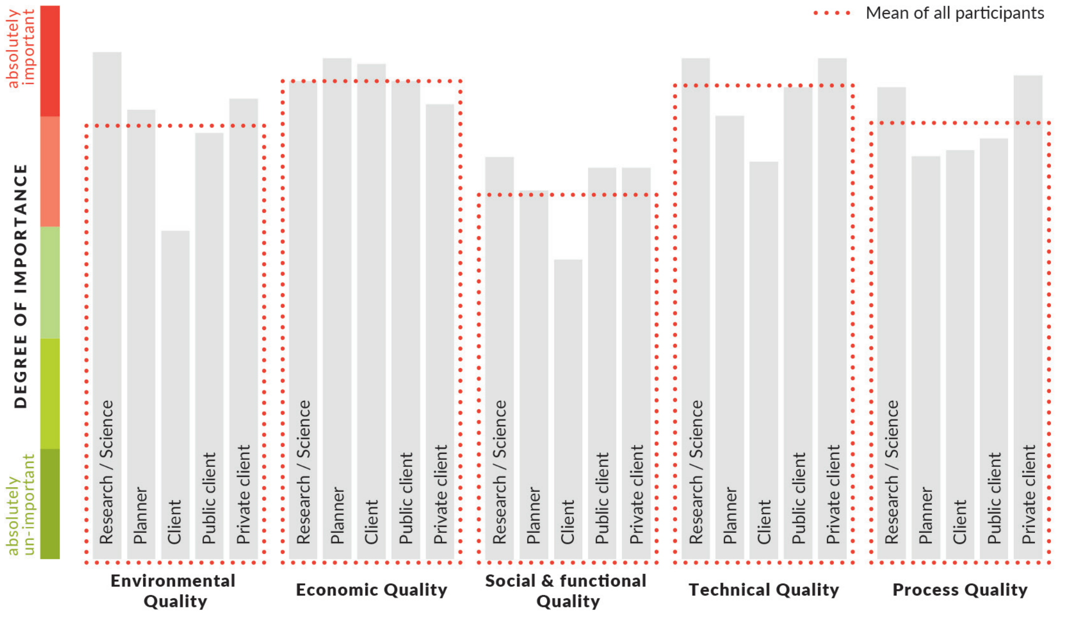

FIGURE 1-4: ASSESSMENT OF THE SUBJECT FIELDS

1. STAKEHOLDER PREFERENCE

The status quo regarding the understanding of sustainability in practice and the target expectations for the optimisation of a sustainable implementation was obtained via empirical data collection from a survey of construction sector experts asking questions concerning the fundamentals of sustainable building planning, sustainable quality assurance together with sustainable tendering and awarding. In order to identify the stakeholder's preferences, a first step was to ask the participants for their views on the individual subject fields.

FIGURE 1-4 shows that the average values for the participants for all subject fields were over 60% and hence estimated as being "rather important". Only the economic aspects and the technical aspect of sustainability were assessed as "absolutely important". A low rating of social and functional aspects is recognisable. By dividing the participant groups up, deviations from the average values become apparent.

Regarding the differences between the different stakeholders, it can be seen from the survey that architects have balanced goals when it comes to environmental, economic, social, functional and technical targets. According to the survey, architects, in contrast to other planning process participants, interpret their role in the planning process such that they consider all five sustainability dimensions equally.

The analysis of the survey results shows that other stakeholder groups display largely different preferences that are generally consistent with the core competences of each professional group and their associated activities within the planning process. The different objectives held by the investigated stakeholder groups are characterised by the group's presumption that the largest potential for optimisation of the selected process quality lies in their area of expertise and activity. This situation renders the implementation of integral planning difficult in practice, but also shows that early incorporation of players is essential in order to reach cross-expertise consensus over the course of the planning process.

In summary, with regard to the future-oriented implementation of sustainable building, the results show that:

- Sustainable construction is not yet sufficiently implemented in practice
- The challenges of implementation arise largely from the lack of integrative collaboration between project participants in early planning stages
- There is a need for deeper research to commit sustainability aspects in tendering and awarding

Furthermore, there is the need to implement sustainability aspects over all project stages, based on comprehensive requirements planning and detailed user analysis. Requirement planning and user analyses are not only the benchmarks for the project's objectives, but also the foundation for the implementation of sustainable construction. The majority of those surveyed already used policies, directives or guidelines for the practical implementation of sustainable buildings. In this regard, harmonisation is desirable. The remuneration of "sustainable" planning work is considered to be insufficient.

Experts presume that a large potential for the consideration of sustainability aspects exists in the area of extensions, as particularly operating and maintenance costs can be positively influenced by the application of innovative building technology. Regarding tendering, award criteria such as "costs for operation and maintenance", "life-cycle costs" and "use of recyclable materials" are helpful concerning the awarding of contracts under consideration of sustainability aspects.

Suitability criteria are regarded as being less helpful. The highest appreciation is for criteria such as "organisational and technical performance", "expert qualifications of key personnel" and "references". The responders were also unanimous in that the use of the principle of lowest bidder makes the implementation of sustainability aspects more difficult. The experts also view that the solution for the implementation of sustainable building is not always present using the principle of "best bidder".

The survey also uncovered a tendency towards descriptions of constructive performance to consider sustainability aspects.

In summary, the results from the survey show the urgent need for an adapted approach in project management and in the planning process that takes sustainability aspects into account when implementing sustainable façades.

2. INTERACTION BETWEEN STAKEHOLDER OBJECTIVES

In order to investigate the mutual influence between processes and object qualities, the effect of concrete process qualities from real life was formulated in firm statements for selected, façade-relevant object qualities from the certification system. The representation of the results was allocated to the main criteria groups according to environmental, economic, social, functional and technical quality. Once the final evaluation was available, a cross-link matrix was used to focus on the interactions deemed to be significant between object and process quality in the form of a new process model for the evaluation of the sustainability of façade constructions. The following process qualities were selected:

- The early integration of all expert planners during the creation of an energy concept
- The definition of a higher energy efficiency standard (e.g. passive house standard instead of the minimum standard required by law)
- The execution of thermal building simulation considering the user furnishings and the user behaviour
- The creation of a concept for the ability to dismantle and replace technical building energy supply systems
- The consideration of the interaction between building envelope and building systems in the planning phase
- The consideration of technical, environmental Life Cycle Assessment (LCA) and economic Life Cycle Cost Assessment (LCCA) variant comparisons during the creation of the energy concept

FIGURE 1-5 shows the results from the expert survey for the main criteria groups. The interactions among the selected process qualities and the environmental quality (green), the economic quality (turquoise-blue), the social and functional quality (red) and the technical quality (grey) can be identified.

SEQUENTIAL PLANNING VERSUS INTEGRATED PLANNING

The survey results indicate that the interviewees estimate that the integral method of planning, compared to the traditional sequential method of planning, is better able to fulfil the sustainability requirements for buildings, particularly due to reduced complexity and higher planning efficiency. Other advantages described in literature regarding an integral method of planning such as increased user satisfaction, reduced life-cycle costs (LCC) or the increase in value of the real estate, confirm the survey participant's assessments. However, according to the responders, creative design is only enabled to a limited degree by an integrated planning process. This low rating even indicates that creative design possibilities are actively limited or even hindered by integrated planning.

SUCCESS FACTORS OF INTEGRATED PLANNING

According to the research results, the most important success factor for integrated planning is the early inclusion of all planning participants. The survey shows that this is due to the low flexibility of traditional planning practices, in which the participants are still involved consecutively and sequentially, whereby the planning participants cannot share their expertise in a satisfactory way and therefore only have limited ways of shaping the planning process. Early inclusion of the players, in conjunction with open communication and joint objective definition, can be seen as a central prerequisite for a successful implementation of integrated planning methodology in practice.

INTEGRATED PLANNING PROCESS

Since the early inclusion of all expert planners when creating an energy concept represents exactly that process quality that simultaneously can be seen as a prerequisite for the implementation of an integrative planning process, the corresponding assessments by the survey responders can be regarded as particularly significant. From the six selected process qualities, the early inclusion of expert planners when creating an energy concept is, according to the responders, the one with the highest potential for improvement for the four object qualities under investigation. With the exclusion of economic object qualities, the survey results show above average high and balanced effects on all object qualities. This result underlines the essential significance of the early inclusion of all players in the planning process for the optimisation of building quality. The measure of early inclusion of all expert planners however was rated with an overall under-average low potential for improvement of economic object qualities, as were all other selected process qualities. This makes it clear that the generally higher costs in the planning stage caused by an integrative planning approach represent an important barrier for its implementation in practice.

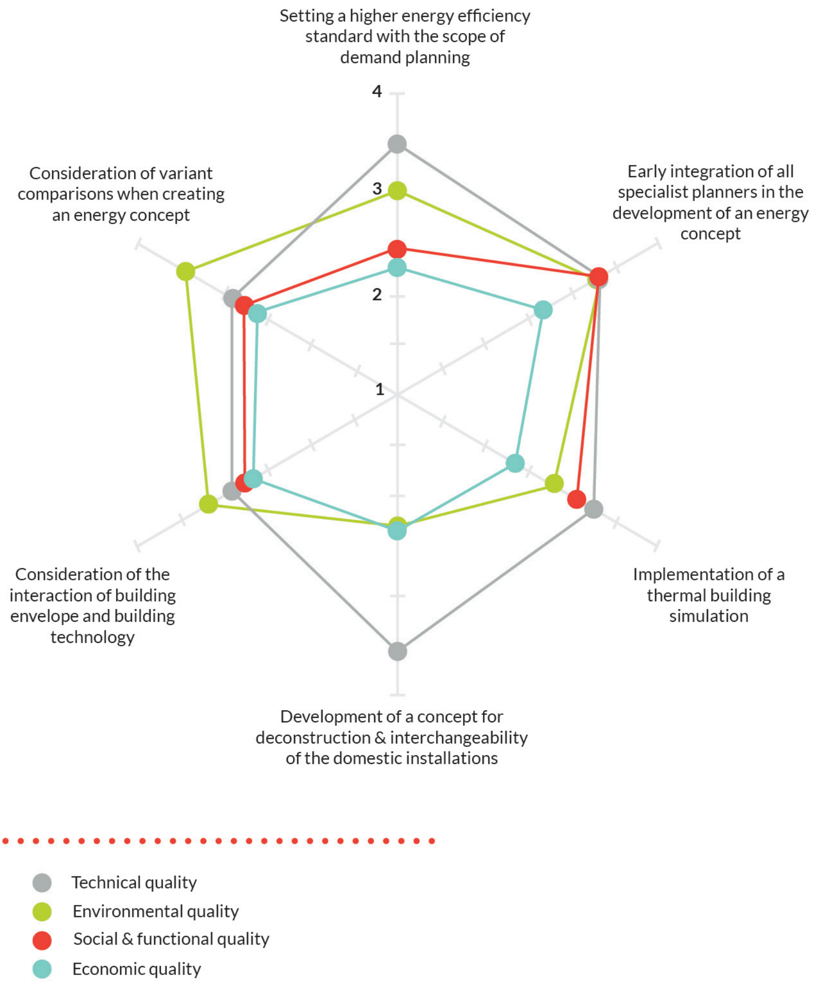

FIGURE 1-5: INTERACTION BETWEEN PROCESS AND OBJECT QUALITIES

THE PATH TOWARDS OPTIMISED PROJECT MANAGEMENT & PLANNING PROCESS

(TO FULFIL A HOLISTIC REQUIREMENT PROFILE)

In the scope of the research project, the ÖGNI/DGNB evaluation system was used on the one hand as the basis for objective definition for the decision maker, and on the other as a basis for the modelling of systemic relationships in a new process model **(SEE CHAPTER 2)**. In addition to the object-related building qualities in the ÖGNI/DGNB evaluation system (environmental, technical, social, economic, etc.), process qualities such as quality of the project preparation, integrative planning, sustainability aspects in the tender and award, etc., are also described. The application of the ÖGNI/DGNB building evaluation system in the planning process is currently within the scope of a first assessment of a building, the so-called pre-assessment that defines the objectives regarding evaluation criteria together with the decision maker. In doing so, the ÖGNI/DGNB building evaluation system does not define concrete requirements that are later used and evaluated during a building certification. This process is normally very time-consuming due to the scope of the evaluation. In addition, the interactions among the evaluation criteria and the required management processes are mainly insufficiently defined due to the complexity of the holistic and life cycle oriented evaluation in this early project stage. Furthermore, the decision maker's frequently diverging requirements, objectives and requirements demand the possibility of a "dynamic" objective definition, something that requires the further development of evaluation tools and the improvement of the framework for the implementation of an integrative planning process in practice.

The set of criteria according to the ÖGNI/DGNB scheme for the evaluation of sustainability in office and administration buildings contains >100 evaluation criteria. This permits a comprehensive evaluation of the finished building. For use in early planning stages, for example within the scope of integrative planning to determine the effects of planning measures, the system has only limited suitability in its current form. This is justified by the resulting complex evaluation situations with simultaneously high pressure on completion date and costs in early project stages. Current analytical approaches are not able to satisfactorily represent possible trade-offs and/or synergies regarding the later building quality (for example due to planning changes).

For these reasons, a method is required that first acquires the criteria interactions in a systemic fashion and enables an evaluation regarding the systemic effects of individual planning decisions.

The growing complexity of requirements due to the life cycle oriented planning and project management process increases the number of processes that must be implemented in building practice and their possible interactions. The basis for a holistic sustainability evaluation is thus a model that also evaluates the quality of the processes (a process in this context is a set of interrelated or interdependent activities that converts inputs into results, according to ÖNORM ISO/IEC 15504 **[52]**).

FIGURE 1-6 shows the allocation of process qualities to object qualities. When a building certification system is used in the planning process, the objectives concerning the evaluation criteria are defined together with the decision makers at the pre-assessment stage. The integral evaluation of

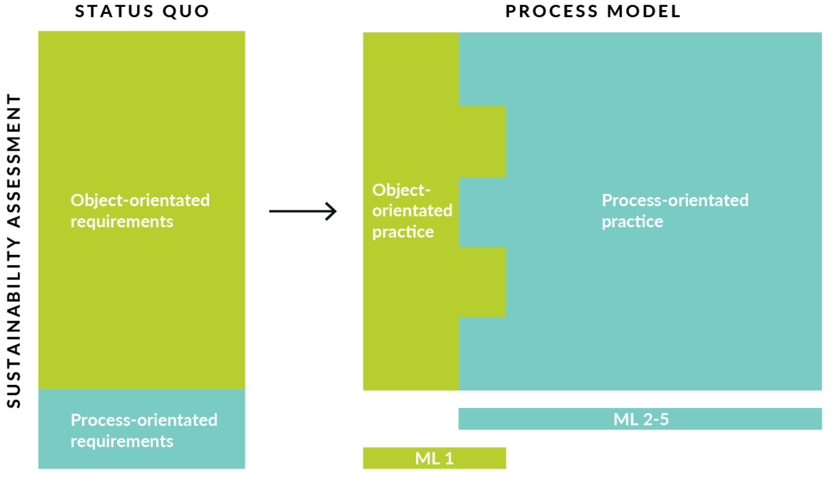

FIGURE 1-6: THEORETICAL APPROACH FOR THE LINKING OF PROCESS AND OBJECT QUALITIES

object and process qualities is intended to reflect the influences of optimised project management processes on individual object qualities. These allocated, process-oriented practices are, in contrast to the current situation, not additional requirements, but rather holistic, life cycle oriented activities that are necessary due to the defined objective definitions for the sustainable implementation of a building.

Based on the new approach, the mutual influences between process-oriented and object-oriented practices can be visualised, trade-offs and synergies made visible and the quality of the implementation of these processes can be rendered by measurable maturity levels (ML).

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02

PROCESS MODEL FOR THE MATURITY ASSESSMENT OF SUSTAINABLE FAÇADES

HELMUTH KREINER
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ALEXANDER PASSER

The origin of systemic thinking, with its thesis "the whole is greater than the sum of its parts" and the introduction of the concept of causality, lies 2000 years in the past. Compared to analytical thinking, systemic thinking is context-related, meaning that an arbitrary system can only be understood if it is regarded in the context of the whole. Process thinking developed in parallel to context-related thinking where the concept of cybernetics appeared for the first time, whereby it was thus possible to describe feedback loops and self-regulation in systems. Due to the multi-criteria evaluation situation in the context of sustainability evaluations, system-theory approaches, for example in the form of systems engineering or building cybernetics, are also becoming more important in today's construction sector **[1-3]**. The first approaches to describe systemic relationships between sustainability criteria are mentioned in expert literature Dzien **[4]**, Thomas and Köhler **[5]**, Schneider **[6]**, Kreiner **[7]**, together with approaches for systemic optimisation in Hafner **[8]** and Wittstock **[9]**.

If a building is regarded as an open, dynamic "system"[1] **[10]**, interventions do not usually manifest themselves as simple cause-effect relationships. The optimisation of a sustainability criterion via the implementation of a planning measure is mainly associated with interactions with other evaluation criteria. In addition, the planning measure is based on and requires a planning process itself that again causes corresponding interactions in the system "building". Today for example, sensitivity models such as that from Vester **[3]** are available for the operationalization of complex evaluation systems. The core of the sensitivity model is an intensity-relationship matrix (the so-called "paper computer") with which the mutual influence of different system criteria can be assessed. With the aid of such methods, as opposed to purely quantitative evaluation methods, even so-called "soft factors" can be included in the evaluation of a system in order to represent the suitable adjustment points for system optimisation. A modified form of the paper computer is used in a process model for the first, rough estimate of possible criteria interactions.

SYSTEMIC APPROACH AS THE BASIS FOR A PROCESS MODEL

Today, the increasing complexity of planning sustainable buildings requires so-called "integrative planning processes". This means the early inclusion and coordination of individual expert planners is necessary while taking the use profile based on the decision maker's objectives into account. The multi-criteria character of different planning measures frequently

	N#	CRITERION	SHARE OF TOTAL SCORE
ENVIRONMENTAL QUALITY	1	Global warming potential (GWP)	3.4
	2	Ozone depletion potential (OWP)	1.1
	3	Photochemical ozone creation potential (POCP)	1.1
	4	Acidification potentials (AP)	1.1
	5	Eutrophication potential (EP)	1.1
	6	Local environmental impact	3.4
	8	Responsible procurement	1.1
	10	Nonrenewable primary energy demand	3.4
	11	Total primary energy demand + proportion of renewable	2.3
	14	Potable water demand and wastewater volume	2.3
	15	Land use	2.3
ECONOMIC QUALITY	16	Building related life-cycle costs	13.5
	17	Suitability for third-party use	9.0
SOCIAL & FUNCTIONAL QUALITY	18	Thermal comfort winter	1.6
	19	Thermal comfort summer	2.4
	20	Indoor air quality	2.4
	21	Acoustic comfort	0.8
	22	Visual comfort	2.4
	23	Occupant control	1.6
	24	Quality of outdoor spaces	0.8
	25	Safety and security	0.8
	26	Access for all	1.6
	27	Space efficiency	0.8
	28	Suitability for conversion	1.6
	29	Public access	1.6
	30	Cyclist facilities	0.8
	31	Design and urban quality	2.4
	32	Integration of public art	0.8
TECHNICAL QUALITY	33	Fire prevention	4.5
	34	Noise protection	4.5
	35	Building envelope quality	4.5
	40	Ease of cleaning and maintenance	4.5
	42	Ease of dismantling and recycling	4.5
PROCESS QUALITY	43	Comprehensive project brief	1.3
	44	Integrated design	1.3
	45	Design concept	1.3
	46	Sustainability aspects in tender phase	0.9
	47	Documentation for facility management	0.9
	48	Environmental impact of construction	0.9
	49	Prequalification of contractors	0.9
	50	Construction quality assurance	1.3
	51	Systematic commissioning	1.3
		TOTAL SCORE	100

leads to trade-offs between individual building qualities. The previously available methods for the optimisation of building sustainability in early planning process stages are only suitable to optimised single sustainability qualities. A holistic optimisation in early planning stage is only possible with very high time expenditure. Currently, existing instruments for the evaluation of sustainability mainly describe "measure-oriented" optimisation opportunities and less the required "process-oriented" optimisation in the sense of quality assurance. In order to be able to describe a requirement profile for the planning process from a holistic perspective, a process model is required that starts with the decision maker's objectives and defines the key planning processes while taking possible trade-offs into account.

1. DETERMINATION OF POSSIBLE CRITERIA INTERACTION

Expert surveys[3] were conducted in 2009 and 2013 to identify possible relationships among the evaluation criteria. Within the scope of the

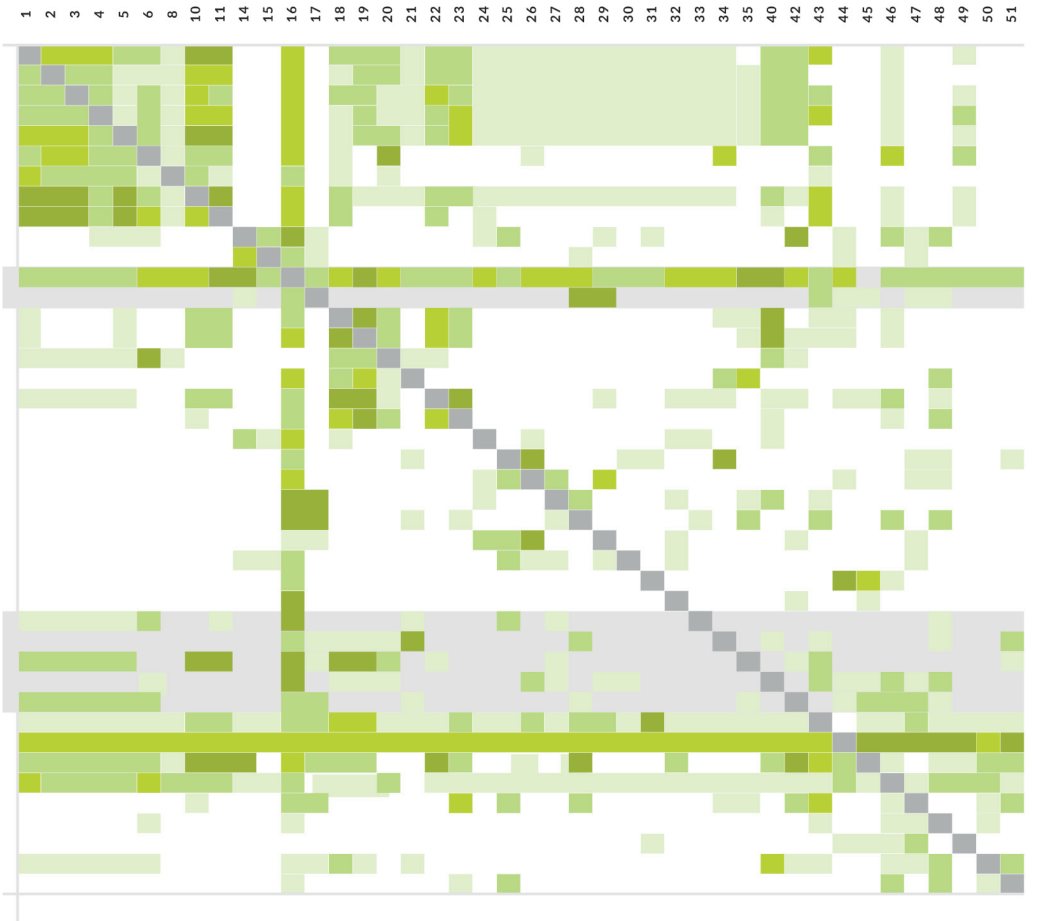


FIGURE 2-1: INTERACTION BETWEEN THE ÖGNI/DGNB EVALUATION CRITERIA[2]

UNAB project, the evaluation of the results was carried out on the basis of the survey regarding the qualitative investigation of the interactions among the ÖGNI/DGNB evaluation criteria. The evaluation was performed based on Vester's sensitivity matrix. The complexity of the observation is portrayed by a 42*42 criteria matrix[4] (theoretically 1.722 possible interactions). The coloured fields in **FIGURE 2-1** represent the focus of responses for each expert group. The evaluation of the matrix forms the basis for a subsequent detailed analysis of criteria interactions.

In a next step, the identified areas were subjected to detailed analysis regarding their systemic behaviour. Due to the fact that the interaction of just a few factors leads to no longer plausible, assessable holistic effects, suitable software is required **[11]**.

2. SOFTWARE FOR THE VISUALISATION OF CAUSAL RELATIONSHIPS

The concept of "causal network" proposed by Vester **[11]** represents a cross-section of reality. Instead of using a matrix, the influencing inputs could be connected via relationships in the form of arrowed lines, linked together and a topic could be abstracted and portrayed in this manner. The result, or the holistic effect, is not based on the influence of a single value, but is the interaction of all values in the form of a systemic perspective.

There are several software solutions that digitise this causal network, such as the Malik sensitivity model Prof. Vester[5], Heraklit[6], STELLA[7], Dynasis[8], Powersim[9] or Consideo Modeler[10].

The software tool "iMODELER" was selected to develop the process model. The software tool "iMODELER" forms the basis for the cross-link analysis of the previously identified criteria interactions among the ÖGNI/DGNB evaluation criteria. The input data required by "iMODELER" for the qualitative cross-link analysis in the form of object-specific and organisational processes simultaneously form the basis for the maturity evaluation model to be developed.

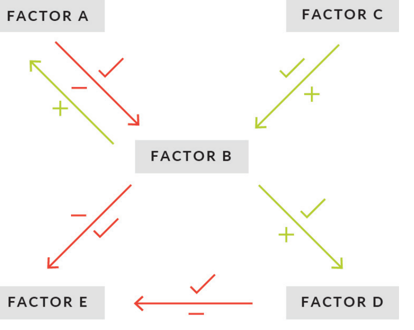


FIGURE 2-2: SCHEMATIC REPRESENTATION: CAUSAL NETWORK IN THE SOFTWARE TOOL iMODELER[11]

"iMODELER", from the company Consideo GmbH, is a software that is designed to support the representation of complex systems in a graphical manner and to consider interdependencies and influences of the elements. A so-called "insight matrix" displays the size of the influence per element over a period of time. The software offers the possibility to store models that have been created in the cloud and to access them from other devices to enable further editing. In addition, storing models in the cloud enables other people to collaborate on the same model. In order to obtain results from the model, the user needs to define what type of results is to be displayed. There are two different possibilities of modelling. A qualitative model produces an order of magnitude describing how strong the influence of individual elements is and how this can change over time.

The qualitative evaluation provides the following possibilities to describe a connection:

- The effect can amplify (support) or attenuate (oppose)
- The relationship can have a time delay that is short, medium or long term
- The strength of the effect can be strong, medium or weak

A relationship is fundamentally uni-directional, however, a loop can be used to show mutual influence (called “feedback loop” in cybernetics).

FIGURE 2-2 shows a schematic of an causal network with various factors from the “iMODELER” program. The thickness of the connection arrows reflects the strength of the effect and any time delays are shown as crossbars. The number in the example, which can be positive or negative (amplifying or attenuating the effect), represents a relative weighting on the influence of a factor over another factor. In order to be able to consider dynamic objective preferences, the previously mentioned factors, whose structure is defined by the ÖGNI/DGNB evaluation system, are accordingly linked in the causal network.

The so-called insight matrix displays the influence of individual factors on the system “building” (or on individual factors), as shown in **FIGURE 2-3**. This enables the critical adjustment points for the optimisation of the planning process to be identified taking the decision maker’s objective preferences into account. Subsequent detailed analysis is able to analyse the influence of practices that have been identified as being critical using so-called cause and effect chains and possible synergies or trade-offs can be displayed. This permits suitable measure to be determined, for example in the form of a requirements document for the planning).

The influence on each factor by other factors can be output out of the overall total of direct and indirect influences resulting from the qualitative weighting of cause-effect chains and delays, together with the effects of stabilising and self-amplifying loops. The horizontal x-axis represents the total of all effects over all influence paths that a factor has to the selected factor. The vertical y-axis shows the changes of the effect due to influence loops and delays.

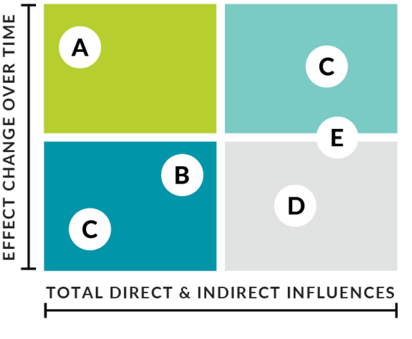


FIGURE 2-3: SCHEMATIC REPRESENTATION: INSIGHT MATRIX IN THE SOFTWARE TOOL iMODELER[12]

The four areas in the insight matrix can be defined as follows:

- Green area: reduction in decreasing factors
- Turquoise-blue area: increase in increasing factors
- Water-blue area: increase in decreasing factors
- Grey area: reduction in increasing factors

The positive and negative influences of the selected factor (e.g. system "building") can be viewed by plotting the results in a bar chart (see **FIGURE 2-4**).

3. DEFINITION OF STAKEHOLDER OBJECTIVES

The decision maker defines the required level of quality for the optimisation targets in the "iMODELER" software tool. The definition of the quality level is done in four quality steps that are oriented on the quality steps in the ÖGNI/DGNB building certification system. This means that targets are defined in the steps "target value", "partial target value", "reference value" and "limit value". This grading is designed to consider the decision maker's preferences and to weight them appropriately in the "iMODELER" software.

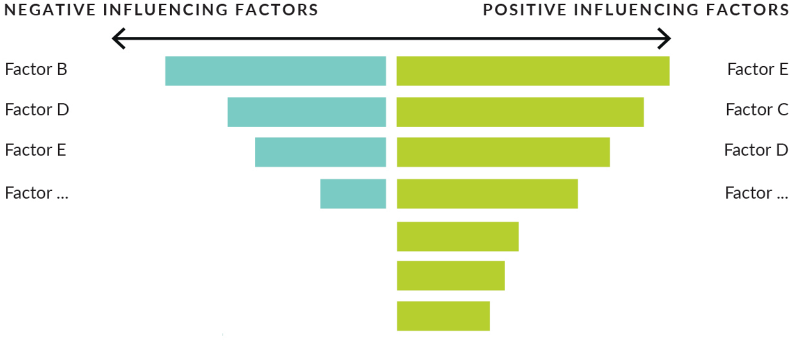


FIGURE 2-4: SCHEMATIC REPRESENTATION: EFFECTS OF BASE PRACTICES ON THE SYSTEM "BUILDING"[13]

EVALUATION OF MATURITY LEVEL

The increasing complexity of building projects in conjunction with the necessary networking of involved stakeholders has an effect on costs, deadlines and quality **[12]**. Companies thus strive to optimise their processes. The demands on quality **[13]** and the connected ideas of process-capability **[12]** are an integral part of industrialisation in our world. One possibility is the application of maturity level models.

Maturity level models support companies by enabling the evaluation of work methods. These evaluations can be subsequently used as benchmarks for the maturity of a company. A process maturity level model offers a starting point for process improvements since it builds upon the experience of earlier users and makes appropriate use of it. Next to being a framework for the prioritisation of actions, a process maturity model also enables the comparison of organisations with respect to the process maturity.

Process maturity level models can be differentiated into models that target the potential for improvement on a company level (process maturity) and in models that target the potential for improvement within an individual process area (process capability).

The process maturity level represents the maturity of a company regarding the execution of the processes of one or more process areas. The lowest maturity level is decisive. For example, a company that has a maturity level of 3 in the process area “production”, a maturity level of 1 in the process area “management” and a maturity level of 2 in the process area “customers” has an overall maturity level of 1. The representation of process maturity levels offers an organisation a tried and proven path for improvement.

The degree of process capability deals with the execution of the processes within a process area. The representation of the degree of process capability is done separately for each process and, in contrast to the process maturity level, there is no aggregation.

The different focus for the degree of process capability delivers a detailed view of a process area and hence the possibility to optimise its workflows. This view also enables different workflows to be improved at different speeds. In contrast with this, the application of process maturity levels delivers the possibility to determine the path for improvement of an organisation. Achieving one level guarantees the foundation for improvement for the next highest level.

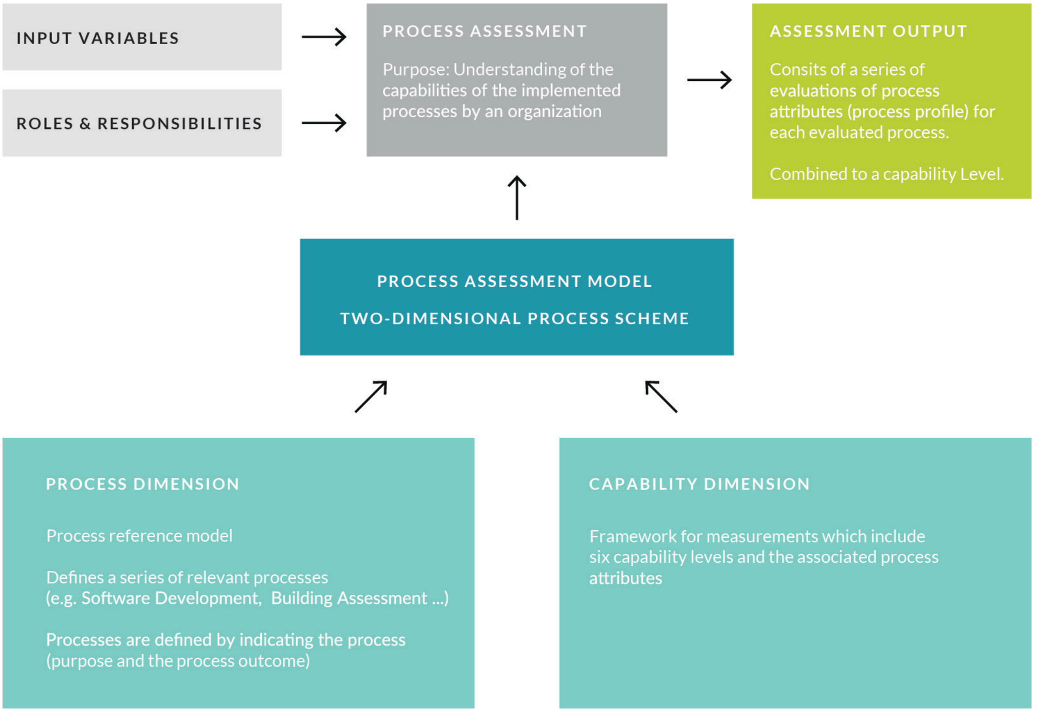


FIGURE 2-5: ELEMENTS OF THE SPICE PROCESS ASSESSMENT MODEL[14]

The representation in the UNAB project was done on one hand in degrees of capability for the evaluation of the individual processes (functional requirements) and on the other by maturity levels for the merging of individual processes to sustainable qualities or to an overall building quality.

Several process maturity level models have established themselves on the market in current practical applications, including CMMI[15] und SPiCE[16] **[14]**. CMMI and its predecessor CMM[17] were developed as a “capability maturity model” concept for the evaluation of maturity in software processes by a company called SEI[18], originally as a contract from the US Air Force, then subsequently adapted for the civil market. CMMI is widely used, particularly in the American market. The idea of maturity level models was also conceived in Europe, where above all SPiCE was used as well as CMMI. SPiCE was designed by ISO[19] and developed further as a technical report ISO/IEC TR 15504 in 1998. The currently valid norm series was taken over on a national level as ÖN ISO/IEC 15504 parts 1-6. The advantage of SPiCE is the ability to develop sector-specific models. For example, SPiCE was adapted for the space and automotive sectors **[14]**.

Process assessments, i.e. the evaluation of a company’s processes, are based on a two-dimensional process figure, and the process assessment model (**FIGURE 2-5**). This includes a process dimension and a maturity level dimension. The process dimension is based on a process-reference model. This defines a series of processes that are described by the definition of the process' purpose and the process results. The maturity level dimension consists of a framework for the measurements with a scope of six process maturities and their process attributes. Starting with the assessment process, the input variables are defined along with the definition of roles and responsibilities of the persons involved. The execution of the assessment process delivers the assessment results. This provides a series of evaluations of the process attributes of several processes for one or more process areas. When collated, the result is the maturity level of the organisation.

FIGURE 2-6: OVERVIEW MATURITY LEVELS[20]

FIGURE 2-6 shows the hierarchy of the maturity levels. Within the framework, the maturity is based on a series of process attributes (PA). Each process attribute defines a particular aspect of the degree of capability. A fixed evaluation scale describes the degree to which a certain process attribute is achieved. In conjunction with a defined grouping of process attributes, the degree determines the process maturity level to which a certain process attribute has been fulfilled.

MATURITY LEVEL 1 PERFORMED

The purpose of each process is fulfilled, based on training, experience or according to workflows that follow generally known guidelines. There is no organisation-wide process management; performance is largely dependent on the personnel and varies from project to project. Improvements are a daily occurrence.

The results of the process execution are available. The execution is only dependent on the knowledge of the project participants. If guidelines were used, they could be certification systems for example. However, their use is not uniform throughout the organisation; measures for planning, management and repeatability are not implemented.

MATURITY LEVEL 2 MANAGED

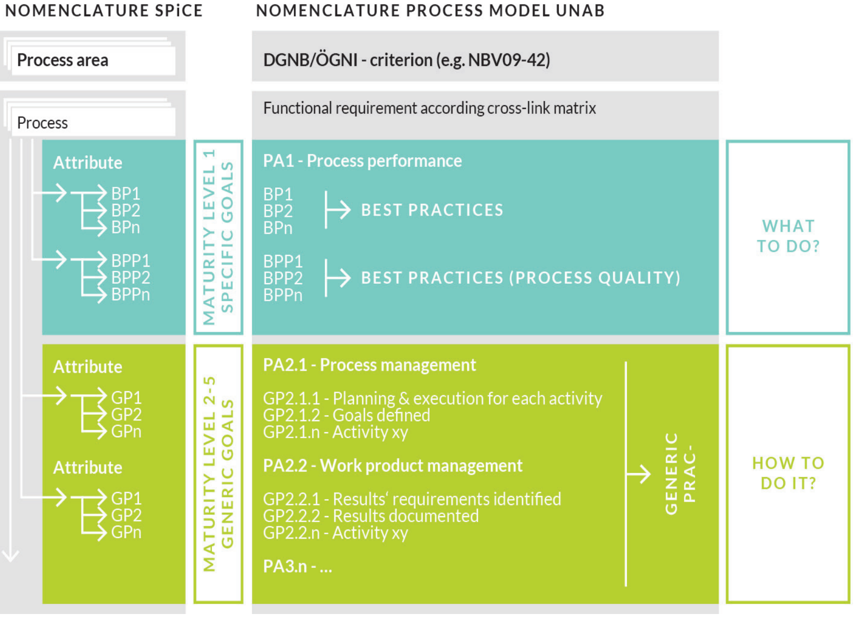
The execution of a process is planned and managed. Resources, responsibilities and tools are planned based on realistic experience. Project targets are defined; monitoring, management and checks of the work occur. The guidelines to be used on a project level are known and are applied.

The execution of work is planned and executed on individual project levels. Quality assurance and requirements management are available. Sub-processes such as project planning, or monitoring of costs, milestones and project progress are defined and implemented. Planning of project-specific guidelines.

MATURITY LEVEL 3 ESTABLISHED

As far as is meaningful standard processes are standardized organisation-wide. The execution thereof is standardised through the use of application guidelines and/or adaptation of processes. This forms the basis for standardised project management and planning. The process is independent of individuals and is institutionalised.

A model for the standard approach is available (process model). This is documented and standardised on an organisation-wide level. Processes are independent from individuals. Simulation (for example LCC or thermal simulations) is executed.



MATURITY LEVEL 4 PREDICTABLE

Key performance indicators resulting from measurement and analysis and their continuous monitoring are able to systematically identify weaknesses. This leads to an improvement in forecast accuracy. Qualities are known quantitatively. Risk management is established. The process is quantitatively understood and monitored on a project level.

Quality and productivity are measured and the parameters can be identified. Effort assessments are carried out methodically and a PLAN-ACTUAL comparison is executed. Analysis and management possibilities can be defined.

MATURITY LEVEL 5 OPTIMISING

The information gained from maturity level 4 is subsequently used to initiate an improvement process. New methods and procedures are designed, simulated and prototyped. If successful, they are institutionalised.

An improvement of the processes results from the measurements (input for process model). There is a systematic acquisition and reuse of experiential values and fault analysis. Possibilities for improvement arising from new technologies and concepts are researched. Long-term improvement targets and visions can be defined.

APPLICATION EXAMPLE FAÇADE

NBV09-42 - Deconstruction & disassembly

FR - Deconstruction

PA1 - Process performance

BP1 - Construct durable building envelope
BP2 - Use demountable building products
BPn - Avoid construction joints

BPP1 - Increase consideration of sustainabilty aspects in tender & contact award
BPP2 - Increase the requirement planning for building envelopes' constructions
BPPn - Increase integral design

PA2.1 - Process management

GP 2.1.1 - Define sustainability goal definiton & plan sustainability demand
GP 2.1.2 - Define processes for an accompanying control of sustainability
GP 2.1.3 - ...

PA2.2 - Work product management

GP 2.2.1 - ...
GP n - ...

PA n - ...

FIGURE 2-7: TRANSFER OF SPICE NOMENCLATURE TO UNAB INCL. APPLICATION EXAMPLES[21]

In order to achieve a level of maturity, all process attributes belonging to this maturity level must be predominantly or completely fulfilled - and the process attributes of the subordinate maturity level must all be completely fulfilled.

DESCRIPTION OF THE SPICE MATURITY LEVEL MODEL

SPiCE defines several process areas with thematically similar processes that provide recommendations as "best practices" for activities and processes within a company or an organisation. These correspond to experience values that describe established and functioning processes. The concrete implementation is left open; there is a recommendation "what is to be done", but not "how to do it".

FIGURE 2-7 shows the transfer of process area, process and process attribute to the nomenclature in the UNAB research project and the interpretation of ÖGNI/DGNB nomenclature in this context. For example, the process area "ease of dismantling and disassembly" as a superordinate level covers all questions concerning dismantling and disassembly. This level is divided into several processes, for example functional requirement (FR) "ease of dismantling", where the use of material or the effort of assembly that covers the client's needs is enquired. Further examples would be "separation effort" or "service life of building components".

The attainment of capability level 1 (CL 1) is necessary for the fulfilment of the process attribute requirements PA1.1. This consists of several object-oriented and process-oriented base practices. Process attributes with higher levels of maturity consist solely of generic practices. Base practices apply to a specific process. They describe the activities that are necessary for the execution of the process. In contrast to this, generic practices apply to several processes.

Base practices such as "manufacture permanent building envelope" or "use dismountable and recyclable building products and use HVAC" represent the smallest rateable unit and are evaluated according to the four-step evaluation scale. The total and percentage evaluation of these ratings fulfil the specific targets and result in the corresponding maturity level. Maturity levels cannot be skipped and in order to achieve the next higher maturity level, the targets of the lower maturity level must be fulfilled. In order to achieve maturity level 2, requirements must be fulfilled, on the one hand for maturity level 1, and the generic practices corresponding to the process attributes allocated to maturity level 2 on the other.

Solely generic practices from maturity level 2 are rated, since from here, as per definition, processes determine the workflow within an organisation. Achieving higher levels of maturity follows the same pattern. Generic practices that consist of process attributes from 2.1 to 5.2 are identical in structure and content for each process. However, process attribute 1.1 is only relevant for maturity level 1 and is different for each process.

The previously described methods of system analysis and maturity level evaluation need to be incorporated into early planning phases if the targeted consideration of sustainability aspects is to be supported.

PROCESS MODEL

Basically, the following three processing steps are necessary for the new process model to be applied, which result in a “sustainability report” related to different façade types. The basic procedure for the use of the model is shown schematically in **FIGURE 2-8** and explained subsequently.

1. TARGET DEFINITION

Step A consists of target definition. This is based on the ÖGNI/DGNB assessment criteria that has been thematically clustered. The target definition is done on the basis of the functional requirements that

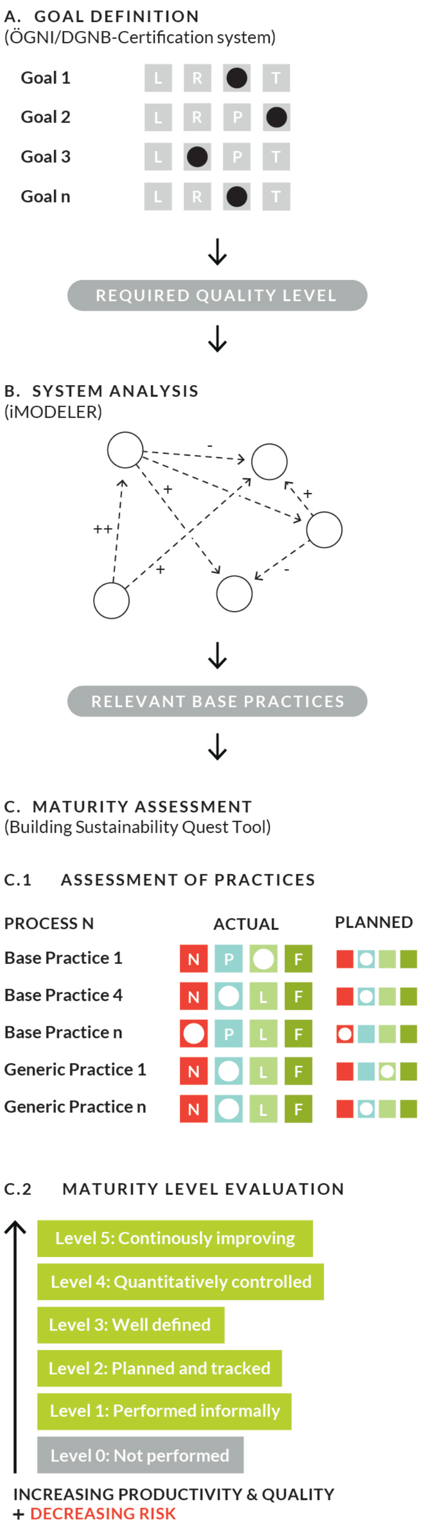


FIGURE 2-8: PROCESS MODEL

have been defined by the stakeholder by selecting four quality levels. The decision makers define the required quality level for the optimisation targets in "iMODELER" (all developed functional requirements from the cross-link matrix).

In order to consider the individual stakeholder targets and to represent their overarching optimisation strategy (e.g. overall sustainability, costs, social and functional, etc), a target definition matrix was developed to provide a basis for the evaluation of selected façade constructions. In a further step, four optimisation strategies were devised.

The result of the target definition (step A) is thus a recommendation for a scenario (= understood as a specific type of façade (e.g.: UNAB façade) that represents the basis for the analysis of the causal network (step B). In a further step, the execution of the Monte Carlo simulation can check the potential for risk and success in the recommended scenario.

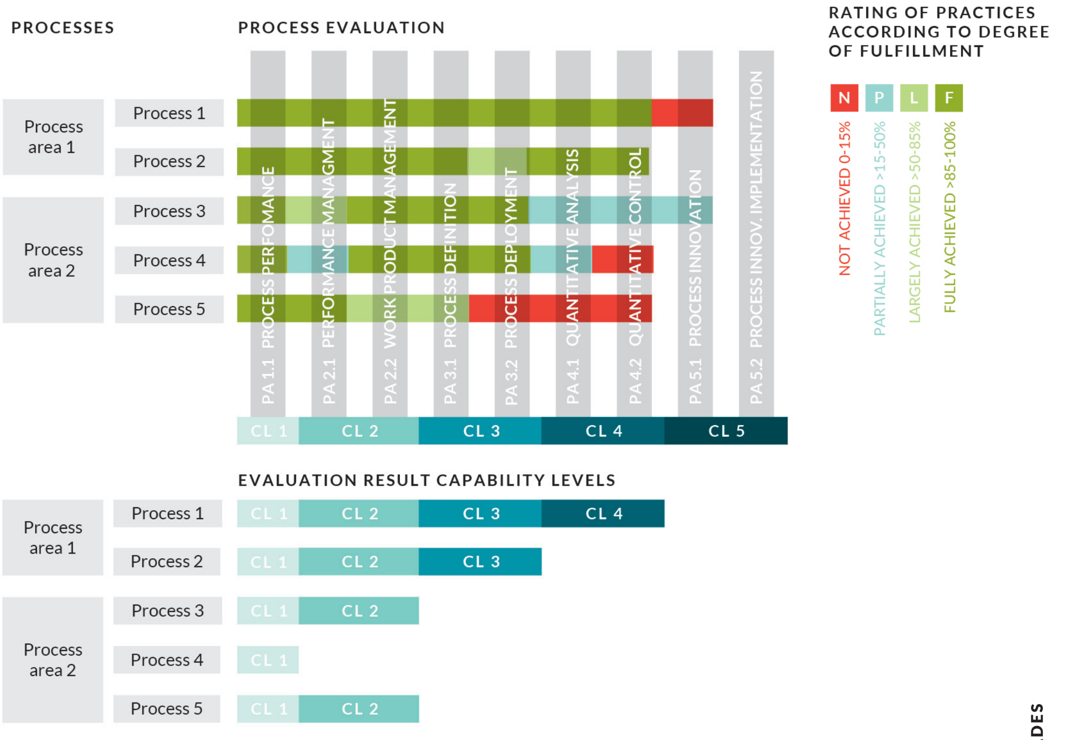
2. SYSTEM ANALYSIS

As mentioned previously, a cross-link matrix was developed based on the causal network in order to execute a 2-stage integral evaluation of possible optimisation targets for the new façade concept.

To achieve this, qualitative evaluation of the potential synergy and/or trade-off potential was carried out between base practices and technical measures. Furthermore, qualitative evaluation of the potential synergy and/or trade-off potential of process base practices on life-cycle management measures were carried out. Finally, the changes made to the causal network by the inclusion and weighting of the evaluated façade types and their optimisation scenarios were implemented into the process model.

The linking of base practices and the possibility of considering target goals into a process model was done during the cross-link analysis. Each individual connection was then qualitatively weighted according to its effect during expert workshops.

The results of the causal network analysis defines a selection of those base practices based on the target definition of the scenario that show a high significance for the fulfilment of the target goals desired by the decision maker. The sub-division of the technical measures and the life-cycle management measures into building and building component level permits the model to be extended at a later date.



DETERMINATION OF CAPABILITY LEVELS
CAPABILITY LEVEL PER PROCESS BASED ON PROCESS ATTRIBUTES

PROCESS ATTRIBUTES

1	2.1	2.2	3.1	3.2	...	aCL
>50%	n.e.	n.e.	n.e.	n.e.	...	CL 1
>85%	>50%	n.e.	n.e.	n.e.	...	CL 2
>85%	>50%	<50%	n.e.	n.e.	...	CL 1
>85%	>50%	>50%	n.e.	n.e.	...	CL 2
>85%	>85%	>85%	>50%	n.e.	...	CL 3

n.e. = not evaluated

FIGURE 2-9: EVALUATION ALGORITHM[22]

3. EVALUATING MATURITY

Application of the SPiCE maturity level model to the construction sector: Project UNAB uses the SPiCE system approach, however the process areas and the processes for requirements and scope conditions for the system "building" need to be adapted in an appropriate manner. The implementation requires corresponding software support. The program used, called "Quest Tool", is a software program that enables the assessment of companies and organisation using ÖN ISO/IEC 15504 (SPiCE) **[15]**. For use in the construction industry, the Quest Tool was configured and adapted to a prototype "Building Sustainability Quest Tool" SQT.

This prototype (SQT) was used to implement all defined processes that had been worked out based on the ÖGNI/DGNB certification system over the course of the cross-link analysis. This evaluation tool also contained descriptions of these processes with references to item-relevant requirements of the certification system. In addition, all practices were implemented in the SQT. To reduce the evaluation effort, relevant practices can be identified during system analysis and hence a targeted evaluation can be done. Practices that are not earmarked as being relevant can remain unconsidered in the evaluation. This results in a specification of base practices. It is important to differentiate between “object-oriented” and “process-oriented” base practices. Object-oriented practices are allocated to the technical measures to implement a functional requirement. In contrast, process-oriented practices define those practices required for a specific process that are allocated to so-called “life-cycle management measures” (i.e. those derived from processes out of the ÖGNI/DGNB main criteria group “process quality”). Furthermore, it must be differentiated between a positive (optimising) or negative (trade-off) base practice with regard to a specific optimisation target.

The evaluation algorithm shown in **FIGURE 2-9** was implemented for the evaluation of the practices.

All relevant practices must be evaluated in order to determine the level of capability for each process. The evaluation is done using the “N-P-L-F” principle (N = Not achieved, P = Partially achieved, L = Largely achieved, F = Fully achieved). The expert rating of the scenarios in the cross-link matrix determines whether a practice is evaluated with N, P, L or F. The clustering of the evaluated practices results in a percentage value for the corresponding process attribute. The capability level per process based on the process attributes is calculated using the percentage values achieved (see **FIGURE 2-9**).

In order to be able to adapt and extend the evaluation tool, editing software was also developed with which processes including process attributes can be subsequently created. This “SynEdit” editing software also permits the development of new evaluation tools for other areas of expertise and processes.

The modified process model delivers the structure for a general sequence model of the required steps, from the selection of a functional requirement up to the sustainability report, as the basis for a general sustainability tender document for an optimised planning and project management process (**FIGURE 2-10**).

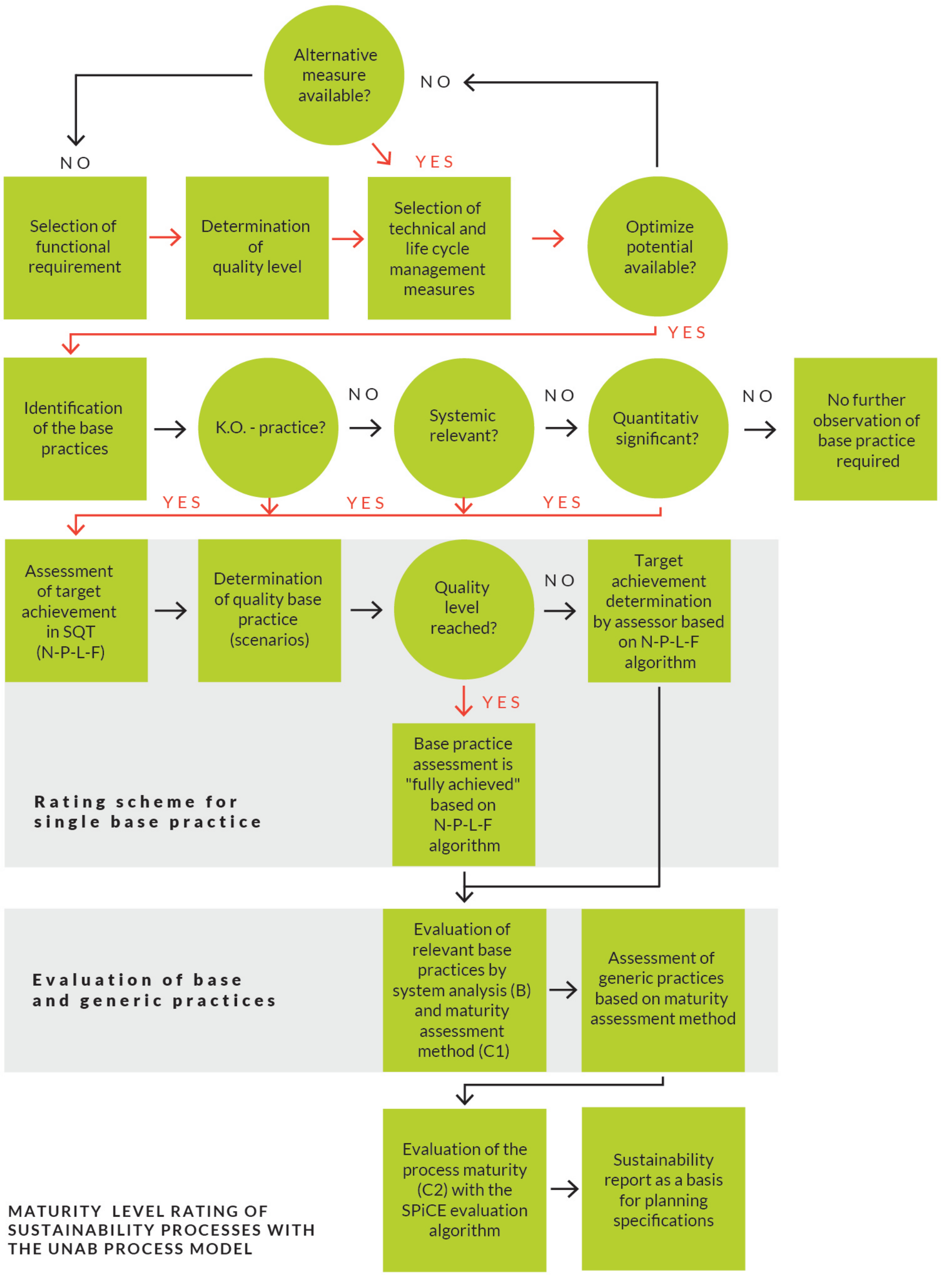


FIGURE 2-10: SEQUENCE MODEL

A detailed description of an application of the sequence model, using different façade concepts by way of example, can be found in **CHAPTER 8.**

After execution of the maturity level evaluation (N-P-L-F) in step c, the practices that were identified as critical adjustment factors are read and thus represent the requirement for further planning process steps. The quality of the status quo of a planning process can also be checked using the process model and modifications (i.e. process optimisation) can be carried out if required. The comparison of planned/actual stati rendered possible by this evaluation permits statements to be made concerning the maturity of the building and planning process and thus forms the basis of quality assurance from a holistic perspective.

FIGURE 2-11 shows a summary of the basic steps during the evaluation of maturity (process model section C) in the Building Sustainability Quest Tool and the interfaces with target definition and system analysis in the process model. The main advantage of applying the previously described process model compared to a conventional pre-check (initial classification of a project regarding sustainability qualities to be achieved) is the reduction in complexity with respect to multi-criteria evaluation. A conventional approach requires that all evaluation criteria be analysed in detail with the decision maker, which leads to a comparatively high amount of time expenditure due to the high number of sub-criteria. In practice, this often leads to deviations from holistic perspectives in early planning stages. However, by using the process model, potential trade-offs arising from stakeholder targets are displayed transparently and possible synergetic effects among evaluation criteria can be taken into account.

A formulation of process qualities required to achieve the targets can be made based on a holistic perspective. The process to implement the sustainability qualities is no longer left to the individual project participants. A basis exists for the project management of sustainability qualities of a building from a holistic perspective.

In summary, the advantages of the new process model for the evaluation of the level of maturity can be described as follows:

- Identification of base practices that are suitable for the fulfilment of dynamic, functional stakeholder targets
- Knowledge of the relationship between base practices and functional requirements
- Visualisation of possible potential of synergies and trade-offs

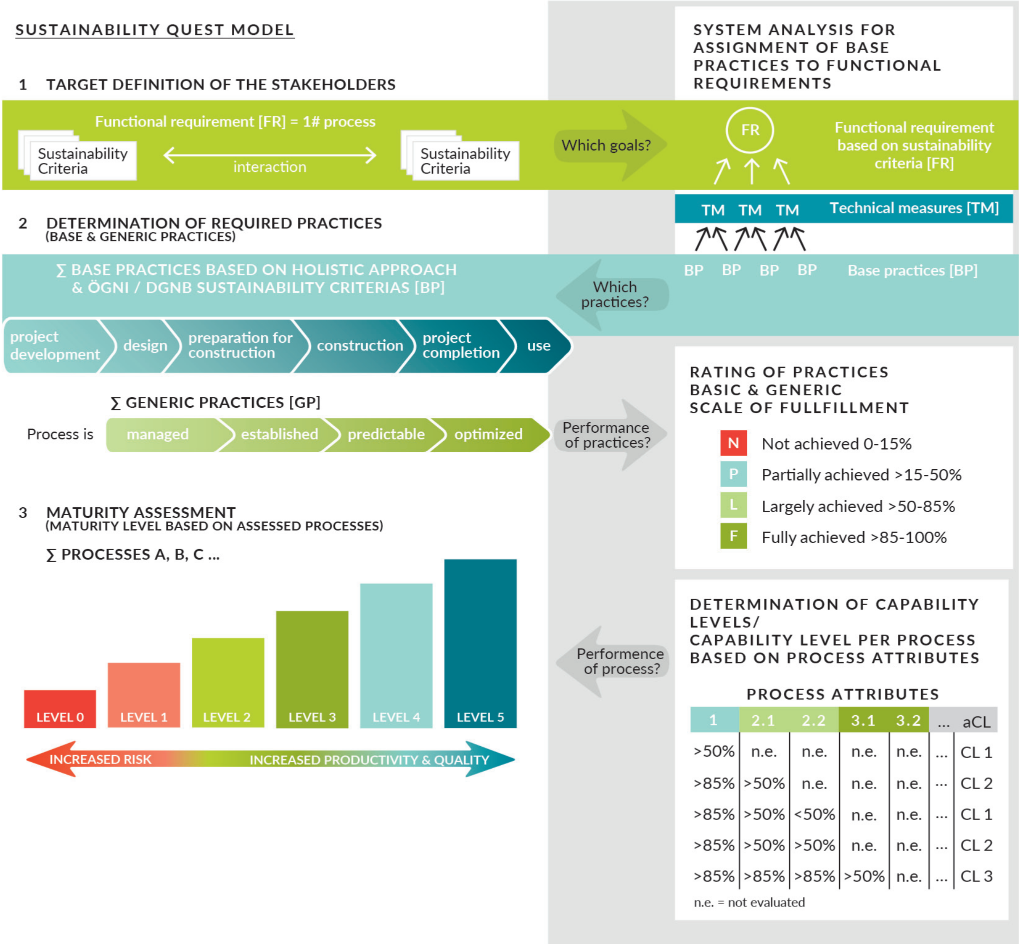


FIGURE 2-11: BUILDING SUSTAINABILITY QUEST – MODEL

- Visualisation of the qualitative influence of process-oriented base practices (BPP) on planning costs
- Determination of the qualitative potential for the optimisation of complete scenarios
- Visualisation of the qualitative influence of these scenarios on the economic and environmental building quality
- Knowledge of the achieved maturity level (for a given planning stage) of a sustainability process compared to the planned process maturity and hence the implementation of quality assurance from a holistic perspective

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ENDNOTES

[1] In the context of the system "building", "dynamic" is associated with the life-cycle perspective and "open" with the diverging decision maker's objectives.

[2] The different shades of green describe the intensity of the possible criteria interactions (i.e. strong, middle and weak interactions). The evaluation was based on the ÖGNI/DGNB certification system (Use profile new building for offices and administration - ÖGNI – NBV09_AUT_01 – version 2010-03)

[3] A total of 26 experts (8 groups) took part in the surveys in university courses from the following areas of expertise: architecture, civil engineering, industrial engineering, building services planning, facility management, structural physics, legal sciences, real estate management and interior design. A further evaluation was conducted by the Working Group Sustainable Construction.

[4] Use profile new building for offices and administration (ÖGNI – NBV09_AUT_01 – version 2010-03)

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[11] Own representation AG-NHB acc. to Consideo GmbH

[12] Own representation AG-NHB acc. to Consideo GmbH

[13] Own representation AG-NHB acc. to Consideo GmbH

[14] Own representation AG-NHB acc. to ÖN ISO/IEC 15504

[15] Capability Maturity Model Integration

[16] Software Process Improvement and Capability Determination – ISO/IEC 15504

[17] Capability Maturity Model

[18] Software Engineering Institute at the Carnegie Mellon University/Pittsburgh (SEI)

[19] International Organisation for Standardisation

[20] Own representation AG-NHB acc. to ÖN ISO/IEC 15504

[21] Own representation AG-NHB acc. to: ÖN ISO/IEC 15504

[22] Own representation AG-NHB acc. to: ÖN ISO/IEC 15504

03

ASPECTS OF INTEGRAL FAÇADE ANALYSES

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BUILDING TECHNOLOGY IN THE FAÇADE

The integration of building components and systems inside façades is a broad topic. The term building technology ranges from simple devices that fulfil a function such as the targeted de-humidification of constructed façade layers via convection flow, to complex systems for the energy conversion, storage and supply of interior rooms.

The subsequent focus in this document will be placed on building-related components and systems that have a major influence on the energy-related behaviour of the façade construction itself and on the interior rooms in the background. Hence simple technical components such as air cavities or flaps are seen as parts of the building services and are dealt with by way of example.

1. ENERGY-RELATED ELEMENTS IN THE FAÇADE

The targeted integration of air cavities in façade constructions can be regarded as a simple energy-related element. The simplest form is a air cavity that is either permanently closed, permanently open or can be controlled to be open or closed according on demand. **FIGURE 3-1** shows a simple schematic view of the most important energy and flow related processes in an air cavity.

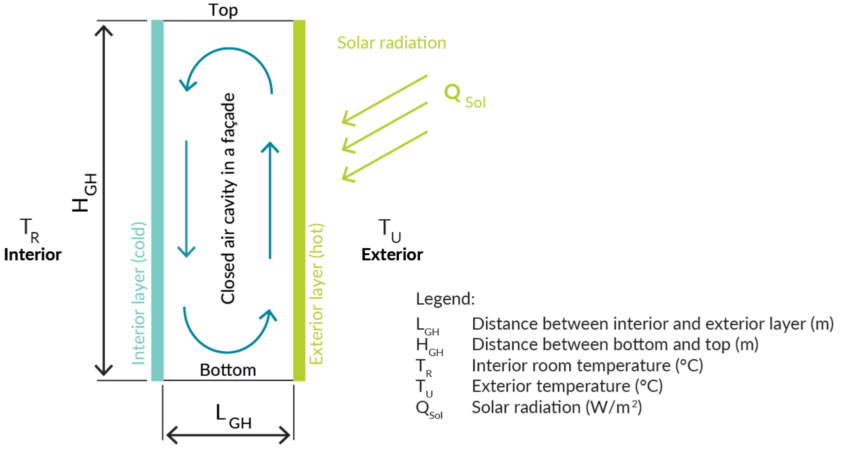

FIGURE 3-1: SCHEMATIC REPRESENTATION OF THE THERMAL BEHAVIOUR IN A CLOSED AIR CAVITY IN A FAÇADE

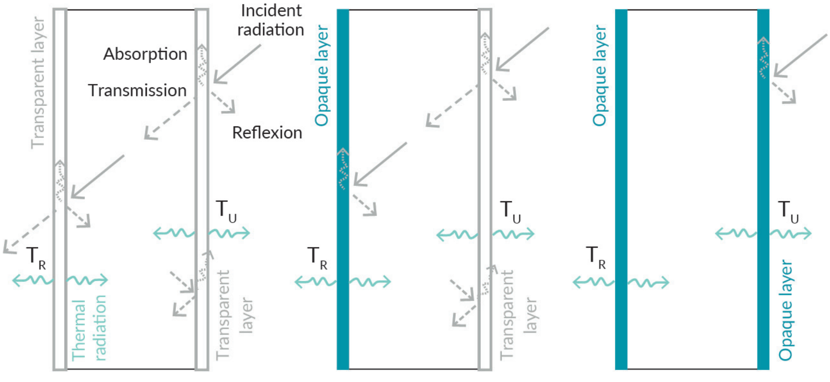

FIGURE 3-2: RADIATION PROCESSES IN THE FAÇADE FOR TWO TRANSPARENT LAYERS (LEFT), AN OUTER TRANSPARENT LAYER AND AN INNER OPAQUE LAYER (CENTRE) AND TWO OPAQUE LAYERS (RIGHT)

FIGURE 3-2 shows the possible variations existing in various construction forms obtained if the nature of the sidewall surfaces in the air cavity is differentiated regarding the permeability of solar radiation into an opaque and a transparent layer. The most important of these processes from a thermal viewpoint are the absorption, reflection and transmission (transmission only for transparent media) of solar radiation. The individual components heat up at different rates according to their material characteristics. A further influence is the exchange of heat radiation between the corresponding surfaces, whereby the hot surface transmits energy in the form of long wave radiation to the cold surface. An air flow (circulation) is established due to the temperature differences between the materials. The air is heated up on the hot wall and rises due to the reduction in density. At the top of the air cavity, the warmed air transfers from the hot to the cold side. The air cools on the cold side and sinks to the base of the air cavity. This causes an additional (convective) heat transfer between the hot and cold sides, whereby the rising air absorbs heat from the hot side and releases it on the cold side.

Façades not only have closed but also ventilated air cavities, whether they are caused by inaccuracies during manufacture or by design to deliberately guide air through the façade. Such ventilation channels are required to either guide fresh air into the space from the exterior (ventilation), or, for example, to partially vent the heat generated in the façade to the environment. **FIGURE 3-3** shows a schematic of the most important thermal processes.

In this case, the air no longer circulates in the air cavity, but flows in one side and exits via the other. In addition to the processes shown in **FIGURE 3-3**, heat is now transported via the air flow into and out of the façade air cavity (depending on whether the temperature of the air or the façade is higher). The flow can establish itself naturally, either due to the heating or cooling of the façade surface, or forced artificially (for example with the aid of ventilators). The ventilation openings and channel forms can vary significantly (depending on the application).

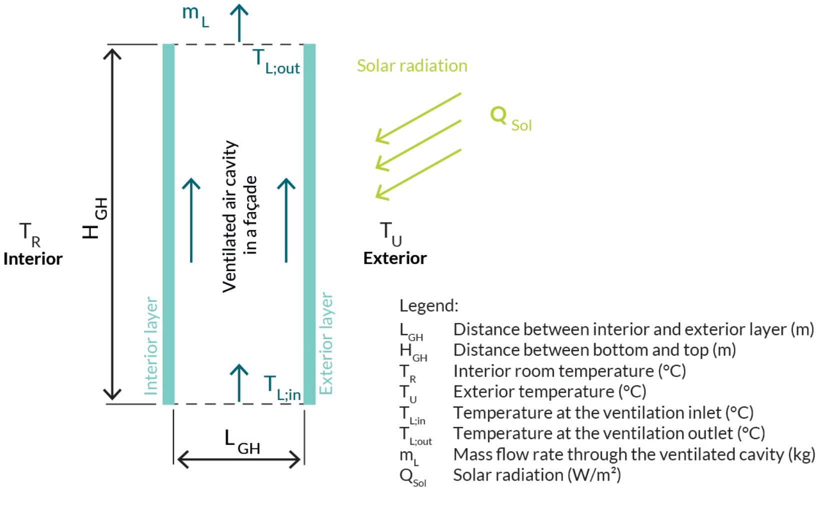

FIGURE 3-3: SCHEMATIC REPRESENTATION OF THE THERMAL BEHAVIOUR IN VENTILATED AIR CAVITIES IN A FAÇADE

2. ENERGY HARVESTING IN THE FAÇADE

On one hand, the energy supply to our buildings over the last decades has been exclusively based on fossil energy sources (**FIGURE 3-4**). Climate change, increasing energy costs and the looming scarcity of fossil resources have resulted in a shift in the supply of fossil energy to buildings.

The demand for regenerative forms of energy, at least as a partial replacement for oil, natural gas and coal, is increasing steadily. Solar systems that convert and use solar radiation to provide heat and electricity can contribute substantially to the future energy system.

On the other hand, the increasing population, the production of biofuels and industrial products, and above all the rapid increase in urban areas are creating increasing pressure on land use. In this context, a building façade, primarily intended for protection against environmental influences, lends itself to the integration of regenerative energy production systems. The energy requirements of a building can be covered locally, either completely, or at least partially. As a consequence, connections to overarching energy grids can be designed leaner and in extreme cases, can even be eliminated.

A range of problem situations naturally accompanies the advantages of integrating thermal energy conversion systems into the façade. The integration of systems to use solar radiation significantly increases the complexity of the entire façade construction's thermal behaviour. For example, the greenhouse effect causes very high temperatures in thermal collectors. This influences the thermal

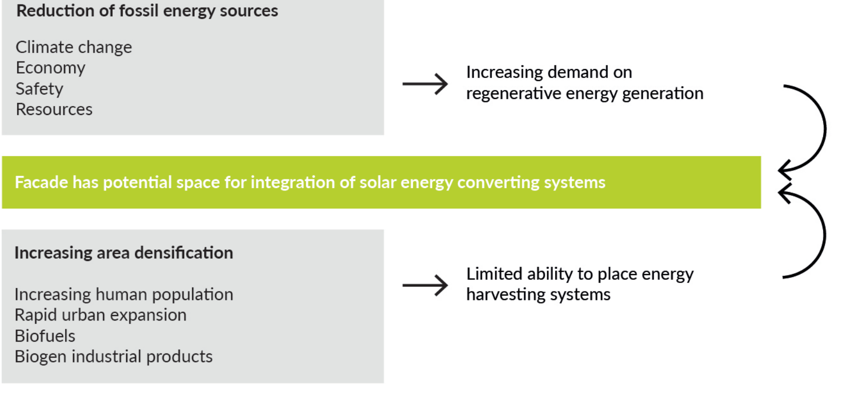

FIGURE 3-4: WHY HARVEST ENERGY IN THE FAÇADE?

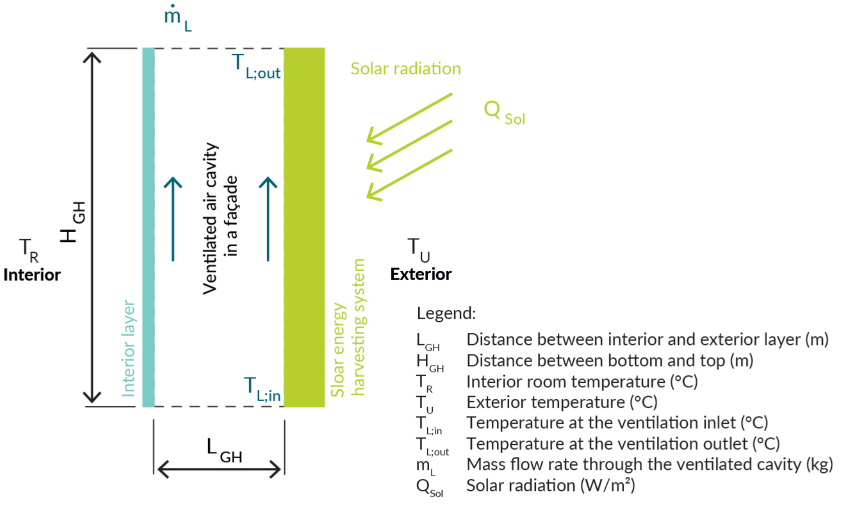

FIGURE 3-5: SCHEMATIC REPRESENTATION OF THERMAL BEHAVIOUR IN THE VENTILATED AIR CAVITY IN A FAÇADE WITH INTEGRATED ENERGY HARVESTING SYSTEM

behaviour of the façade construction and can lead to uncomfortable thermal situations (overheating) in the interior rooms behind the façade.

If the effect of transporting the heat of a ventilated air cavity is combined with an energy harvesting system, then a large part of the heat energy flowing towards the interior rooms via the façade construction can be captured and transported away to the exterior, whereby the comfort in the interior rooms behind the façade can be increased. The principle involved is shown in **FIGURE 3-5**.

In the meantime, there are many scientific reports that investigate the thermal effects, the measures for an increase in performance and improvement of room climate. In addition, other ideas have emerged for the integration of functional components in the façade. The energy harvesting systems can be categorized into solar thermal systems and photovoltaic systems. There is also often a combined application of both of these systems in façades (hybrid systems).

3. ENERGY HARVESTING FROM THE FAÇADE

The useful energy that can be harvested from the surface of a façade depends on a large number of factors. The simplest form of the use of solar radiation is via transparent surfaces, normally in the form of glass. Apart from this widely used form of so-called “passive solar use”, the application of opaque façade surfaces allows the conversion of solar radiation via the so-called “active solar use” into useful energy.

The first group of input values that control the possible amount of useful energy that can be harvested can be summarized as “climatic conditions”. The location of the building is critical here. Since even the same location can experience variations over individual years, the question is how to characterise the years under consideration.

FIGURE 3-6 shows an evaluation that can be used representatively for Europe. Helsinki is the capital city in Europe with the coldest winters and Madrid is the European capital that has the hottest and sunniest summers. Ljubljana corresponds almost exactly to the average of all European capitals.

The second group of input variables consists of geometrically defined parameters. This mainly includes the orientation and angle of the façade surface.

The list in **FIGURE 3-6** is divided into vertical surfaces for north, south, east and west orientations and horizontal surfaces.

The third group of input parameters to determine the amount of useful energy that can be harvested depends on the characteristics and efficiencies of the technology used or by the energy system that is connected. The current solar thermal and photovoltaic technologies represent the most important technologies for façade inte-

		Northern Europe Helsinki		Central Europe Ljubljana		Southern Europe Madrid	
		cold year	hot year	cold year	hot year	cold year	hot year
Solar Radiation (kWh/m²a)	horizontal	801	1117	947	1331	1475	1852
	North	357	366	354	391	421	402
	East	598	818	600	838	906	1138
	South	737	1159	685	1087	1035	1444
	West	616	837	591	836	874	1101
Output Solar-Thermal (kWh_{th}/m^2a)	horizontal	373	540	487	706	816	1038
	North	153	165	166	192	211	211
	East	284	414	303	443	490	642
	South	353	594	336	567	529	780
	West	299	433	303	450	479	635
Outpout Photovoltaic (kW_{he}/m^2a)	horizontal	79	110	91	128	142	177
	North	32	31	30	33	36	34
	East	58	80	56	79	87	109
	South	73	115	65	106	100	140
	West	59	80	55	78	82	103
ST/PV Ratio (kWh_{th}/m^2a) (kW_{he}/m^2a)	horizontal	4.7	4.9	5.3	5.5	5.7	5.9
	North	4.8	5.3	5.5	5.8	5.8	6.3
	East	4.9	5.2	5.4	5.6	5.7	5.9
	South	4.9	5.1	5.2	5.4	5.3	5.6
	West	5.1	5.4	5.5	5.7	5.9	6.2

FIGURE 3-6: RANGE OF POSSIBLE ENERGY GAINS FROM THE FAÇADE IN EUROPE[1]

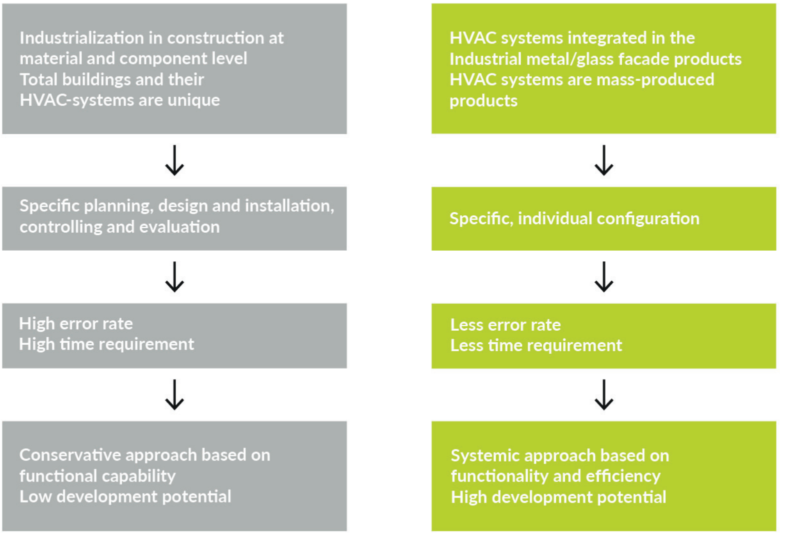

FIGURE 3-7: COMPARISON OF THE CONVENTIONAL APPROACH TO HVAC PLANNING (LEFT) AND THE DECENTRALISED APPROACH TAKEN IN THE RESEARCH PROJECT "MULTIFUNCTIONAL PLUG&PLAY FAÇADE" (RIGHT) [1]

gration. Solar thermal systems use the heat generated by the solar radiation impinging on the façade surface and photovoltaic systems generate electricity. **FIGURE 3-6** also shows the useful energy that can be harvested by each technology and their relative sizes to each other. An extended form of evaluating the useful energy that can be harvested includes the time-dependency of the energy harvesting in the considerations and compares them with the corresponding time-dependent demand. If the energy harvested at a defined point in time exceeds the demand at that time, then the excess energy harvested cannot be consumed locally and is thus lost and cannot be included in the balance. The creation of different storage possibilities or the connection of further consumers and/or a grid connection can reduce or prevent such system losses.

4. ENERGY SUPPLY FROM THE FAÇADE

Systems for heating, cooling and ventilating are installed in buildings to ensure comfortable conditions for people. These systems are called HVAC systems. Conventional HVAC systems consist of individual, industrially manufactured components that are combined with systems adapted to each application in the planning phase. These on-request configurations and installations require a lot of time effort, and hence costs, and tend to be susceptible to errors.

In contrast to this is the decentralised approach, where the entire system is separated into individual decentralised systems. The approach adopted by the research project "multifunctional plug&play façade" integrated and configured the desired HVAC system locally in the façade construction. This approach results in that not only are the system components industrial mass products, but the system itself is too, resulting in all the associated advantages such as efficient manufacture with high production volume (**FIGURE 3-7**).

HYBRID STRUCTURES

1. DEFINITIONS

In engineering, a hybrid system is defined as something that is constructed out of two different technologies. Hybrid thus means an assembled whole, constructed from different forms or processes. It is worth emphasizing that each individual component represents a functioning system or solution and the act of bringing the systems together may create new, desirable emergent properties **[2, 3]**.

2. HYBRID STRUCTURES AT THE COMPONENT LEVEL

The conceptual starting point of every hybrid construction is the division of the component under consideration into functionally different sub-areas. Since these sub-areas experience different stresses, they can be constructed using different materials that are optimal for the intended function.

Taking bending beams as an example, the initial structural separation can be represented on the level of material combination. The beam, which is subjected to bending moments, longitudinal forces and lateral forces, is first divided into sub-areas. The material in each sub-area is then optimised based on the loads being applied. For example, this may result in composite girders or sandwich elements (**FIGURE 3-8, FIGURE 3-9**).

Sandwich panels are known in many different forms. The core assumes very different functions, apart from providing a strong connection for both cover sheets (e.g. steel sheet composite boards), it insulates, ensures the highest possible leverage between cover sheets and stabilises them against buckling (**FIGURE 3-10**).

Honeycombed cores are used to save material and hence weight for special areas of application. **[4]**

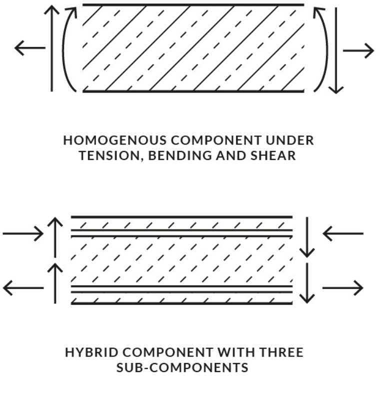

FIGURE 3-8: SEPARATION OF FUNCTIONS FOR A GIRDER [4]

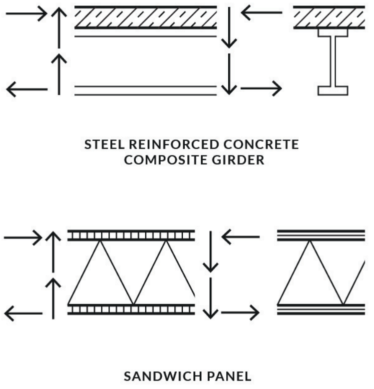

DIAGRAM 3-9: POSSIBLE OPTIMISATION OF HYBRID COMPONENT MATERIAL [4]

3. HYBRID BEHAVIOUR OF STRUCTURES

The difference between the two components does not necessarily have to be on the material level, but can be determined by the load carrying functions of the component.

Especially when discussing hybrid structures, hybridity often occurs despite identical materials since the system behaviour of the components inside the whole structure is different. **[5]**

According to Eisert, Noack and Ruth, a hybrid supporting construction has the following attributes:

- It consists of two or more individual structures that mutually engage in supporting the load.
- Each individual structure is also capable of supporting the load on its own.
- The system behaviours of the individual structures, defined by its geometry and constituent materials, have different qualities.
- Each individual structure maintains its characteristic supporting behaviour even in combination
- The load distribution between the individual structures and the deformations can be directly influenced via active measures (e.g. pre-stressing).

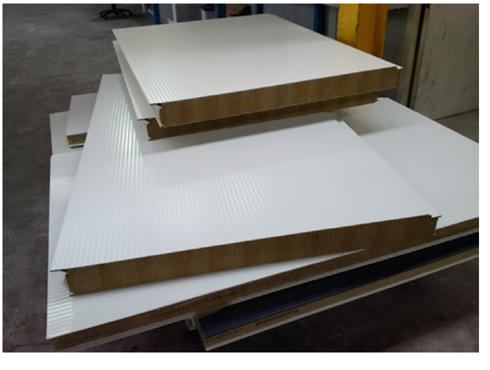

FIGURE 3-10: SANDWICH PANELS WITH STEEL COVER SHEETS AND A MINERAL WOOL CORE (BRUCHA)

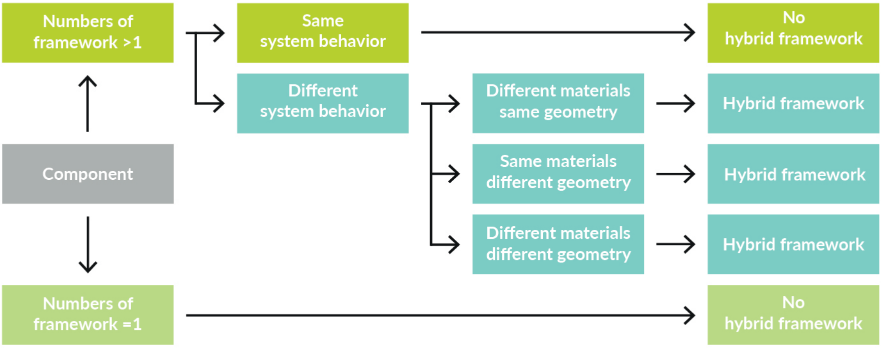

FIGURE 3-11: DECISION FIGURE FOR HYBRID SUPPORTING STRUCTURES [5]

Hybrid structures are not characterised by the individuality of the load transfer with typical structure forms, but by a specific operating principle through system pairing and system coupling. Constructions are not hybrid where the original system plays a subordinate role or each system only carries out a single function in the load transfer process (load-bearing, load balancing, load distribution) **[3]**.

LITERATURE

[1] Forschungsprojekt “multifunctional plug&play façade” (mppf), Ausschreibungslinie COMET, 2008-2013

[2] U. Pfammatter, „Hybride Konstruktionen,“ Detail, pp. 1382-1388, 2012.

[3] H. Engel, Tragsysteme, Ostfildern-Ruit: Gerd Hatja, 1997.

[4] V. Schmidt, „Hybridkonstruktionen in der Tragwerksplanung,“ Detail, pp. 1452-1464, 2012.

[5] D. Eisert, T. Noack und J. Ruth, „Bewertungsstrategie für hybride Tragwerke“.

ENDNOTES

[1] Raw data from the climate data generator: METEONORM

04

ARCHITECTURAL DESIGN OF FAÇADE ELEMENTS

FERDINAND OSWALD
ROGER RIEWE

INTRODUCTION

The goals of this section "Architectural Design of Façade Elements" were as follows:

- An analysis and report on the current situation
- Modification of existing public and office buildings in Graz using solar collector panel
- Investigation of a façade element surface design regarding branding, pipework as well as shading and privacy
- In general terms, presentation of the architectural relevance of façade elements from the point of view of a single element and from a complete perspective.
- Possible applications of sandwich panels with integrated openings.

The content of this working package is the presentation of three concepts using design projects with solar collector sandwich panels in Graz. These three concepts were then applied to two case studies in Graz (MPPF and Karmeliterhof). The application of the three systems on identical building topologies was designed to portray the advantages and disadvantages of the individual systems. At the same time, this investigation intended to illuminate other areas worthy of research for continuing research projects.

COMPARISON OF THE SYSTEMS AND RESEARCH REQUIREMENTS

1. ADVANTAGES AND DISADVANTAGES OF THE SYSTEMS

The three systems are:

- SYSTEM 01: Printed, moveable panel (**FIGURE 4-1, FIGURE 4-2**)
- SYSTEM 02: Integrated Openings (**FIGURE 4-3, FIGURE 4-4, FIGURE 4-5**)
- SYSTEM 03: Sandwich panel in a horizontal position

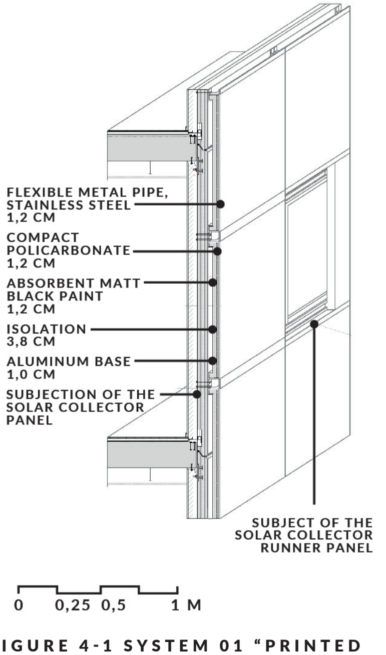

FIGURE 4-1 SYSTEM 01 "PRINTED AND MOVEABLE PANEL ": CROSS-SECTION ISOMETRIC PANEL [1]

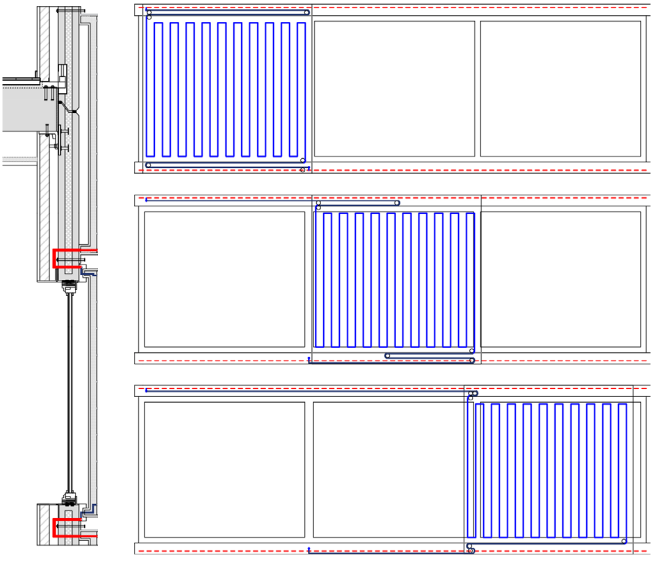

FIGURE 4-2 SYSTEM 01 "PRINTED AND MOVEABLE PANEL": MOVEABLE SOLAR COLLECTOR PANELS, CABLE CONNECTIONS WITH FLEXIBLE CONDUIT MOVEABLE VIA ROLLERS: LEFT, CROSS-SECTION AND RIGHT, VIEWS: TOP; STARTING POSITION, CONDUIT POSITION AT BUILDING CONNECTION POINT; CENTRE; PIPEWORK SYSTEM STRETCHES OVER A FAÇADE OPENING; BELOW; PIPEWORK SYSTEM STRETCHES OVER 2 FAÇADE OPENINGS [1]

One significant advantage of the "integrated opening" sandwich façade panel (SYSTEM 02) is the possibility to define the openings in various sizes and position them at different places in the panel. This offers the architect considerable design freedom. The panels could also be in an "L" form, such that the window frame functions as an outside edge of the panel on two sides. The opaque solar collector surface needs to run vertically from storey ceiling to storey ceiling in order for the panel to be mounted on each storey without additional constructions being required on the building.

Principle advantage of SYSTEM 02 compared to SYSTEMS 01 and SYSTEMS 03 is the simple mounting procedure, since compared to the other systems no additional construction elements are required. The system construction consists of a single sandwich panel. All required components are already available in this case ("all-in-one" sandwich panel).

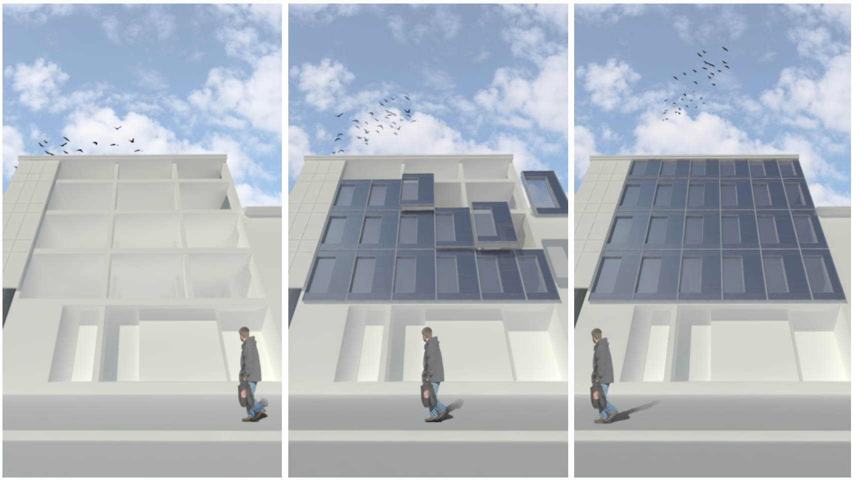

FIGURE 4-3 SYSTEM 02 "INTEGRATED OPENINGS" INSTALLATION STEPS FOR SANDWICH PANELS IN AN EXISTING BUILDING [2]

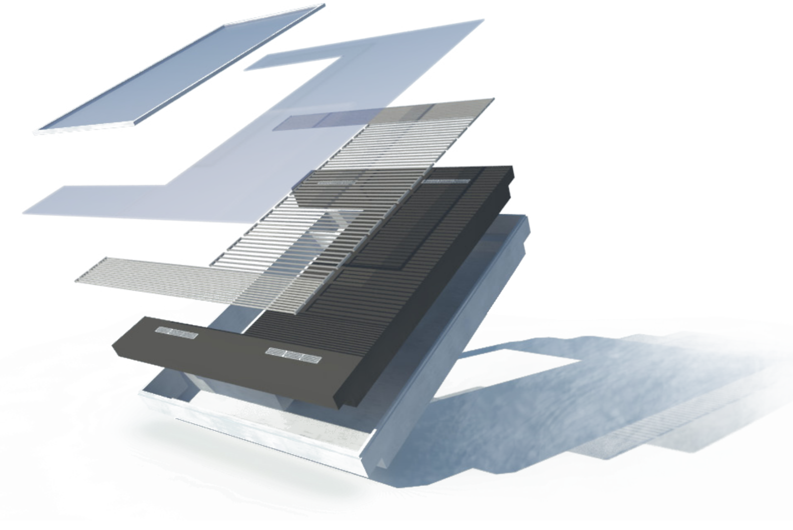

FIGURE 4-4 SYSTEM 02 "INTEGRATED OPENINGS": CONSTRUCTION OF SOLAR COLLECTOR SANDWICH PANELS - [2]

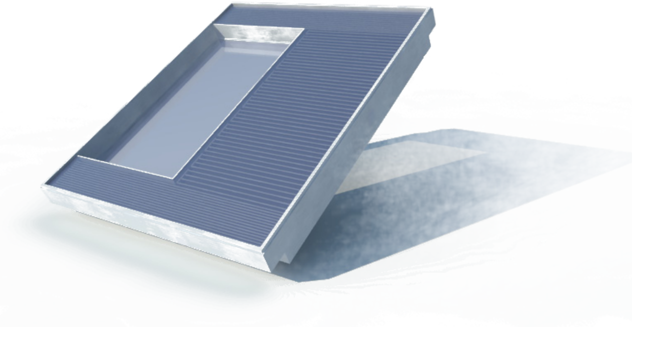

FIGURE 4-5 SYSTEM 02 "INTEGRATED OPENINGS": SOLAR COLLECTOR SANDWICH PANELS [2]

Principle advantage of SYSTEM 03 to SYSTEM 01 is the simpler installation process, since compared to SYSTEM 01, it contains no curtain wall solar collector elements. However, a steel support is used as an additional construction element for the structural load transfer and for the stabilisation of the sandwich panel and window openings. The system thus consists of a sandwich panel, supports and window elements.

SYSTEM 01, "printed, moveable panel" has the disadvantage that it is more complex in terms of construction and material: It requires two insulation layers. The first is located in the solar collector panel and provides thermal effectiveness of the pipework. The second insulation layer is located in the separating façade walls and is required for the heat insulation of the building skin.

SYSTEMS 02 and SYSTEMS 03 have only a single insulation layer integrated in the respective sandwich solar collector panel and provides simultaneous thermal effectiveness of the pipework and heat insulation of the building skin.

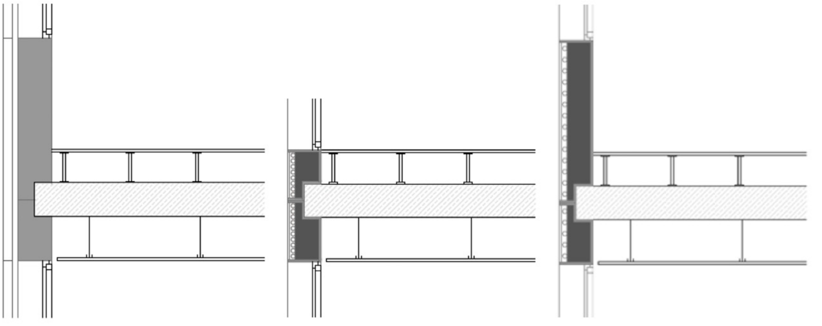

FIGURE 4-6 DETAIL FAÇADE CONNECTION TO STOREY CEILING: CASE STUDY MPPF, LEFT: SYSTEM 01 "PRINTED MOVEABLE PANEL"; CENTRE: SYSTEM 02 "INTEGRATED OPENING"; RIGHT: SYSTEM 03 "SANDWICH PANEL HORIZONTAL POSITION" [3]

COMPARISON GRID DIMENSIONS FAÇADE VIEWS

The following **FIGURES 4-7 TO 4-13** show the façade views for each of the three different systems for the two case studies in pairs. The first two figures show the façade view of SYSTEM 01 "printed moveable panel" on the left for the Karmeliterhof case study, and on the right for the MPPF case study. The façades in the upper storeys are shown without the curtain wall, printed solar collector panels. The façades in the façade view for the lower storeys are printed, moveable solar collector panels. The separating wall panels can be seen with window elements and the correspondingly different. modified sizes.

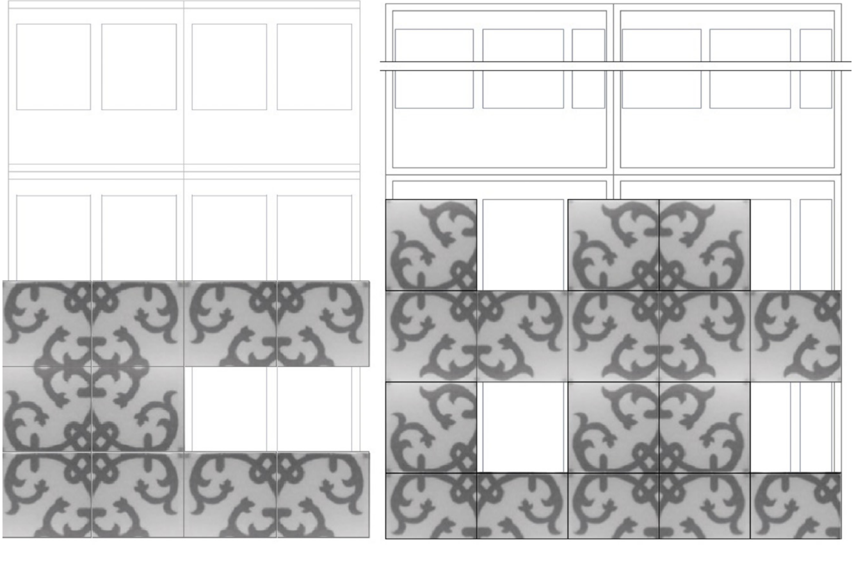

FIGURE 4-7 FAÇADE VIEW SYSTEM 01 "PRINTED MOVEABLE PANEL ", LEFT: KARMELITERHOF CASE STUDY; RIGHT: MPPF CASE STUDY [3]

The solar collector panel grid size and the separating wall façade elements with openings need to be coordinated with each other, since the situation is dealing with two parallel façade elements. Two window openings with a grid size of 2.25 m was defined for the Karmeliterhof case study. In the initial position of the moveable panels, a grid size (2.25m) with two window openings (1.71m) should be visible and not obscured by the solar collector panel. The parapet panel covers the lintel and the parapet is continuous and immoveable.

The right-hand case study MPPF defined three window openings with a grid size of 5.00m. Two window elements measured 2.00m and one smaller one measured 1.00m. In the initial position of the moveable panels, one window element (2.00m) with one window opening should be visible and not obscured by the solar collector panel. To ensure an identical visual impact of the openings in the initial position of the moveable panels, the façade module would have to be mirrored with alternate window openings. This was not done in this study. Please refer to the view right (MPPF case study). The parapet panel also covers the lintel and the parapet is continuous and immoveable.

The following two figures show the façade view of SYSTEM 02 „Integrated Opening“; case study Karmeliterhof is on the left and case study MPPF on the right.

The solar collector sandwich panel consists of a single element („all-in-one“ panel). This made the façade planning less complicated than for SYSTEM 01 with the additional curtain panel. The dimensions of the corresponding solar collector panels in the case studies were different.

In the Karmeliterhof case study on the left, the grid size was defined as 2.39 m. The integrated window opening had a height of 2.27 m. The upper and lower edges of the U-formed panel covered the lintel and the parapet and was defined with a height of 0.45 m such that the window was not as high as the room, and a lintel and low parapet were visible from the interior of the office building.

In the MPPF case study on the right, three window openings were defined in the grid size of 2.5 m. The integrated window openings had a height of 3.00 m. The upper and lower edges of the U-formed panel covered the lintel and the parapet and the height was defined as 0.45 m (lower) and 0.55 m (upper) in such a way that the elevated floor and suspended ceiling were covered. The result corresponds accordingly to a room-high window.

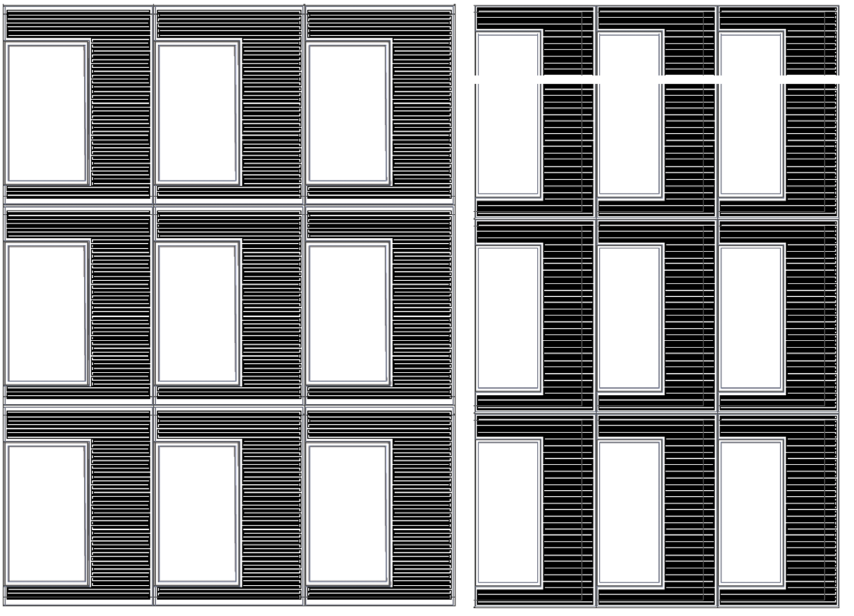

FIGURE 4-8 FAÇADE VIEW OF SYSTEM 02 "INTEGRATED OPENING", LEFT: CASE STUDY KARMELITERHOF; RIGHT: CASE STUDY MPPF [3]

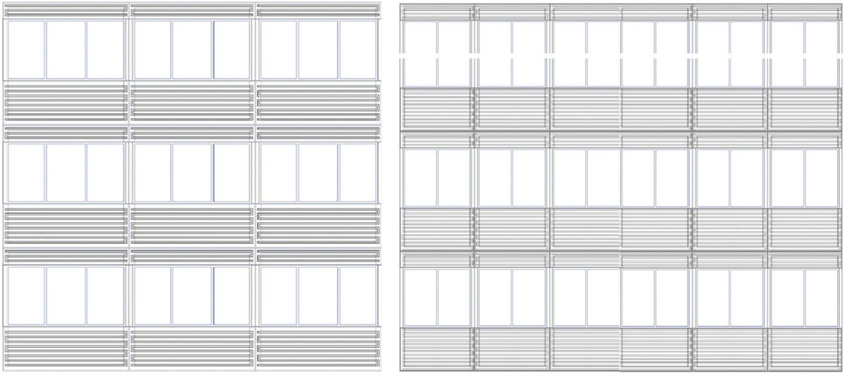

FIGURE 4-9 FAÇADE VIEW OF SYSTEM 03 "SANDWICH PANEL HORIZONTAL POSITION" LEFT: CASE STUDY KARMELITERHOF; RIGHT: CASE STUDY MPPF [3]

Both case studies provide the architect with copious freedom to modify the window position and hence the height and width of the opaque solar collector panels, thus designing the overall impression of the building façade. For example, the window opening could be shrunk such that the optical illusion of a punctuated façade appears.

As described, SYSTEM 03 „sandwich panel horizontal position" is similar to SYSTEM 02, except that an additional supporting construction must ensure appropriate stability, since the system is not mounted across storey. The leeway for architects to modify the dimensions of the solar collector panels is the ability to change the width and height of the panels.

The height of the sandwich panel depends on the height of the storey and the desired parapet height. The availability of a larger panel width depends on the manufacturing process and the static load-bearing capacity of the UNAB sandwich panel. Both aspects would require further research in a more detailed research project.

COMPARISON OF BUILDING AND FAÇADE GRIDS

The building grid has a substantial influence on the planning and dimensioning of façade panels in new buildings and in the modification of existing buildings. Solar collector sandwich panels can be very easily integrated in regular grid such as in the MPPF case study. Karmeliterhof, on the other hand, required panels or blind panels that were dissimilar in size because the „all-in-one“ elements were dependent on the existing building grid. In comparison, SYSTEM 01 „printed moveable panel“ offered the advantage of being able to be hung in front of a room-enclosing façade element if required. The following six figures show the 3 different façade systems (1 to 3) from the two case studies by way of comparison.

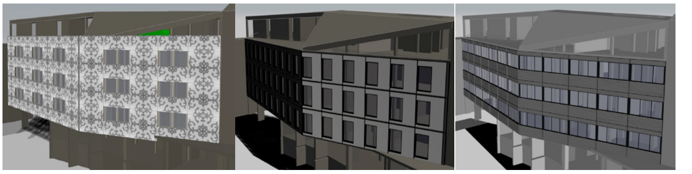

FIGURE 4-10 REPRESENTATION OF THE KARMELITERHOF CASE STUDY, LEFT: SYSTEM 01 “PRINTED MOVEABLE PANEL“; CENTRE: SYSTEM 02 “INTEGRATED OPENING”, RIGHT: SYSTEM 03 “SANDWICH PANEL HORIZONTAL POSITION” [3]

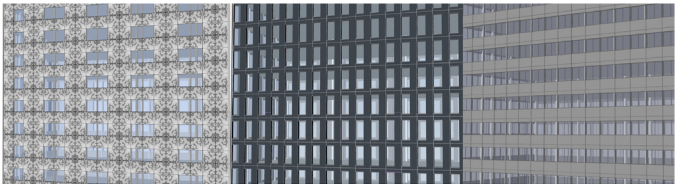

FIGURE 4-11 REPRESENTATION OF THE MPPF CASE STUDY, LEFT: SYSTEM 01 “ PRINTED MOVEABLE PANEL; CENTRE: SYSTEM 02 “INTEGRATED OPENING“, RIGHT: SYSTEM 03 “SANDWICH PANEL HORIZONTAL POSITION“ [3]

2. RESEARCH REQUIREMENTS

VISIBLE PIPEWORK

An important research requirement was the idea of making the pipework visible and to use it as a design element. Use of the pipework in the façade as a design element can be seen in the following two figures. Further work needs to be done to determine whether the sandwich panel glass cover could be transparent and whether this would influence the harvesting of solar energy. Currently, the UNAB panel investigations are being run in parallel in a 1:1 mock-up. Among the various aspects being researched is the energetic efficiency of the UNAB panel without a glass cover. The results are interesting in that pipework with a glass cover would be far more conspicuous and also that a glass surface can never be completely transparent but will always be reflective. This subject will be dealt with in the next section.

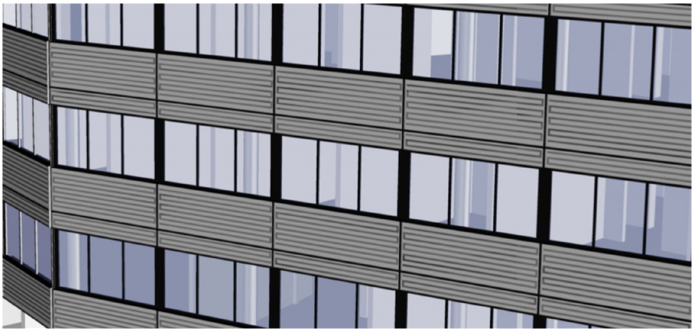

FIGURE 4-12 SOLAR COLLECTOR SANDWICH PANELS WITH VISIBLE PIPEWORK AND ANTI-REFLECTION COATING FOR SURFACE GLASS [3]

FIGURE 4-13 SOLAR COLLECTOR SANDWICH PANELS WITH VISIBLE PIPEWORK AND ANTI-REFLECTION COATING FOR SURFACE GLASS [2]

REFLECTION

FIGURE 4-14 shows a façade where the solar collector sandwich panels have visible pipework. The simulation shows what influence the panel's surface glass has on the appearance of the building's façade. Since a glass surface will never be completely transparent, but will always be reflective, the pipework is less visible than in the previous simulation. Further research is required to determine how much non-reflective glass would change this phenomenon and what degree of anti-reflection delivers which visibility. Of course, anti-reflective glass would increase the total costs of the solar collector sandwich panel, which then need comparing with variants.

PRINTED GLASS SURFACE

As shown in SYSTEM 01, it may be possible to print on the glass surface, which would extend the design freedoms of the façade system. Further research is required to evaluate the exact reduction in efficiency caused by non-transparent or semi-transparent printing. At the same time, it would be an important scientific gain to discover to what degree the solar energy harvest would be increased by a dark print (absorber characteristic).

DIMENSIONING

A fundamental research question concerns the possible dimensioning of the new UNAB sandwich panel. Currently, a panel length of 3.50 m is being tested in a 1:1 mock-up. Lengths of up to 5 m or more would be more advantageous for mounting because they would require fewer installation steps and would offer more freedom in designing the façade. This depends on the manufacturing process and the static load-bearing capacity of the UNAB sandwich panel and should be investigated in a further research project.

EDGING WINDOW CONNECTION

Further, the dimensioning of the window frame needs to be checked, the edging with window connection could be achieved with appropriate window types with different large depths. A 1:1 mock-up to check the use different window topologies (moveable and immoveable window frames) would bring clear results.

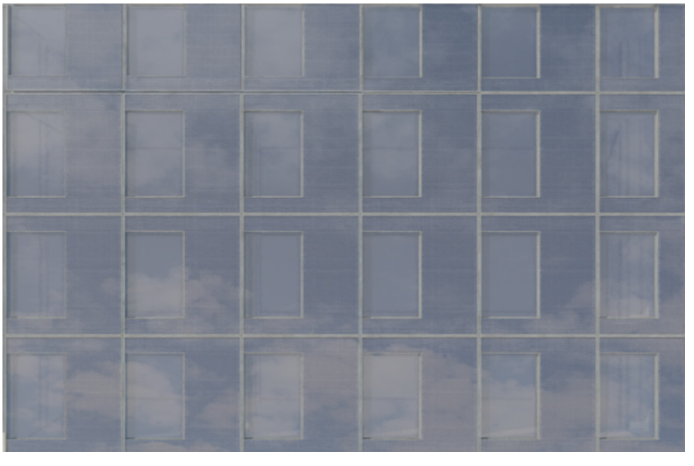

FIGURE 4-14 SOLAR COLLECTOR SANDWICH PANELS WITH VISIBLE PIPEWORK AND REFLECTING SURFACE GLASS [2]

LITERATURE

[1] Copyright Institute of Architecture Technology, Graz University of Technology, Ferdinand Oswald und Rocio Delgado Martinez-Fons, 2016.

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[3] Copyright Institute of Architecture Technology, Graz University of Technology, Ferdinand Oswald, 2016.

05

DEVELOPMENT OF THE UNAB FAÇADE

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BUILDING TECHNOLOGY PROFILE

This section discusses the three most important aspects of a façade from the point of view of building technology. These are the use of the outer shell to capture impacting solar radiation, the use of the inner shell to condition the climate of the interior room and the use of the layer between these two shells as thermal insulation (**FIGURE 5-1**).

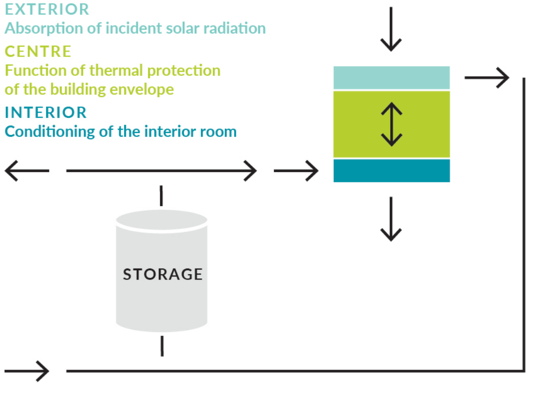

FIGURE 5-1: INTEGRATION APPROACH

1. USE OF IMPACTING SOLAR RADIATION (OUTER LAYER)

All opaque surfaces use the impacting solar radiation, whereby the choice of conversion technology should be determined by the requirements of the building (decentralised approach) and the available solar radiation. The energy conversion systems are generally differentiated into solar-thermal and photovoltaic (conversion to electrical power) systems.

SOLAR-THERMAL COLLECTORS

The construction and operating principle of solar-thermal collectors have been described in detail in the previous analysis. Here in the development profile, the most important technical requirements for the façade element are described and used to extract and represent parameters (dimensions, technical details) in different ways.

SOLAR-THERMAL COLLECTORS WITH GLASS COVERS

In one of the possible façade designs, covered solar-thermal collectors are integrated into the outer shell. **FIGURE 5-2** shows four different possible variants of locating absorber and pipework. In variant (1), the channels form the connection between the individual absorber sheets in the collector. In variant (2), the channels are located on the absorber in the front air cavity of the collector. The absorber in variant (3) is located directly on the masonry/thermal insulation, whereby the collector only contains one air cavity. The channels themselves are mounted directly on the absorber sheet. In variant (4), the channels are located behind the rear collector's air

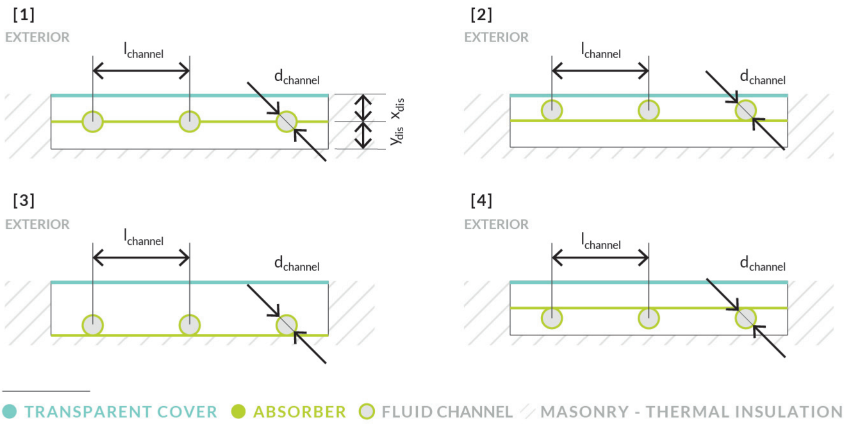

FIGURE 5-2: SCHEMATIC SHOWING POSSIBLE VARIANTS OF COVERED SOLAR-THERMAL COLLECTORS

cavity and fastened to the absorber.

In addition to the principally different layouts, other parameters can be varied:

- The distance ($l_{channel}$) between the channels in the collector
- Absorber thickness
- The channel diameter ($d_{channel}$) in the collector
- The location (x_{dis} and y_{dis}) of the absorber in the collector
- Use of different transparent covers (transmission, absorption and reflection of solar radiation)
- Use of different absorber materials (absorption, reflection, heat transfer)
- Use of different channel materials

SOLAR-THERMAL COLLECTORS WITHOUT GLASS COVERS

Solar-thermal collectors are often manufactured without transparent covers. In this case, the channels are integrated in the building skin, which acts as a solar thermal absorber. **FIGURE 5-3** shows four possible layouts for uncovered collectors in the façade. In variant (1), the channels are directly located behind the outer skin within the façade. In variant (2), the channels are outside the façade and fastened directly to the outer skin. In variant (3), the outer skin has inbuilt recesses to contain the channels. The outer surface of the channel is thus a part of the façade. In variant (4), the façade has square recesses that are larger than the channel diameter. The channel is thus hidden in the periphery but is fastened to the outer building skin. The uncovered solar-thermal collectors also have additional variable parameters:

- The distance (l_R) between the channels in the collector
- Absorber thickness
- The diameter of the channels (d_R) in the collector
- The mounting depth ($t_{channel}$) of the channels in the façade

FIGURE 5-4: FROM THE TOP MONOCRYSTALLINE PV CELL BLACK, BLUE, POLYCRYSTALLINE PV CELL

- Geometric layout (n_{dis}, m_{dis}) of the exterior surface
- Material properties (insulation core, fluid channel, cover sheets)

PHOTOVOLTAIC CELLS

Instead of using the solar radiation to heat a fluid, photovoltaic cells can be mounted on the surface layer of a façade to convert solar radiation into electricity. There are a number of different technological approaches and variations in which solar radiation can be converted into electrical power.

OPAQUE SILICON CELLS (MONOCRYSTALLINE, POLYCRYSTALLINE)

The simplest and (so far) most efficient photovoltaic cells are monocrystalline and polycrystalline silicon cells (**FIGURE 5-4**) **[1]**.

SEMI-TRANSPARENT THIN LAYER PV CELLS

In order to be able to use transparent surfaces for energy conversion, so-called “semi-transparent” PV cells have been developed. These consist of very thin layers that are able to absorb some of the impacting radiation and to transmit the rest, for example to provide an interior room with daylight (**FIGURE 5-5**).

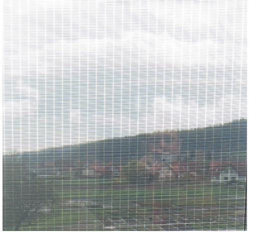

FIGURE 5-5: THIN LAYER PV CELL EXAMPLE TAKEN FROM THE RESEARCH PROJECT “MULTI-FUNCTIONAL PLUG & PLAY FAÇADE (MPPF)” [2]

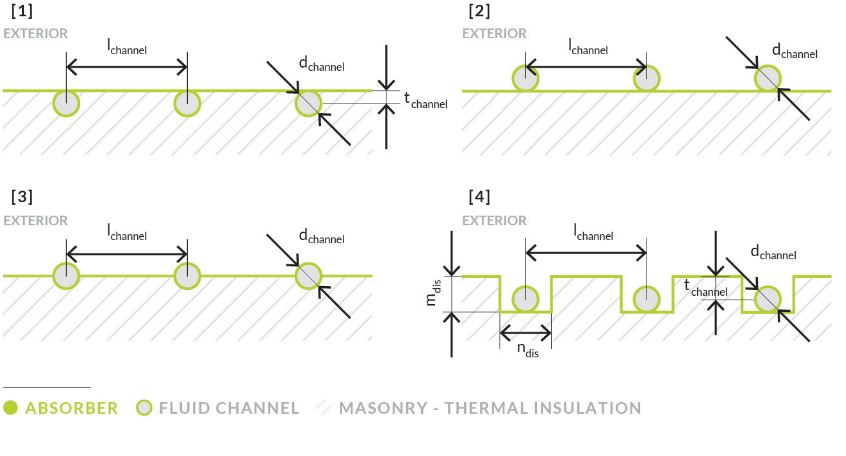

FIGURE 5-3: SCHEMATIC OF POSSIBLE COLLECTOR VARIANTS WITHOUT COVERS

TRANSPARENT GRÄTZEL CELL

The Grätzel cell is a new technology for the conversion of solar radiation into electrical power **[3,4]**. A part of the impacting radiation is transmitted in a similar way to the semi-transparent cell and a part is absorbed and converted into electrical power.

COMBINATION OF SOLAR-THERMAL COLLECTOR AND PHOTOVOLTAIC

Depending on installation space available and the requirements, a combination of solar-thermal collectors and photovoltaic systems can be integrated into a façade, however with penalties regarding the efficiency of the individual, integrated components (e.g. reduction of fluid heating due to shading or partial absorption of solar radiation by the PV cells).

2. THERMAL BUILDING ENVELOPE (MIDDLE LAYER)

The middle layer of the façade element has, apart from the static requirements, only one important role from a thermal point of view. Its task is to separate the interior from the exterior. This results in the protection of the interior against temperature fluctuations caused by the weather conditions.

3. INTERIOR CONDITIONING (INNER LAYER)

The inner surface of the compact element must be thermally activated to be useful for heating or cooling. The best case would be a direct transfer of the harvested energy from the outer to the inner layer. Different systems can be used for the inner layer depending on the energy conversion system on the outer shell.

HEATING AND COOLING WITH FLUID SYSTEMS

These are heating (or cooling) systems using fluids that are first heated (cooled) and then emit (absorb) energy via pipework to (from) one room (or surface) due to the prevailing different temperature levels. For example, a fluid heated by the solar-thermal collectors can be used for this.

FIGURE 5-6 shows three variants for pipework installation on the inner layer of the façade. In variant (1), the pipework is installed within the façade close to the inner layer. In variant (2), the pipework is outside the wall mounted on its inner layer. In variant (3), the inner layer has corresponding recesses as the outer layer in the previous case in which the pipework can be partially hidden in the façade.

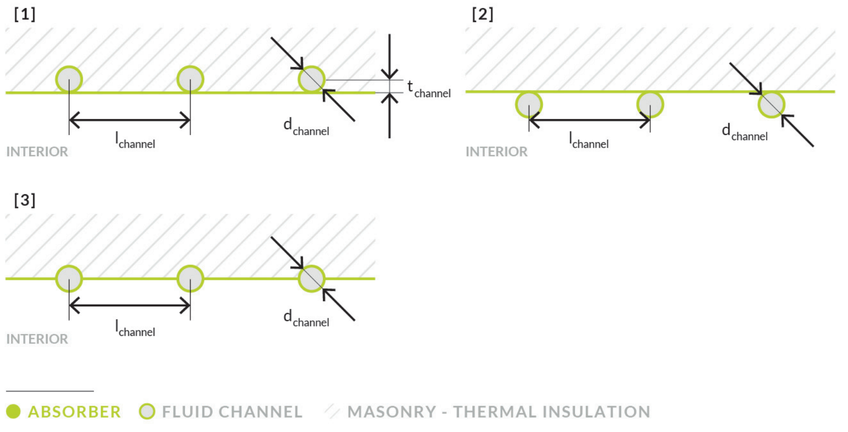

FIGURE 5-6: SCHEMATIC OF POSSIBLE VARIANTS OF HEATING AND COOLING PIPEWORK FOR THE CLIMATIC CONTROL OF AN INTERIOR ROOM

Other variable parameters regarding pipework on the inner layer of the façade are:

- The distance ($l_{channel}$) between the channels in the collector
- Absorber thickness
- The diameter ($d_{channel}$) of the channels in the collector
- The mounting depth ($t_{channel}$) of the channels in the façade
- Material of the channels and the absorber

PROFILE HYBRID SUPPORTING STRUCTURES

1. DEVELOPMENT APPROACH

The evaluation of the results of the analysis processes for hybrid supporting structures for the façade points in the direction of the development of a special, flat, however even conceivably curved, thermally activated sandwich element. Other hybrid constructions on the component level for use as façade elements would also be conceivable, however more potential is expected from a sandwich panel due to its simple manufacturability and suitability for mass production. Millions of sandwich panels are used in the construction sector, above all in the industrial and cold storage building markets, as ready-to-mount elements to create a thermal building envelope for walls and roofs.

The partial use of panel surfaces for solar energy harvesting on the outer layer and the thermal conditioning (heating or cooling) of the interior rooms on the inner layer formed one of the basic development ideas within the research project UNAB. The goal was not an architectural-technical special solution, but the development of a generally applicable, mass production-capable façade element that can be easily modified according to architectural design requirements (“mass customization”).

Currently, the sandwich panels available on the market normally only have one at the most two of the following four characteristics:

- Hybrid supporting structure
- Thermal building shell
- Energetically activated
- Architecturally formed

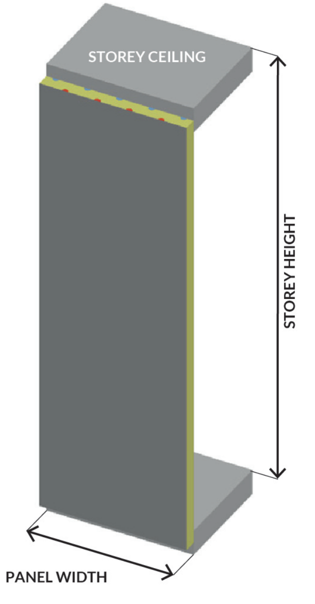

FIGURE 5-7: STOREY HIGH UNAB PANEL IN A LEVEL VERSION

For this reason, the decision was made to develop a façade element that is able to fulfil all requirements. The buzzword chosen for this integrated approach is "UNAB panel".

As far as possible, horizontal and vertical supporting elements as sub-constructions have been minimized. The aim is not to develop a (conventional) post and beam façade. A consequence of this is that only the available storey ceilings, between which the façade is mounted, are used to transfer horizontal and vertical loads (**FIGURE 5-7**).

The further development of this approach would be the transition to even larger sandwich panels spanning across more than one storey (multi-span beams), because this would be advantageous for the static behaviour. The question of the handling of structural elements of approximately 11 m and more in terms of production, logistics and assembling would need to be investigated separately. The idea of manufacturing non-planar, doublecurved surfaces is not exclusively motivated as an act of architectural design, but also has functional advantages, for example regarding the supporting behaviour or energetic activation.

Curvature in the macro structure can, assuming compliance with certain boundary conditions, achieve a bending-free load transfer (shell load support effect), while curvature in the micro structure increases the local buckling strength against loss of stability within areas under compression. Simultaneously, curvature in the micro and/or macro structure can be used to focus and to distribute radiation, and to be used for shading purposes (**FIGURE 5-8**).

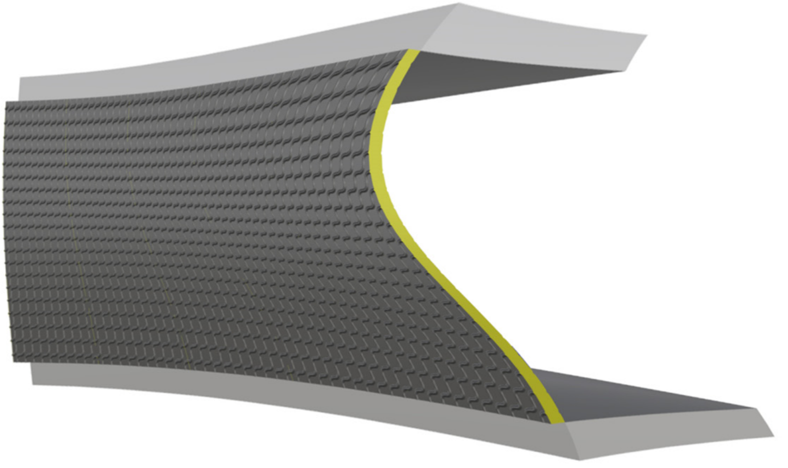

FIGURE 5-8: STOREY HIGH UNAB PANEL WITH CURVATURE IN THE MICRO AND MACRO STRUCTURE

Two variations for the supply of panels with pipework are conceivable: On the one hand, the inlet and outlet for the fluid channels can be located in the horizontal panel edges at storey height in the form of a “distribution panel”, or directly in the floor construction, or in a suspended ceiling. On the other hand, the pipework could also be located in the vertical area between the individual panels using an “adapter profile”. The use of multi-storey panels would also have the advantage that the pipework distribution would not require special building components.

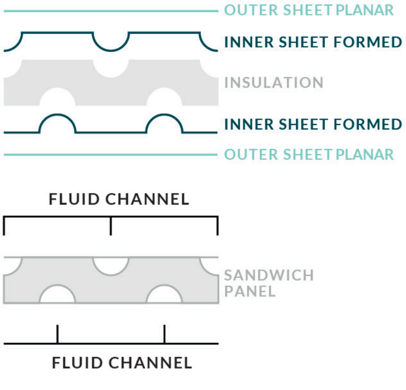

FIGURE 5-9: LEVEL LAYOUT UNAB PANEL (4 SHEETS)

2. PANEL LAYOUT

The approach of using the metal cover sheets of a sandwich panel for fluid-filled channels, manufactured using forming technology, is seen as a promising development. For this purpose, two sheets are located on both the outer and inner covers. Each inner sheet is processed such that special hollow areas are formed, while the outer cover sheets remain planar and assume the role as a seal (**FIGURE 5-9**).

FIGURE 5-10: FORMING VIA ROLL-BONDING

The way in which both sheets are joined together to achieve the required seal is a question of the forming technology employed. “Roll-bonding” is a promising approach in this context. (**FIGURE 5-10**).

As an alternative, there is the possibility that the two sheets are not directly formed to channel cross-sections, but conventional shaped tubes (circular, elliptical, square, triangular, etc) are welded to the outer (planar or curved) cover sheet.

By connecting forming the sheets hollow spaces in the sandwich panel representing channels through which fluids can flow are created. The outer side acts as an absorber that harvests the solar energy. According to the season the fluid channels of the inner side can be used for heating and cooling the interior rooms.

3. HYBRID SUPPORTING STRUCTURE

The energetic activation of the façade is but one advantage the UNAB panel has. The fluid channels not only function as pipework for liquids, but also simultaneously increase the rigidity of the sheets many times over and hence also the complete façade element. The buckling strength of the sheets is significantly increased by the forming, in particular by the number of fluid channels per length unit and their cross sectional form. **FIGURE 5-12 (A-E)** shows the potential.

The metallic cover sheets in a sandwich panel are joined together with the insulation core in a shear and tensile-resistant manner (composite section). The insulation material in the core is however not immune to shear forces. Generally, the sandwich panels display hybrid supporting behaviour, which means that applied loads (such as wind) result in bending moments (composed of tensile and compression forces) being transferred via the cover sheets and the shear forces being transferred via the insulation core. The material in the insulation core, resp. its shear stiffness, has a direct effect on the

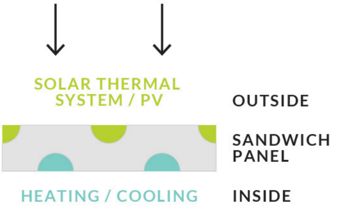

FIGURE 5-11: SANDWICH PANEL WITH FLUID CHANNELS (UNAB PANEL)

previously described supporting behaviour and the deformations of the complete system that occur. Increasing the sheet thickness or the installation of several sheets (cover sheet and fluid channels) on the inside and outside of the façade panel influences its bend-

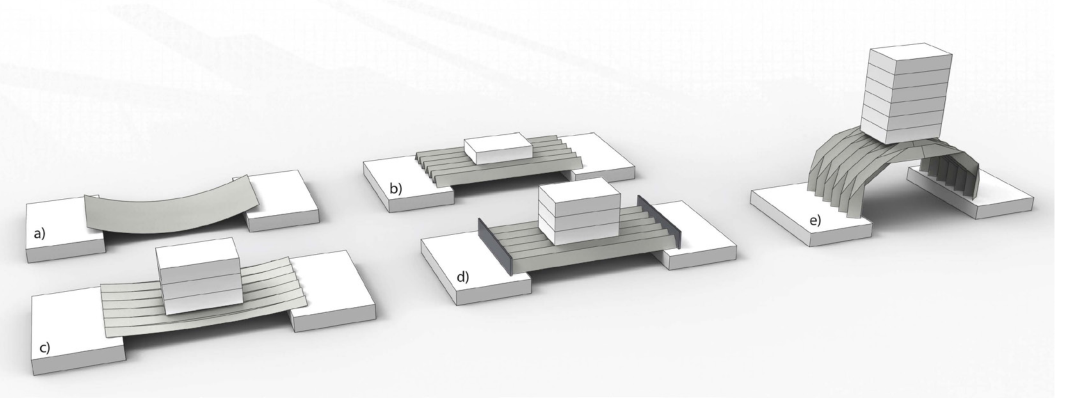

FIGURE 5-12: RIGIDITY DUE TO FOLDING [5]

ing stiffness. The optimisation of energetic, static and economic aspects are the subject of subsequent investigations.

PROFILE FORMING TECHNOLOGY

This section provides more detail on the manufacture of the panels. This is done by regarding different forming techniques and considering their advantages and disadvantages. The two most suitable forming techniques in this case are cold roll bonding and deep drawing. Furthermore, the possibility of manufacturing different forms need to be investigated. The façade structure also poses huge challenges regarding insulation and design.

1. POSSIBLE FORMING PROCESS

In order to fulfil the requirements placed upon the panels, the first step is to find a suitable forming process for the production process of the absorber. This task has proved to be very difficult, since a three-dimensional external contour of the panels was demanded, which furthermore can change from element to element.

In conclusion, the “deep drawing” process was selected with “cold roll bonding” being identified as the best alternative.

COLD ROLL BONDING

Cold roll bonding is used in heat exchangers in flat collectors or in refrigerators. The advantage of this process is than it is possible to form the fluid channels optimally and the joining process is combined with the rolling process. The disadvantage however is that due to the channels in the sheet, subsequent forming is limited.

In order to achieve useful results, further research could focus on either optimising the formability after the roll bonding process, or the inflation process is executed in a three-dimensional surface after the forming of the flat sheet (**FIGURE 5-13**).

The forming operation and the following inflation process in order to produce three-dimensional panels is described in **CHAPTER 7**.

MECHANICAL DEEP DRAWING

The process intended to be used first is deep drawing. However, this requires two different sheets to be formed for each cover sheet and then joined into a single entity later. The big advantage here is than practically any arbitrary three-dimensional surface can be formed. The disadvantage is that the sheets must have a sealing joint, which poses a huge challenge for joining technology (**FIGURE 5-14**). There are several possibilities to join the sheets together. The sheets can either be glued or welded together, or joined by using a powder in conjunction with subsequent heat treatment. The optimum joining process however still needs to be discovered in tests and then optimised.

2. MATERIALS

A further challenge is the insulation of the panels. Due to the fact that fluids flow between the sheets, which leads to different temperature zones on the sheet, the thermal insulation must prevent the formation of condensation as far as possible and also prevent mould or algae growth through the presence of water.

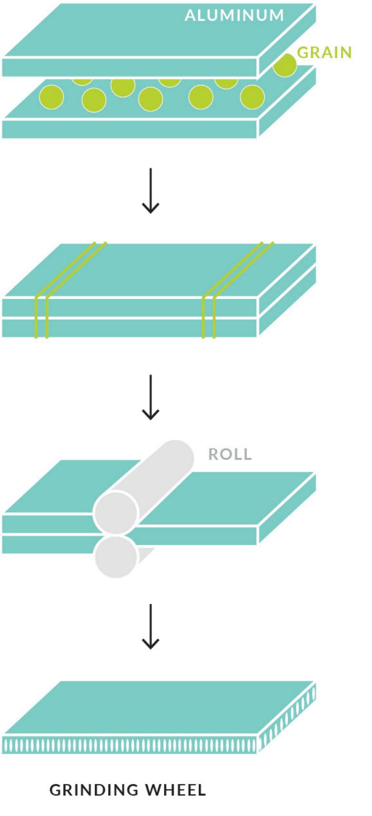

FIGURE 5-13: COLD ROLL BONDING [6]

These requirements can be fulfilled very well using a cellular glass core. It can be cut in arbitrary forms and in inorganic, meaning that algae and mould growth will not occur.
Finally, a suitable material for the sheets must be found that is extremely robust yet simultaneously as lightweight as possible and possesses good heat insulation properties. Aluminium would be very suitable, but a more exact selection of materials must be tested and the results validated before an optimal material can be selected.

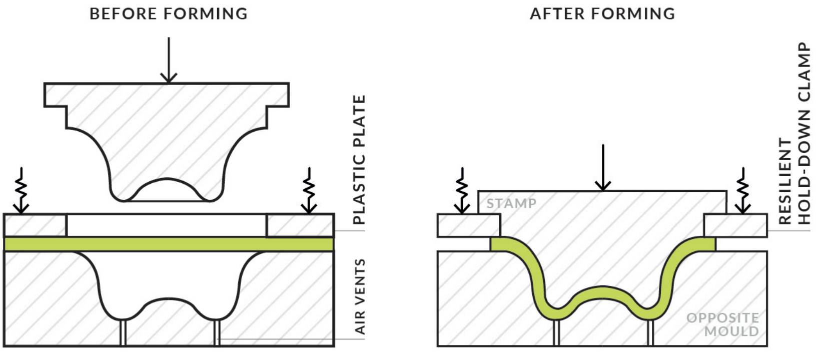

FIGURE 5-14: DEEP DRAWING [7]

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06

DEVELOPMENT OF A HYBRID FAÇADE ELEMENT

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THOMAS MACH

THERMAL SIMULATION OF THE FLUID CHANNELS TO DETERMINE THE CROSS SECTION

The thermal and flow-related behaviour of a number of previously selected scenarios was analysed during the development of hybrid supporting constructions in which fluid channels were to be integrated for solar energy conversion and conditioning of the interior. The aim of these investigations was to determine a suitable configuration for the fluid channels on the outer layer for the previously selected supporting structures and to select the corresponding geometric details of the channels.

1. METHODOLOGY

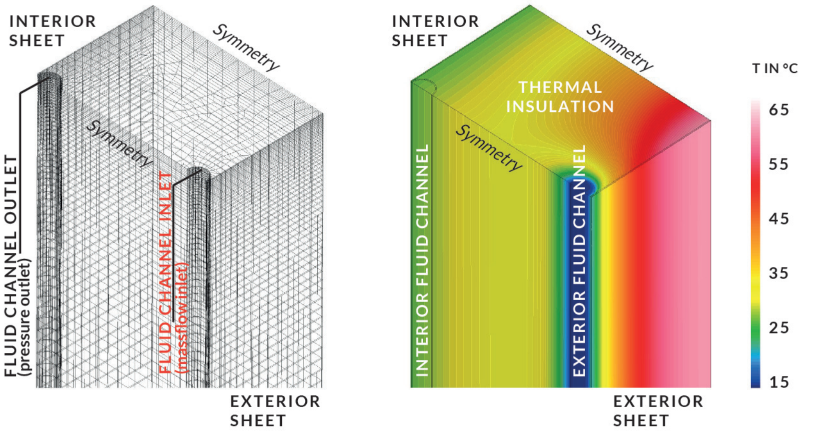
All the investigations into thermal behaviour employed the method of Computational Fluid Dynamics (CFD). In CFD, a geometric model is divided into a number of small volumes (finite volumes) and then the prevailing phenomena (e.g. temperature, flow velocity) are calculated iteratively for each cell using previously selected numerical equation models (e.g. flow, heat transfer) in order to obtain upon completion a coherent simulation result for the complete model geometry.

The commercial software used in this investigation was supplied by the company ANSYS. The meshing of the geometric models was carried out with the included meshing tools and the simulations were executed using ANSYS Fluent **[1]** software. These software tools enabled the detailed simulation of convective flow processes occurring in the supporting structure in combination with the heat and radiation transport (heat and solar radiation). The fluid flow are represented in all simulations by the k-ε turbulence model that, according to experience and the Fluent User Guide **[2]**, is best suited for such flow characteristics.

The energy equation was activated in order to enable the heat transport in the simulation model. This contains convective heat transfers between fluids and solid components as wells as the heat transfer in and between the individual solid components.

2. MODEL CONSTRUCTION AND BOUNDARY CONDITIONS

The construction of the CFD model used for the pre-investigation needs to be as simple as possible in order to obtain fast initial results and cover the largest possible range of scenarios. For this reason, the pre-investigation was limited to a one meter high section of the façade. The CFD mesh and the model structure are shown in **FIGURE 6-1**.



Material	Density [kg/m³]	Specific heat capacity [J/kgK]	Thermal conductivity [W/mk]
Water	998.2	4189.0	0.6
Steel	7850.0	490.0	54.0
Aluminium	2700.0	896.0	201.0
Copper	8978.0	381.0	387.6
Polyurethane	40.0	1400.0	0.025

FIGURE 6-1: REPRESENTATION OF THE CFD MESH FOR THE REFERENCE SCENARIOS RF (LEFT) AND THE PRINCIPLE CFD MODEL STRUCTURE FOR ALL CALCULATED SCENARIOS (RIGHT), MATERIAL PROPERTIES (BELOW)

The model consists of an outer and an inner metal sheet (thickness 0.8 mm) with thermal insulation between (made out of rigid polyurethane foam, insulation thickness 150 mm). A pipe (fluid channel) was integrated in the outer sheet within the thermal insulation in the CFD model, which permits fluid flow. The material data are summarized in the table. In the CFD model, a contact strip with a width of 4 mm (for example, as would occur in consequence of a welding seam) was created between the sheet and the fluid channel.

Heat is transported to the channel via the outer sheet, which heats up due to the impacting solar radiation, and is partially absorbed by the fluid. There is also a fluid channel on the inner side that could increase or lower the temperature in the interior room if required. The sandwich panel can be considered as a theoretically endless façade by assuming symmetrical conditions on both sides of the CFD model. The heating effect in the analysis was defined with an outside temperature of 40 °C and a solar radiation of 1000 W/m² with a room temperature of 26 °C.

A heat transfer coefficient of 5 W/m²K was assumed for the inner wall and a value of 25 W/m²K for the outer wall. The absorption coefficient for solar radiation on the surface of the outer sheet was defined in the simulation with a value of 0.8. The fluid enters the channel with a temperature of 15 °C and runs with a mass flow of 100 kg/h.

3. SUMMARY OF THE ANALYSIS FOR THE DETERMINATION OF THE CROSS SECTION

More detailed describtion of the cross section investigated can be found in **[3]**.

FIGURE 6-2 shows a comparison of the water outlet temperature and the average outer sheet temperature for the scenarios investigated.

In scenarios SZ0 to SZ2, the shape of the fluid channel cross section was varied. The reference scenario assumed a fluid channel with a circular cross section and an inner diameter of 8 mm; scenario SZ0 contained a channel with a semicircular cross section with a radius of 11.3 mm. In scenario SZ1, the circular channel was replaced by a channel with a rectangular cross section with an edge length of 14.2 mm and the last scenario

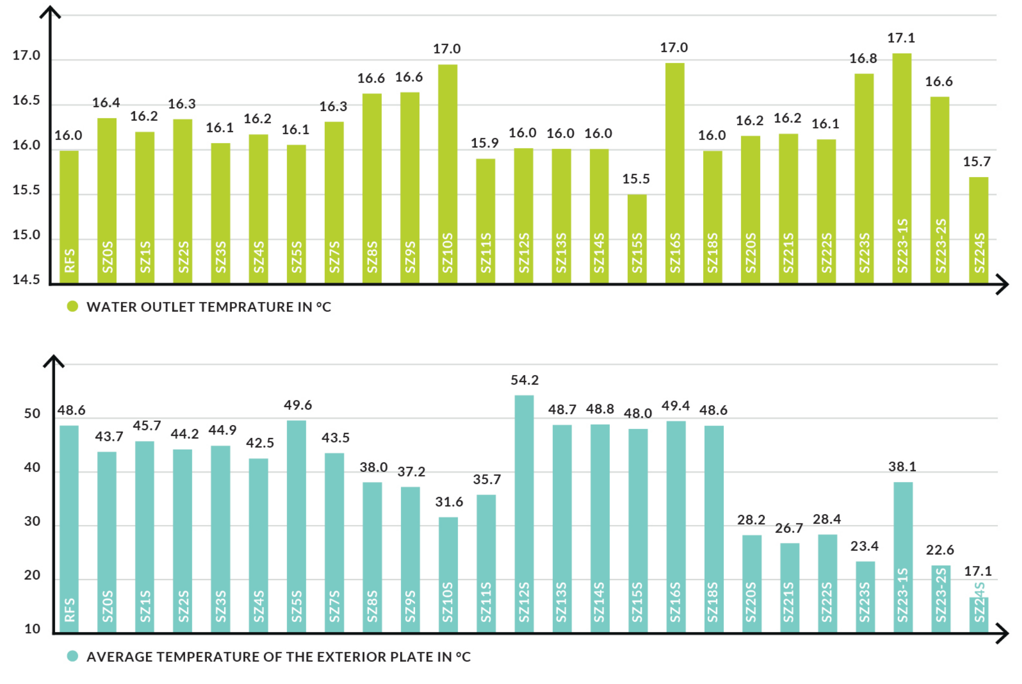


FIGURE 6-2: TABULAR COMPARISON OF SIMULATED FLUID CHANNEL VARIANTS (FOR THE CASE OF SUMMER) IN THE SANDWICH PANEL

(SZ2) for the shape of the cross section contained an equilateral triangle with an edge length of 21.6 mm.

In scenarios SZ3 and SZ4, the position of the fluid channel was varied. SZ3 placed the fluid channel, which in the reference scenario was integrated within the thermal insulation of the panel, protruding halfway (half the channel casing surface) outside the panel. In this case, the outer sheet is in two parts and on both sides joined with the fluid channel. In scenario SZ4, the fluid channel is completely external to the panel and the contact point between the outer sheet and the channel is 4 mm, as in the reference scenario. In scenario SZ5, the inner radius of the fluid channel was extended from 8 mm to 12.5 mm.

After variations in the position and radius of the fluid channel, the next two scenarios increased the wall thickness of the sheets and of the fluid channel. In scenario 7, beginning with the 0.8 mm in the reference scenario, the wall thickness was increased to 1.6 mm. In scenario SZ8, the wall thickness was increased to 3.2 mm.

The next two scenarios investigate the influence of the thermal conductivity of the sheet material on the thermal panel behaviour. To do this, the steel sheets and the fluid channels were replaced by materials with higher thermal conductivity. In scenario SZ9, the steel sheet was replaced by aluminium sheet with a thermal conductivity of 201 W/mK. In scenario SZ10, copper replaced steel as the material for all sheets with a thermal conductivity of 387.6 W/mK.

The next variation in the parameter analysis concerns the distance between the fluid channels. In the phase of creating the reference model, a width factor y_B was defined with a value of 50 mm (= 100 mm fluid channel distance). In the reference scenario, the distance between the channels was 200 mm, corresponding to $2 \cdot y_B$. The broadening of the CFD model automatically results in a larger channel distance due to the symmetrical boundary conditions. In scenario SZ11, the fluid channel distance was halved compared to the reference scenario (separation = y_B). The distance between the fluid channels in scenario SZ12 was increased from $2 \cdot y_B$ to $3 \cdot y_B$.

Following on from the variation of the fluid channel separation, the influence of the thermal insulation thickness between the outer and inner sheets was investigated regarding thermal behaviour. An initial insulation thickness factor x_T was defined with a value of 75 mm. In the reference scenario, the insulation was defined with a thickness of 150 mm (= $2 \cdot x_T$). In scenario

SZ13, the insulation thickness was reduced compared to the reference value by half (= x_T). In scenario SZ14, the insulation thickness was increased from $2 \cdot x_T$ to $3 \cdot x_T$.

A part of the parameter analysis was dedicated to investigate the thermal influence and the heating mass of the fluid in the façade by varying the flow rate. To achieve this, the next two scenarios regard the mass flow, beginning with 100 kg/h in the reference scenario with both a higher (200 kg/h) and a lower (50 kg/h) mass flow rate.

Scenario SZ18 integrated a further fluid channel in the inner sheet (within the insulation) of the sandwich panel in order to cool the interior room in summer.

A rectangular cross section was defined for scenario SZ20 with a ratio of length (a_R) to width (b_R) of 3:2. The fluid channel distance was defined as 100 mm; both the thickness of the sheet and the fluid channel was configured with 1 mm. The cross section of the rectangle possessed the same area as the circular channel cross section in the reference scenario.

The circular cross section in scenario SZ21 used the same area as the fluid channel in the reference scenario, since this performed well from the point of view of heating the water in the fluid channel. However, the thickness of all sheets and the fluid channel was increased here to 1 mm and the fluid channel distance was set to 100 mm.

In order to improve the heat transfer from sheet to fluid channel, the contact strip between the circular channel and the sheet is increased in scenario SZ22 by a relatively thick welding seam and hence achieving higher water outlet temperatures. In the simulation model, the welding seam thickness is approximately 6 mm. The circular channel radius in this variation is 8 mm, the sheets and the fluid channel have a thickness of 1 mm and the fluid channel distance in this case is 100 mm.

A wave channel profile with a radius of 11.5 mm was defined for scenario SZ23. Sheet and fluid channel thickness are again 1 mm and the fluid channel distance is 100 mm.

For comparison reasons, scenario SZ23-1 differs from SZ23 only therein that the fluid channel distance is increased from 100 mm to 200 mm.

In scenario SZ23-2, the wave channel profile was reversed and now lies within the insulation. The fluid channel distance is again 100 mm.

In the last scenario SZ24 of these detailed investigations, SZ23 acted as the base and the fluid channel distance was reduced to the minimum possible distance y_B (41 mm).

Once the very different variants and, above all, the characteristically relevant cross sections in the scenarios had been considered regarding the fluid heating, one particular cross section stood out, namely the cross section with the wave channel profile. This profile was selected for further analysis in the following chapters.

4. CONCLUDING ANALYSIS OF THE SELECTED FLUID CHANNEL CROSS SECTION

The wave profile for the fluid channels in hybrid structures was selected for the further investigations. **FIGURE 6-3** shows the temperature contours for the scenarios selected for the parameter analysis (SZ30 and SZ31).

The wave profile has a radius of 11.5 mm, the thickness of both the sheets and the fluid channels in these scenarios was 0.6 mm, the panel height was 3.5 m and the insulation consisted of 150 mm rigid polyurethane foam. In order to determine more specific dimensions for the construction, the investigations examine the sensibility of the following parameters regarding water outlet temperature and thermal performance of the water in the fluid channels.

The mass flow in scenarios SZ30 and SZ31 were increased in steps from 3.125 up to 800 kg/h (each doubled).

The fluid channel separation was increased, starting from the minimum possible distance of 41 mm up to a distance of 500 mm.

Simulations were carried out in scenarios SZ30 and SZ31 each for the nine different steps of the mass flow. This was done in a detailed study to investigate the influence of the mass flow on the

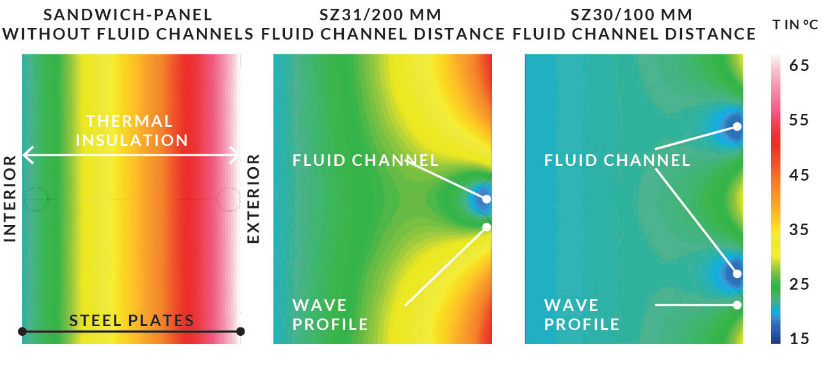


FIGURE 6-3: VISUALISATION OF THE TEMPERATURE CONTOURS FOR THE SANDWICH PANEL CROSS-SECTION FOR SCENARIOS SZ30, SZ31 (FOR A MASS FLOW OF 50 KG/H) AND FOR A SANDWICH PANEL WITHOUT FLUID CHANNELS FOR THE SUMMER SCENARIO

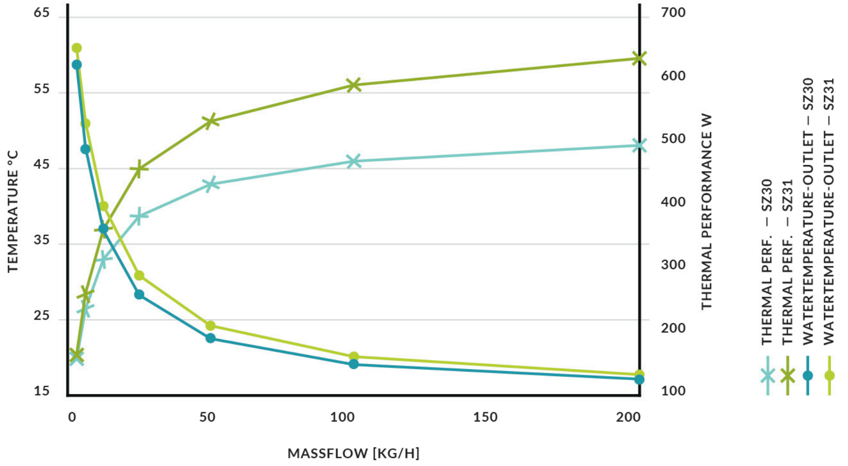


FIGURE 6-4: COMPARISON OF WATER OUTLET TEMPERATURE AND THE RESULTING THERMAL PERFORMANCE FOR DIFFERENT MASS FLOWS IN THE FLUID CHANNEL IN THE SUMMER SCENARIO

thermal behaviour in hybrid supporting structures with fluid channels possessing wave profile cross sections.

FIGURE 6-4 shows a comparison of the water outlet temperatures and thermal performance.

The thermal performance consists of the temperature increase of the water ($T_{W,out}$ - $T_{W,in}$) after passing through the fluid channel in the panel, the mass flow m_W and the specific heat capacity $c_{p,W}$.

$$\dot{Q}_W = \dot{m}_W \cdot c_{p,W} \cdot (T_{W,out} - T_{W,in})$$

Since there was hardly any change neither in the water outlet temperature nor in the thermal performance with a mass flow exceeding 200 kg/h, **FIGURE 6-4** only plots the area up to 200 kg/h.

The water temperature could be raised by more than 45 °C with a very low mass flow of 3.125 kg/h. However, the low flow rate resulted in low thermal performance. Proceeding from 3.125 to 50 kg/h, the water outlet temperature falls away rapidly, whereas the thermal performance is significantly increasing. Between 50 and 200 kg/h, both cases demonstrate only slight changes.

Since the two scenarios SZ30 and SZ31 only differ in the distance between of the fluid channels, it is sufficient to deal with only one of the two scenarios in this analysis. In this case, the fluid channel distance was continuously increased from the smallest possible distance resulting form the geometry of the wave profile. **FIGURE 6-5** shows the achieved water outlet temperature and the thermal performance, as previously used in the investigation of the influence of the mass flow.

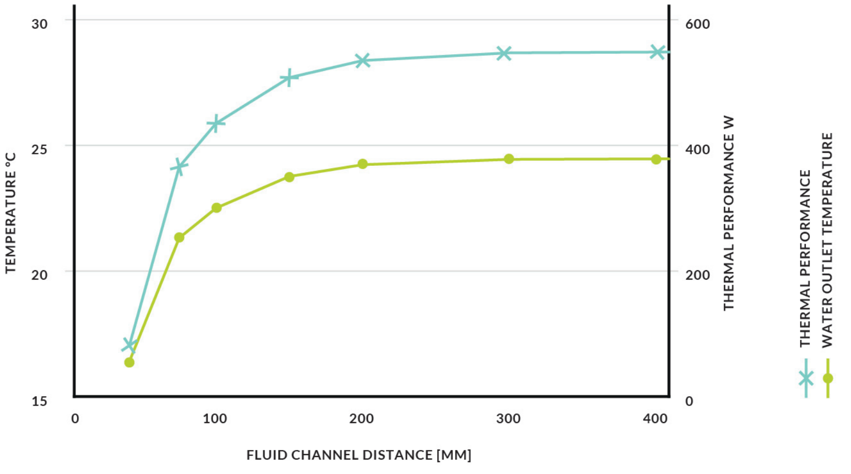


FIGURE 6-5: COMPARISON OF WATER OUTLET TEMPERATURE AND THE RESULTING THERMAL PERFORMANCE FOR DIFFERENT FLUID CHANNEL DISTANCES FOR THE SUMMER SCENARIO

In total, 8 different fluid channel distances (from 41 to 500 mm) in scenario SZ30 with the wave profile were used in the simulations to determine the thermal behaviour. A rapid increase both in the water outlet temperature and in the thermal performance can be observed for fluid channel distances between the minimum and a distance of 100 mm, which decreases with further increase of the fluid channel distance. From a channel distance of 200 mm, hardly any increase in both values can be observed. In contrast to the variation of the mass flow, both values (water outlet temperature and thermal performance) rise and fall with the change in the fluid channel distance. The traces in the figure indicate that a distance greater than 200 mm between the fluid channels makes no sense, since an increase in the distance also reduces the number of fluid channels for a certain façade area. However, a too low value of distance significantly reduces the water outlet temperature and thermal performance and should therefore be avoided. Insights from this figure lead to the recommendation that a fluid channel distance should be between 100 and 200 mm for the hybrid structure.

5. SUMMARY OF THE PARAMETER ANALYSIS WITH THE WAVE PROFILE

Both the the mass flow in the fluid channels and the channel distance have a very large influence on the outlet temperature of the fluid in the calculated scenarios with the wave profile. Depending on the application in which either high or low fluid temperatures are required, the panels are suitable for operation with a mass flow of approximately 100 kg/h. Further, the analysis shows that the fluid channels should not be more than 200 mm apart, without accepting noticeable loss of efficiency regarding energy harvesting.

SUPPORTING BEHAVIOUR OF THE SOLAR-THERMALLY ACTIVATED FAÇADE PANEL

For investigation of the supporting behaviour of sandwich panels with a flow-function, a conventional cover sheet was first used as an absorber upon which the fluid channels were welded inside in the form of circular channels. In a second step, the study regarded sandwich panels whose cover sheets possessed a wavelike cross-section (**FIGURE 6-6**). This so-called "wave profile" corresponds well to the cross sectional form obtained when the sheets are inflated with compressed air after the roll bonding process.

1. LAYOUT OF THE SIMULATION MODEL

The analysis of the supporting behaviour of sandwich panels with flowing fluid was done using the CAE software tool Abaqus **[4]** with a three dimensional FEM model. The thermal insulation core of the sandwich panel was modelled with volume bodies (Elementcode C3D20) and the cover sheets as surface elements (Elementcode S8R) due to their low thickness. The centre plane layers of the cover sheets were joined in shear-rigid connections with both outer surfaces of the insulation core, whereby an eccentricity of half the sheet thickness was taken into consider-

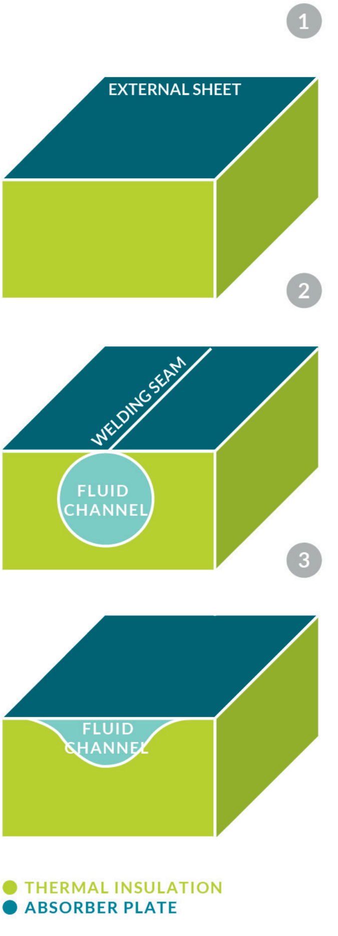


FIGURE 6-6: THE CROSS SECTION STUDIED: STANDARD SANDWICH PANEL (1), WELDED CIRCULAR CHANNEL (2), ROLL BONDING FORMED "WAVE-PROFILE"

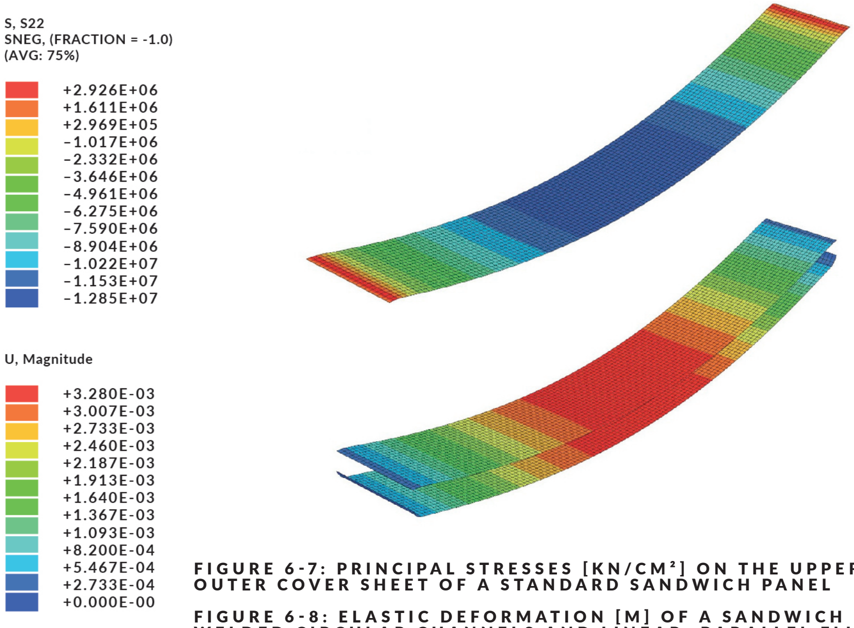


FIGURE 6-7: PRINCIPAL STRESSES [KN/CM²] ON THE UPPER SIDE OF THE OUTER COVER SHEET OF A STANDARD SANDWICH PANEL

FIGURE 6-8: ELASTIC DEFORMATION [M] OF A SANDWICH PANEL WITH WELDED CIRCULAR CHANNELS AND LINEAR, PARALLEL FLUID CHANNELS (INSULATION CORE NOT SHOWN)

ation. For the calculation the following assumptions were made:

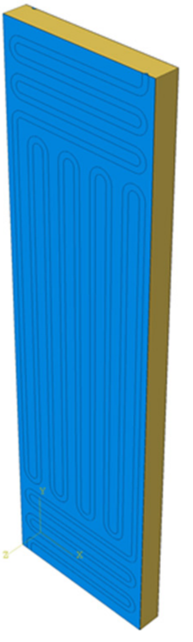
- Static system: Single span beams, span 3.5 m (storey height), influence width 0.5 m
- Support constraints: Statically determined support (line and point support)
- Loads: Standardised surface load (1 kN/m²) perpendicular to the component surface (wind)
- Cross sections: Insulation core d_c=15 cm, sheet thickness d_s=0.8 mm, fluid channel distance 20 cm, A=2 cm²
- The material attributes were taken from **[5]**: Cover sheet: steel S275, density 7850 kg/m³, Young´s Modulus 21000 kN/cm², Poisson number 0.3 Insulation core: polyurethane foam, density 40 kg/m³, Young´s Modulus 1.4 kN/cm², Poisson number 0.3

2. RESULTS FOR THE STANDARD SANDWICH PANEL

The results have shown that the bending behaviour of the sandwich panel equipped with fluid channels, assuming identical material usage, is not significantly improved compared to the standard sandwich panel. The differences regarding the principal stresses and deformations that occur are only in the range between 0 and 3 %. The reason is that the moment of inertia of the cross section due to the forming of the sheets to fluid channels is insignificantly changed.

FIGURE 6-7 and **FIGURE 6-8** show by way of example the main principal stresses (**FIGURE 6-7**) and the elastic deformation

FIGURE 6-9: SANDWICH PANEL WITH MEANDERING FLUID CHANNELS



of a standard sandwich panel with a cover sheet thickness of 0.8 mm each.

3. VARIATION OF THE FLUID CHANNEL LAYOUT

The next working step, as prescribed by the IWT, was to alter the layout of the fluid channels from parallel to a meander form to achieve an increase in the water outlet temperature (**FIGURE 6-9**). At the same time, the cross -sectional area of the wave profile was reduced to approximately 0.5 cm^2 and subsequently the centre distance of the fluid channels was reduced to 100 mm.

The previously described situation regarding principal stresses and deformation also occurred for the scenario in **FIGURE 6-10**. It can be generally noted that the stresses and deformation from standardised wind load can be regarded as low, the horizontal deformation of the sandwich panel was only approx. 2 mm, which corresponds to a factor of 1:1750 in relation to its length. This fact

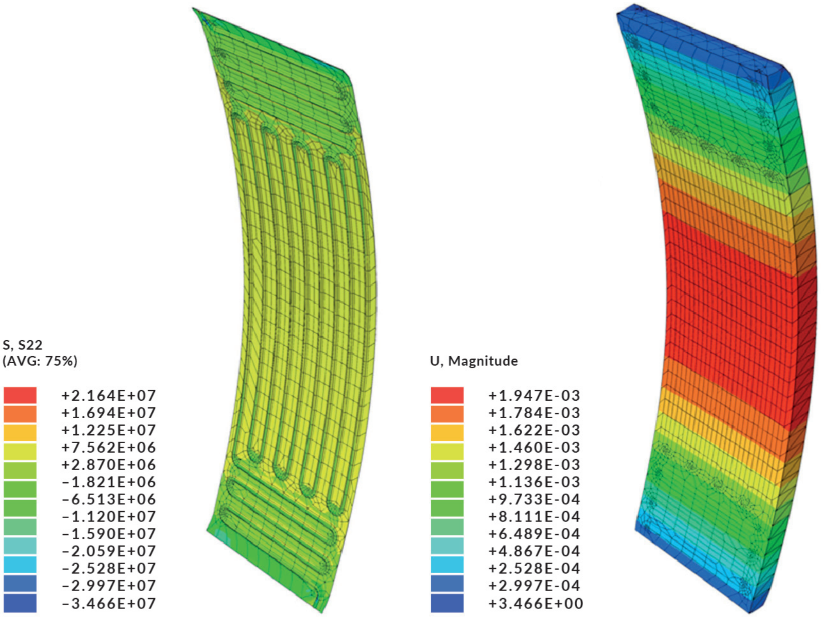


FIGURE 6-10: PRINCIPAL STRESSES AND ELASTIC DEFORMATION OF A SANDWICH PANEL WITH MEANDERING FLUID CHANNEL LAYOUT, INSULATION THICKNESS 150 MM, COVER SHEET THICKNESS 2 X 0.8 MM PER PANEL SIDE

emphasizes the efficiency of hybrid supporting structures.

4. RESULTS OF THE COMPARISONS CALCULATION

FIGURE 6-11 summarizes the calculation results of the comparison between a sandwich panel with meandering fluid channel geometry and a standard sandwich panel regarding principal stresses and elastic deformation.

The calculation results indicate that the influence of the fluid channels on the principal stresses and elastic deformation of the component is low. The smaller the selection of fluid channel cross section is, the larger is the correlation with a standard sandwich panel. Since the error is not larger than 3 % even with a fluid channel cross-sectional area of 2 cm², it is recommended to generally use the standard sandwich panel for preliminary design of the façade component and to neglect the influence of fluid channels.

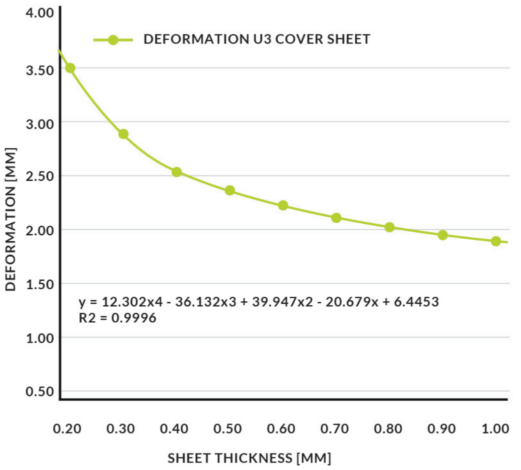
5. PARAMETER STUDY PRELIMINARY DESIGN

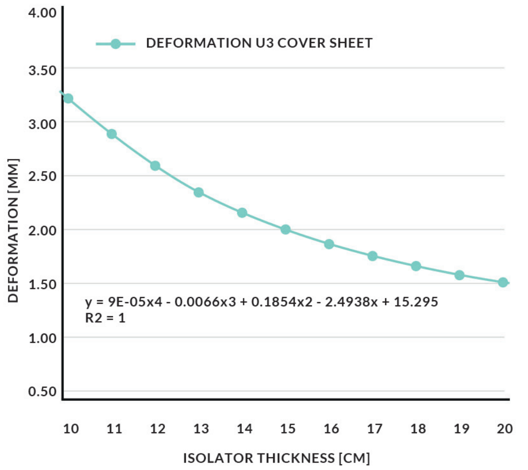
A parameter study was conducted in order to be able to assess the required thickness of the cover sheets or that of the thermal insulation for a static preliminary design of the solar-thermally activated façade panel. The values of the influence parameters sheet thickness (**FIGURE 6-12**) and thickness of the insulation core (= insulator) (**FIGURE 6-13**) were varied with an assumed free span of 3.5 m and a horizontal wind load of 1.0 kN/m² and the corresponding horizontal deformation of the sandwich panel was calculated.

FIGURE 6-12 can be used to read off the required sheet thickness for compliance with a given maximum deformation of the

Cross-section	Own weight (sheets) [kN]	Own weight (sheets) [%]	Principal normal stress [kN/cm²]	Principal normal stress [%]	Elastic deformation [mm]	Elastic deformation [%]
Standard-panel sheets 0,8 mm	0,44	100,00	±1,29	100,00	3,28	100,00
Standard-panel sheets 1,6 mm	0,88	200,00	±0,66	51,13	2,03	61,86
Wave profile Mäander	0,88	200,00	±0,67	51,94	1,95	59,36

FIGRURE 6-11: RESULTS OF THE COMPARISON CALCULATIONS





ELASTIC DEFORMATION OF THE FAÇADE ELEMENT [MM] IN HORIZONTAL DIRECTION
FIGURE 6-12 (LEFT): FOR VARIABLE SHEET THICKNESSES AND CONSTANT INSULATION CORE THICKNESS OF 15 CM
FIGURE 6-13 (RIGHT): FOR VARIABLE INSULATION CORE THICKNESS AND CONSTANT SHEET THICKNESS OF 2 X 0.5 MM

sandwich panel (e.g. according to the Eurocode) and an insulation core thickness of 15 cm. The required insulation core thickness for a given sheet thickness of 2 x 0.5 mm can be read off **FIGURE 6-13** in an analogue way.

TEMPERATURE LOAD CASE FOR A SOLAR-THERMALLY ACTIVATED FAÇADE PANEL

Sandwich panels display special deformation behaviour under temperature load due to their layered construction. Even with a constant temperature present on one of the two sides, the entire composite component will always display uneven thermal loading as a result of the thermal insulation effect of the core material. In addition to strain/ compression, this also produces deflection towards the hotter side.

Since experience has shown that the changes in sandwich panel shape under temperature load is an important criteria for their dimensioning, the UNAB panel also needs to be subjected to a static analysis of its behaviour under thermal load.

1. BOUNDARY CONDITIONS FOR THE SIMULATION

The results from the CFD simulation (in the form of point measurements of sheet temperature both on the inner and outer side) were used as boundary conditions and start values for the deformation analysis. A three-dimensional CFD model was used, similar to the parameter analysis in the previous **CHAPTER 6.2.** The boundary conditions in the CFD simulation were as follows:

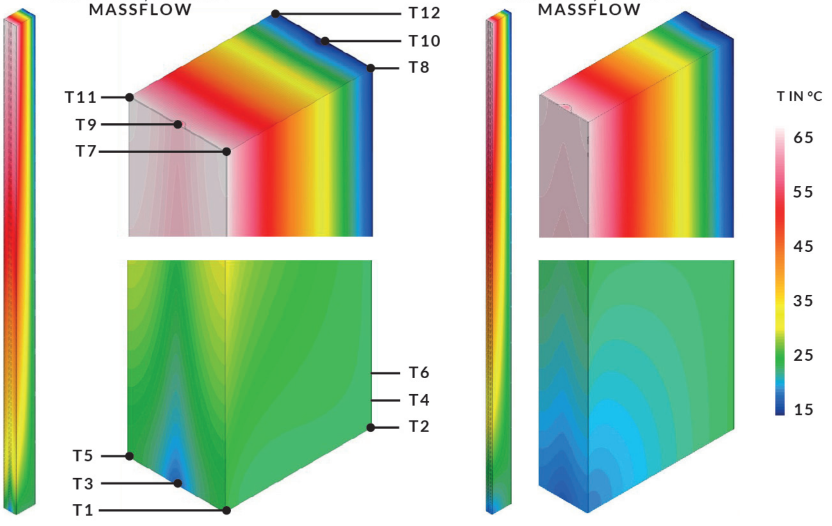


FIGURE 6-14: PARTIAL VIEW OF THE CFD MODELLING TEMPERATURE CONTOURS FOR THE CALCULATION OF DEFORMATION UNDER TEMPERATURE LOAD

- The object of the study was a sandwich panel with a height of 3.45 m and a width of 1 m, whereby an imagined endless façade in both directions was achieved using symmetrical boundary conditions in the CFD simulation.
- The sheets on the inner and outer sides of the panel were made out of aluminium with a sheet thickness of 0.6 mm each.
- The thermal insulation of the panel consisted of a 150 mm thick polyurethane layer.
- A room temperature of 26 °C with a heat transfer coefficient of 3.2 W/m^{2}K was assumed for the inner surface.
- An outside temperature of 35 °C with a heat transfer coefficient of 5 W/m^{2}K was assumed for the exterior surface. In addition, the exterior was subjected to heating by solar irradiation of 1000 W/m^2 at an angle of incidence of 55 °. A solar radiation absorption factor of 0.95 was assumed for the outer sheet (which corresponds to a solar paint coating).
- Fluid channels were integrated in both inner and outer sheets of the panel. The fluid inlet temperature for both was 15 °C to increase the temperature of the fluid on the exterior and to reduce the temperature of the interior. The mass flow in the fluid channel on the inner side was 10 kg/h; the entry point was located on the upper side of the panel. The heating effects on the outer side were investigated with mass flows of 50 kg/h und 100 kg/h, whereby the water flowed from the bottom of the panel to the top. Fluid channel distances of 50 and 100 mm were studied. This resulted in four further variants for the deformation analysis in addition to the reference scenario

(sandwich panel without fluid channels).

FIGURE 6-14 shows excerpts of the CFD models to illustrate the temperature points that acted as boundary conditions for the solar-thermally activated sandwich panel in the deformation analysis. To ensure that the deformation behaviour can be compared, the temperature points for both the solar-thermally activated panel were determined as well as for the standard sandwich panel.

The output data from the CFD simulation (**FIGURE 6-15**) were transferred in a first step as punctiform temperature loads on the CAE simulation model presented in this chapter. In order to simplify the three-dimensional temperature field within the panel, additional points between the fixed temperature values on its surface were calculated in vertical direction (over the height of the panel) as well as in horizontal direction (over the thickness of the panel) by linear interpolation.

Massflow	50 kg/h	50 kg/h	100 kg/h	100 kg/h
Fluid channel distance	100 mm	50 mm	100 mm	50 mm
T-out-exterior	49.72	52.02	35.49	36.47
T-out-interior	21.74	21.96	21.54	21.73
T 1	22.37	18.00	21.34	17.34
T 2	21.85	21.99	21.99	21.76
T 3	17.61	16.88	16.95	16.35
T 4	21.80	21.99	21.61	21.76
T 5	22.38	18.01	21.35	17.34
T 6	21.85	21.99	21.65	21.76
T 7	54.67	53.85	41.98	38.99
T 8	15.65	15.34	15.62	15.32
T 9	52.69	53.49	39.37	38.49
T 10	15.33	15.25	15.31	15.24
T 11	54.67	53.85	41.98	38.99
T 12	15.65	15.34	15.62	15.32

FIGURE 6-15: CFD SIMULATION OUTPUT DATA

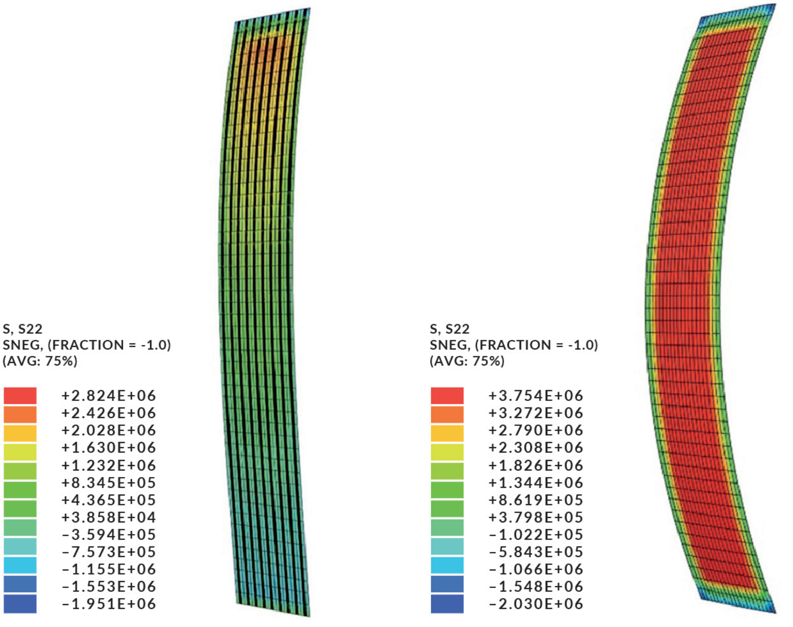


FIGURE 6-16: PRINCIPAL STRESSES [KN/M²] FOR A THERMALLY ACTIVATED SANDWICH PANEL (LEFT) AND FOR A STANDARD SANDWICH PANEL (RIGHT) UNDER TEMPERATURE LOAD

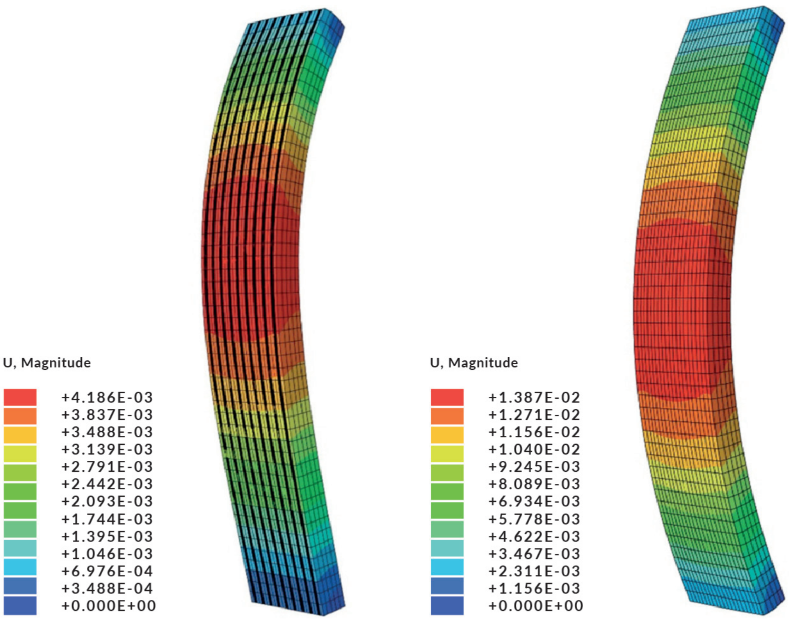


FIGURE 6-17: HORIZONTAL DEFORMATION [M] FOR A THERMALLY ACTIVATED SANDWICH PANEL (LEFT) AND FOR A STANDARD SANDWICH PANEL (RIGHT) UNDER TEMPERATURE LOAD

2. CALCULATION RESULTS FOR TEMPERATURE LOAD

FIGURE 6-16 and **FIGURE 6-17** compare the results of the static simulation regarding the principal stresses and horizontal deformation under temperature load for a thermally activated sandwich panel and for a standard sandwich panel. Due the “cooling effect” of the fluid channels in comparison to the standard panel, there is a significant reduction both in temperature stresses and in its horizontal deflection. The asymmetry of the stress distribution and deformation figure of the thermally activated sandwich panel is due to the increasing intensity of the temperature field towards the top of the panel, whereas the standard sandwich panel is heated uniformly by the solar irradiation and is not cooled by fluid channels.

LITERATURE

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[5] S. Torsakul, Modellierung und Simulation eines Verbundes von Sandwichplatten zur Entwicklung einer mechanischen Verbindungstechnik. PhD-thesis, RWTH Aachen, 2007.

07

THE SOLAR-THERMALLY ACTIVATED UNAB FAÇADE ELEMENT

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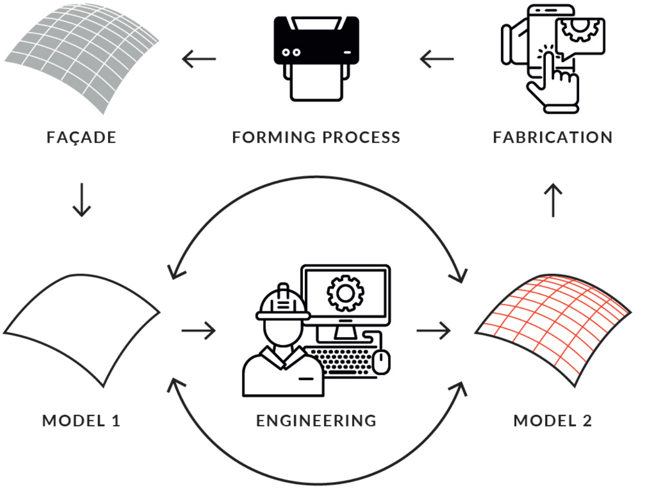


FIGURE 7-1: DIGITAL DESIGN2PRODUCTION WORKFLOW

DIGITAL PLANNING PROCESSES AND MANUFACTURING

The application of computer-aided tools in architectural practice and the concepts in Industry 4.0 are transforming the organisation of the design, planning and manufacturing processes in the construction industry in general and building envelopes in particular. The demand for suitable manufacturing processes and forming techniques relating to complex metallic façades has become inevitable in recent years. As a result, the significance of digital process chains has increased and is simultaneously the prerequisite for the guaranteeing of the seamless data exchange between architectural design, engineering, production and assembly processes (**FIGURE 7-1**). The control of data models and their relevant parameters enable the cost monitoring of the assembly and also the planning. In addition, the correct assembly is inseparable from the interactions between the stakeholders and a continuous data exchange in order to progress from the original idea of material use to precise implementation. The focus of the research work is on the integration of design and manufacturing parameters in a digital process chain for the manufacturing of façades made of aluminium or steel. The research approaches were oriented towards the automotive and aviation industries, who have already integrated design and production departments in order to guarantee innovative solutions by the responsible designers and manufacturers. This will also be necessary in architecture, since conventional practices will be replaced by new ones in the near future.

1. UNAB PARAMETRIC DESIGN SYSTEM

The UNAB Parametric Design System is a tool for the manufacture of planar, single curved or doubly curved panels (**FIGURE 7-2**). The Parametric Design System is an open system and permits further designs, requirements and boundary conditions (materials, static characteristics) to be inte-

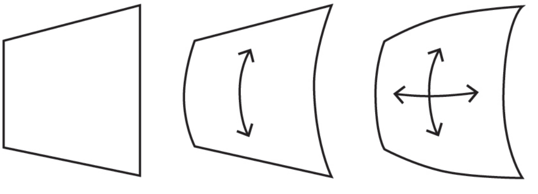


FIGURE 7-2: UNAB PANEL GEOMETRY – PLANAR, SINGLE CURVED AND DOUBLY CURVED

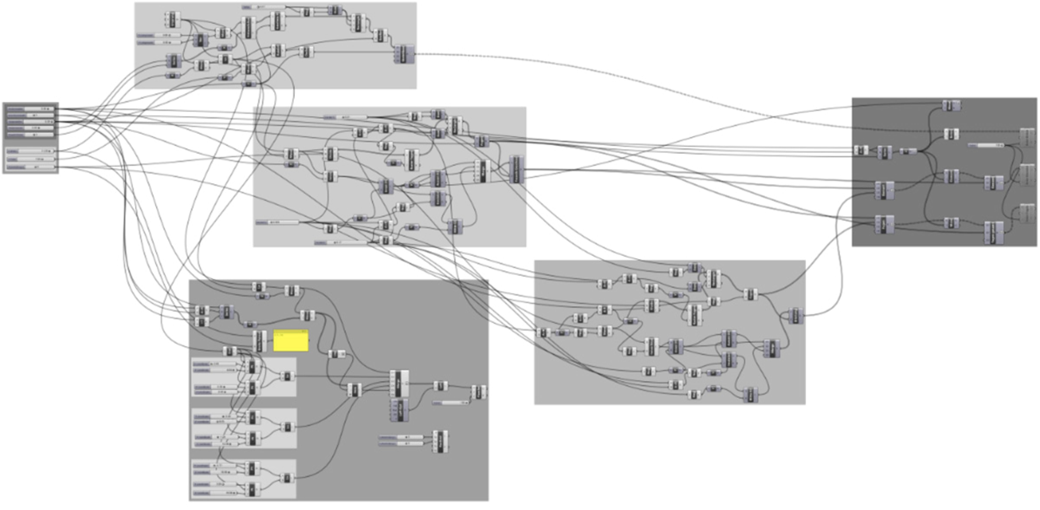


FIGURE 7-3: UNAB PARAMETRIC DESIGN SYSTEM – VISUAL PROGRAMMING

grated in the tool. The tool has been implemented with Rhinoceros software and the plugin of a visual programming environment (**FIGURE 7-3**).

The dimensions (width, depth and height) and the layer composition (roll-bond sheet of aluminium/ thermal insulation/roll-bond sheet of aluminium, see **FIGURE 7-4**) are defined as parameters and can be modified for each possible combination (scenarios). The system also permits element libraries to be built to construct user-friendly BIM software solutions so that this type of façade element and its technology can be made accessible to a large number of planners and applications. The UNAB Parametric Design System not only permits panels to be produced and designed, but also large façade surfaces and complete building envelopes. Over the course of the

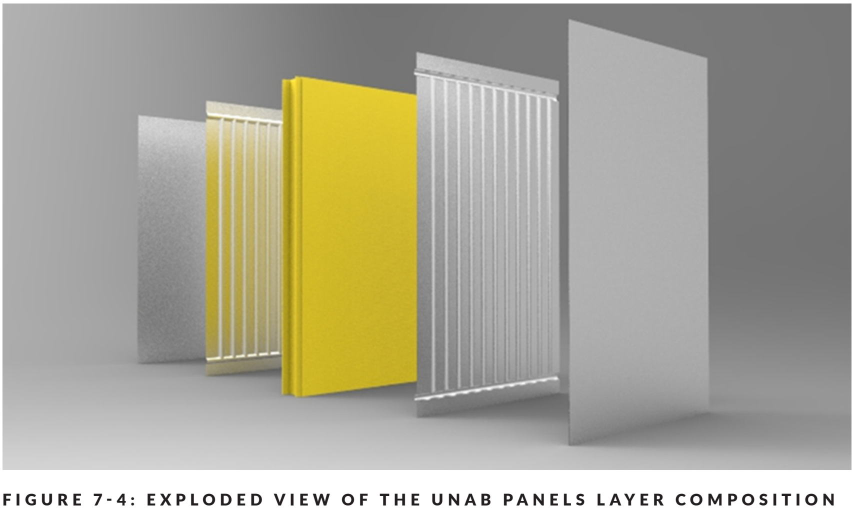
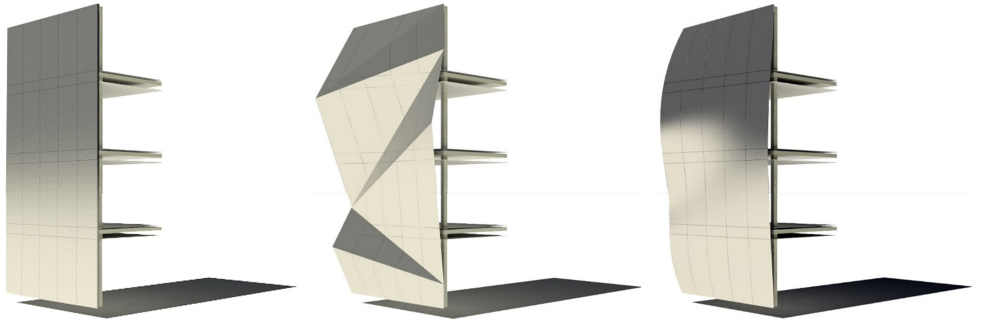


FIGURE 7-4: EXPLODED VIEW OF THE UNAB PANELS LAYER COMPOSITION



UNAB CONCEPT VISUALISATION FROM LEFT TO RIGHT /
FIGURE 7-5: PLANAR FAÇADE SYSTEM
FIGURE 7-6: FOLDED FAÇADE SYSTEM
FIGURE 7-7: DOUBLY CURVED FAÇADE SYSTEM

investigations, one design each for planar, single curved, doubly curved and folded panels was created using the UNAB Parametric Design System (**FIGURE 7-5**, **FIGURE 7-6** and **FIGURE 7-7**).

2. DESIGN AND FORMATION OF THE FLUID CHANNELS

The possibilities for the layout of the fluid channels, which represent a significant design and functional element of the sandwich panel, were investigated in detail in different variations. The harp form emerged as the most efficient layout of the fluid channels in the thermal simulations (**FIGURE 7-8**).

3. MULTI-POINT FORMING (MPF) TOOL

Multi-point Forming (MPF) is a manufacturing technique for three-dimensional metal sheets. The technology is still at an experimental stage but enables many different panel geometries to be manufactured according to the principle of individual mass production. An MPF tool and a (hydraulic) press are required both controlled by a CAM system to create the desired 3D geometry.

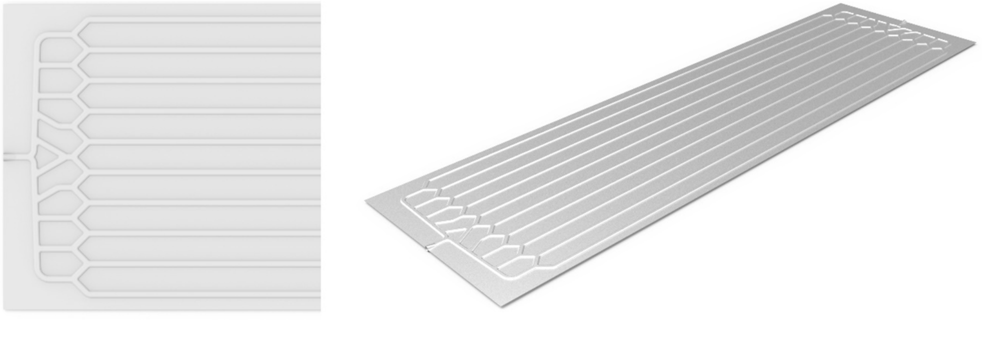


FIGURE 7-8 ACTIVE FLUID MEDIUM DESIGN – RESULT FLUID CHANNEL SYSTEM IN HARP FORM

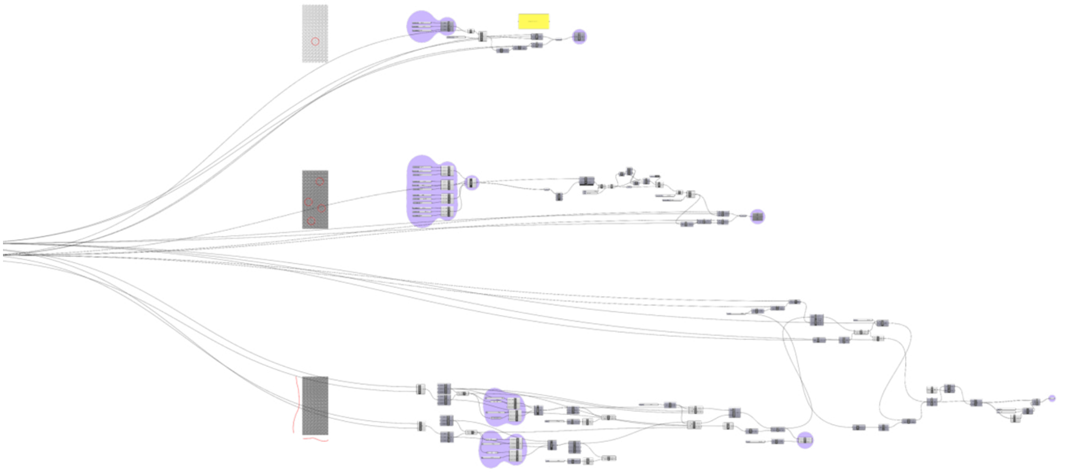


FIGURE 7-9: PARAMETRIC MPF-TOOL – VISUAL PROGRAMMING WITH GRASSHOPPER

As shown in **FIGURE 7-9** the MPF forming tool consists of movable stamps that are arranged in X- and Y-axis. Changes in the Z-axis enable arbitrary surfaces to be created. The control of the movable stamps in the Z direction is done by the Parametric MPF tool (**FIGURE 7-9**, **FIGURE 7-10**).

Three principles for the creation of a multi-point forming (MPF) system were developed and investigated. The position of the stamps in the Z-axis is defined in the first example via an attractor that is marked red in **FIGURE 7-11**. As can be seen in **FIGURE 7-12** several attractors can be selected

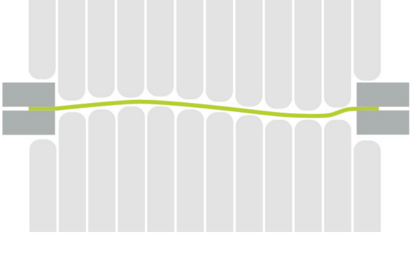


FIGURE 7-10: SYSTEM SKETCH OF THE OPERATING PRINCIPLE OF A MULTI-POINT FORMING (MPF) TOOL

for the position of the stamp. The final variant (**FIGURE 7-13**) permits the stamps to be arranged according to reference surfaces.

FORMING SIMULATION

This section deals with the investigation of the forming process for façade elements that have been manufactured using the roll-bonding process and subsequently expanded using a working medium. The limits of the manufacturing process and the maximum achievable cross-sectional area as a function of the sheet thickness regarding the material thinning are determined in a first step.

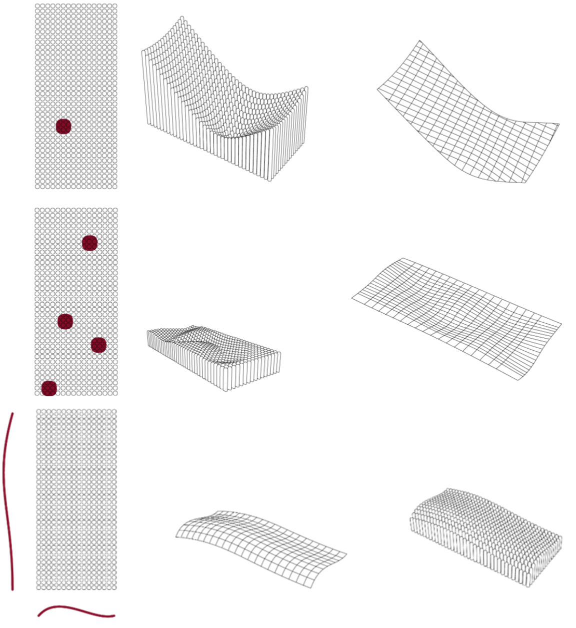
In a second step, the formability of the expanded fluid channels will be investigated. The studies will be carried out using FEM simulations. Suitable software needs to be found to simulate these special processes.

Due to the small radii relating to the expansion of the component, the use of volume elements rather than shell elements for the calculation is preferred. Above all, the simulation program must be able to execute the process of forming by working medium. Furthermore, it is also necessary to have the possibility of creating a virtual deep drawing process.

After in-depth research and comparisons of the pros and cons of the different simulation programs, the software Pam-Stamp 2G from the company ESI was selected for this project, since it fulfilled all necessary requirements.

In general, shell elements can be used in Pam-Stamp as long as the smallest radius of curvature is twice as large as the thickness of the sheet. If the smallest radius of curvature measures between single and double sheet thickness, the simulation is on a critical area. This can be lead to material crushing at the curvature, which can not be represented with shell elements. If the smallest radius is less than the sheet thickness, shell elements can no longer be used. Furthermore, the ratio between component thickness and total size of the component must be regarded.

The use of volume elements in a working medium simulation is complex and relatively difficult to do in Pam-Stamp. Not only do the volume elements need to be modelled, so-called “Null Shell Elements” (without thickness or mate-



MPF TOOL STAMP MATRICES AND 3D SURFACE
FROM TOP TO BOTTOM
FIGURE 7-11: SIMPLE ATTRACTOR
FIGURE 7-12: MULTIPLE ATTRACTORS
FIGURE 7-13: REFERENCE SURFACE

rial behaviour) are also required and must be linked to the actual volume elements since hydrostatic pressure can only be applied to shell elements. Furthermore, the computation time for volume elements in Pam-Stamp increases enormously.

While the simulation model was being built, it was noted that the process could be simulated by using the contact definition “Accurate Contact”, an additionally necessary effective area definition for this contact (areas require a defined thickness when used with volume elements) and the “User-Defined Attributes”. Latter permit the use of additional, non-standard attributes in Pam-Stamp. This makes it possible to use the option “Fluid-Cell” for volume elements, which is normally only available for shell elements. This option enables the application of working media

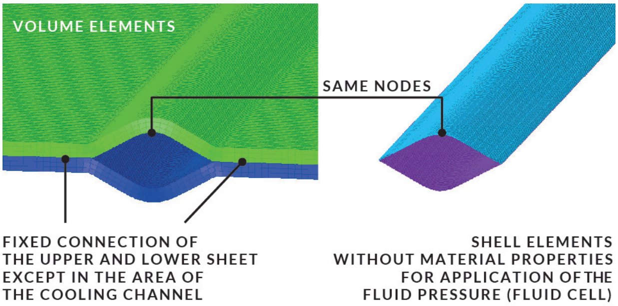


FIGURE 7-14: MESHING THE SHEETS

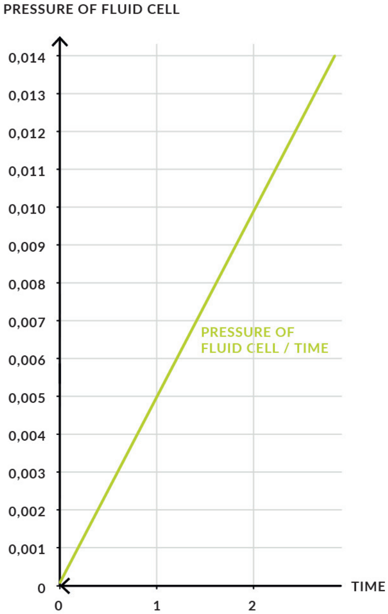


FIGURE 7-15: PRESSURE CURVE WORKING MEDIUM EXTENSION

in virtual forming processes.

In order to emulate the roll bonding process with subsequent inflation using a working medium, the component meshing must be specially defined. The surface nodes of the upper and lower sheets are permanently connected to each other and only in areas where the working medium is effective do the upper and lower nodes remain independent. An additional shell mesh is created to apply the internal pressure of the working medium to the nodes of the volume mesh. It does not possess any material properties and is again permanently connected to the volume mesh. Only then it is possible to apply the pressure forces of the working medium on the volume mesh (**FIGURE 7-14**).

The simulation was analysed regarding component failure. This was done using the failure limit curve (FLC) and the cross-section, respectively the resulting volume of the fluid channel. The application of working medium pressure was done using a linear pressure curve from 0 to 150 bar, which was reached after 3 seconds (**FIGURE 7-15**).

The material was described using the data set Al 1050 (Al 99.5) in the internal Pam-Stamp 2G database. The material chart describes the physical parameters (density, Young´s modulus, Poisson´s ratio) and in particular the yield curve, the anisotropic characteristics for the yield point and the failure limit curve for the material failure. This document will only describe and graphically visualise the most important variants from a large number of simulations.

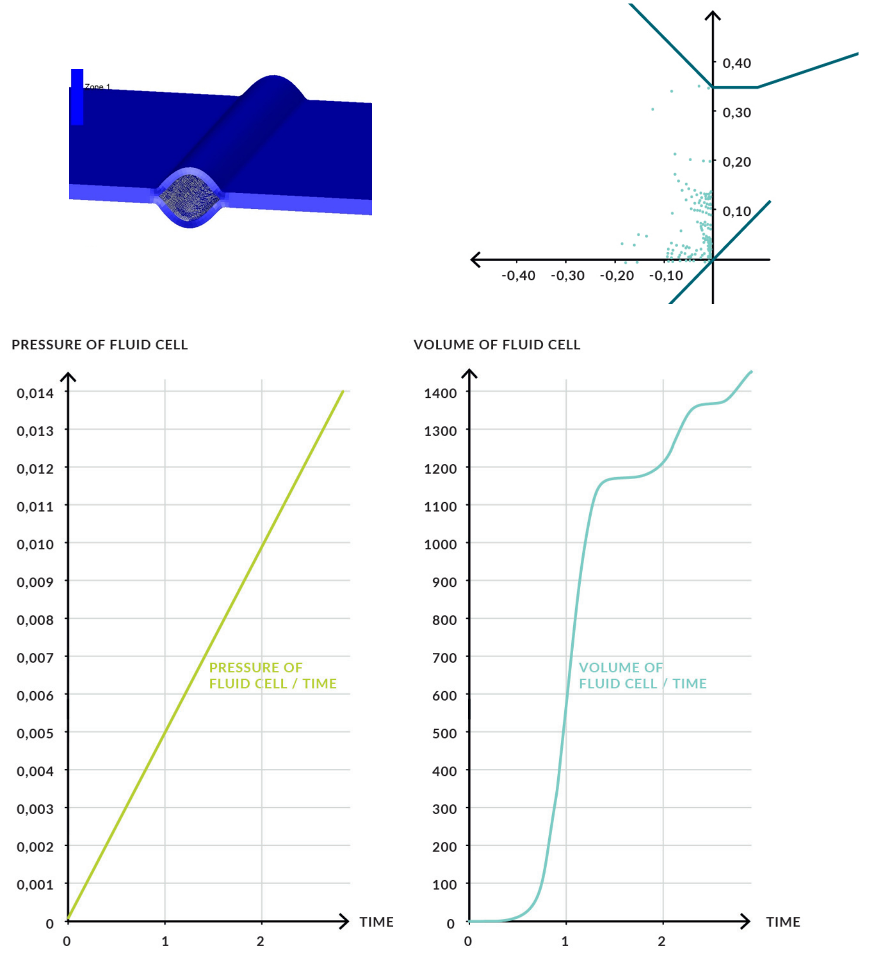


FIGURE 7-16: SIMULATION "WIDENING WITHOUT SPACING" (GEOMETRY, FLC, PRESSURE CURVE, FLUID CHANNEL VOLUME)

1. SIMULATION "WIDENING 10 MM WITHOUT SPACING"

In this simulation, a double sheet (roll-bonded) with the dimensions 100 x 100 mm and a fluid channel of 10 mm was inflated by a working medium without counter tools. The upper and lower individual sheets consisted of the material Al 1050 with a thickness of 1 mm. The meshing was achieved with three volume elements over the thickness. The pressure curve and the failure limit curve at the end of the process at 150 bar internal pressure are shown in **FIGURE 7-16**. The cross-sectional area can be approximated from the volume curve shown by dividing the total volume is divided by the length of the component. No material failure was observed up to the end of the process at 150 bar internal pressure. The elements on the parting plane in some cases lay just below the failure limit curve, but in no area did they exceed it.

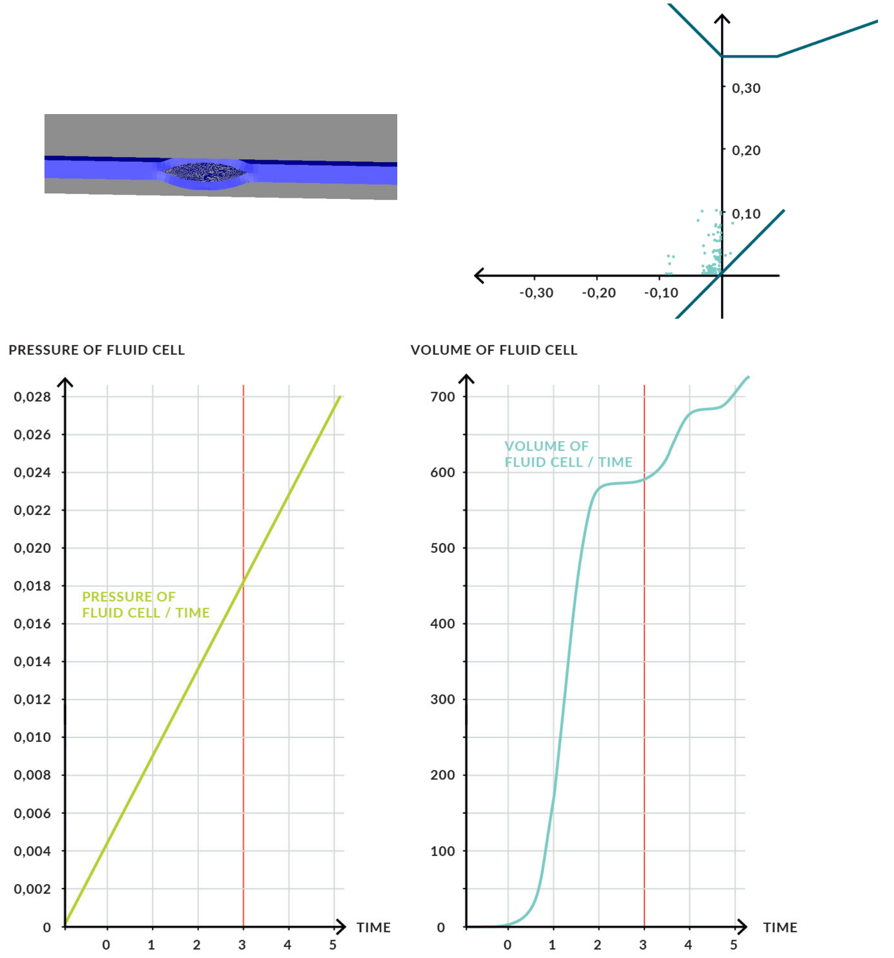


FIGURE 7-17: SIMULATION “INFLATION WITH SPACING“ (GEOMETRY, FLC, PRESSURE CURVE, FLUID CHANNEL VOLUME)

2. SIMULATION “WIDENING 10 MM WITH SPACING 4 MM“

In this scenario, a double sheet (roll-bonded) with the dimensions 100 x 100 mm with a fluid channel width of 10 mm was inflated using working medium with counter tool (spacing 4 mm). The upper and lower individual sheets consisted of material Al 1050 with a thickness of 1 mm. The meshing was achieved with three volume elements over the thickness. The pressure curve and the failure limit curve at the end of the process after 4 seconds at 200 bar internal pressure is shown in **FIGURE 7-17**. The cross-sectional area can be approximated from the volume curve shown by dividing the total volume by the length of the component. No material failure was observed up to the end of the process at 200 bar internal pressure. All material elements lay far below the critical failure limit curve.

3. SIMULATION OF "SEVERAL FLUID CHANNELS"

In this simulation a double sheet (roll-bonded) with the dimensions 100 x 100 mm and a fluid channel width of 10 mm was inflated by working medium with counter tools (spacing 4 mm) (**FIGURE 7-18**). The special feature here is that several fluid channels were calculated in parallel. The upper and lower individual sheets consisted of the material Al 1050 with a thickness of 1 mm. The meshing was achieved with three volume elements over the thickness. The pressure curve can be seen in **FIGURE 7-16**. As for the previous scenarios, no material failure was observed. All material elements lay far below the critical failure limit curve. This enables the simulation of more complex real geometries whereby external meshing software needs to be used for the meshing strategies of curved fluid channels since PamStamp is currently only able to process meshes with linear fluid channels.

4. SIMULATION OF A PREVIOUSLY FORMED SHEET

The following examples investigated the possibility of previous forming of the roll bonded sheets with subsequent inflation. This is of particular interest since the widening of the roll-bonded sheet can be

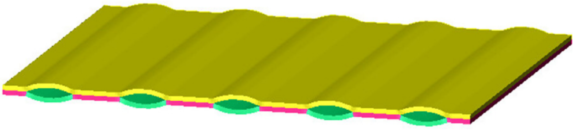


FIGURE 7-18: SIMULATION OF "SEVERAL FLUID CHANNELS"

limited to one side with suitable combinations of materials of both joined sheets and additional adaptation of sheet thickness. This variant is preferable in view of the optical appeal of the façade element.

A formed double sheet (roll-bonded) with the dimensions 100 x 100 mm and a fluid channel width of 10 mm (located 45 ° to the main forming) was inflated in simulation 1550 (**FIGURE 7-19**) by using working medium with counter tools (spacing 4 mm). The upper and lower individual sheets consisted of the material Al 1050 with a thickness of 1 mm. The meshing was performed with three volume elements over the thickness. At the end of the process after 4 seconds, an internal pressure of 200 bar was achieved. All material elements lay far below the critical failure limit curve. Due to the identical characteristics of the upper and lower sheets, the forming of the extension is similar in both directions. In the simulation 1500 (**FIGURE 7-20**), a formed double sheet (roll-bonded) with the dimensions 100 x 100 mm and a fluid channel width of 10 mm

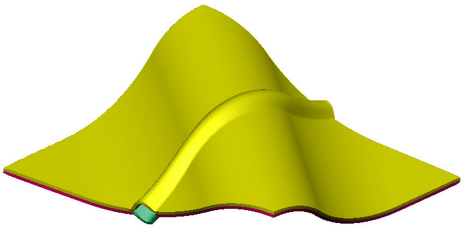


FIGURE 7-19: SIMULATION 1550, UPPER AND LOWER SHEET AL 1050.5, 1 MM

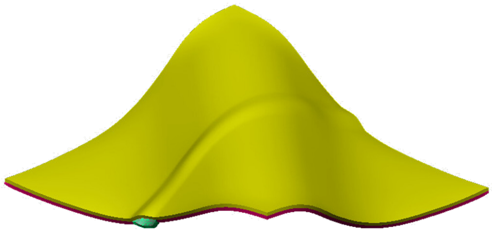


FIGURE 7-20: SIMULATION 1500, UPPER SHEET AL 6016, 1 MM, LOWER SHEET AL 1050, 1 MM

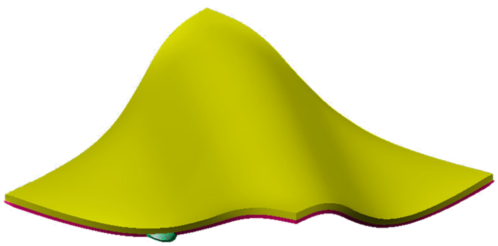


FIGURE 7-21: SIMULATION 1600, UPPER SHEET AL 6016, 2 MM, LOWER SHEET AL 1050, 1 MM

(located at 45 ° to the main forming) was inflated using working medium with counter tools (spacing 4 mm). The upper sheet consisted of the material Al 6016, the lower sheet of material Al 1050. Both sheets had a thickness of 1 mm. The meshing was performed with three volume elements over the thickness. At the end of the process after 4 seconds, an internal pressure of 200 bar was achieved. All material elements lay far below the critical failure limit curve. The widening was primarily identifiable on the lower side, but the upper side also displayed a slight bulge.

Finally, in the simulation 1600 (**FIGURE 7-21**), a formed double sheet (roll-bonded) with the dimensions 100 x 100 mm and a fluid channel width of 10 mm (located at 45 ° to the main forming) was inflated using working medium with counter tools (spacing 4 mm). The upper sheet consisted of the material Al 6016, the lower sheet of material Al 1050. The upper sheet had a thickness of 2 mm, the lower sheet a thickness of 1 mm. The meshing was performed with three volume elements over the thickness. At the end of the process after 4 seconds, an internal pressure of 200 bar was achieved. All material elements lay far below the critical failure limit curve. Due to the doubling of the thickness of the upper sheet the widening at the upper surface could be avoided. The inflation of the fluid channel only exists at the lower surface because of its softer sheet.

5. SUMMARY, OUTLOOK, POTENTIAL FOR OPTIMISATION

The simulation methodology described before makes it possible to emulate the virtual production process of sheets, which have been connected with roll bonding and subsequently inflated with a working medium. The simulation software Pam-Stamp 2G from the company ESI proved to be very suitable for this task.

In order to be able to evaluate the quality of the simulation results, a comparison with real construction components is essential. The neg-

1	SEALING TAPES	7	VAPOUR BARRIER
2	INSPECTION COVER	8	UNAB PANEL
3	CONNECTION SLEEVE	9	SUSPENDED CEILING
4	FLUID SUPPLY FOR PANEL (FLOW/RETURN)	10	ADJUSTING DEVICE
		11	ADAPTER (ALUMINUM PROFILE)
5	STEEL BRACKET	12	THERMAL SEPARATION
6	HALFEN RAIL	13	INSTALLATION SPACE

SECTION A-A
HORIZONTAL

SCALE 1:10

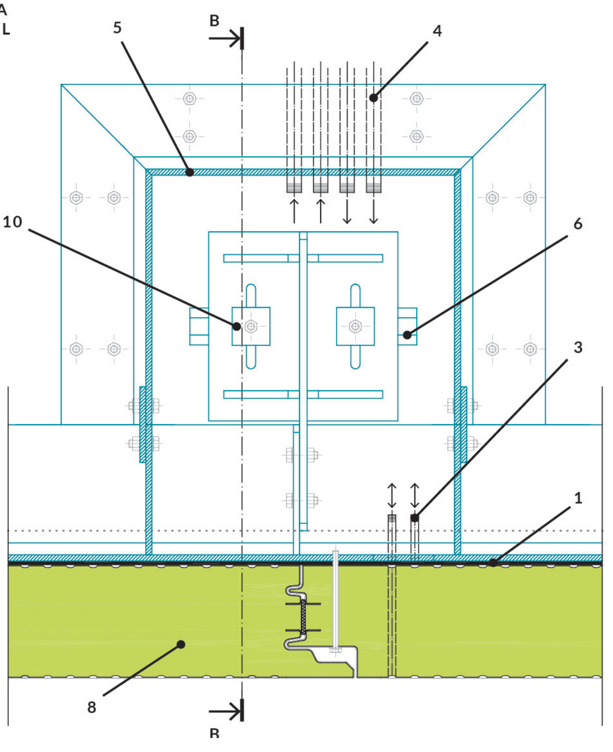


FIGURE 7-22: CONNECTING THE UNAB-PANEL TO THE STOREY CEILING AND FEEDING THE FLUID CHANNELS VIA THE FLOOR CONSTRUCTION, HORIZONTAL SECTION

leted simulation parameters (e.g. friction conditions with the forming tools) need to be suitably adapted and optimised such that the virtual model corresponds in the best possible way to reality.

The quality of the simulation results is strongly depending on the accuracy of the material parameters used. In order to achieve the best possible results, it is recommended that the most important properties of the materials being used are determined.

This study only considered geometries with linear paths for the extension using a working medium. A strategy needs to be developed for the meshing of curved/non-linear paths for the inflation in order to investigate real components. This is not directly possible with the Pam-Stamp software, but there is the possibility to import meshes generated from other software such as HyperMesh from the company Altair into Pam-Stamp 2G, which have been specifically designed for these applications.

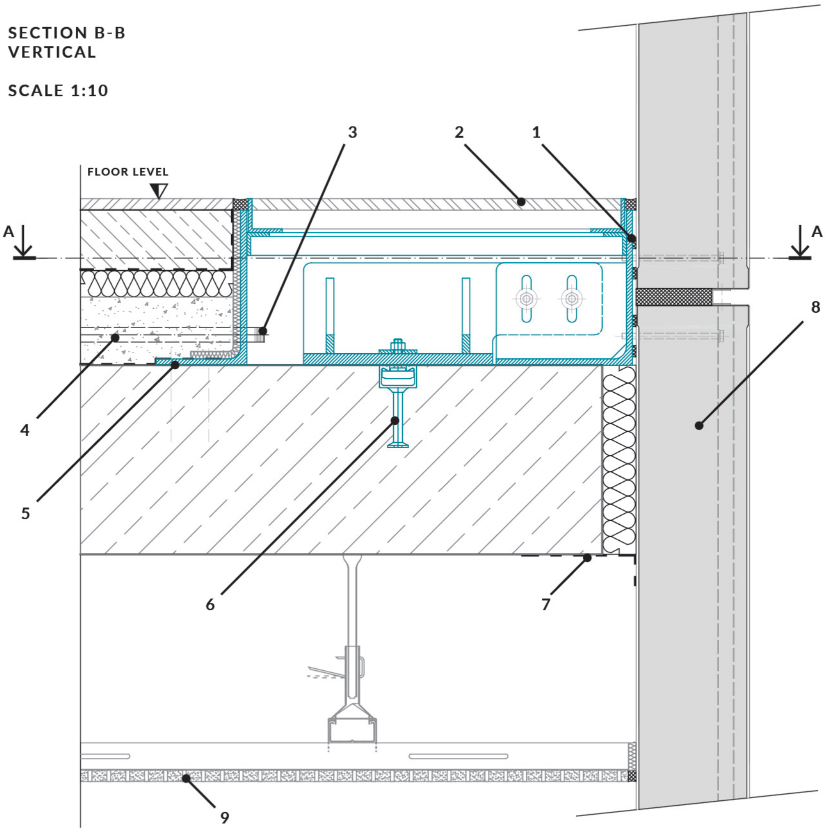


FIGURE 7-23: CONNECTING THE UNAB-PANEL TO THE FLOOR SLAB AND FEEDING THE FLUID CHANNELS VIA THE FLOOR CONSTRUCTION, VERTICAL SECTION

DEVELOPMENT OF CONSTRUCTION DETAILS

This section demonstrates, as a consequence of the integrated planning approach, how the connections of the UNAB panel relating building construction and building technology can be solved (**FIGURE 7-22, FIGURE 7-23** and **FIGURE 7-24**).

A mounting bracket is suggested to fix the UNAB panel to the floor slab of a building that can only transfer horizontal forces (e.g. resulting from wind load) to the structure. Vertical forces (e.g. dead load) are transmitted from the panel to the base of the building and from there into the foundation. The connection is made on the upper edge of the raw ceiling via a "Halfen rail" embedded in the concrete and an adjustable steel fin to which the panel is attached. The required vapour proof connection of the panel is ensured via a floor fill bracket and suitable seals. The floor construction has to be acoustically decoupled via the floor fill bracket.

Regarding the connection of the supply for the fluid channels to the

1	SEALING TAPES	7	VAPOUR BARRIER
2	INSPECTION COVER	8	UNAB PANEL
3	CONNECTION SLEEVE	9	SUSPENDED CEILING
4	FLUID SUPPLY FOR PANEL (FLOW/RETURN)	10	ADJUSTING DEVICE
		11	ADAPTER (ALUMINUM PROFILE)
5	STEEL BRACKET	12	THERMAL SEPARATION
6	HALFEN RAIL	13	INSTALLATION SPACE

ADAPTER PROFILE
HORIZONTAL SECTION

SCALE 1:5

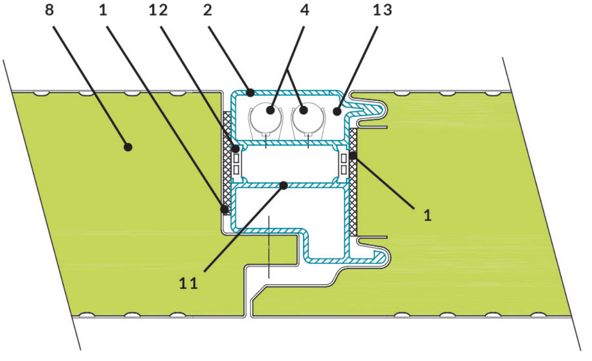


FIGURE 7-24: FEEDING THE FLUID CHANNELS IN THE UNAB PANEL VIA AN "ADAPTER PROFILE", HORIZONTAL SECTION

building installation, it is suggested that this is achieved via the floor construction (**FIGURE 7-22** and **FIGURE 7-23**). The bridging of the fluid channel connection on the panel to the building installation is done inside an inspection opening with the aid of a flexible hose. This guarantees that should a panel needs to be replaced, it can be disconnected from the building installation with no great effort. Whereas the variation of supplying the fluid channels from below via the floor construction is always possible (provided that sufficient construction height is available) a non-visible supply from above is only possible with a suspended ceiling. A further possibility of supplying the UNAB panel is shown in **FIGURE 7-24**. In this case, the vertical distribution is achieved via a thermally separated "Adapter Profile" that contains the pipes for supply and return lines. An inspection opening in the adapter profile permits access for maintenance purposes. Since the adapter profile simultaneously represents a reinforcement against horizontal loads, this variant should be considered because larger spans can be achieved (e.g. for walls in industrial buildings).

08

COMBINED THERMAL EVALUATION OF THE UNAB FAÇADE PANEL

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DANIEL BRANDL
THOMAS MACH

TEST FACILITY

In order to verify the thermal simulations of the UNAB façade panel's actual energy generation, the decision was taken to build a prototype including test facility. The absorber sheets with the fluid channels were manufactured by the aluminium producer TALUM d.d. in Kidričevo (Slovenia) using roll-bonding technology. Subsequently the prototype was completed in the production line of Brucha Ges.m.b.H in Michelhausen (Lower Austria), where the insulation material was added and the components glued together into a sandwich panel. All in all, three prototypes were built, two with polyurethane and one with mineral wool as insulation core (**FIGURE 8-1**).

The aim was to study not only the energy generation on the exterior cover sheet, but also the conditioning of an interior room (heating and cooling) by supplying the fluid channels on the interior cover sheet of the UNAB panel. To achieve this, the façade panel was installed in front of a thermally insulated box.

Two identical boxes were envisaged to enable the simultaneous comparison of the UNAB panel with a conventional, non-activated sandwich panel. A wooden shelter was constructed to protect the boxes as well as the measurement and control equipment within them from the elements.

FIGURE 8-1: UNAB FAÇADE PANEL PROTOTYPE

Further targets defined for the in-situ measurements were acquisition of the surface temperatures at different points of the façade panel and the degree of heating of the fluid flowing through the channels. Finally, the characteristic curves of the UNAB panel's collectors were to be determined (= non-covered collector, untreated aluminium surface) and for the first variant (= non-covered collector, aluminium surface painted with black solar varnish).

1. TEST FACILITY REQUIREMENT PROFILE

The test facility needed to be designed to represent a real installation situation for the UNAB façade panel. It had to be possible to vary the following parameters in order to investigate different scenarios **[1]**:

- Mass flow
- Inlet temperature
- Single side flow
- Double sided flow
- Further variants of the façade panel

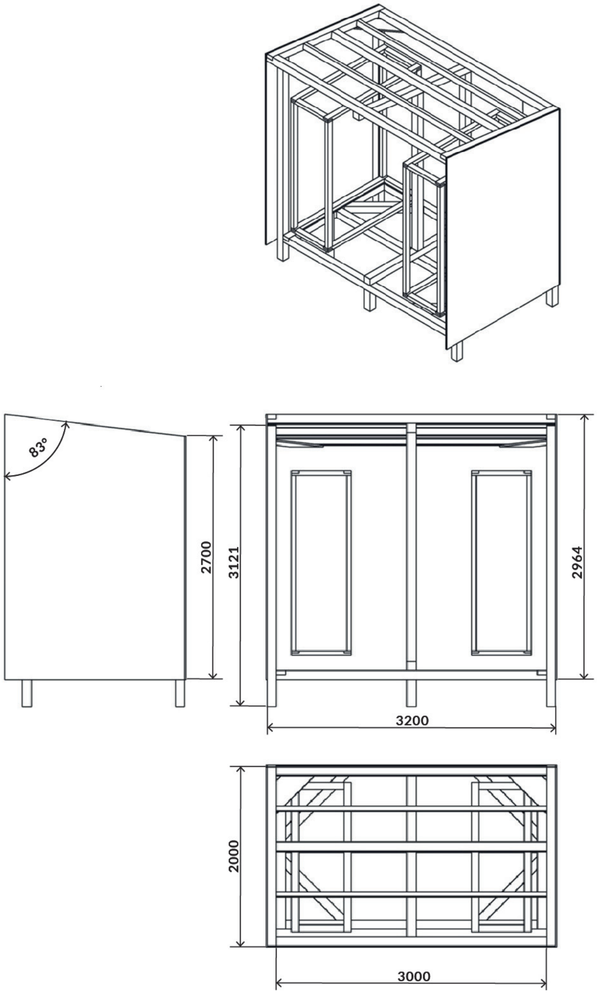


FIGURE 8-2: DESIGN DRAWINGS FOR THE TEST FACILITY [1]

2. TEST FACILITY DESIGN

Design drawings for both boxes and the shelter were completed within the scope of a master´s thesis **[1]** at the Institute of Thermal Engineering in cooperation with the Institute of Building Construction (**FIGURE 8-2**). This is located on the TU Graz campus at Inffeldgasse 24, close to the Laboratory for Structural Engineering.

The shelter and the boxes were constructed from square timber and oriented strand board (OSB). Two layers of EPS façade insulation boards were used to insulate the boxes with a total thickness of 15 cm, which corresponded exactly to the thickness of the façade panel, were fixed to every side of the boxes except to the front. Corrugated bitumen sheets were mounted on the roof to provide weather protection and a diffusible (breathable) wind- and rainproof membrane was attached to the walls (**FIGURE 8-3**).

Finally, the façade panels were screwed into a frame of oriented strand boards and thermocouples were fixed them. The missing thermal insulation was added at the front of the boxes up to the façade panels, the connection joints were sealed with tape, and the hydraulic components were installed (**FIGURE 8-4**).

MEASUREMENT AND RESULTS

This chapter presents the first results regarding heating of the panel surfaces and the water in the fluid channels. **FIGURE 8-5 (LEFT)** shows the results for solar radiation, exterior temperature, mass flow, inlet and outlet water temperature for both the thermally activated and non-thermally activated façade panel (= reference panel) from 15.09.2016, between 6 am and 6 pm.

FIGURE 8-3: COMPLETED SHELTER WITH THE TWO BOXES

The average exterior temperature during the observed time period was 22.3 °C, the recorded global radiation was on average 394 W/m². The water inlet temperature increased abruptly with the occurrence of sunshine by approximately 2 K and increased slowly over the course of the day. The outlet temperature was lower than the inlet temperature until sunshine occured, then the temperature increases were significantly higher than those of the inlet temperature. A maximum temperature increase of 21.3 K was achieved. All in all, the energy harvest was 3.48 kWh/(m²d), whereby the mass flow, which was initially set to approx. 25 kg/h, slowly decreased until 12:00 a.m. and then finally settled at a value of approx. 20 kg/h.

FIGURE 8-4: COMPLETED TEST FACILITY – LEFT, THE NON-ACTIVATED, RIGHT, THE ACTIVATED UNAB FAÇADE PANEL

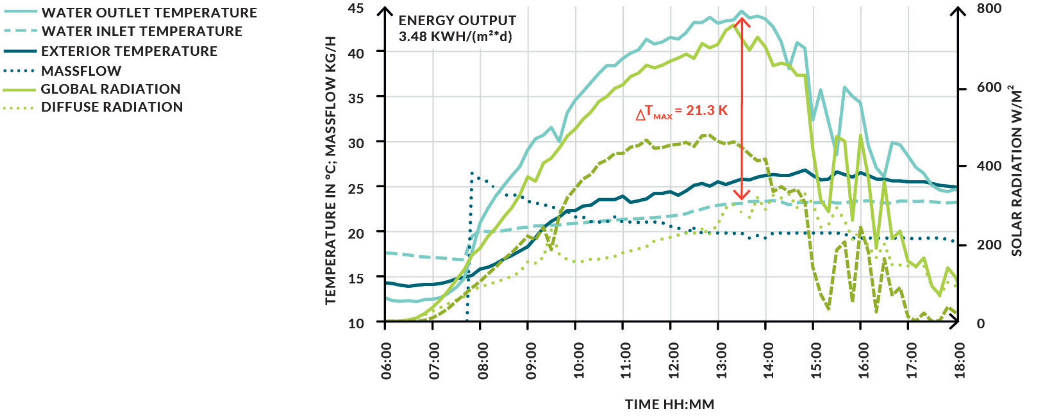


FIGURE 8-5: DAILY RESULTS (LEFT) FOR THE MEASURED EXTERIOR TEMPERATURE, (SOLAR) GLOBAL RADIATION, WATER OUTLET TEMPERATURE AND THE CALCULATED ENERGY HARVEST FOR THE THERMALLY ACTIVATED FAÇADE PANEL FROM 15.09.2016

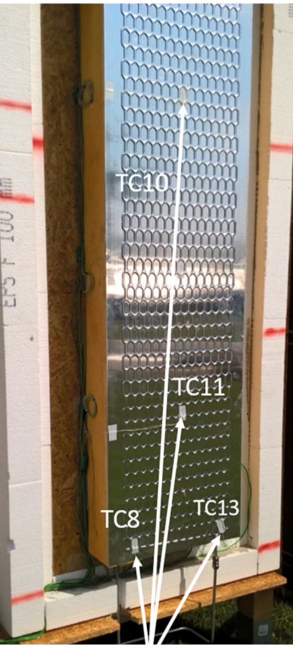


FIGURE 8-6: THERMOCOUPLE POSITIONS ON THE SURFACE OF THE ACTIVATED FAÇADE PANEL'S SURFACE

FIGURE 8-5 (RIGHT) shows the temperature curves recorded by the thermocouples on the surface of the thermally activated panel (TC7-TC13) and the reference panel (TC6) on the same day. It can be concluded, that the surface temperature of the reference panel on the same day rapidly reached values of just over 70 °C. The maximum surface temperature of the thermally activated panel reached just below 50 °C. The maximum temperature difference was approx. 25 K. The individual positions of the thermocouples on the surface of the panels are shown in both **FIGURE 8-6** and in the following **FIGURE 8-7**.

COMPARISON BETWEEN MEASUREMENTS AND CFD SIMULATIONS

Test bench measurements were partially accompanied by thermograhic photographs. These photographs were used to evaluate the results from the CFD simulations. On the one hand, a comparison was made between the measured and simulated heating up

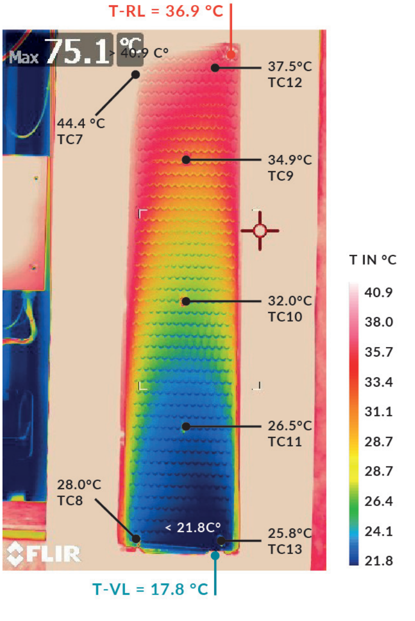


FIGURE 8-7: COMPARISON OF SURFACE OF THE ACTIVATED FA-GRAPHIC CAMERA SHOTS (LEFT)

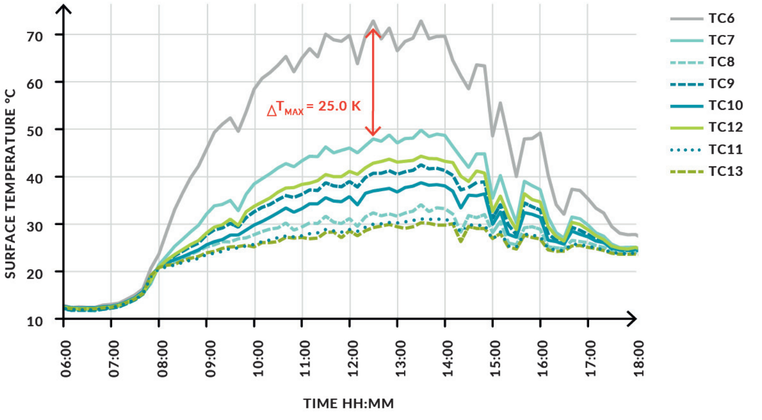
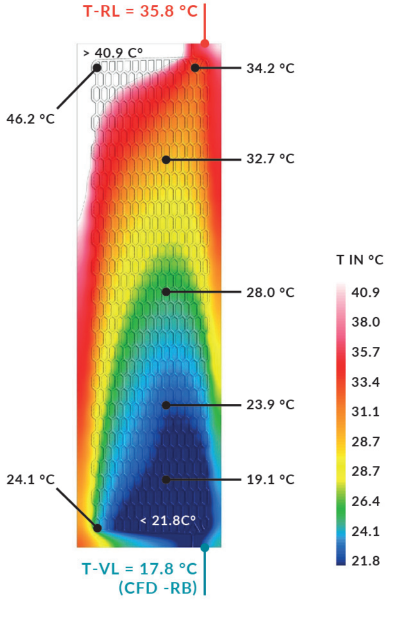


FIGURE 8-5: DAILY RESULTS
(RIGHT) FOR THE RECORDED SURFACE TEMPERATURES FOR THE THERMAL-LY ACTIVATED FAÇADE PANEL (EXCEPTION IS THE THERMOCOUPLE TC6 – THIS IS LOCATED ON THE REFERENCE PANEL AND IS ONLY SHOWN TO COMPARE THE SURFACE TEMPERATURES

characteristic of the panel, to the other hand, the measured and simulated water outlet temperatures should correlate as well as possible in order to foster confidence in the CFD simulation of heat transfer mechanisms and the energy harvest for further variants of thermally activated panels, without the need to conduct very time intensive measurements.



TEMPERATURE CONTOURS ON THE ÇADE PANEL BETWEEN THERMO- AND CFD SIMULATION (RIGHT)

FIGURE 8-7 shows a comparison between a photograph taken by a thermographic camera (on 21.09.2017 at 12:00 a.m.) and the CFD simulation with the same boundary conditions as were true for the measurement. The temperature contours correlate very well, even the water outlet temperatures fit well. Generally, the simulation resulted in minimally lower temperatures for the water outlet. It can therefore be assumed that the simulation will not forecast an excessively high energy harvest and that the CFD model is eminently suitable for use as a planning, analysis and optimisation instrument for thermally activated façade panels. The deviation between the simulated and locally measured energy harvest is 5.8 %.

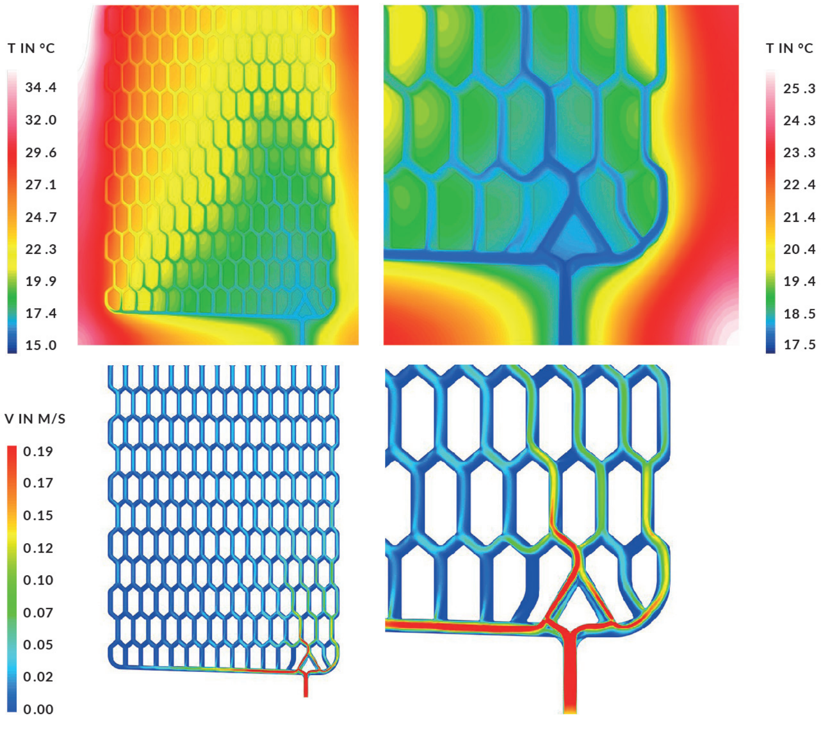


FIGURE 8-8: EXCERPT FROM THE FLOW AND TEMPERATURE CHARACTERISTICS IN THE OUTER SHEET'S FLUID CHANNELS IN THE LOWER PANEL SECTION

FIGURE 8-8 and **FIGURE 8-9** show distinctive details regarding temperature distribution and fluid channel flow characteristics in the thermally activated façade panel. It can be clearly seen that the distribution of the inflowing water in this variation of fluid channel layout does not yet work 100 % optimally, since there appeared local hot spots on the surface of the panel. Further analyses are required to achieve an improved temperature distribution by varying the channel branches and positioning of the water inlets. The aim is to achieve the most consistent flow possible through all of the fluid channels.

The measurement data and the CFD simulation results are used to create so-called "collector characteristic curves" that provide information concerning the efficiency of energy transmission from the panel to the fluid. Such characteristic curves can be subsequently used in suitable simulation tools (building and system simulation) to calculate the annual harvest under the influence of measured or estimated climatic conditions.

The collector characteristic curves created from the measurements and simulations are shown in **FIGURE 8-10**. The curve is the result of the equation (taken from the script Solar Energy Utilisation **[2]**) that is also contained in this illustration. The factor C_0 describes the theoretical energy yield, C_1 the convective energy loss and C_2 the

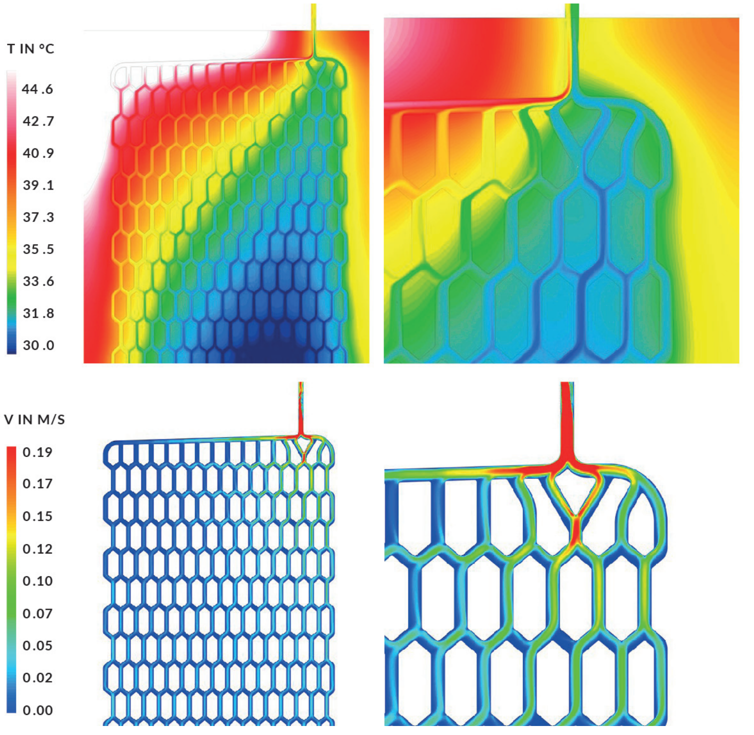


FIGURE 8-9: EXCERPTS FROM THE FLOW AND TEMPERATURE CHARACTERISTICS IN THE OUTER SHEET'S FLUID CHANNELS IN THE UPPER PANEL SECTION

energy component that is lost via radiation. The radiation losses can be neglected for the thermally activated façade panel in contrast to commercially available collectors with glass covers due to the lower absorber temperatures. For this reason, factor C_2 is assigned a value of 0 for all characteristic curves relating to the UNAB façade panel. The continous lines in the diagram represent the collector characteristic curves for the façade panel that have been generated from the measurement data (both for the bare aluminium absorber sheet and for the solar painted sheet). In contrast to the measurements, the characteristic curve in the simulation was calculated under constant wind influence (in the form of a heat transfer coefficient a in W/m²). The individual points in the diagram represent the calculated collector efficiencies from the simulation, the dashed lines with the same colour represent the calculated collector characteristic curve. The characteristic curves of commercially available collectors (dotted lines) were taken from the script **[2]** for the purpose of comparison.

The influence of the solar varnish of the absorber can be clearly deduced from the characteristic curves generated from the measurements (done within the scope of a master´s thesis **[1]** financed by the UNAB project **[3]**). The efficiency with the solar varnish is almost twice as high as without. The rapid decrease in efficiency

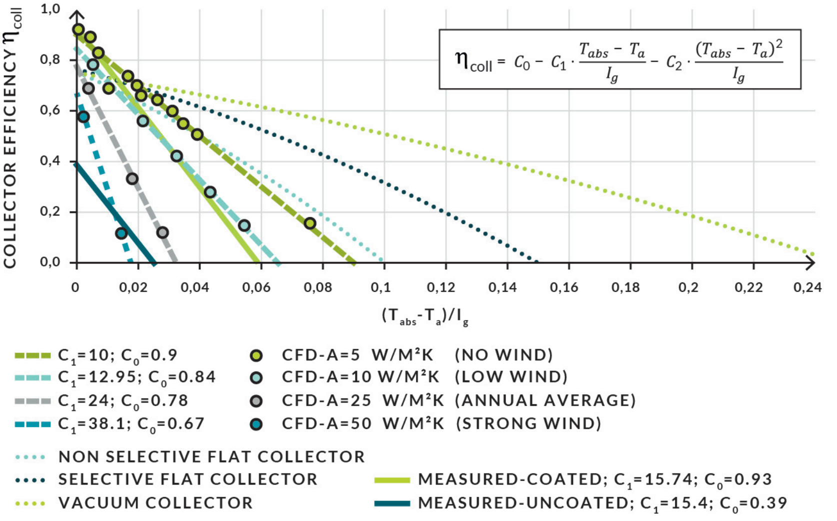


FIGURE 8-10: COMPARISON BETWEEN COLLECTOR CHARACTERISTIC CURVES CALCULATED FROM THE CFD SIMULATION AND MEASURED DATA FOR THE THERMALLY ACTIVATED FAÇADE PANEL FOR DIFFERENT HEAT TRANSFER COEFFICIENTS

with increasing wind is clearly recognisable by regarding the characteristic curves calculated from the simulation results. Even if the results from the UNAB façade panel can not keep up with high efficient solar-thermally energy conversion systems (such as selective coated flat collectors or vacuum collectors), the efficiency is nonetheless comparable to non-selective collectors at low levels of wind speed. Unfortunately there were no exact wind measurements near the test facility, only data from a remote climate station were available. However, it can be assumed that the influence of the wind on the test bed location was relatively low. This is supported by a comparison of the characteristic curve derived from the measurement data (light green continuous line) and the characteristic curve derived from the simulation results (turquoise dashed line) for low wind.

LITERATURE:

[1] M. Hörtenhuber, Konstruktion, Aufbau und Inbetriebnahme eines Versuchsstandes zur Ermittlung des thermischen Verhaltens eines integralen Fassadenelementes, Graz: Technische Universität Graz, 2017.

[2] W. Streicher, Sonnenergienutzung (Vorlesungsskriptum), Institut für Wärmetechnik: Technische Universität Graz.

[3] Umsetzung nachhaltigen Bauens durch optimierte Projektsteuerungsprozesse und integrale Gebäudehüllen (UNAB), Projekt: gefördert vom Zukunftsfonds des Landes Steiermark.

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09

PRACTICAL APPLICATION OF THE PROCESS MODEL

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A SPiCE-based application of maturity assessment requires a reference model for the implementation of sustainable façades. As explained in the description of the process model and the description of the methodology used to evaluate the quality of processes for the implementation of sustainable façade in Chapter 2, base practices and generic practices are necessary for the practical application and maturity assessment of façade types.

DEVELOPMENT OF A CROSS-LINK MATRIX

Once the targets had been defined taking sustainability requirements from the ÖGNI/DGNB certification system into account, a requirement profile could be defined within the scope of process optimisation and subsequently a cross-link matrix could be developed for the holistic evaluation of optimisation potential. Base practices and process-oriented base practices were defined to fulfil the primary optimisation targets (functional requirements). These base practices contribute to the fulfilment of functional requirements according to degree of cross-linking and weighting in the model. Hence the base practices form the foundation for the evaluation of the cross-link matrix. In a holistic evaluation, these base practices also induce, parallel to the primary optimisation targets, possible synergy or trade-off potential on other optimisation targets regarding sustainability.

Building upon the requirements profile for energetic, activated hybrid façades, possible primary sustainability optimisation targets were identified (resource conservation, energy conservation, ability to disassemble, etc.). This is done with the assistance of a case study of an office building (Case study - Karmeliterhof) and subsequently based on selected practical implementation measures (base practices) that represent the reference measures for the subsequent variant comparisons. The result is a cross-link matrix that is intended to enable the assessment of the potential for optimisation of the new façade design from a holistic perspective.

This involved working out evaluations of the interactions of the identified base practices with the functional requirements, the effects on environmental and economic qualities and the influence of the required process requirements when implementing the corresponding base practice.

During the development of the cross-link matrix, the team decided that apart from evaluating on a building component level, an evaluation on a building level at an early development stage in the façade design is not expedient due to the high number of undefined parameters. The evaluation on a building

FIGURE 9-1: CASE STUDY - KARMELITERHOF

level was thus limited as far as an evaluation of the interactions with the fundamental parameters is possible at this point in time. The results of the expert survey on the building component level represented a further input for the detailed planning of the UNAB façade concept. Furthermore, the previously identified optimisation goals on a building level based on the comparison with case study - Karmeliterhof were considered for the further development of the façade design.

SIDE NOTE: CASE STUDY

The Karmeliterhof is a building belonging to the company Landes-immobilien-Gesellschaft mbH. The project UNAB considered the new construction that can be seen in **FIGURE 9-1**. The most important building parameters are shown in **FIGURE 9-2.**

The Karmeliterhof was used as a "reference case" for the initial application during the development of the process model. Initially the object and process qualities of the object were analysed in order to be able to take the insights acquired into account when designing the process model.

FUNDAMENTALS & STRUCTURE OF EVALUATION METHODOLOGY FOR THE CROSS-LINK MATRIX

A cross-link matrix was constructed in several expert workshops by combining the different expert perspectives, a result of the interdisciplinary constellation of the project team (construction engineering, heat engineering, construction business and sustainability evaluation). Expert values (= expected value) were defined for each base practice along with the bandwidth of the scope of possible positive and negative effects of the base practices (minimum and maximum).

During the development of the cross-link matrix, care was taken to ensure compatibility with the fundamental process model and hence four quality standards (target value, partial target value, reference value, limit value) were defined (see **FIGURE 9-9**). These quality standards were defined as follows:

T: The target value represents the "best practice", i.e. the application of the UNAB façade construction

Area	2300 m² (gross floor area)
Stories	5+1
Outer wall construction	Reinforced concrete, Brick walls, thermal insulation system
Energy efficiency class	B (39 kW/m²*a)
Surface-volume ratio	0,21 [m-1]
Heat generation	District heating
LEK value	33 [-]
Average U-Value	0,565 [W/m²*K]

FIGURE 9-2: KEY DATA OF CASE STUDY

P: The partial target value is achieved by a building larger than/equal to an ÖGNI/DGNB certification in the award level "silver" (it is used to create a virtual scenario)

R: The reference value is an office building. The case study Karmeliterhof was used as the basis for evaluation of other scenarios

L: The limit value corresponds to a building according to the "minimum standards" based on fulfilment of the OIB guidelines

The cross-link matrix contains base practices that can be allocated to the following primary optimisation targets (functional requirements) based on the dimensions of sustainability reflecting the ÖGNI/DGNB:

SOCIAL, FUNCTIONAL AND TECHNICAL QUALITIES

- Thermal comfort in summer/winter
- Air tightness
- Visual comfort
- Noise protection
- Room acoustics
- Pollutant content in building products
- Ability to be dismantled and recyclability
- Flexibility and re-purposing
- Durability
- Degree of pre-construction
- Building method
- Influence of user/operator
- Adaptability of technical systems
- Safety and risk of failure
- Final energy requirements

ENVIRONMENTAL QUALITY

- Embodied greenhouse gas emissions – manufacturing stage
- Embodied greenhouse gas emissions and greenhouse gas emissions in the – use stage
- Embodied greenhouse gas emissions – end-of-life stage
- Non-renewable grey energy– manufacturing stage
- Non-renewable grey energy and operational energy – use stage
- Non-renewable grey energy – end-of-life stage

ECONOMIC QUALITY

- Construction costs
- Planning costs
- Disposal costs
- Maintenance costs construction
- Maintenance costs HVAC
- Cleaning costs
- Demolition, recycling and removal costs

PROCESS QUALITY

- Requirement planning
- Target agreement (sustainability targets)
- Integral planning
- Designs
- Tender and award requirements
- Object documentation
- Handover to operation
- Systematic commissioning

The first results from the cross-link matrix are used as a basis for the creation of a development profile for the design of energetically activated, integral building envelopes. The merging of development profiles and the formulation of integrative questions and development spectra is done taking sustainability aspects based on the created matrix of sustainability aspects on a façade level into account. The development of profiles for hybrid construction and building technology are done after the development profiles have been completed. Finally, the developments for hybrid construction are combined with the elements of building technology taking sustainability criteria into account.

	Façade type	Construction	Energy generation	Conditioning
Scenario 1	**UNAB panel**	Element façade with polyutethane insulation (Aluminium sheet-PU-Aluminium sheet)	x	x
	Mullion and transom façade	Curtain wall (Skeleton construction)	x	x
	ETICS façade (Karmeliterhof)	Massive wall construction with window bands Plaster-Brick (20 cm)-EPS (16 cm)-Plaster	x	x
	ETICS façade (Minimum requirement)	Massive wall construction with window bands	x	x
Scenario 2	**UNAB panel** with energy generation (element-integrated solar modules)	Element façade with polyutethane insulation (Aluminium sheet-PU-Aluminium sheet)	Element-integrated energy generation (No glass plate)	x
	Mullion and transom façade with energy generation (façade-integrated solar modules)	Curtain wall (Skeleton construction)	Element-integrated energy generation (Façade collectors)	x
	ETICS façade (Karmeliterhof)	Massive wall construction with window bands Plaster-Brick (20 cm) -EPS (16 cm)-Plaster	x	x
	ETICS façade (Minimum requirement)	Massive wall construction with window bands	x	x
Scenario 3	**UNAB panel** with energy generation (glued photovoltaic pad)	Element façade with polyutethane insulation (Aluminium sheet-PU-Aluminium sheet)	Energy generation (glued photovoltaic pad)	x
	Mullion and transom façade with energy generation (façade-integrated photvoltaic modules)	Curtain wall (Skeleton construction)	Energy generation (Photovoltaic modules)	x
	ETICS façade (Karmeliterhof)	Massive wall construction with window bands Plaster-Brick (20 cm) -EPS (16 cm)-Plaster	x	x
	ETICS façade (Minimum requirement)	Massive wall construction with window bands	x	x
Scenario 4	**UNAB panel** with conditionig (element-integrated fluid channels)	Element façade with polyutethane insulation (Aluminium sheet-PU-Aluminium sheet)	x	Room conditioning (Heating and cooling system UNAB panel)
	Mullion and transom façade with conditioning (building component activation)	Curtain wall (Skeleton construction)	x	Room conditioning (Heating and cooling system - building element activation)
	ETICS façade (Karmeliterhof)	Massive wall construction with window bands Plaster-Brick (20 cm) -EPS (16 cm)-Plaster	x	Heating via convectors and floor heating system No cooling system
	ETICS façade (Minimum requirement)	Massive wall construction with window bands	x	Heating via convectors No cooling system
Scenario 5	**UNAB panel** with energy generation & conditioning (element-integrated solar modules & element -integrated fluid channels)	Element façade with polyutethane insulation (Aluminium sheet-PU-Aluminium sheet)	Element-integrated energy generation (No glass plate)	Room conditioning (Heating and cooling system UNAB panel)
	Mullion and transom façade with energy generation & conditioning (façade-integrated solar modules & building component activation)	Curtain wall (Skeleton construction)	Element-integrated energy generation (Façade collectors)	Room conditioning (Heating and cooling system - building element activation)
	ETICS façade (Karmeliterhof)	Massive wall construction with window bands Plaster-Brick (20 cm) -EPS (16 cm)-Plaster	x	Heating via convectors and floor heating system No cooling system
	ETICS façade (Minimum requirement)	Massive wall construction with window bands	x	Heating via convectors No cooling system
Scenario 6	**UNAB panel** with energy generation & conditioning (glued photovoltaic pad & element-integrated fluid channels)	Element façade with polyutethane insulation (Aluminium sheet -PU-Aluminium sheet)	Energy generation (glued photovoltaic pad)	Room conditioning (Heating and cooling system UNAB panel)
	Mullion and transom façade with energy generation & conditioning (façade-integrated solar modules & building component activation)	Curtain wall (Skeleton construction)	Energy generation (Photovoltaic modules)	Room conditioning (Heating and cooling system - building element activation)
	ETICS façade (Karmeliterhof)	Massive wall construction with window bands Plaster-Brick (20 cm) -EPS (16 cm)-Plaster	x	Heating via convectors and floor heating system No cooling system
	ETICS façade (Minimum requirement)	Massive wall construction with window bands	x	Heating via convectors No cooling system

FIGURE 9-3: OVERVIEW OF THE SCENARIOS DEVELOPED

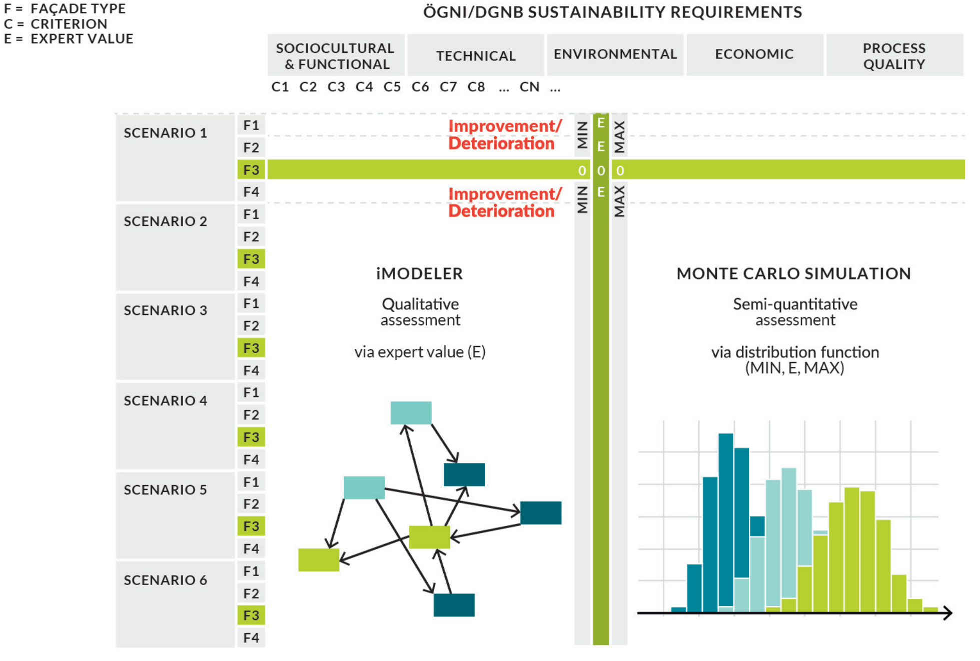


FIGURE 9-4: SCHEMATIC REPRESENTATION: CROSS-LINK MATRIX

In order to enable the evaluation of different façade types, scenarios were developed over the course of the project (see **FIGURE 9-3**) and all practical implementation measures (base practices) and process-oriented implementation measures (base practice process) were evaluated with expert support.

EVALUATION OF THE CROSS-LINK MATRIX AND DEFINITION OF DISTRIBUTION FUNCTIONS

The application of the opportunity/risk analysis in the process model is done during model step "B" during the filtering/evaluation of the scenarios depending on the stakeholder targets.

The qualitative expert evaluations of the defined scenarios are done based on base practices and their influence on selected functional requirements. The potential qualitative influence on the individual functional requirement when applying a base practice was rated on a scale (-2 to +2) by the project partners, taking specific expert knowledge into account. The reference scenario (Case study – Karmeliterhof) represented the baseline and is "neutral", i.e. rated at "0". The consideration of possible variables (i.e. risks/opportunities) is done via the classification done in expert workshops within the defined specific bandwidth per base practice (min./max. values).

FIGURE 9-4 shows the cross-link matrix. The expert values (green column) were always used for the evaluation of the scenarios for the purposes of modelling in "iMODELER". All three values (minimum, expert value, maximum) are necessary for the Monte-Carlo simulation.

A distribution function needs to be defined to consider the bandwidth of a parameter that shows the probability of the values occurring within the selected bandwidth. Next to deterministic values six distribution functions have been applied within the project (see **FIGURE 9-5**). In a rectangular distribution, the minimum and maximum values of a parameter are known; each value within this bandwidth is allocated the same probability of occurrence. All the other five variations for the consideration of uncertainties use triangular distributions that are defined by a minimum, expected and a maximum value. The distances between the values define the form (skewness) of the triangle and hence determine the influence on the calculation. In principle, symmetrical and asymmetrical triangles are conceivable. If a symmetrical triangle is selected, the probability for the lowest and highest values is allocated an identical weighting in relation to the expected value (mode). The distance between minimum and expected value is the same as between the expected value and maximum. If a right-skewed distribution is used, smaller values have a larger, and for left-skewed distribution a lower probability. Right and left-skewed triangles where the expected value coincides with the minimum or maximum value are special cases. Here, only distributions upwards or downwards are expected.

The selection of an input parameter for calculation in the form of a deterministic value can only be done if the value is known and no deviations are expected from this value. If no guaranteed quantification of the size of a value is possible, then it is recommend this value be expressed in the form of a distribution function in order to consider uncertainties.

Three values were determined by the expert rating. The average value that represented the actual expert value was the result of averaging all expert opinions. The values left and right of the expert value form the “worst case” and “best case” values of the practice and hence form the upper and lower limit values around the expert value. These three values enable the rectangular and triangular distribution functions as the basis for sensitivity analyses using Monte-Carlo simulation.

Every decision, and hence also those regarding the value of input parameters for operational and economic construction perspectives, has associated uncertainties, and subsequently, risks (and also opportunities). Basically two ways of viewing the subject of “risk” need to be differentiated. There are always positive and negative deviations from a current value to a planned value. On the one hand, “risk” only describes the negative deviations, on the other, the positive deviations are named “opportunities". Furthermore, "risks" can also be understood as the possibility of a positive deviation "opportunity" and a negative deviation "danger". Here risk implies both danger and opportunity.

BASICS FOR A PRACTICAL APPLICATION OF THE MONTE-CARLO SIMULATION

The Monte-Carlo method is a numerical method that employs random numbers to execute simulations. The result of each simulation step (also called iteration) is a random value that is calculated on the basis of a stochastic model. The Monte-Carlo simulation enables the probability distribution of a sought quantity to be determined via a previously defined calculation rule. In an arbitrary number of iterations, a software program generates random numbers for the input parameters (in this case, "@RISK"), which are inserted into the correspondingly pre-defined distribution density function, and combines out of that the distribution function of the results according to a calculation guideline (calculation equations).

Input parameters for the simulation (apart from the calculation guideline) are:

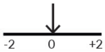
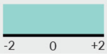
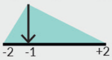
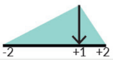
- Bandwidth
- Distribution functions
- Correlations between input parameters (only meaningful if the relationships are known and close to reality)

1. BANDWIDTH

This is an area in which input parameters can occur. By definition, values will not occur above or below this bandwidth. The bandwidth is enclosed by minimum and maximum values (see MIN and MAX in **FIGURE 9-5**). A rating was executed using a distribution function for the current calculation model associated with the cross-link matrix developed in UNAB. The MIN describes the lowest (most negative) influence of the optimisation measure and the MAX describes the highest (most positive) influence of the optimisation measure. The definition of the bandwidth for the project parameters was done during the joint workshops with the project partners.

2. DISTRIBUTION FUNCTIONS

Aside from the limits of calculation parameters, particular interest is focussed on how the probability is distributed within the defined bandwidth. If no further informa-

DISTRIBUTION FUNCTION		MIN	EXP	MAX	DESCRIPTION
Deterministic Value			0		The expected value is known, no deviations are expected.
Rectangular distribution		-2		+2	Minimal & maximal values are known, the expected value can not be predicted
Symetrically triangular distribution		-2	0	+2	The expected value is known, deviations downwards & upwards are expected to be the same size
Right-skewed triangular distribution		-2	-1	+2	The expected value is known, deviations upwards are expected to be larger than downwards
Left-skewed triangular distribution		-2	+1	+2	The expected value is known, deviations downwards are expected to be larger than upwards
Right-skewed triangular distribution (Exception)		-2	-2	+2	The expected value is known & equal to minimum, deviations are expected upwards
Left-skewed triangular distribution (Exception)		-2	+2	+2	The expected value is known & equal to maximum, deviations are expected downwards

ASSESSMENT: MIN / EXP / MAX

FIGURE 9-5: DISTRIBUTION FUNCTIONS FOR THE EVALUATION OF OPTIMISATION POTENTIAL OF THE CROSS-LINK MATRIX

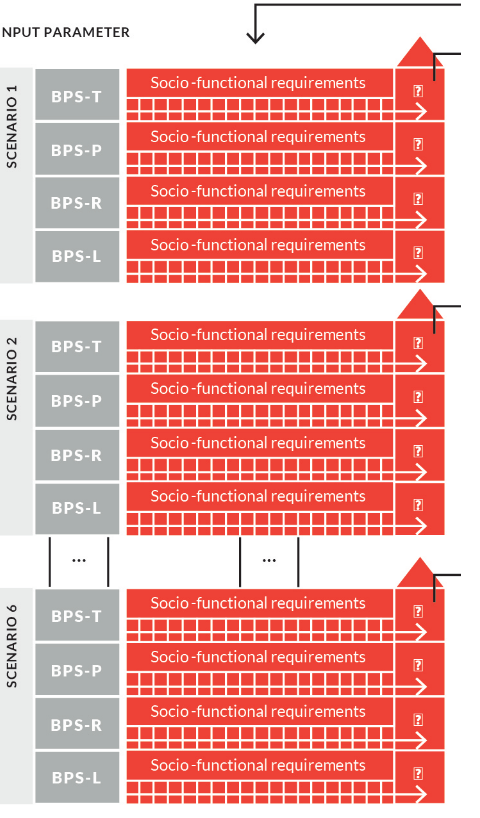
tion is available, a uniform distribution (rectangular distribution) can be assumed. In this case, each value has the identical probability of occurrence within the defined limits. If a certain value within the bandwidth can be allocated a higher probability (expected value or modal value), a triangular distribution can be employed for the model generation (**FIGURE 9-5**) **[1]**.

A further advantage of triangular distribution is that their parameters (minimum, expected value and maximum) are relatively easily estimated by experts. The required mathematical statistical expertise to define a triangular distribution is significantly lower than the definition of logistic distributions or similar, for example. Triangular distributions were deemed to be sufficient for the simulations carried out regarding the evaluation of the optimisation measures of the cross-link matrix. Subsequent investigations could also analyse the use of other distribution functions with the given input parameters and defined bandwidths in order to determine whether the selection of different distribution functions would lead to fundamentally different rating totals.

3. CORRELATION

Correlation permits the dependencies between different input parameters (in this case rating evaluations) to be mapped. The inclusion of correlation in the simulation requires careful consideration and analysis of data structures.

Furthermore, when defining or determining the correlation coefficients, care must be taken that consistent correlation matrices are used. To be precise, only positive definite and positive semi-definite correlation matrixes are permissi-



ble in the "@RISK" software. The consistency check for the inputted matrix is done by calculating its inherent values. A positive definite matrix only has positive inherent values; a positive semi-definite matrix has inherent values that are greater than or equal to zero. In accordance, a matrix that has at least one negative inherent value is rejected for further calculation stages and must be redefined or adapted **[2]**. In the case at hand, the consideration of correlation was waived; it was assumed that the input parameters to the simulation were independent (correlation coefficient r = 0).

4. SAMPLING METHOD

The selection of random numbers for a (repeating) iteration step from the defined distribution of the input values can be done via two different sampling methods in the "@RISK" software:

MONTE-CARLO SAMPLING METHOD

Latin Hypercube sampling methode both procedures select random values out of the defined bandwidth based on the cumulated probability distribution (total curve). The randomly sampled values are subsequently used in the calculations. The advantage of the Latin Hypercube sampling method is that a large range of sampled values can be collected with just a few iteration steps. It requires fewer iteration steps in total than the Monte Carlo sampling method to attain a stable simulation result.

The Latin Hypercube sampling method is used exclusively for the simulation during the evaluation of the optimisation measures for the cross-link matrix. This method is still described as a Monte-Carlo simulation, since the Latin Hypercube sampling method is only an improved (reduced computational effort) procedure for the execution of Monte-Carlo simulations.

FIGURE 9-6: SCHEMATIC REPRESENTATION: CALCULATION PROCEDURE

5. MODEL GENERATION

The model is generated using the UNAB cross-link matrix. The project partners define the weightings (deterministic values shown as arrows in **FIGURE 9-6**) and the ratings for the individual optimisation measures (triangular distribution shown as triangles in **FIGURE 9-6**).

The ratings are subsequently separated and totalled in the Monte Carlo simulation according to the requirements (social and functional, economic, environmental and process quality). The result of adding the weighted ratings results in histograms from which the probability of exceeding or falling below the reference value (= 0) can be directly read off and a direct comparison made between different scenarios. The ratings totals over all requirements per scenario results in a total rating that can be used for comparisons.

6. CALCULATION AND INTERPRETATION OF RESULTS

The input parameters for deterministic calculations are usually associated with large uncertainties and need to be determined via qualified estimation. A systematic consideration of these uncertainties using deterministic calculation procedures results, in the best case, in percentage additions or subtractions. The quantification of an opportunity-risk ratio is thus not possible. The low confidence and the apparent high accuracy of deterministic results is a problem. Probabilities cannot be determined from a deterministic result (a single number). Any knowledge of possible input parameter bandwidths and their interrelationships is lost in a deterministic perspective **[3, 4]**.

The Monte Carlo simulation, for which a cross-link matrix has been developed, provides histograms (**FIGURE 9-6**) separated by requirements (social and functional, technical, economic, environmental and process quality) and for the total ratings of the six scenarios. The range of the histograms and the comparison between them indicates the distribution and uncertainty of the rating. If the bandwidth of the histogram is narrow, then the rating has low uncertainty.

The reference scenario (Case study – Karmeliterhof), with a deterministic evaluation of 0 points, serves as a reference value for the evaluation of ratings. This reference value is adjusted using the sliding limiter at the top of the figure for every output histogram. This enables the probability of exceeding or falling below the deterministic reference value to be read directly from the histogram. Based on this reference value, the associated opportunity-risk ratio can also be read off. If a different deterministic base value is used for further comparisons, the opportunity-risk ratios can be calculated in an analog fashion.

The mean values in the histograms can be used for an initial evaluation of the ratings. These deliver an initial order of the scenarios. However, it must be noted that regarding the mean values alone will not lead to a satisfactory comparison of the scenarios. If the histograms of different scenarios overlap in a certain value range, then deeper analysis and interpretation of the results are necessary.

Overlaps are to be interpreted such that the order related to the total points within a Monte Carlo simulation for two observed scenarios based on rating evaluation can change using a distribution function. Hence the simulation may produce potential iteration results that cause the order to be reversed. If this is the case, it is of particular interest to discover what is the probability that such a reversal can occur. To do this, the ranking of the scenarios and the number of points per scenario can be automatically calculated. Such an occurrence is, however, very improbable with the use of continuous distributions and the large number of criteria. The output of the simulation can be used to determine the rankings including probabilities for this rank **[5]**.

7. BENEFITS

The evaluation of the scenarios is carried out based on hard as well as soft factors with uncertainties. The advantage of the Monte Carlo simulation is that these uncertainties are represented by bandwidths and distribution functions and integrated into the calculation. If the evaluation is unambiguous, the simulation confirms this with the representation of the results as a range. If two procedures have similar total points, this can be seen in the histograms as an overlap and an opportunity-risk ratio can be shown with the aid of the rankings. If this ratio is not significant for a decision, the allocation of points and/or the weighting may need to be checked, or further criteria added.

An overlap in the histograms for the total points is only possible with probabilistic calculations. Pure deterministic observations only have one value for total points per scenario. This compression of available information to a single number means that no statement can be made concerning distribution of the points or opportunity-risk ratio for deterministic observations.

Decisions are put on a more meaningful basis as a whole through the knowledge of the opportunity-risk ratio and systematic considerations regarding uncertain input parameters.

PRACTICAL APPLICATION OF THE PROCESS MODEL

The software “iMODELER” was used, as mentioned previously, to model and obtain a practical application of the processed contents of the cross-link matrix and to visualise the multitude of interrelationships between them. Using the Building Sustainability Quest Tool to implement the base and generic practices enables the creation of a planning guide for the implementation of sustainable construction via optimised project management processes and integral building envelopes.

The basis of the process model is formed by the five qualities of sustainability based on the building certification system ÖGNI/DGNB. They are the environmental quality, economic quality, social and functional quality, technical quality and the process quality. By connecting the main criteria groups of the corresponding sustainability qualities and the requirements placed upon them, the corresponding optimisation targets (functional requirements) from the cross-link matrix can be linked with the requirements according to ÖGNI/DGNB.

FIGURE 9-7 shows a schematic of the model levels and the linking of the scenarios in the “iMODELER” software tool.

EVALUATION PROCEDURE

FIGURE 9-8 represents the evaluation procedure showing the required process steps of a systemic maturity assessment based on different stakeholder requirements.

A - Goal definition

It is necessary as a first step to determine the individual stakeholder targets. This is done via the target definition in the “iMODELER” software tool. The target definitions can be determined for all functional requirements (optimisation targets). Alternatively, there is the possibility to define individual requirements just for single functional requirements.

Four fictional stakeholder scenarios have been developed to determine the target definition:

- Total sustainability
- Investor
- User
- Community

The stakeholder scenario “total sustainability” reflects a scenario in which all sustainability qualities are weighted equally. In the requirement scenario „Investor“, the economic qualities are in the foreground. The environmental quality in the scenario developed for the “investor” group is without

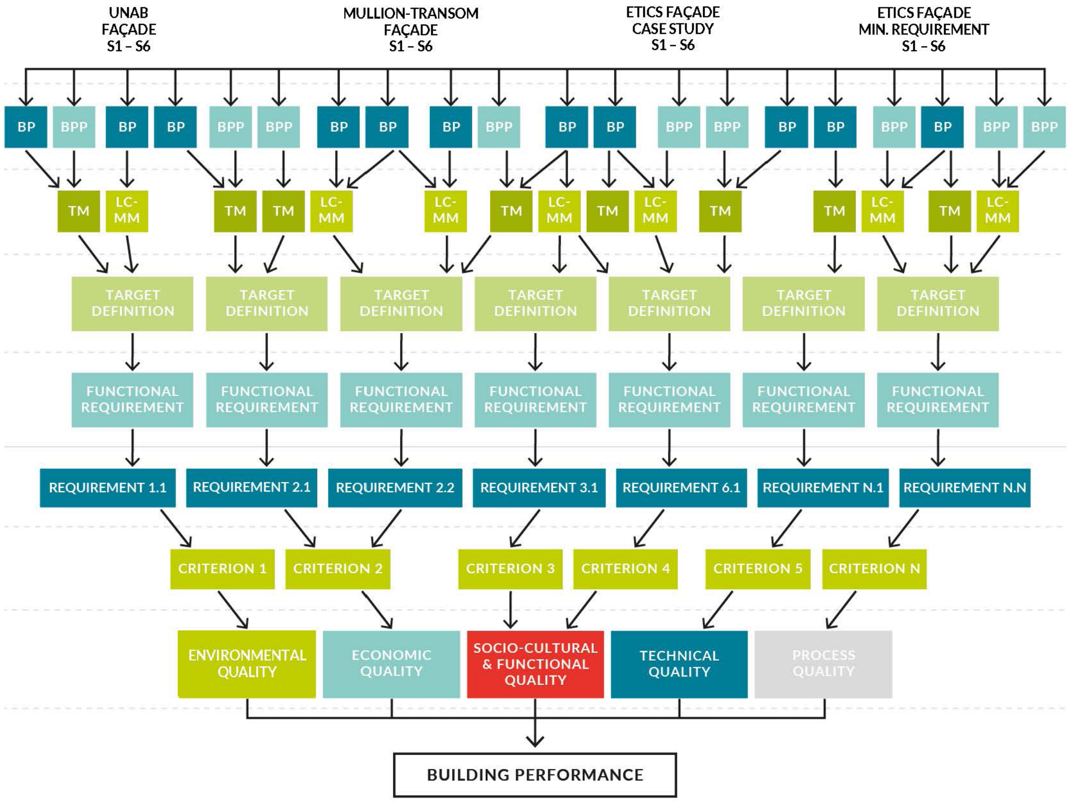


FIGURE 9-7: LINKING THE SCENARIOS IN THE iMODELER SOFTWARE TOOL[1]

meaning. The third stakeholder scenario "user" places the highest significance on the social and functional qualities. The environmental quality in this scenario does not carry much relevance. The last scenario "community" places environmental qualities in the foreground. This stakeholder group places little relevance on social and functional aspects.

a. Selection of a functional requirement (FR)

The procedure for evaluation of sustainability processes begins accordingly at the fifth model level (see **FIGURE 9-7**). The sequence model describes the steps from the selection of a functional requirement up to the evaluation scheme for a base practice. For an overall evaluation, it is recommended in practice that all functional requirements are included in the planning and evaluated according to the sequence model. The systemic meaning of

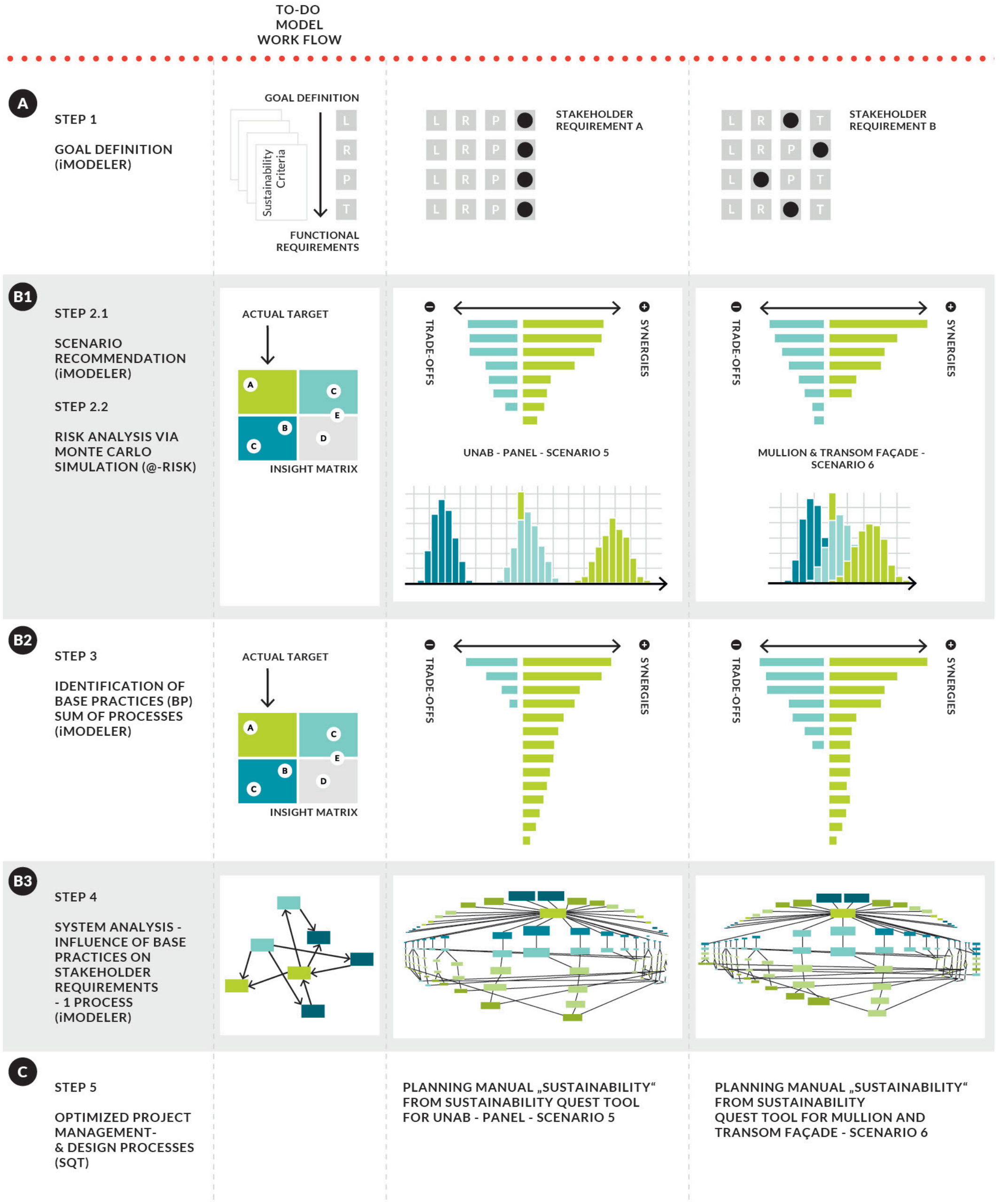


FIGURE 9-8 : SCHEMATIC REPRESENTATION: PROCEDURE OF A COMPARATIVE AND SYSTEMIC MATURITY ASSESSMENT [2] the functional requirement in the total target achievement in the ÖGNI/DGNB certification system can be represented by the insight matrix in "iMODELER" (as the result of the cross-link analysis) either for the evaluation criteria, for the main criteria group or for the aggregated total result of all main criteria groups.

b. Determination of the quality level

The decision maker defines the required quality level for the optimisation targets (all developed functional requirements from the cross-link matrix) in "iMODELER". The definition of the quality level enables individual stakeholder requirements to be considered.

TARGET DEFINITION

Scenario level	Weighting iMODELER	Linguistic meaning
Target value	100%	Absolutely important
Partial target value	66%	Important
Reference value	33%	Less important
Limit value	0%	Not important

FUNCTIONAL REQUIREMENT

FIGURE 9-9: QUALITY LEVEL FOR FUNCTIONAL REQUIREMENTS

B1 – STEP 2.1
System analysis – scenario recommendation

Once the quality levels for the optimisation targets according to individual stakeholder have been defined, an initial system analysis in "iMODELER" provides a scenario recommendation.

FIGURE 9-10 shows an example of a recommendation for the implementation of scenario 5 regarding the specific requirements, which compared to the ref-

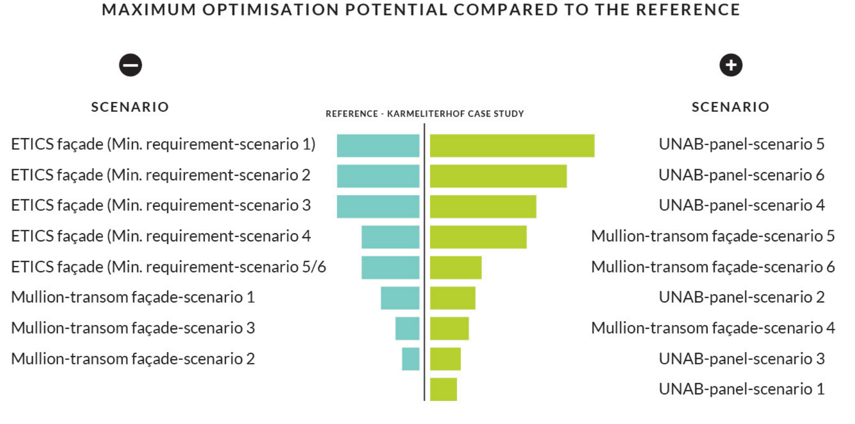


FIGURE 9-10: SCENARIO RECOMMENDATION FOR REQUIREMENTS PROFILE "USER"[3]

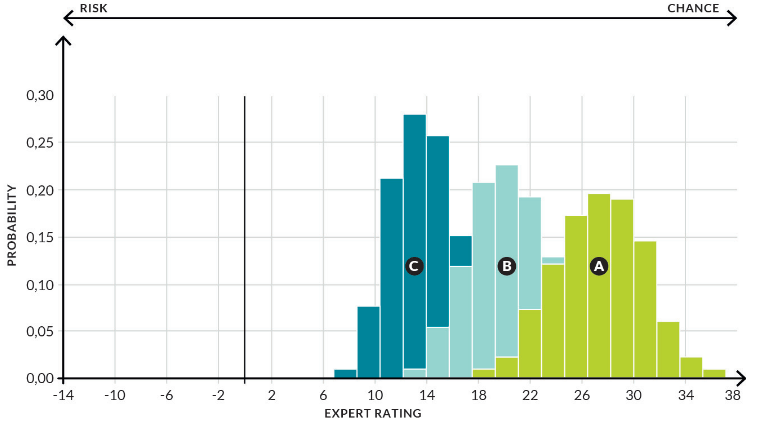


FIGURE 9-11: OPPORTUNITY AND RISK POTENTIAL OF THE SCENARIO RECOMMENDATION[4]

erence variant, shows the greatest optimisation potential. Due to the expert evaluations previously carried out, the strength and weaknesses of the selected scenarios can be recognised. Assuming that expert evaluations have been carried out for other scenarios, i.e. for other façade types, the model can be extended for an unlimited number of additional scenarios.

B1 – STEP 2.2
System analysis – Assessment of opportunity and risk potential

The data provided by the expert evaluation (minimum, expert value, maximum) and the results from the Monte-Carlo simulation enables an initial assessment of the opportunities and risks regarding the fulfilment of the specific stakeholder targets for the suggested scenario.

In this context, **FIGURE 9-11** shows an example of the optimisation potential of different scenarios compared to the reference variant. Overlaps are to be interpreted here as indicators that the order related to the total points may change within the Monte-Carlo simulation for the two scenarios (based on the rating evaluation carried out via distribution function). In such a case, further detailed analysis and interpretation of the results is required.

B2 – System analysis – identification of base practices

For every optimisation target, there is at least one technical measure and one life-cycle management measure available for implementation. The base practices developed over the course of the project influence these measures for the practical implementation.

In addition, the qualitatively most meaningful base practices for the optimisation of sustainability can be identified (if necessary) for all the next levels down in the process model.

Once the base practices have been identified, they can be evaluated according to their relevance. If the identified base practice is a minimum requirement according to ÖGNI/DGNB (k.o. criteria) or if a base practice has systemically relevant and/or quantitatively relevant influence on other optimisation targets, then it is rated according to the N-P-L-F evaluation principle. If these base practices are closely observed during the planning or later execution stages, then the probability that the executed scenario corresponds to the requirements increases. If the base practice has no particular relevance, then no detailed observation of the base practice is necessary.

FIGURE 9-12 shows the relevant base practices for the stakeholder requirement scenario "user" by way of example.

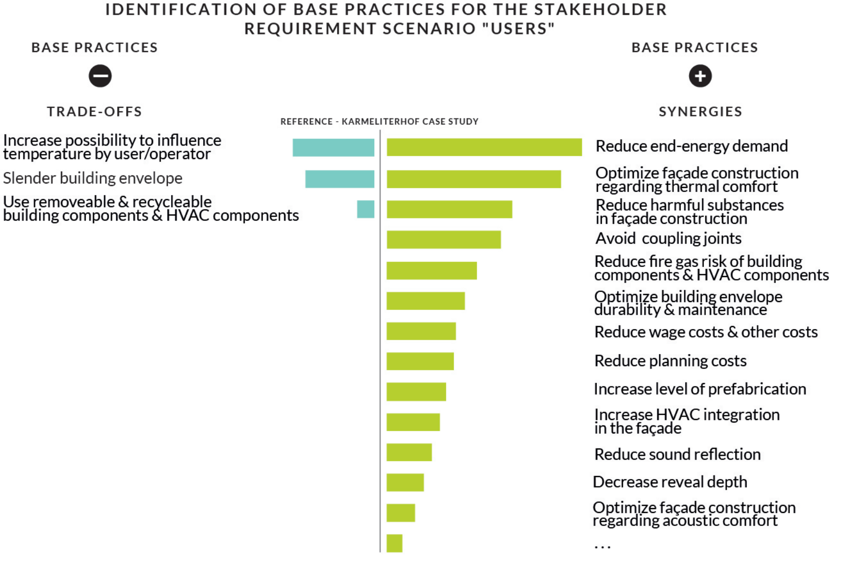


FIGURE 9-12: IDENTIFICATION OF THE BASE PRACTICES FOR THE REQUIREMENTS PROFILE "USER"[5]

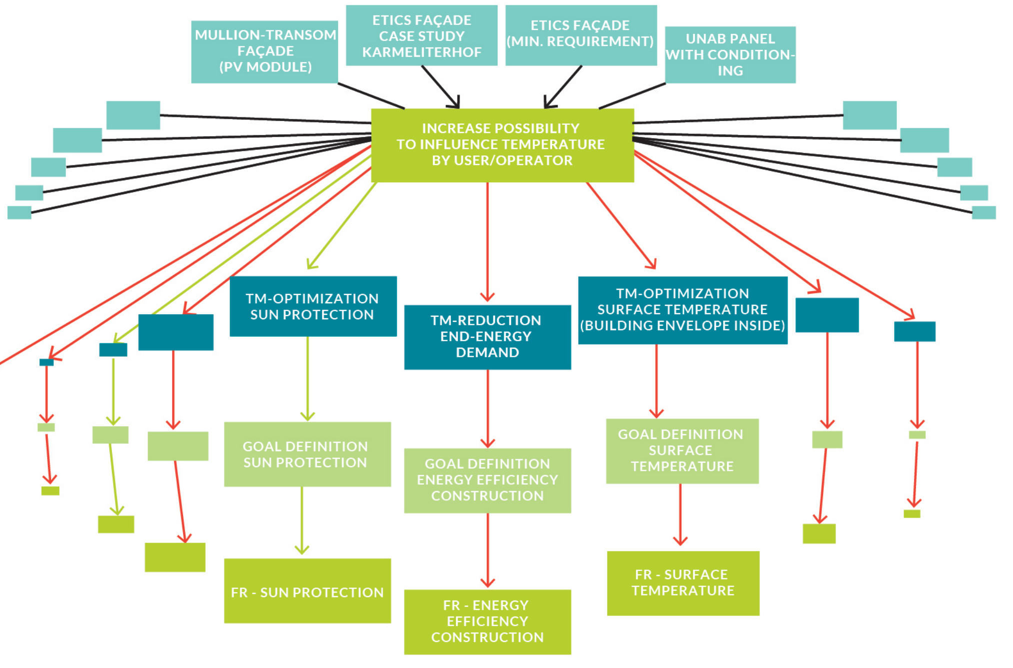


FIGURE 9-13: SYSTEM ANALYSIS IN THE SOFTWARETOOL iMODELER[6]

B3 – System analysis – influence of base practices on stakeholder requirements

The last step of the system analysis investigates the mutual influence of the base practices and the defined optimisation targets.

This step visualises base practices that have a positive influence (potential for synergy) and those that have a negative influence (potential for trade-off) on the technical measures and subsequently on the functional requirements (stakeholder's optimisation targets).

The role (systemic meaning) of the base practice is visible in the insight matrix and in the histogram within the "iMODELER" software tool. The visualisation enables the decision maker to be sensitized, since it can be seen which possible effects a decision to implement a practical implementation measure (base practice) can have on other optimisation targets. Since the quality level was previously defined, the potential for trade-offs with stakeholder targets that are of particular relevance can be identified in an early planning stage. Trade-offs with stakeholder targets that have low relevance can possibly be ignored.

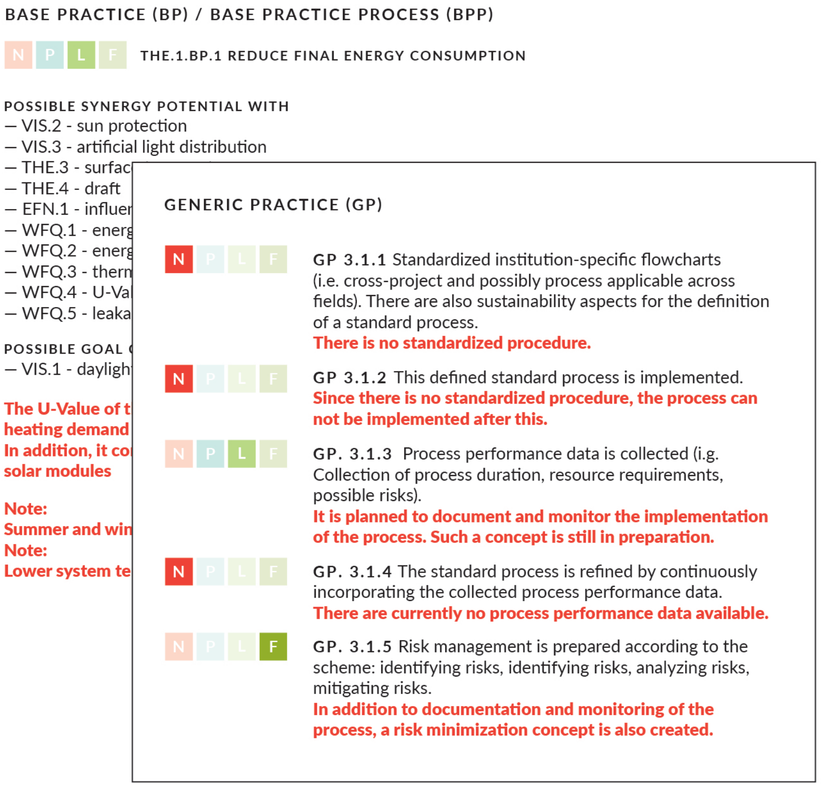


FIGURE 9-14: EXEMPLARY ASSESSMENT ACCORDING TO SPICE

Specific management processes (base practices – process) also need to be executed alongside the identified base practices in order to fulfil the defined optimisation targets as best as possible. The influence of processes is visible due to the allocation of the processes to the optimisation targets and hence can be considered in early planning phases.

FIGURE 9-13 shows a section of the visualisation concerning the possible potential for synergies and trade-offs for the base practice “increase possibility to influence temperature by user/operator”. The green arrows in **FIGURE 9-13** denote potential for synergy for the corresponding functional requirement (optimisation target). The red arrows show the potential for trade-off.

C – Maturity assessment – optimised project management and planning processes

The evaluation of the practices according to the N-P-L-F scheme is necessary to determine the capability level of the individual processes.

The final maturity assessment is done using the “Building Sustainability Quest Tool”.

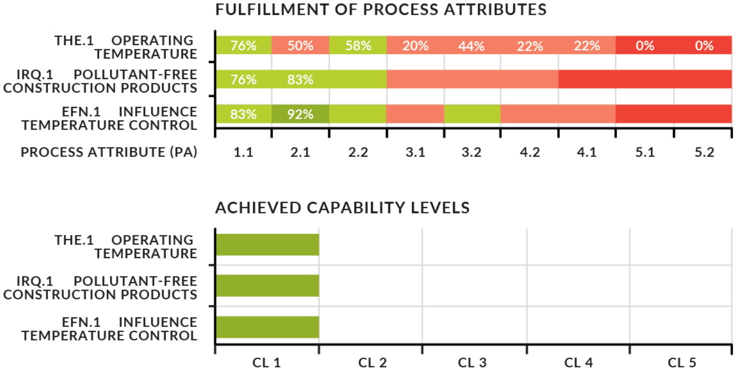


FIGURE 9-15: EXAMPLE FOR THE VISUALISATION OF CAPABILITY LEVELS PER PROCESS

Once this evaluation scheme has been completed for all relevant base practices and base practices – process using the system analysis and the maturity level model, then generic practices can also be evaluated for the optimisation targets. The generic practices are valid for all processes to the same degree, but need to be separately evaluated for all processes. To do this, generic practices were developed specifically for the subject area of sustainable construction. In contrast to the base practices, the generic practices are exclusively defined in the process model under step "C". Trade-offs when achieving an optimisation target can be visualised with the detailed report from the "Building Sustainability Quest Tool" and hence the potential for optimisation can be made visible. The evaluation with the "Building Sustainability Quest Tool" and the generation of a sustainability report serve as the basis of a sustainability requirements document for planning.

FIGURE 9-14 shows the assessment of the practices based on SPiCE as an example. The results of the evaluation of the practices according to the N-P-L-F scheme are the process attributes per process and subsequently the capability level (see **FIGURE 9-15**).

This fictive example shows that no process has reached capability level 2. This means that practical implementation measures (base practices) and generic practices for planning have not been sufficiently defined according to expert opinion.

In parallel to maturity assessment of the sustainability processes, possible potential for synergies and trade-offs are visualised and can be used as a basis for further planning processes and any required optimisation strategies.

To summarize, the main advantages of the process model for the evaluation of the maturity level and its practical application can be described as follows:

- Possibility for scenario recommendation for defined façade types depending on individual stakeholder requirements
- Knowledge of base practices that are required to fulfil dynamic, functional stakeholder requirements
- Knowledge of the influence of individual base practices on other optimisation targets
- Visualisation of potential synergies and trade-offs of individual base practices
- Possibility to execute sensitivity analyses
- Extendable process model
- Knowledge of the attained level of maturity at a particular planning stage in a sustainability process compared to the planned process maturity and hence quality assurance from a holistic point of view
- Possibility to create a sustainability report as the basis for a planning manual

LITERATURE

[1] Hofstadler/Kummer (2017). Chancen- und Risikomanagement in der Bauwirtschaft. S. 213 ff.

[2] Hofstadler/Kummer (2017). Chancen- und Risikomanagement in der Bauwirtschaft. S. 224ff

[3] Kummer/Hofstadler (2013). Einsatz der Monte-Carlo-Simulation zur Berechnung von Baukosten. S. 178ff.

[4] Hofstadler/Kummer (2017). Chancen- und Risikomanagement in der Bauwirtschaft. S. 239 ff.

[5] Hofstadler/Kummer (2017). Chancen- und Risikomanagement in der Bauwirtschaft. S. 597 f.

ENDNOTES

[1] Own representation AG-NHB acc. to Consideo GmbH

[2] Own representation AG-NHB acc. to Consideo GmbH

[3] Own representation AG-NHB acc. to Consideo GmbH

[4] Own representation AG-NHB acc. to Palisade

[5] Own representation AG-NHB acc. to Consideo GmbH

[6] Own representation AG-NHB acc. to Consideo GmbH

10

SUSTAINABILITY ASPECTS IN PLANNING & PROJECT MANAGEMENT

JOHANNES WALL
MARKUS KUMMER
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The following chapter is divided into two subject areas. The first area focuses on approaches for the consideration of sustainability aspects in the description of construction work. Possibilities of the constructive (detailed) and functional work description will be introduced as well as approaches for the consideration of sustainability aspects.

The second area focuses on the effects of the consideration of sustainability aspects on the range of services offered by the participating architects and engineers. An analysis of existing service portfolios will be done using the work and remuneration models LM.VM.2014. "Further optional services" will be worked out based on the optimisation scenarios for the component "façade". This will provide the planning and project management participants with a suitable aid for orientation in order to be able to factor in such work for sustainability aspects.

STATEMENT OF THE DESCRIPTION OF SERVICES

The scope of work for the construction plan is defined by the description of the work, the technical specification and the plans and target agreements. Further provision of services is derived from this.

The Austrian Federal Contracts Act (BVergG) divides the description of services into functional and constructive ones **[1]**.

As the project progresses, the information contained in the planning increases and hence, directly proportionally, the scope of work. The earlier the work is described, the more incomplete it is, with the consequential emergence of a range of problems regarding design interpretation and understanding.

The following **FIGURE 10-1** shows the increasing level of clarity over the project stages together with the relevant possibilities of scope description (functional or detailed) required for project awarding. The relationship between client and contractor is defined by information asymmetries. The client (representing the owner of the building) always has information earlier than the individual bidders, since he or she has clearer ideas what requirements they have on the building. It is therefore necessary to reduce these information asymmetries and clarify the construction plan together.

There are basically two approaches to describe the scope of service.

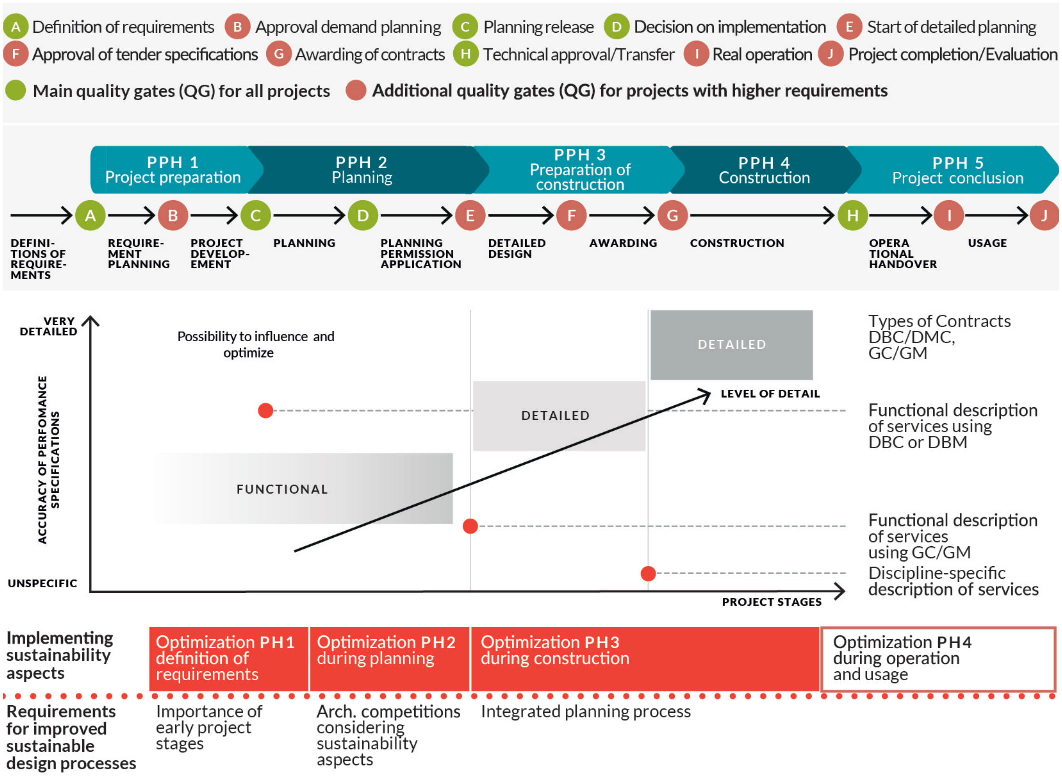

FIGURE 10-1: STEP-BY-STEP CLARIFICATION OF THE SCOPE OF SERVICE[1]

1. CONSTRUCTIVE (DETAILED) DESCRIPTION OF SERVICES

A constructive description of services requires a completed (pre-) planning from the tenderer. This forms the foundation of a detailed bill of quantities which is organised in items and which contains the exact description of the qualities required by the client with the corresponding quantities. The constructive description of services must be complete and described neutrally for reasons of comparability. The technical specifications must be articulated and represented by plans and drawings. Product-specific descriptions of individual positions (even if accompanied by the phrase “or equivalent”) can be understood to be specifications.

The prerequisite for a detailed scope of service is a corresponding depth of planning including description of scope (per item and constructive) along with the required details. The concept of constructive scope of service is defined as follows: “The services in a constructive scope of services are to be described so unambiguously, completely and neutrally, that the comparability of bids is guaranteed. A constructive scope of service must contain technical specifications and must be supplemented if necessary by plans, drawings, models, samples and similar” **[1]**.

The definition of the scope of services is typical for a unit price contract. Working out the line items requires a lot of time. The contractor is only involved at a late stage, if at all. The opportunity to influence the planning is already very low at the time of awarding. The creation of a suitable service description requires specific know-how on the part of the client as well as personnel resources. The exact formulation is done by the corresponding planner.

The Federal Ministry for Traffic, Innovation and Technology (bmvit) publishes a standard description of services for construction works (LBH)[2] that is used to create the service description for construction tenders in Austria. The LB-construction is divided into service groups that describe relatively homogenous tasks. The constructive service description requires the quality standards for the service to be defined from an economic and legal viewpoint, whereby the prerequisites for the lowest bidder principle are attained. The possibility of standardising the work to be done enables the price to be used as the main awarding factor.

During the procurement process, the client is often unable to clearly define what he needs to procure. This leads to the use of functional service descriptions. These are not service descriptions worked out in great detail but simply formulated as targets. The contractor thus has to conduct a part of the planning. This results in the difficulty of evaluating alternative bids.

2. FUNCTIONAL DESCRIPTION OF SERVICES

The services are described as tasks through the definition of services or functions, mainly based on the planning submission or building permission plan including a comprehensive, functional scope of work. It can be defined as follows: "In a functional scope of work, the technical specifications according to § 98 must be described neutrally and in sufficient detail that all relevant conditions and situations necessary for the generation of the offer are recognisable. The purpose of the finished work and the requirements placed upon the works must be recognisable in technical, economic, artistic and functional terms in such a way that the comparability of the offers regarding the scope and functional requirements demanded by the client is guaranteed. Work and functional requirements must be so precisely described that they transfer a clear image of the contract subject matter to the contractors and suppliers and enable the client to award the contract. A functional scope of service must contain technical specifications, plans, drawings, models, samples and similar, as far as they are available to the client" **[1]**.

Further planning occurs in parallel with construction and can be executed by either the contractor's planners or the client's. Contractors mainly act as general contractors/main contractors or total contractors. Projects are generally run as turnkey-projects. The contractors are not only responsible for the complete execution of the planning but also guarantee the amounts and completeness as well as carrying the quality related risks. Mutual planning brings significant added value that also takes the client's know-how into account. This enables the development and implementation of innovative approaches.

For this reason, the description is deliberately kept functional in order to permit and enable relevant optimisation arising from the contractor's specific know-how. Optimisation is achievable particularly regarding operation and use[3]. The content of a functional scope of services consists of excerpts from contractual conditions, the bill of quantities, the room book, interfaces as necessary, framework or rough milestone planning, artistic representations and results from previous work phases.

Scope of services and functional requirements must be sufficiently precise to allow the bidder to have a clear picture of the contractual subject matter and also allow the client to award the tender.

The use of functional-description of services always targets the application of the best bidder principle, since there are no clear, unambiguous quality standards. The choice of the best offer requires awarding criteria that need to be weighted.

A problem occurs with the comparability of offers in the context of functional scope of services. It is possible that although the planning target is given, no list of services is provided that constitute the solution of the task. This is also true for the client's solution seeking process: which people with which qualification work on the project, with what number of hours at which planning stage (personnel plan) and which company-internal guidelines are being used for quality assurance management. This is all in the domain of the bidder **[2]**.

Two strategies are dominant in current construction practice. One follows the traditional route with the individual awarding being based on disciplines. The client contracts planners and executing companies and manages the project himself. In the second route, the client sells his projects as he is unable to manage the project himself due to unavailable capacity/ competence and cannot be solely/ mainly responsible. This results in general contractor/total contractor awarding based on functional descriptions of scope **[3]**.

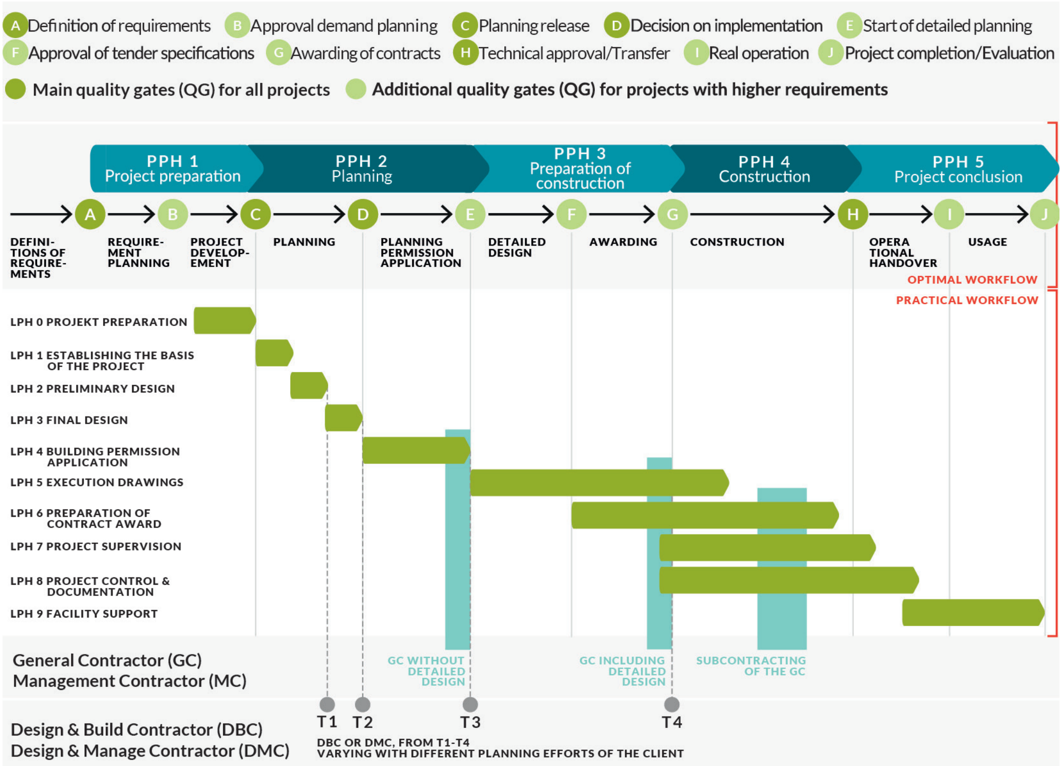

FIGURE 10-2: SCHEMATIC REPRESENTATION OF SELECTED AWARDING PROCEDURES[4]

3. APPROACHES FOR THE INTEGRATION OF SUSTAINABILITY ASPECTS INTO THE SCOPE OF SERVICES

FIGURE 10-2 shows the possible awarding variants in conjunction with the service descriptions. Sustainability aspects are closely associated with the client's building requirements (use over the lifecycle) (see optimisation targets of the cross-link matrix - Chapter 9). As soon as the client knows what is required, it is more meaningful to take the route of the constructive description of services of supply and to gradually increase the level of detail of the intended contents. *Lechner* describes that the client can only know what he wants if he has already pre-planned the project or has identified and documented the requirements. Functional descriptions are only meaningful if the object to be constructed has constrained areas of application suitable for series production. This would include for example system objects, business units or wind power parks. The functional description is therefore particularly suitable for simple standard constructions, since the advantages of awarding a general contractor can be reaped here. Complex constructions required detailed pre-planning and differentiated viewpoints in the early design phases whereby a more constructive service description would be recommended due to the increasing level of detail.

The developments over the past few years are critical. Often, general contractors no longer build themselves, but prefer to work on a contract level, whereby the work is done by sub-contractors. (This becomes clear via the sub-sub awarding chains and the resulting effects on wage and social dumping **[4]**.

EFFECT OF THE CONSIDERATION OF SUSTAINABILITY ASPECTS ON THE SCOPE OF WORK

The following section goes into more detail on the effects of the consideration of sustainability aspects on the scope of work (list of duties), i.e. the service portfolio of the architects and engineers involved in the course of planning and construction. The service model (recommended schedule on fees) LM.VM.2014 is used to analyse existing scopes of work and to represent "further optional works" for the façade building component.

1. BASICS OF THE SCOPE OF WORK

Planning describes the attempt to move from the initially unclear order (description of needs) in a series of processing iterations (work phases) to deepen the level of planning detail to reach the desired state "unambiguously, completely ... drawn/described/organised" **[5 ,6, 7]**. The scope of work and remuneration models provide an orientation of the various processing content. The concrete requirements placed on the project are a combination of general services and optional services[5].

The time structure model for the schematic representation of the sequence of the work packages, the overlapping of object and expert planning, is used to apply the LM.VM.2014. The complete execution of a project is done over 5 project stages from the viewpoint of the client, and in 9 work stages from the viewpoint of the planner, as shown in **FIGURE 10-2**. According to the LM.VM.2014, the scope of services for each work stage (see time structure model) is shown as general services and optional services.

GENERAL SERVICES

General services consist of those services that are required for the orderly and proper fulfilment of a contract in general. Thematically related general services are clustered into separate work stages. This is designed to provide trust-promoting cooperation (integration and coordination). General services are normally necessary, regularly occurring services for average projects.

OPTIONAL SERVICES

Optional services (planner) can be added to the general services or appear at other locations if special requirements are placed upon the fulfilment of the contract that exceed or modify the general services. Therefore they are not listed in the service scope and not allocated prices in the HOAI (they serve as limits for the general services). Optional services require written agreement from the contractual partners before they can be executed.

Scopes of work provide a simple description of services for average projects. They also enable statements to be made of results that are to be worked in the each work stage. The requirements placed on planning have changed considerably over the past few years **[8]**. Major changes can be seen for the planning disciplines (structural planning, building technology and structural physics) due to the increasing emphasis being placed on subject areas such as sustainability, social matters, economics, as well as legal and environmental aspects **[9]**. These stricter requirements are a result of the increasing value of environmental matters and the Green Building Initiatives. Use profiles and the associated, periodically required technical systems in buildings play a further important role. The holistic planning that is necessary for this, together with the required planning method of integrated working, creates additional work effort in the areas of recognition of a dis-

GENERAL ARRANGEMENTS	MODELS, STRUCTURES, STAGES, DECISIONS			
Shared elements	Architecture	Expert planning	Engineering	Area planning
Project management	Project management	Structure planning	Infrastructure	Urban planning
Project development	Building planning architecture	Project development	Bridges	Enviromental planning
Project development	Interior Design	Geotechnics	Highways	Landscape design
Project control	Outdoor facilities	Building physics & fire protection	Railways	
Accompanying control		Building services	Inventory audits-tunnels	Surveying
Building KG			Inventory audits-bridges	
General planning			Water management	

PARTICULARLY RELEVANT SCOPE OF WORK FOR FAÇADES
RELEVANT SCOPE OF WORK FOR FAÇADES

FIGURE 10-3: (PARTICULARLY) RELEVANT SCOPE OF WORK FOR FAÇADES advantageous solution (= falsification of a working hypothesis), analysis in more than one expert area (architect, building physics etc), interdisciplinary solution finding and its coordination as well as feedback.

According to *Lechner*, planning in early work stages is characterised by the representation of functional requirements. Technical solutions are finalised successively in the work stages, step-by-step but not necessarily systematically by the enlargement of the plan (scale) and increasing level of detail **[10]**.

2. ANALYSIS OF THE LIST OF DUTIES

Over the course of the UNAB research project, the duty lists were considered in more detail regarding their application to work done on façades by architects and engineers. **FIGURE 10-3** shows the relevant lists of duty for the research project UNAB (focus on the area of façades). These were investigated in more depth regarding the consideration of sustainability aspects related to the façade building component.

LM.VM.2014 understands services for "certification systems" to be awarded a building certificate not to be "general services". This is because of the allocation to "optional services". The consideration of sustainability aspects is hence only for the application within the scope of certification systems. These are only mentioned in optional services as keywords. In the context of the discussed research project, the section "further optional services" was extended. This was done with particular focus on the requirements of the façade that were the result of the evaluation of the UNAB cross-link matrix (see **CHAPTER 8**).

FIGURE 10-4 shows the procedure for the analysis. In the first stage, an analysis of the LM.VM.2014 was carried out with the performance models of the object planning architecture, the building physics and the technical equipment especially relevant for the research project. In a second stage, the recommendations on the HOAI list of duties for sustainable building were analysed. The applicability of the contents of the expert guideline for integrated planning duties was investigated in stage 3 and aligned with the requirements of the processes that were identified during the evaluation of the cross-link matrix. This results in "further optional services" shown for the individual façade-relevant service models.

3. OBJECT SERVICE MODEL (LM.OA)

The object planner has a major part of the successful implementation of a sustainable building. In the course of the sustainability assessment of the building, the

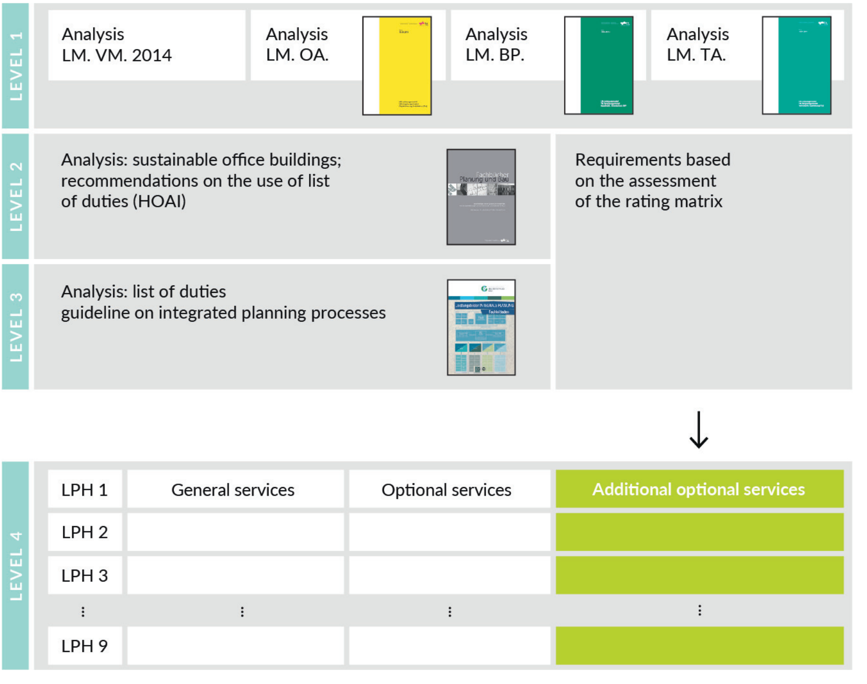

FIGURE 10-4: PROCEDURE TO INTEGRATE SUSTAINABILITY ASPECTS IN THE LIST OF DUTIES

object planning / architecture also includes the activities of the auditor / coordinator. An analysis of the service model showed similarities with the service model for object planning / architecture that are covered under the further optional services. With regard to the UNAB façade, focus was placed on the load transfer of the façade panels and the associated joining technologies. In a real application, the interrelationships with other expert planners (building physics, technical equipment) must be clarified within the framework of integrated planning.

4. BUILDING PHYSICS & FIRE PROTECTION SERVICE MODEL (LM.BP)

The work encompasses the areas of expertise of thermal building physics: Calculation, measurement, planning and in particular to measure and limit thermal and moisture flows from the surroundings and from use, as well as room hygiene. Other parts of the service model include the areas of noise protection (measures to reduce irritating noises on/in/from the object or its use); room acoustics (calculation, measurement, planning and the development of details to render/improve listening conditions appropriate for use); fire protection (calculation, measurement, planning) to provide optimised solutions according to the requirements of the authorities for system-spanning solution approaches (building/technical equipment, organisational precautions by the user).

5. HVAC SERVICE MODEL (LM.TA)

The model comprises services for new buildings or for extension and modernisations for the system group (systems for waste water, domestic water, gas, heat and chilling), air systems, HV and electric installations, telecommunication information and safety equipment up to user-specific systems and building automation.

6. EFFECTS OF CONSIDERING SUSTAINABILITY ASPECTS ON THE LIST OF DUTIES

Regarding the possible application of LM.VM.2014 to innovative façades, it is recommended that before the project starts, a contract is set up between client and contractor (planner) that specifies which services are to be executed over and above the general services and which optional services are relevant. Over the course of the project the existing scope of work can be extended by "further optional services". For example, requirements for energetically active hybrid façade elements can be considered. These extensions are shown in detail in the final report of the research project.

The LM.VM.2014 already considers sustainability aspects in many parts. Depending on the project-specific focus, appropriate adaptations are necessary. This requires the inclusion of the integral planning approach and the documentation of the results at the end of each individual performance phase, in particular through the exchange between the performance models of building physics, technical development with the object planning already in early planning phases. For example, in the context of applying certification systems, criteria such as visual comfort in the practical building implementation are subject to a continuous planning changes. In the service models, however, the aspects of visual comfort are considered only up to the LPH 2, but the on-going adaptation requires consideration to at least LPH 5, which means that integral planning is therefore of particular importance.

In this regard, the "IG Lebenszyklus" published scopes of work for project management, which is devoted to the management and the task, the formulation of the ideas and the selection of the participants **[11]**.

SUMMARY

The increasing holistic view in the construction industry requires an expansion of the classical triangle (costs, deadlines, quality) beyond the project objectives, taking into account the operational objectives. Life cycle costs, sustainable quality standards, as well as warranty and service agreements are becoming increasingly important.

This extension to the observed horizon is depicted graphically in **FIGURE 10-5**. With the aid of spider charts, the degree of attainment or fulfilment of the desired requirement can be visualised for each project stage (planning, construction, operation). It is necessary to create awareness, and to raise awareness, that not only the construction phase is to be considered, but also that the use of the building must be taken into account. A particular challenge is the description of these (life-cycle-oriented) services, especially with regard to sustainability aspects. These are in their scope and formulation dependent on the requirements of the client or later user. As a result, the inflow of sustainability aspects into the selection of architectural competitions is becoming increasingly important **[12]**. The more exact and detailed this is articulated by the client, the more appropriate is a transfer into a constructive description of the service **[13]**. The structures of the LM.VM.2014 allow suitable framework conditions to discuss with the

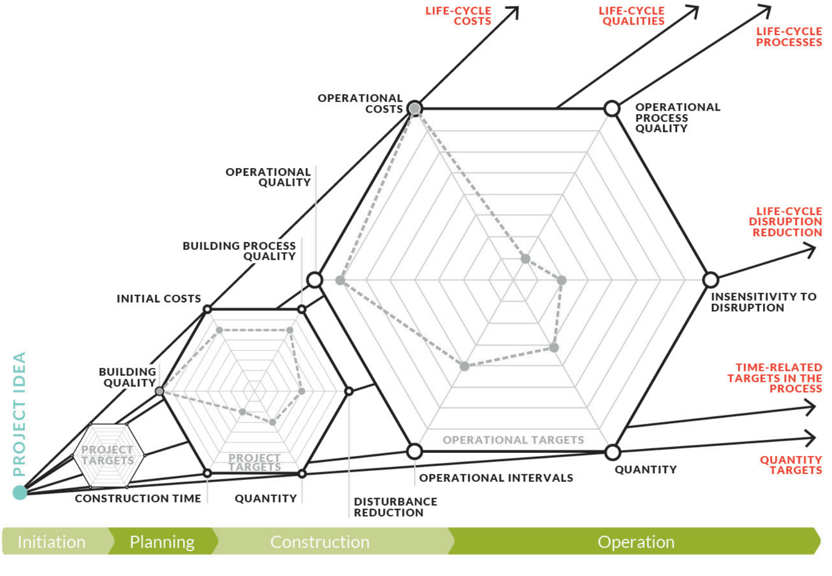

FIGURE 10-5 : EXTENSION OF THE TARGET SYSTEM FOR THE LIFE CYCLE OF BUILDING PROJECTS[6] respective (specialist) planner the task position according to the situation and concrete requirements in the form of general services as well as optional services and to successively concretise them and to make a constructive (detailed) description of the services.

If, in this context, the intention is to use innovative façade constructions, the requirements can be mainly articulated in a functional manner, and some of the design planning services are transferred to the bidder or later contractor. With regard to the increased requirements of energy active, hybrid façade elements (UNAB panels), it is therefore necessary to supplement and secure the related expenses and additional services, which are already partly described in the optional services of LM.VM.2014 , for the respective services model of the specialist planner.

„Further optional services“ were developed for this purpose. It became clear during the analysis of the service models that the early project phases were of particular importance for the successful implementation of a project (development of an energy active façade) with regard to their contribution to the requirements planning, the definition of goals and the related concepts such as energy concept, disposal concept, etc. Furthermore, it was shown that a corresponding energy active façade requires an orderly transfer and commissioning in order to be able to use its functionality accordingly and to be able to fine-tune during operation.

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11

LIFE CYCLE ASSESSMENT OF SELECTED FAÇADE TYPES

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The construction sector is of great importance regarding the implementation of sustainable development in our society. Reducing potential environmental impacts and minimizing life-cycle costs is also necessary, as is the consideration of functional and technical quality in order to ensure the sustainability of components and buildings. On the basis of life cycle assessment (LCA), the assessment methods for environmental quality are first described in this chapter. Followed by a closer look at the key parameters related to LCA.

The basis for comparison is a virtual office building where the different types of façades are mounted. The results of this LCA show the influence of the respective material and building components, which are decisive for the development of the potential environmental effects. The results of the study also clearly show that in the future, product, element and building assessments will have to form a critical basis for the optimization of building structures regarding environmental quality.

The purpose of the available calculations is to identify the differences between three different façade types (solid construction, mullion-transom façades and UNAB façade) via a comparative LCA using generic life cycle data (EcoInvent V3.3 **[1]**). The functional equivalent, i.e. the quantifiable functional requirement, was used as the basis for comparison and linked to a virtual building.

CASE STUDY – VIRTUAL OFFICE BUILDING

In order to compare different façade types, the modelling was performed on a virtual office building (MPPF building[1]). This was necessary in order to define a functional equivalent for the LCA. The façade types under investigation were normed to the façade surface area size of the virtual office building. In addition, the virtual building was used to calculate the heating energy requirements for the different façade types.

The MPPF building was an 8-storey office building with a total height of approximately 32 meters. The rectangular floor plan measured 40 meters by 20 meters and hence resulted in a gross floor area (GFA) of 800 m². The U-values for the LCA were assumed to be identical for windows, roof and floor.

1. FUNCTIONAL EQUIVALENT

The functional equivalent describes the technical characteristics required and the functions of the building envelope. It is defined as follows by the ÖNORM EN 15978 **[2]**: “Quantified functional requirements and/or technical requirements for a building or a constructed construction component (building section), that serves as the basis for comparisons"

This is necessary in order to create the basis for standardised and comparable evaluations. According to the ÖNORM EN 15978 the following parameters have been defined for the functional equivalent:

- Building or building component: Façade
- Use profile: Office and administration building
- The unit of façade surface area is defined per 1 m² (GFA) and year.
- Further technical requirements placed on different façade types have been defined in **FIGURE 11-1**: Consideration of the total façade surface window ratio of 50%
- Consideration of different U-values against energy input according to heating requirements of the virtual building
- No energy gain from PV
- Planned lifespan 50 years
- End of life – phase (Aluminium recycling, disposal of other building materials)
- Composition of aluminium UNAB façade profile (68% primary aluminium, 32% secondary aluminium)
- Electricity mix Graz
- District heating mix Graz

2. REFERENCE STUDY PERIOD

The reference study period forms the base for the calculation of the environmentally related quality for each façade type. According to ÖNORM EN 15978 the study period must be equal to the required use life of the building. Deviations of the reference study period from the use life must be explicitly justified and stated in accordance with ÖNORM EN 15978. The reference study period for the UNAB research project was set by the project partners to 50 years. This makes it necessary to consider the stages for manufacture (A1 – A3), the use stage (B4 and B6) and disposal (C1 – C4) for the calculation of environmentally related qualities (see **FIGURE 11-2**). The replacement cycles and energy consumption during operation are dependent on the defined period of use and were also taken into account.

3. SYSTEM BOUNDARY

The definition of those processes that must be taken into consideration according to ÖNORM EN 15643-5 **[3]** for the evaluation object was done by determining the system boundaries. Since the following calculations deal with façade types for a virtual building, a calculation for the complete life cycle must be carried out. **FIGURE 11-2** highlights the considered modules.

GENERAL ASSUMPTIONS

BUILDING DIMENSIONS		
Lengths	North East South West	40m 20m 40m 20m
Height	Storey height Storeys Max. height	4m 8m 32m
Surfaces	Floor area Total floor area Façade north Façade east Façade south Façade west	800m² 6400m² 1280m² 640m² 1280m² 640m²
Volume	Heated	25500 m³
Windows	50% glazed area Window area north Window area east Window area south Window area west	9.1m²/20m² 582.4m² 291.2m² 582.4m² 291.2m²
U-VALUES		
Windows	3x Insulated glas	Uw = 0.9 W/m²K
Roof	Area U-Value	800m² U = 0.1 W/m²K
Floor	Area U-Value	800m² U = 0.2 W/m²K
ASSUMPTIONS		
Room temperature		Ti = 20 °C
Therm. transmittance		0.05 W/m²K
Ventilation rate		0.5
Location		Graz

FAÇADE TYPES

	UNAB FAÇADE	REFERENCE VARIANT (KARMELITERHOF)	MULLION TRANSOM FAÇADE
Façade construction	Alu. sheet Adhesion PU foam Adhesion Alu. sheet	Int. plaster Bricks/concrete Adhesion EPS Ext. plaster	Alu. sheet Mineral wool Alu. sheet Adhesion Safetyglass
Load bearing elements	Self-supporting (vertically braced)	Bricks and reinforced concrete lintels	Mullions and transoms (Aluminium)
Building materials to be replaced in the use phase	None	Adhesion EPS Ext. plaster	None
Glazed area	50%	50%	50%
Thermal energy	District heat Graz	District heat Graz	District heat Graz
Losses in heat demand calculation	Not considered	Not considered	Not considered
Thermal energy demand	19.3 kWh/m²a	19.6 kWh/m²a	24.2 kWh/m²a
Fastener	Not considered	Not considered	Not considered

FIGURE 11-1: GENERAL ASSUMPTIONS AND INVESTIGATED FAÇADE TYPES

INFORMATION REGARDING THE LIFE CYCLE OF THE BUILDING																ADDITIONAL INFO
PRODUCT STAGE			CON-STRUC-TION PROCESS STAGE		USE STAGE							END OF LIFE STAGE				POTENTIAL BENEFITS &LOADS
A1	A2	A3	A4	A5	B1	B2	B3	B4	B5	B6	B7	C1	C2	C3	C4	D
Raw material supply	Transport	Manufacturing	Transport	Construction – installation process	Use, installed products	Maintenance	Repair	Replacement	Refurbishment	Operational energy use	Operational water use	Deconstruction	Transport	Waste processing	Disposal	Recovery, reuse, recycling potential
✓	✓	✓						✓		✓				✓	✓	

FIGURE 11-2: REPRESENTATION OF THE CONSIDERED MODULES FOR THE DIFFERENT LIFE CYCLE STAGES[2]

4. DESCRIPTION OF FAÇADE TYPES

Six scenarios were developed in total for the four different façade types. The LCA carried out here calculated three façade types (UNAB façade, mullion-transom façade und solid construction = Case study - Karmeliterhof).

CALCULATION METHOD

SELECTION OF DATA/ FOREGROUND DATA

Data surveys, manufacturer's data and literary searches acted as sources for the reference data. A prototype of the UNAB façade was created that provided the basis for the bill of quantities. The bill of quantities for the reference variant Case study – Karmeliterhof was based on its implementation plans. The quantities for the mullion–transom façade system were derived from the manufacturer's documentation. The production foreground data were implemented in SimaPro 8 and linked with the background data. The base data for the LCA of general processes such as transport and base materials originated from the EcoInvent V3.3 database. The composition of the energy supply (electricity mix, district heating mix) for Graz was modelled based on information from the energy provider. Care was taken during the creation of the data set that comparable modelling depths were used. The resulting foreground data are shown below and could be divided as follows:

- Assumed data:
  - Aluminium composition - Degree of reinforcement
  100 kg/m³
- Surveyed data:
  - District heating composition mix Graz (Energie Steiermark)
  - Electricity composition mix Graz (Energie Steiermark)
- Calculated data:
  - Bill of quantities
  - Heating energy requirement

SELECTION OF DATA/ BACKGROUND DATA

When selecting data, attention was paid to how up-to-date and complete the data and information used was. The requirement for standardised data quality was achieved through the exclusive use of the Ecoinvent V3.3 database (April 2017 edition). The information contained in this database displays high, complete and consistent quality due to the exact requirements for the collection and calculation of environmentally related quality for construction products.

1. ENVIRONMENTAL IMPACTS, ASPECTS AND ASSOCIATED INDICATORS

The impact assessment for the aformentioned impact categories was carried out with the EPD2013 and Cumulative Energy Demand methods implemented in SimaPro. EPD2013 is a method for the generation of environmental product declarations. The characterisation factors from the Institute for Environmental Sciences at the university of Leiden (CML-IA v4.1 from October 2012) were used together with data from the intergovernmental panel on climate change report **[4]** for the calculation. The method of cumulative energy demand is based on the published data in Ecoinvent V2.0 that were extended by SimaPro. No distinction was made between renewable and non-renewable primary energy in order to provide better representation of the results for the total primary energy requirement.

INDICATORS OF POTENTIAL ENVIRONMENTAL IMPACT

The calculation of potential environmental impact was based on indicators from the ÖNOEM EN 15978. The fundamental method according to ISO 14040 **[5]** is known as Life Cycle Impact Assessment (LCIA). These indicators represent the quantifiable environmental impacts and environmental aspects over the life cycle. Environmental impacts are expressed as environmental indicators according to the LCIA (e.g. Global Warming Potential), whereby environmental aspects are based on influences from the Life Cycle Inventory (LCI) (e.g. primary energy requirement). Out of the 22 environmental indicators, the following were selected for the comparison of the results:

- GWP - Global Warming Potential
- AP - Acidification Potential
- EP - Eutrophication Potential
- ODP - Ozone Layer Depletion Potential
- POCP - Photochemical Ozone Creation Potential
- PET - Primary Energy Total

2. CALCULATION METHOD & APPROACH

METHODS TO EVALUATE THE ENVIRONMENTAL PERFORMANCE OF FAÇADES

The LCA of the façade types is based on the European norms published by CEN/TC 350, who provide a framework for the life cycle oriented sustainability evaluation of construction works. According to this concept, sustainability includes environmental, economic and social as well as technical and functional aspects, which exist in close relationships. The evaluation quantifies the impacts and with quantitative and qualitative indicators. The evaluation of the environmental performance of buildings is based on the method of LCA that is expressed with quantitative evaluation categories.

ALLOCATION SYSTEM MODEL

The EcoInvent V3.3 system model "allocation, limit according to classification" (cut-off system model) is based on the recycled content or cut-off approach. In this approach, the allocation of the primary material production is always done directly to the primary user. If a material is recycled, the primary producer does not receive credit for the supply of recyclable materials. Recyclable materials are thus considered in recycling processes. Secondary and recycled materials only receive the impacts of the recycling processes.

	Façade type	Construction	Energy recovery	Conditioning
Scenario 1	UNAB - façade	Element façade with polyurethane insulation Alu - PU - Alu	X	X
	Mullion-transom façade	Curtain wall as mullion-transom façade (frame construction)	X	X
	ETICS - Karmeliterhof	Massive wall construction as a band façade plaster - brick (20 cm) - EPS (16 cm) - plaster	X	X
	ETICS (OIB - Minimum requirement)	Massive wall construction as a band façade	X	X

FIGURE 11-3: SHORT DESCRIPTION OF THE FAÇADE TYPES

RESULTS

FIGURE 11-3 shows the comparison results of the LCA for the selected environmental indicators for the considered façade types. Case study – Karmeliterhof represents the reference variant and is evaluated at 100% for all considered modules over the life cycle.

TOTAL PRIMARY ENERGY REQUIREMENT (PET):

Due to the low material requirements for the production of the UNAB façade, it can be seen that the reference variant (Case Study - Karmeliterhof) has a higher PET in the manufacturing phase. The PET for the manufacturing of the mullion-transom façade is considerably higher due to the increase effort aluminium production and the enormous amount of material required. A composition of 68% primary aluminium and 32% secondary aluminium was assumed for the aluminium manufacture. The results in the manufacturing phase can be influenced by the composition of the aluminium components (see **FIGURE 11-4**).

Similar results can be seen in the use phase due to the superior U-value of the UNAB façade and the fact that the UNAB façade does not need to be replaced excepting damage over the complete use phase of 50 years compared to the reference variant (Case Study – Karmeliterhof). The assumed U-value of 1.2 W/m²K for the mullion-transom façade results in a higher PET than the UNAB façade (U = 0.15 W/m²K) and the reference variant (U = 0.17 W/m²K). In the end-of-life phase, the aluminium components are recycled. It is assumed that all other components will be disposed of in a landfill.

The UNAB façade shows a lower PET over the total life cycle and for a use period of 50 years than the reference variant. Due to the reduced weight and the reduced installation effort compared to the reference variant and to the mullion-transom façade, the UNAB façade demonstrates enormous potential for a reduction in PET in the constructon process stages (A4, A5 - **FIGURE 11-2)**.

GLOBAL WARMING POTENTIAL (GWP):

In the manufacturing phase (A1 – A3), the UNAB façade has the lowest GWP due to the lower thickness of the aluminium panel compared to other façade types. The reference variant (Karmeliterhof) performs a little worse than the UNAB façade due to the amount of brick and steel reinforced concrete. As with the primary energy requirement, the GWP is determined by the U-value and, as a result, by the heating energy requirement as well as the replacement cycles of the building materials.

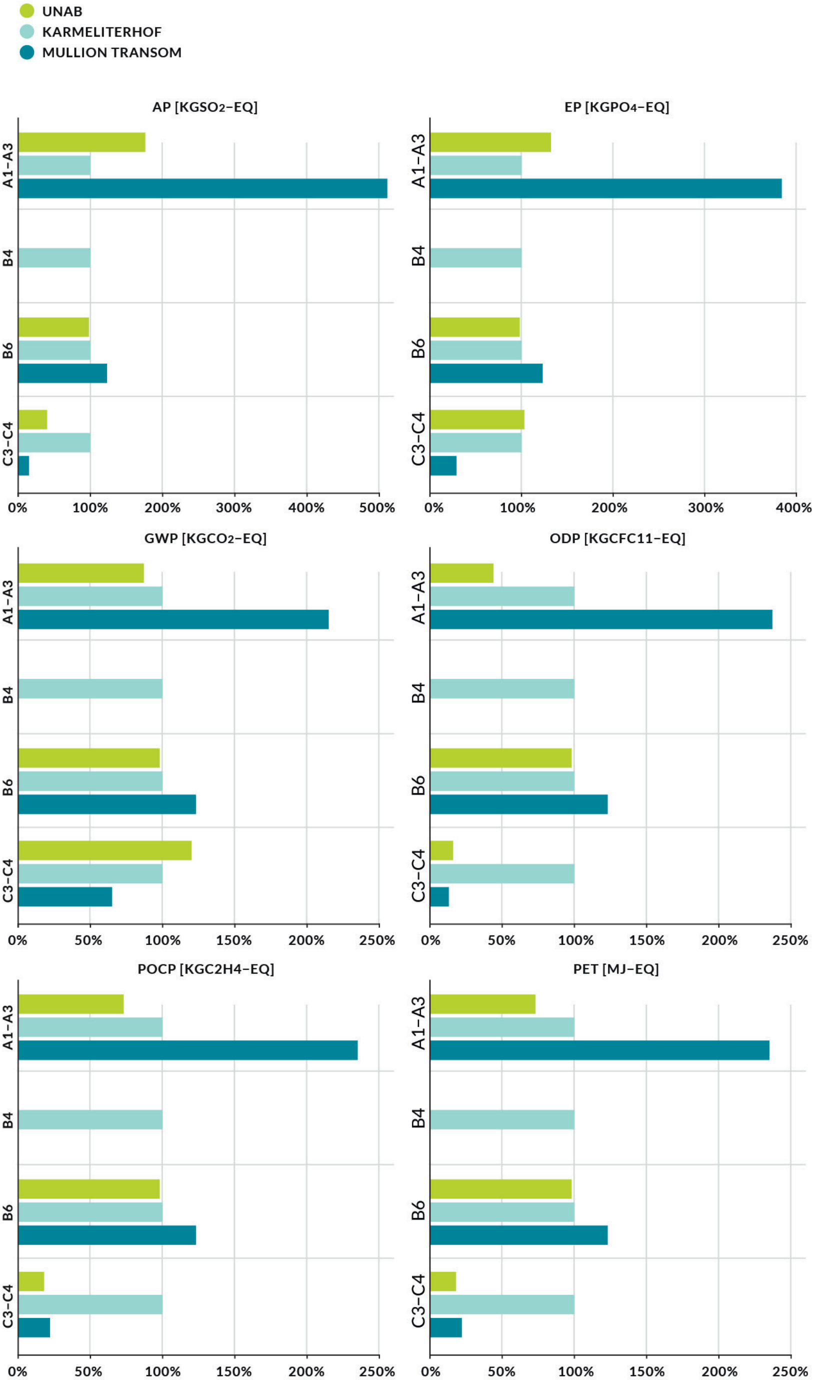

FIGURE 11-4: SELECTED LCA RESULTS FOR THE CONSIDERED FAÇADE TYPES

The UNAB façade only performs worse than both of the other façade types in the end-of-life phase due to the employment of PU foam in the heat insulation. In this phase, even the mullion-transom façade has a better value than the reference variant (Karmeliterhof) since the deposition of mineral wool has less impact on the GWP value than the deposition of expanded polystyrene (EPS).

Overall, the UNAB façade has the lowest GWP. Even for this impact indicator, there is potential for optimisation in the installation and execution phase particularly due to the low transport weight.

SENSITIVITY ANALYSIS OF ALUMINIUM COMPOSITION

In order to identify further potential for optimisation, the composition of the aluminium was investigated in more detail since this plays a major role for the LCA results in the manufacturing phase.

The aluminium composition used in the calculations was 68% primary aluminium and 32% secondary aluminium (see SimaPro data set: Aluminium, production mix 68% Prim/ 32% Sec Alloc Rec U 3-3). The environmental indicators for the manufacturing phase (A1 – A3) were accordingly calculated for this and two other aluminium compositions.

The effects of the aluminium composition of the environmental indicators for three composition ratios of primary and secondary aluminium are shown in **FIGURE 11-5**:

- Lower boxplot antenna:
  32% Primary aluminium /
  68% Secondary aluminium
- 100% reference:
  50% Primary aluminium/
  50% Secondary aluminium
- Upper boxplot antenna:
  68% Primary aluminium/
  32% Secondary aluminium

The sensitivity analysis shows that there is a recognisable potential for optimisation for the GWP and the primary energy requirement with an aluminium composition of 32% primary and 68% secondary aluminium of up to 20% compared to the prescribed composition from SimaPro.

IMPACT OF ADDITIONAL FUNCTIONS

FIGURE 11-6 compares the LCA for the UNAB façade in the manufacturing phase (A1 – A3) with the application of additional functions (energy recuperation via solar and PV). Once scenario of the UNAB façade with PV mats glued to the surface and the other UNAB façades with integrated solar module.

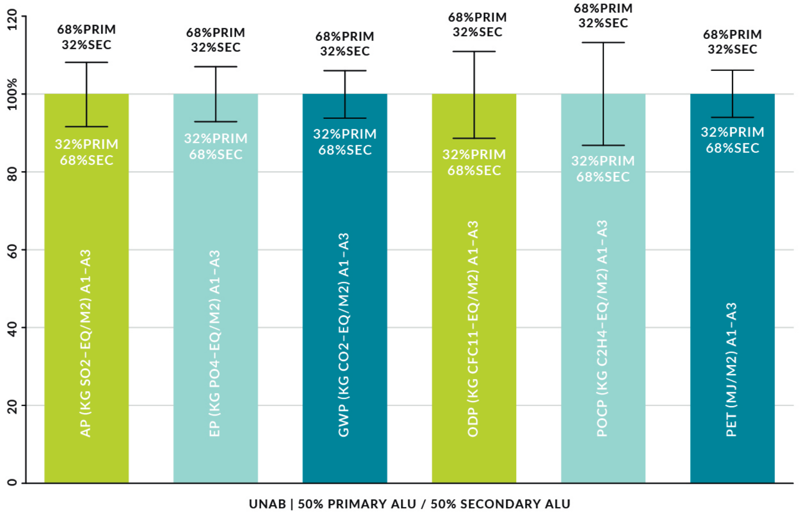

FIGURE 11-5: SENSITIVITY ANALYSIS OF ALUMINIUM COMPOSITION

In order to compare the results, the UNAB façade – scenario 1 (construction without additional functions) was used as the reference value (100%). It can be seen that the application in the manufacturing phase of the additional function for solar thermal energy results in an increase of all indicators by approximately 25%.

The complex simulations required to calculate the additional energy harvest resulting from the applied solar modules were not part of this research project; hence no statements regarding the amount can be made. These simulations are recommended for a holistic view in order to consider the results from the use phase. However, questions regarding the consumption of electricity (feedback into the grid and storage) would require separate attention.

The LCA results for the GWP and the PET were more than doubled for the UNAB façade with the glued PV mats. The available data (background) for the PV module seem worthy of further scrutiny taking experience so far into account. However, the data could not be separately collected in the research project and hence remain unconsidered. Detailed simulation needs to be carried out, especially for energy recuperation by PV (electricity), in order to be able to make a statement concerning the additional energy harvest and a possible compensation of extra material effort in the manufacturing phase.

OUTLOOK

The requirements placed on buildings to maintain the principles of sustainable development are increasing in significance, both in the private and in the public sector This trend is not only based on market requirements, but also on the requirement for improved life-cycle performance. One of the instruments to evaluate building performance is building certification systems that contain aspects such as LCA and LCCA, social and functional, or technical aspects.

The research project UNAB showed that the form of a façade has a certain potential to optimise building LCA results. Further sustainability aspects such as construction time, degree of pre-fabrication, susceptibility to damage or durability can be optimised positively with an appropriate façade type.

Furthermore, the existing requirements, i.e. the sustainable use of natural resources via the new construction product regulation or the evaluation criteria “ease of disassembly and dismantling”, can only be fulfilled by a façade type that considers all these aspects in an early stage of planning.

It must be noted that the improvement of building performance is a

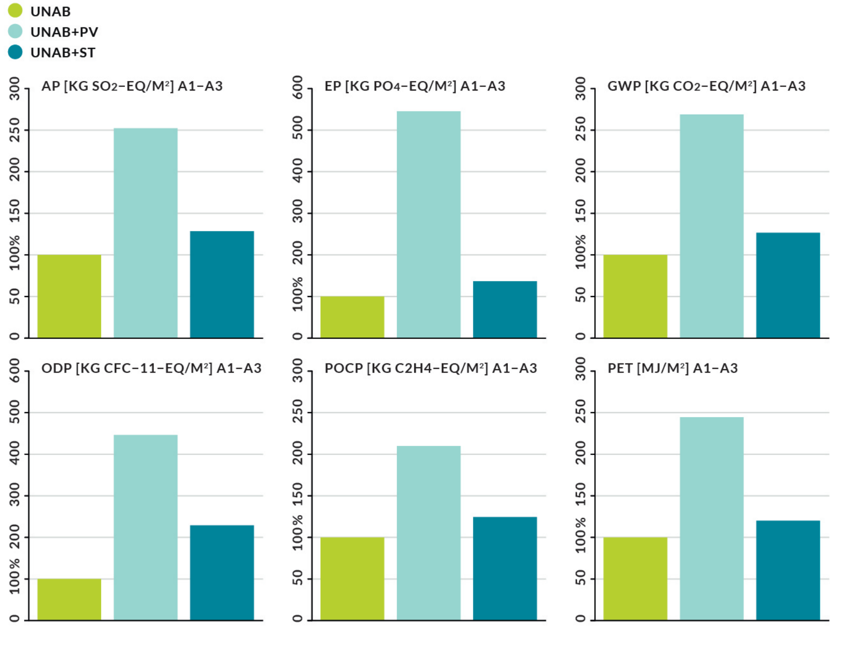

FIGURE 11-6: INFLUENCE OF ADDITIONAL APPLICATIONS ON THE ENVIRONMENTAL INDICATORS (MANUFACTURING PHASE)

non-linear approach, in as far as the different evaluation criteria have a mutual influence. The ambitious challenge of a holistic improvement in building performance can only be guaranteed in the future if the design possibilities are based on a holistic life-cycle evaluation. A systemic approach as was used to develop the process model could be applied to manage the complexity of differing requirements.

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SUMMARY & OUTLOOK

Sustainable construction, in the sense of the application of principles of sustainable development to the construction industry, has a key role to play due to the enormous flows of material and energy and the associated environmental impacts. The aim is to plan, erect and operate buildings holistically from the perspective of the life cycle, such that they represent an asset for future generations and not an inherited burden. The current trend towards increasingly energy-efficient buildings is placing more and more focus on building envelopes, building constructions and the building products contained therein due to their “grey” energy and “grey” greenhouse emissions. A holistic, integrated perspective on a building level also requires the compilation of the different requirements and functions of individual elements into the context of a larger whole. This requires specific strategies to fulfil these complex requirements. This is amplified by aspirations to turn buildings into “energy producers” via functional and building-related requirements, which requires the integration of active elements such as photovoltaic or solar thermal systems.

The UNAB research project faced these challenges with an interdisciplinary, interfaculty research team from the TU Graz with the aim of developing new, integrated, hybrid, building envelopes with particular consideration of sustainability aspects and their implementation in planning processes. The merging of two complementary research approaches and the integration of different research methods from the areas of design, numeric simulation, life-cycle assessment, risk analysis and system perspective enabled a milestone in the operationalization (evaluability) of sustainability in the building trade to be achieved. The first approach targeted the systemic view of sustainability requirements. Knowledge of the relationships between critical sustainability requirements depending on the target preferences of the stakeholders is aimed at the future enablement of planability and the control of real estate qualities from a holistic perspective. The second approach consisted of the constructive implementation of sustainability requirements in the building envelope. The design of the façade as a self-supporting, highly efficient load-bearing construction using new methods of forming and joining technology from the mechanical engineering sector together with the integration of technical building systems into the building envelope presents construction, statics, building physics and technical systems with a new series of challenges that can only be solved by close interdisciplinary collaboration of the participating areas of expertise.

A process model for the implementation of specific sustainability targets was developed within the UNAB project on the basis of a holistic and systemic view of sustainability aspects in the planning and project management process. The possible impacts of decisions in the planning and project management processes and in the implementation status of specific sustainability requirements in the project can be visualised in the three processing steps target definition, system analysis and evaluation of maturity level. This is intended to sensitize the building owner, the planner and the project manager of the potential and manifold influences over the course of the holistic optimisation. The visualisation of interrelationships and the insights regarding the critical processes to implement the specific sustainability targets represent the decisive factors; possible trade-offs due to diverging target preferences become visible, emerging synergies can be deliberately considered in further planning process steps. The practical application of the new process model was done with the hybrid and energetically activated façade panel developed within the scope of the constructive approach. In doing so, a reference model was created for the evaluation of maturity for the UNAB façade element.

In the future, the systemic approach of the process model will also contribute to a reduction in complexity and reduced additional effort (which in practice often leads to a deviation from holistic optimisation targets in early planning stages). The application of the method of maturity assessment is intended to enable quality assurance during the planning and construction stages from a holistic perspective. Building owners, planners and project managers are presented with a first step to structure and traceably process sustainability requirements and to perform monitoring from a holistic perspective. Research is still required to determine whether the “child prodigy” BIM (Building Information Modeling) can offer support with its integrated and cooperative approach.

From the current point of view, it seems that Austria will only be able to fulfil its international climate duties and implement the European strategies (circular economy, resource efficiency and other macro-objectives) with considerable effort, i.e. with clearly more ambitious, concrete and resilient measures. In this respect, the increasing complexity of the planning and execution processes requires a new, fundamentally different approach to the implementation of (more) sustainable buildings. A further development towards networked, integrated sustainability evaluation in the building sector is therefore urgently required in order to guarantee the development of a resiliently constructed environment, given this background.

The experience made in the UNAB research project clearly demonstrates that the future requirements for sustainable construction are only implementable with interdisciplinary solutions and the interaction of different research approaches. In this context the analysis, the visualisation and the understanding of the systemic interrelationships in sustainable construction are decisive factors. This means that in the future, the development and further development of suitable methods for systemic, multi-criteria analysis and decision-making, together with the ability to handle complexity in sustainable construction, is of critical importance.

Editors

December 2018

ANNEX

CONSORTIUM PARTNERS

HM&S IT-CONSULTING GMBH

The „HM&S IT-Consulting GmbH", short „HM&S" was founded to provide research and development in the area of system and software engineering especially for the topic analysis and assessment of system and software development processes. The foundation was guided by TU-Graz and the Swiss/German consulting company SynSpace.
Besides the continuing development and enhancement of the assessment tool SPiCE 1-2-1 and its adoption to different branches and process areas, HM&S conducted several software development projects (e.g. eLearning at the Medical University Graz) and helps other companies and organisations to improve their process quality and maturity.
The know-how of HM&S results from a combination of University connections, international contacts, consulting experiences, and the application in our own organisation. HM&S fields of competence are:

- Software Engineering – especially for the automotive sector including agile methods
- Software Process Assessments and Improvement (SPiCE, ISO 15504 & 33000, AutomotiveSPiCE, CMMI)
- Project Management & Software Quality Management
- Sustainability, Knowledge Management & Intellectual Capital

INSTITUTE OF ARCHITECTURE AND MEDIA

The Institute of Architecture and Media (IAM) at Graz University of Technology is dedicated to the research and application of digital media in architecture and design. The leitmotif of the institute is „Augmented Architecture“: we see digital media as expanding the very notion of architecture: how we design it, how we communicate about it, how we construct it, how we experience it. Our work is focused on these four areas:

- Computers as tools: architectural geometry, simulation, generative methods, parametric optimization, scripting – tools for architects to explore design.
- Computers as media: the networked world is opening up new ways to work together and new forms of collective creativity in architecture.
- Computers as part of construction: digital fabrication (CAD/CAM, rapid prototyping, robots etc) are expanding our repertoire of building methods and forms.
- Computers as part of architecture: sensors, actuators, digital controls and interactive elements are becoming an ever more important part of our built environment.

There is great potential in all four areas. We believe that a playful-experimental, but at the same time well founded and critical attitude is necessary in exploring these new possibilities. In order to really gauge what a new technology or new fabrication method could mean for architecture, one needs to go to its limits, use it in unintended ways, and play with it, own it. For this process of exploration, it is essential not to be content with the role of mere user, but to adjust the new technology to one’s needs. Especially in design, where intuition and efficiency in dealing with complexity play an important role, it is essential to understand and control the tools one works with. For this in our experience a basic understanding of scripting, the “lingua franca” of digital media, is a prerequisite, which is why architecture students at TU Graz learn this already as part of their bachelor studies. The manyfold expansions of our discipline currenly opening up as “Augmented Architecture” should be a motivation to engage with these developments. It is more important than ever that we also design the way we design.

INSTITUTE OF ARCHITECTURE TECHNOLOGY

The IAT|LAB is a part of Institute of Architecture Technology (IAT). The IAT|LAB is the scientific research and development platform of the Institute of Architecture Technology. We work on projects from urban scale to detail planning. The project teams are formed by institute and project staff and eventually extended by external experts. IAT|LAB consists of four research areas: MACRO: Urban densification MESO: Building design MICRO: Construction technologies NANO: Building materials. The project façade4zeroWaste which includes the development, architectural design relevance, grants of patents, results of pre-certification testing's and the product publication in the time frame from 2009 till 2017. Aim of the research project façade4zeroWaste was the idea of a recyclable façade insulation system that can easily be dismantled after its lifetime and reused thanks to an innovative grip fixing system consisting of mushroom-shaped heads and loops - Grip fixing instead of adhesive. The project won numerous prices and awards like the EQAR - Recycling Prize 2015 or the Innovation Award for Architecture and Building 2017. The project is a contract research project tasked by Sto SE & Co. KGaA, Germany and Sto GesmbH, Austria. The façade system was presented to the public in January 2017 as the product Sto Systain R (R = render: seamless plaster layer surface) on the building fair BAU 2017 in Munich.

INSTITUTE OF BUILDING CONSTRUCTION

The Institute of Building Construction merges the engineering fields of analysis, construction, building physics and material science with the architectural topoi of design and form. In research and teaching, the activities of the Institute range from the conceptual design and development of structural systems and building envelopes to façade technology and building physics considering the individual detail to the overall system. Following a highly interdisciplinary approach, the research areas are situated in the exciting environment between architecture and engineering. For this reason the Institute of Building Construction interacts continuously with institutes from other faculties particularly with the Institute of Thermal Engineering. The research topics of the institute are focused on conceptual and cross-material development of advanced building envelopes, structural glass and façade technologies. Because of its long-term experience in special topics in the design of building envelopes the Institute of Building Construction has organized interdisciplinary international conferences on "Advanced Building Skins" in 2012 and

2015 and is currently represented in the COST Actions “Novel Structural Skins TU1303” and “Adaptive Façade Network TU1403”.

SCIENTIFIC LEAD WITHIN UNAB RESEARCH PROJECT FOR CHAPTER 3, CHAPTER 4, CHAPTER 5, CHAPTER 6, CHAPTER 7: OLIVER ENGLHARDT

INSTITUTE OF CONSTRUCTION MANAGEMENT AND ECONOMICS

The Institute of Construction Management and Economics has a central role in the educational provision of the “Construction Management and Civil Engineering Department” at Graz University of Technology.
This Institute provides a thorough grounding in the technical basics and comprehensive knowledge of all construction operational, organizational, economic, legal and environment-related issues. As a progressive university department it regards all new trends in the building industry as key issues for the teaching provision. Subjects as integrated building technologies and building information modelling thus have an established place in its teaching and research work. The research areas of the Institute extend from classical construction-operational research, which deals with working processes and labour organisation in the construction industry, through to the investigation of the costing and performance issues for daily output and labour, productivity losses and the subjects of building project management and building technology.
The Institute is involved in intensive exchanges at numerous scientific conferences including the “Grazer Baubetriebs- und Bauwirtschaftssymposium”, the “Grazer Baubetriebs- und Baurechtsseminar” as well as the “Sichtbeton-Intensiv-Seminar” an intensive scientific exchange is provided. In addition a job training and information fair (BIT-BAU) is hosted each year providing a direct link between the building industry and our students and graduates.

INSTITUTE OF THERMAL ENGINEERING

The Institute of Thermal Engineering (IWT) is a part of „Graz University of Technology“ and has a long and exemplary history in the field of energy research. IWT employs a scientific staff of currently 40 researchers in the research areas Thermal Engineering, Solar Thermal Systems, Building Service Engineering, Heat Pump Technology, District Heating and Utilization of Waste Heat, Biomass Energy, Energy Efficient Buildings, Dynamic Building Simulation, Thermal Storage Systems and Dynamic Thermal System Simulation. In the last ten years the development and analysis of innovative façade systems was a topic in several research projects. IWT has been active or is active in many international projects, e.g. several Tasks of the IEA-SHC, Annexes of the IEA-HPP, and the FP-7 EU-projects MacSheep and COMTES. In the COMET-project (Competence Centers for Excellent Technologies) „multifunctional plug&play façade“ (mppf), IWT had a leading role in the coordination of different subprojects. The main focus of work carried out was placed on investigating thermal aspects by means of thermal simulation and computational fluid dynamics. The laboratory of IWT is equipped with an extensive infrastructure, including heat source and –sink systems, a climate chamber, a chemical laboratory, and measurement and data acquisition equipment. The institute has a well equipped workshop, where most of the apparatus for test rigs can be constructed in-house.

LANDESIMMOBILIEN-GESELLSCHAFT STEIERMARK

In 2001, the Landesimmobilien-Gesellschaft Steiermark (LIG) was founded as a 100% subsidiary of the province of Styria. Today, around 180 properties are owned by LIG. The real estate portfolio consists primarily of buildings leased to the Province of Styria to fulfill its public duties. In the real estate portfolio of the LIG are primarily public buildings such as:

- Office buildings
- Schools
- Nursing homes and social services
- Museums and cultural buildings
- Residential buildings

WORKING GROUP TOOLS AND FORMING [T&F] / INSTITUTE OF MATERIALS SCIENCE, JOINING AND FORMING

The research areas of the institute reach from tool-technology, cutting of “(ultra) high strength” parts to sheet metal forming processes. In order to guarantee research with a practical orientation, the special requirements

of the industry are set as guidelines. In July of 2004, the institute of Tools and Forming was founded and until the end of 2015 Univ.-Prof. Dr.-Ing. Ralf Kolleck was its head. Since January 2016 Univ.-Prof. DI Dr.techn. Christof Sommitsch (head of the Institute for Material Science and Joining) has been the new head of the institute. In 2017 the two institutes were joined together and the Working Group Tools & Forming of the Institute of Material Science, Joining and Forming was founded.
Sustainable lightweight construction and the optimization of production processes are our guiding framework. The focus is on lightweight materials and the forming of metallic material. Lightweight construction brings special demands to the automotive industry. The institute investigates and creates new materials and manufacturing processes. The Institute is one of the leading institutes in the area of tools and forming technologies in Europe. Our focus lies especially on sheet metal forming in an automotive context. The research activities of the T&F are Tool Technology, Virtual Development and Processes and Analysis.

WORKING GROUP SUSTAINABLE CONSTRUCTION [AGNHB] / INSTITUTE OF TECHNOLOGY & TESTING OF CONSTRUCTION MATERIALS

The Working Group Sustainable Construction of the Institute of Technology and Testing of Construction Materials is offering a broad spectrum in the area of sustainability assessment of buildings, life cycle assessment (LCA), life cycle costing (LCC) and systemic sustainability modelling including digitalisation and multi-criteria decision models.
Our research is dedicated on sustainability assessment methods, the work flow within the building design process and the applicability in the built environment as well as their successful implementation and realisation within demonstration projects. In our interdisciplinary projects our foci lie on the optimization of the environmental and economic performance by the use of life cycle assessment, life cycle costing, system analysis and multi- criteria assessment methods.

CONSORTIUM LEADERSHIP AND SCIENTIFIC LEAD WITHIN UNAB RESEARCH PROJECT FOR CHAPTER 1, CHAPTER 2, CHAPTER 8, CHAPTER 9, CHAPTER 10, CHAPTER 11: ALEXANDER PASSER

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Peter Auer, project assistant at the Institute of Tools and Forming, studied mechanical engineering economics at the Graz University of Technology and finished his bachelor degree in 2017. He is working for more than 10 years in the field of Finite Element Simulation of forming processes. In this time he worked in projects like "Residual Formability of preformed und subsequently welded advanced high strength steels", "Investigation and simulation of the hydroforming process of thick-walled T-pieces" „Simulation of thread tube production" and „ Development of forming processes with CIMERA (simulation steel-plastic sandwich material)".

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Matej Banozic has been working for Bollinger+Grohmann since November 2017. He has been working on projects with a focus on multi-dimensional models, complex geometry and the interaction between digital design methods and structural design. From 2015 to 2017 Matej Banozic was a research assistant at the Institute of Building Construction at Graz University of Technology in the field of adaptive façades. Furthermore he held interdisciplinary courses for architects and engineers, including the course advanced geometries and software-based building modeling. Prior and parallel to his work at Graz University of Technology, he worked from 2011 to 2017 at various engineering and architectural firms. In particular, he gained experience in designing, creating and coordinating multi-dimensional models. Matej completed his master's degree in architecture at Graz University of Technology in 2013 with a focus on the relationship between architectural theory and cybernetics.

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Vladimir Boskovic, university assistant at the Institute of Tools and Forming, finished his studies of mechanical engineering (Field of study: Production technologies) in 2013 at the Graz University of Technology. Master Thesis: "Joint welding of aluminum- silicon coated tailored blanks with powdered welding filler". Since 2014, Mr. Boskovic is scientific university assistant at the before mentioned institute with the research focus on "Compensating of spring-back of the AHSS". Additional scientific topics are: Cold and warm forming of high and ultra high strength steels and the corresponding tool and plant technologies. In addition he is enrolled in the doctoral school of Graz University of Technology.

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Daniel Brandl, studied Chemical and Process Engineering with a focus on Process Plant Engineering at the Graz University of Technology. He worked at the Institute of Process and Particle Engineering in the course of his diploma thesis. Currently he is working as project assistant at the Institute of Thermal Engineering at Graz University of Technology, where he will complete his PhD in the field of Mechanical Engineering (Titel: Development of Numerical Models in order to predict Convective Air Flow in Combined Heat Transfer Effects for Functional Façade Applications). His main work deals with numerical simulations in the field of building technology, especially Computational Fluid Dynamic simulations (CFD) of façade systems.

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Susanne Bruner-Lienhart studied architecture at Graz University of Technology, Austria and at the Università di Firenze, Italy. She graduated in 2003 and her research work focuses on the certification of sustainable buildings and on the compatibility of energetic building optimisation with high quality architecture. From 2000 to 2006 Susanne was working at the Energy Agency Styria in the sector of energy certification of residential and office buildings. Parallel to this, she was part of the research team of the Inter-University Research Centre for Technology, Work and Culture (IFZ). There she was involved in several research projects funded by the International Energy Agency (SHC Task 23), the Austrian Federal Ministry of Transport, Innovation and Technology (Climate Research Program, Research and Technology Program „Building of Tomorrow") and several public clients. Inter-linked design as a strategy towards sustainable buildings and research on ecological construction or refurbishment in the one-family house sector are the key topics of her publications. From 2008 to 2010, Susanne worked at the internationally renowned architectural office Dietrich I Untertrifaller Architects in Bregenz, Austria. In 2010/11, a research grant for architectural documentation funded by the Austrian Federal Ministry of Education, Science and Research enabled her to publish her photographs of the development of modern architecture in Vorarlberg. In 2011 she came back as project assistant to Graz University of Technology. At the Institute of Building Construction she performed research on façade refurbishments.

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Richard Deutsch completed his master study Construction Management and Civil Engineering at Graz University of Technology. Since April 2016 he was part of the projects UNAB and for the preparation of an environmental product declaration for ready-mixed concrete. In addition to the projects he dedicated his scientific efforts for his master thesis on the topic of LCA ready-mixed concrete and especially modelling aspects and respective analysis.

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Assoc. Prof. Dipl.-Ing. Dr.techn. Christian Hofstadler is head of the Institute of Construction Management and Economics at Graz University of Technology. In addition to his teaching in Graz he gives numerous guest lectures in the course of his reg-ular international teaching and research exchanges. Furthermore, he is an expert member of several professional committees and working groups related to construction management. He is author and editor of numerous books as also national and international conference documentation. His research focus is in particular on the following areas:

- Lean construction management
- Improvement of production and logistics processes
- Chance and risk management
- Life cycle considerations and calculations
- Investigations of productiveness and disturbances of the construction progress
- Systematic data acquisition as well as information and knowledge generation man-agement for future building technologies
- Consideration of uncertainties in forecasts with Monte Carlo simulations
- Implementing nonlinearities with the calculation of construction times and construction cost

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Helmuth Kreiner studied civil engineering at the Technical University of Graz. He worked in the field of construction supervision for many major infrastructure projects for several years. Currently he holds the position as a senior scientist at Technical University Graz. He is deputy head of the working group Sustainable Construction - Institute of Technology and

Testing of Construction Materials. His research focuses on life cycle sustainability assessments of construction products, buildings and urban districts. His main research topic is the systemic sustainability optimization of buildings and the implementation of complexity management methods in sustainable construction. He has coordinated and worked on several research projects and has supervised diploma | master theses. Since 2009 he is lecturer at the postgraduate university course "Sustainable Construction" and involved in the (further-) development of building certification systems. In 2010 he co-founded a consultancy engineering company. He is green building auditor and member of the certification committee at Austrian sustainable building council (ÖGNI) for several years. Since 2015 he is expert at Austria's Standardization Body ON-AG 011.04 "Requirements for Sustainable Construction" and Austrian Delegate to CEN |TC 350 "Sustainability of Construction Works" WG4 "Economic Performance Assessment of Buildings".

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Dipl.-Ing. Dr.techn. Markus Kummer graduated at Graz University of Technology (major in Construction Management and Civil Engineering). The topic of his master's thesis was "Use of the Monte-Carlo Simulation for Calculation of Building Cost and Construction Time". Since 2011, he is involved in writing expert reports on construction operations assessments for solving operational and economic problems. He works as a university project assistant at the institute of construction management and economics since 2013 and is actively teaching activities since 2016. In his dissertation on "Aggregated Consideration Productivity Loss with the Investigation of Building Cost and Construction Time – Deterministic and Probabilistic Considerations", he focused on non-linearity and uncertainties with the inquiry of building costs and construction time. He completed his PhD in December 2015. His prizewinning dissertation received the "gif Immobilien-Forschungspreis" and the DVP-Förderpreis. Markus Kummer is author and co-author of several national and international conference contributions in the area of the construction management sciences.

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Thomas Mach is Project Senior Scientist at the Graz University of Technology. He holds a masters degree in Architecture and a PhD in Mechanical Engineering. He has been working at the Institute of Thermal Engineering at Graz University of Technology for 17 years, working on and coordinating research projects (national, European and International Energy Agency). His work deals with energy concepts, building renovation, thermal simulation of low-energy buildings, heating systems, the use of solar energy, façade development. He was coordinating the main-subproject in the COMET-project "multifunctional plug&play façade"(mppf) in the years 2008 to 2013. Since 2014 he works with a team of scientists, in cooperation with AEE - Institute for Sustainable Technologies, on the development of methodologies and tools for the analysis, design and optimization of cross-sectional energy systems for urban areas.

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Ferdinand Oswald is University Project Assistant at the Graz University of Technology. He holds a masters degree in Architecture and a PhD in Engineering Science. Born in Stuttgart, Germany, he studied architecture at Escuela Tecnica Superior de Arquitectura in Granada (Spain), Agency of Urban Planning in Bern (Switzerland) and graduated at Technical University Dresden (Germany). In 2007 realisation of the first German apartment block in "Passive House Standard" as project head architect with Stefan Forster Architects in Frankfurt am Main (Germany). He taught at Frankfurt University of Applied Sciences "construction and design". Since 2008 he has been working at the Institute of Architecture Technology, IAT, Graz University of Technology in teaching and research positions. His research and teaching has a specific focus on energy efficient façade technologies: in teaching the main focus is on the topic of structure & façade technology; in his PHD he focused on the aim to reduce A/C in tropic and subtropic regions. He won several research prices like the "European Recycling Award 2015", "Innovation price Architecture and

Building" BAU Munich and granted several European patents. He is Visiting professor at Qingdao Technological University, Department of Architecture, Qingdao, China and German University of Cairo, Department of Architecture and Urban Design Program, Cairo, Egypt.

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CONSORTIUM LEADERSHIP, SCIENTIFIC LEAD CHAPTER 1, CHAPTER 2, CHAPTER 9, CHAPTER 10, CHAPTER 11

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Alexander Passer completed his civil engineering degree at Graz University of Technology (TU Graz, Austria) in 2002. After finishing his studies, he began working at the Institute of Technology and Testing of Building Materials at Graz University of Technology. For his PhD, he focused on the applicability of environmental assessment methods on building products and buildings. After his PhD, he lectured on sustainable construction at TU Graz and the University of Applied Science in Vienna (FH Campus Wien, Austria). In 2010, he co-founded a consultancy engineering company. The focus of his work is on building energy certification, energy optimization of buildings and sustainability certification of buildings. In 2011, he was appointed as Assistant Professor for Sustainable Construction at TU Graz, where he set up a working group for sustainability assessment. Since 2013 is subject editor for construction materials and buildings for The International Journal of Life Cycle Assessment. Additionally, he is Austrian delegate to CEN/TC350 and CEN/TC 442 and other national and international technical committees. In 2014, he was appointed as a Visiting Professor at the Chair of Sustainable Construction at ETH Zürich. In 2017, he was promoted to Associate Professorship and received the venia docendi for the scientific field of sustainable construction.
His research focuses on the Life Cycle Sustainability Assessment (LCSA), the design process and optimization of sustainability performance buildings using a systemic approach. Other foci are Building information modeling (BIM), as well as building material technology, Life Cycle Assessments (LCA) / Environmental Product Declaration (EPDs) and Life Cycle Cost Analysis (LCCA).

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Roger Riewe was born in 1959 in Bielefeld, Germany. He studied architecture at the RWTH Aachen. In 1987 he founded Riegler Riewe Architects in Graz. Together with Florian Riegler he set up further offices in Berlin and Katowice. The oeuvre of Riegler Riewe Architects stretches from urban planning projects, infrastructure projects and cultural buildings right up to facilities for education and research in Austria, Germany, Poland, Croatia, Korea and Rwanda. Their works have received numerous awards, amongst others the AIT Global Architecture Award and 5 nominations for the Mies van der Rohe Prize. Their work has been published extensively internationally and has been widely exhibited.
After visiting professorships in Amsterdam, Prague, Barcelona, Venice, Calgary, Houston and Graz, Roger Riewe became Professor and Head of the Institute of Architecture Technology at the Graz University of Technology in 2001. He has been and is a member of many boards and councils, for example, the city of Cologne's design council and the Scientific Committee Europan. He is author of numerous contributions to journals and publications as well as a co-initiator and former publisher of Grazer Architekturmagazin – GAM, a journal of the architecture faculty of the Graz University of Technology.

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Marco Scherz studied civil engineering at the Technical University of Graz and is now PhD candidate at the Working Group Sustainable Construction. His master thesis focused on the topics sustainable constructions, probability theory and statistics and implementation of sustainable construction in tendering and contracting. The thesis on sustainable design processes was supported by the Institute for Construction Management and Economics and the Institute of Technology and Testing of Construction Materials. As one of the contributors to the research project "Sustainable Design Process & Integrated Façades", he worked on the development of a process model for maturity assessment in the construction industry. Referring to the complexity of numerous interacting criteria in the early design stage and the resulting decision problems, Marco's second master thesis addresses the application of multi-criteria decision aiding/making methods (MCDA/M) in construction industry. His PhD thesis deals with the extension of the systemic approach using fuzzy logic and its application for the implementation of sustainable construction.

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Arch. Dipl.-Ing. Helmut Schober holds a master's degree in architecture from Graz University of Technology since 1997 and has more than 15 years of practical experience in building construction. Between 2004 and 2009 he was university assistant at the Institute of Structural Design at Graz University of Technology. Since 2009 he is managing his own architectural office in Graz and can refer to a large number of realised projects. As an expert in façade engineering he is specialised in the design, structural analysis, building physics and detailing of complex building skins. He is also an expert witness in the field of Building Construction and Architecture and is a member of the standardisation committee 214 "Flexible Sheets for Water Proofing" at Austrian Standards Institute. At this time Helmut Schober is writing a PhD thesis at the Institute of Building Construction on the subject "Thermal Activated Building Envelopes".

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Milena Stavric completed his architectural engineering degree at the University in Belgrade and since 2004, she has been working at the Institute of Architecture and Media at Graz University of Technology.
She lectured at the Academy of fine Arts in Vienna, University of Applied Science in Graz (FH Joanneum), University of Banja Luka, Universidad

Anáhuac, Mexico City, University in Novi Sad and University of Applied Science in Zagreb.
The focus of her work is on architectural geometry, digital methods and presentation, robotic in architecture, parametric modelling and digital fabrication. Since 2014, she holds the position of Assistant Professor for Architectural Geometry and Digital Presentation.
During her time at Graz University of Technology, she was project leader of FWF research project in the field of architectural geometry, co-author of two FWF research projects in the field of digital fabrication and digital heritage and she was Management Committee member in four COST Actions.
She was also visiting scholar at the Harvard University (Graduate School of Design, GSD) joining Material Processes and Systems Group (MaP+S) where her research focused on 3D fabrication process with a 6 axes industrial robot and composites material. She is the author of the book published by Springer "Architectural Scale Modelling in the digital Age". She organized several exhibitions in Graz, Belgrade, Ljubljana, Novi Sad and Banja Luka presenting works of her students.

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Christian Steinmann finished his studies at TU Graz in Technical Mathematics with focus on information and data processing with his master thesis about a new method for assessing the capability of software development processes. Together with the Swiss consulting company SynSpace he was able to establish the method by developing and using a universal software based tool for process assessment – which was enhanced to be compliant with the new ISO standard 15504 "SPiCE".
Based on this co-operation, HM&S GmbH was founded in Graz in 1995, where Christian Steinmann is still managing partner. Besides software development for constructions (CAD, calculation, computing & topographical survey) Christian Steinmann consulted several companies participating in EU projects in the area of process improvement, software engineering and managing of improvement initiatives.
He earned qualifications as an assessor for SPiCE (ISO 15504), Bootstrap and instructor for CMMI. Since more than 14 years he is consulting in the automotive sector, coaching projects on parts-, ECU-, SET- and whole vehicle-level for topics concerning process maturity, quality assurance

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He is visiting lecturer at University of Applied Science FH-Joanneum Graz, teaching introduction to computer science and programming language for degree program "Automotive Engineering" since 1998.

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Dipl.-Ing. Dipl.-Ing. Johannes Wall, BSc studied structural engineering and economic engi-neering at the University of Technology of Graz and the University of Calgary in Canada. His theses dealt with pump storage power plants and hydropower energy payback ratios, performing a life cycle assessment. Starting his scientific career at the sustainable construction working group at the Institute of Technology and Testing of Construction Materials, he focused on implementing sustainable construction in several national and international research projects. He is currently a university project assistant and doctoral candidate on the institute of construction management and economics at the University of Technology of Graz. His research focuses are amongst others on the area of the life cycle orientated building project management. In addition to his activity at the University of Technology of Graz, he is a regular contributor to several working groups including the IG Lebenszyklus. In his dissertation on "Life-cycle orientated Modelling of Planning, Tendering and Awarding Processes" he deals with the consideration of sustainability aspects in planning and project management processes. Johannes Wall is author and co-author of several national and in-ternational publications in the field of the life cycle orientated building project management.

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