Design4Energy - Building life-cycle evolutionary Design methodology able to create Energy-efficient Buildings flexibly connected with the neighborhood energy system

Co-funded by the European Commission within the 7th Framework Programme.
Grant Agreement no: 609380.
2013-10-01…2017-09-30 (48 months).

Report 3.4

Test, Validation and Ramp-up report

Revision..1
Preparation date............................2014-05-31 (m08)
Due date.......................................2017-03-31 (m42)
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1. EXECUTIVE SUMMARY

This report is intended to test the developed concepts and solutions of the technology database (TechDB). It integrates on the one hand users with practical, industrial application and on the other hand project partners that have been involved in the research for it. With the objective to develop a suitable database for the Design4Energy (D4E) workspace, the requirement identification of the component and energy system database started from the analysis of the existing database solutions. The results of this report help the development partners to improve the concept and the technical implementation of the TechDB in the manner that a higher industrial and scientific exploitability can be achieved.

As the basis for evaluation the most important requirements throughout the project are collected and presented as the requirements cluster for evaluation. To focus on the well-defined areas that are firstly relevant for industry and secondly intended to demonstrate the novel design process developed within the project, the methodology of use case-based testing is presented. The testing is therefore differentiated in two mayor fields, namely the technical and the process objectives.

The roles and use cases are specifically derived from the context of the practical tests with the BIM tools and the according technology database and are designed in a bottom-up approach. There are ten use cases which are divided into three groups according to their functionalities: technology management, internal and external collaborative data storage for innovation and product design, and data storage and interface for analysis and decision support tools. The roles commonly existing in the building industry are the building coordinator respectively the client, the project manager, the IT-manager, the process manager, the technical employee, the architect, the engineer, the energy expert, the economic expert, the electrical engineer, the BIM-manager, the technology developer, the BIM-coordinator, the HVAC designer, the building technician and the facility manager.

The feedback from user tests and interviews are summarized; the technical as well as processual performance of the database system is discussed in terms of the main requirements clusters. Especially the practical user tests lead to implications in usability improvements and bug fixing. Improvements dealt especially with building up and filling, integrating, connecting, managing technically and providing technology databases for the open standards community.

The feedback shows important challenges in the implementation of technology databases. It also shows the major merit of it. New versions based on the findings, feedback and improvements of this report and, furthermore, mature concepts will lead to highly valuable and applicable technology databases that improve the design process of buildings many times over. The results of the database evaluation based on the test cases and interviews have shown significant value for the architectural, structural and methodological design of the companies' technological knowledge and therefore the design process. The valid design requirements according to the concrete use cases enable companies to build a robust information management with data consistency.

2. INTRODUCTION

2.1 Purpose and target group

This report is intended to test the developed concepts and solutions of the technology database (TechDB). It integrates on the one hand users with practical, industrial application and on the other hand project partners that have been involved in the research for it.

The results of this report help the development partners to improve the concept and the technical implementation of the TechDB in the manner that a higher industrial and scientific exploitability can be achieved.

2.2 Contributions of partners

Table 1 shows the contributions from different partners in this report. Furthermore, it is to say that the contribution of each partner is clearly indicated and in balance with the allocated resources.

Table 1 Partners' contributions

Partners	Contribution to section
FHR	Chapter 2, 3, 4.1, 4.2, 4.3, 5, 6; structure of report; summaries and evaluation
LU	4.4
SOL, VTT, 3L, SYM, GSM, CAD, TPF	Testing and Feedback

2.3 Baseline

The building industry is said to be slow when it comes to technological adaption [3]. The roots of building information modelling can be found in the late 1970s and early 1980s. The adoption in projects started in the mid-2000s [3]. Yet there is no clear and common definition of what building information modelling is [4].

The building industry has high expectations towards building information modelling (BIM). It is supposed to raise the productivity and efficiency of collaboration of the whole building industry [4]. BIM represents a technology as well as a process [1]. The technology part of it addresses helping the relevant stakeholders in visualising the building in simulation and keeping track of all possible issues that could occur during the construction phase [1]. The process part addresses the close cooperation of all involved stakeholders. This means that there is one model of the building in the centre of the project. This model contains all relevant data. In common building projects well known 3D CAD systems are used to model the specific parts of the building. Regarding the different stages and components that have to be considered in a building project this means that every engineer, specialised in a relevant field will use his own tools to do his work and that the models are generated specifically and will only contain the relevant data for the special topic. BIM mandates a new perspective for the management of the building data. The central model will contain all information generated throughout the development process and can be accessed by every stakeholder to get a detailed overview over the project as a whole.

Design4Energy develops such a tool that brings together all task and processes as well as all relevant stakeholders. This part of the project specialises on the development of a database for technology that supports engineers, developers, building owners, design teams, consultants and architects in the different phases of a project. The database therefore includes technologies concerning insulation, energy systems and lighting.

Throughout a building project there are a lot of processes in that technological information is relevant. The database offers support in different situations to the users (see also report D3.1). It especially offers support in the design stage of a building. The involved stakeholders in the design phase are owners/clients, architects, design teams, engineers and consultants. These stakeholders are interested in a free platform for resources and quality check. This sharing ensures consistency through all phases of the life cycle of the building project and the building itself.

The developed database gives manufacturers and technology providers the possibility to present their products which also gives insight of the maturity of the according technology (see also report D3.1). The database can serve as a platform for sharing technological information which is relevant to the stakeholders for the development of existing or new resources such as software solutions, physical characteristics or distribution of services. The involved stakeholders in this case are developers, researchers, manufacturers, technology providers.

From the life cycle perspective and for the retrofitting phase information about the degradation of the materials used in the building is used to make decisions on the right time for maintenance and retrofitting.

The involved stakeholders in the design process of a building project are the client, energy experts, architects, HVAC engineers and electrical engineers. The concept design of the building is made in collaboration with the client, facility managers and architects (see also report D3.1).

These phases presented above are described in detail in the defined use cases in Section 3.3 that show how the database can be used by all the relevant stakeholders in different phases of a project and how it supports them in making decisions. The use cases are structured in three main areas or phases in a building project. The first one is technology management, where the adaption of existing technologies as well as support of strategic decisions is relevant. The next area that is supported by the database is the internal and external collaborative data storage for innovation and product design. The platform is used to work together in large teams and to integrate the customer. The last main area that use cases are defined for is the data storage for analysis and decision support. Here the stored information is being used for economic evaluation of energy system technologies or products.

The technical implementation is described in detail in the D4E report D3.2. A short summary of the technological background is given here. The database is based on the semantic media wiki technology. This technology offers a web interface that enables the user to search information about current technical solutions, to search of the best fitting technical solution based on parameters, to execute technology radar. The database also provides an interface for exporting data, for example based on gbXML files.

Based on the described situations, the presented database will be evaluated by the use cases presented in the following chapter.

2.4 Relations to other project activities

With the objective to develop a suitable database for the Design4Energy (D4E) workspace, the requirement identification of the component and energy system database started from the analysis of the existing database solutions. The classification, evaluation and analysis of the state of the art of the BIM and energy efficiency oriented database have inspired the requirement identification and also the approach, concept and functionalities design in T3.2. The work reported here builds on what was achieved in the reports D3.1, D3.2 and D3.3. Taking into account the project objectives and the interests of the analysed stakeholders, D3.1 has brought the requirement for simulation outputs which could help the end users or architects to understand the energetic performance of their on-going design, IT requirements in architecture, data structure and interface, as well as the operation and maintenance issues. D3.2 has aimed at creating database system architecture for the novel design process in the building and district energy domain developed in the D4E project. The physical database has provided data for usage in the applications technology database (TechDB), building components catalogue, benchmark tool and decision support. D3.3 has reported on the third phase of the development of the building component and energy system database. It has contained a description of integrating the information base into the D4E database system to prove the value of the novel design process. D3.3 has also contained important considerations of data representation, practical issues in connecting simulation applications and file formats.

The overall Design4Energy use cases and architectures are described in report D7.3. However, in these use cases the TechDB is just mentioned as a single object among other important steps within the novel design process of the Desig4Enery project. In other parts the TechDB is described in technical use case manner. This report D3.4, however, aims at describing the specific use cases of the technology database in a generic, consistent matter, which especially refers to the business process aspects.

Use case 2 has a special relevance since it contains the main step at working with the components catalogue. Users will be able to access the components through a web interface and download parameterized components into the building model. The use case describes also the process of designing the three dimensional model with Autodesk Revit or ArchiCAD, integrating GIS data and conduct simulations. It starts with the collection of requirements which are matched with the component and energy system database. The result should be a calculation of building performance regarding the energy efficiency. Collaboration and visualization takes place on the central BIM collaboration workspace.

Use case 3 describes the process of early assessment of energetic performance and costs. The important aspects of this case are next to intensive communication between the architects, calculations and energy matching, also the provision of the relevant data such as cost and performance over the lifecycle. This information is part of the technology information provided in the TechDB.

The overall use case concepts refer to the component catalogues also in use case 4 in the detailed design stage, and in use case 7 which deals with retrofit and maintenance modelling. This use case is especially underlined in this report by the consideration of the decision support for retrofit alternative design.

As described above, use cases have been already developed in other reports, especially in report D7.3 (Use Case 2, 3, 4, and 7). The use cases in this report differ from the use cases 2, 3, 4 and 7 in report D7.3 because the use cases of the technology database have been considered more comprehensive and have been supplemented, refined and elaborated by the overall works and test applications.

2.5 Relations to other projects

The European Project "NewBEE", funded by the European Commission under Framework FP7, has developed some tools on their own platform; this means Market Place, Pre-Assessment Tool, Financial Calculation Tool, Energy Performance assessment, wiki and Business Model Assessment. For each tool, users have been defined and the functionalities of the tool have been described. For example, users of Market Place are small and medium-sized enterprise or building owner. As the next step, several use cases have been defined according to the functionalities of each tool. Additionally, several metrics as Key Performance Indicators (KPIs) have been used for assessing the NewBEE solution.

The European project "ISES", funded by the European Commission under Framework FP7, has developed a cloud-based data repository. It contains information about energy product and material catalogues containing energy properties of products and materials. This database is used for creating physical constructs incorporated into the building out of product and material properties. The aim of this repository is to bring component manufacturers effectively together with their customers in order to keep the market open to their products. It also helps to choose appropriate components by energy-related characteristics due to high requirements of both designers and MEP specialists. The main focus is to provide the framework and functionality rather than to conduct a user analysis.

3. Method and Object of Evaluation

The following chapter describes the methodology for testing and evaluating the Technology Database.

As the basis for evaluation, most important requirements throughout the project are collected and presented as the requirements cluster for evaluation. To focus on the well-defined areas that are firstly relevant for industry and secondly intended to demonstrate the novel design process developed within the project the methodology of use case-based testing is presented.

The testing of the implemented functionalities can be differentiated in two mayor fields namely the technical and the process objectives. The technical objectives or requirements describe the handling and usability of the database system and therefore an evaluation if the basic system functionality is sufficient to perform the intended tasks and actions. The process objectives or requirements have to ensure the practical relevance of the performed tasks. They are in close relation to the business processes of a company and especially to the interrelated tools and processes developed within the Design4Energy project.

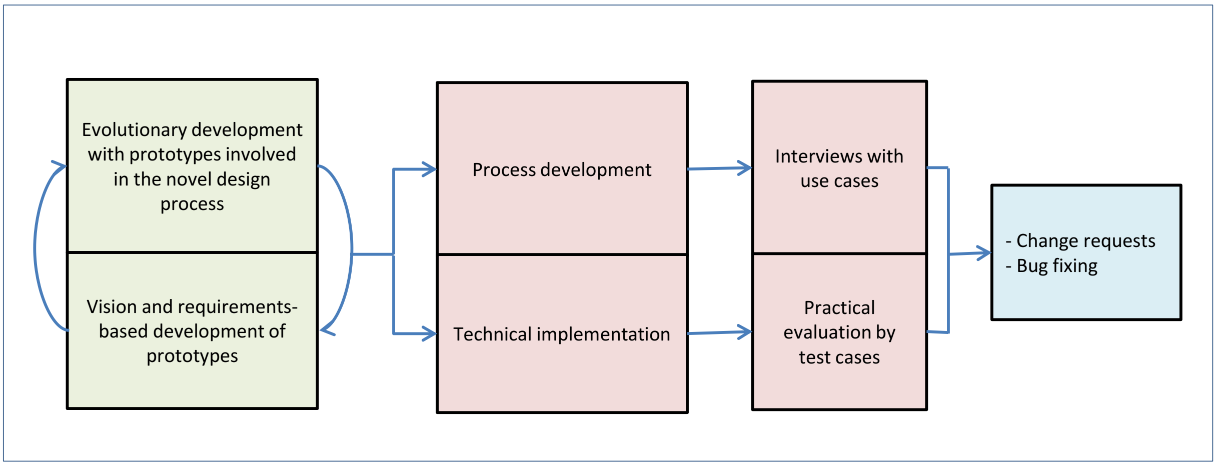


Figure 1: Evolutionary development and evaluation of the Technology Database

According to the two main fields, namely the technical and the process objectives, ten use cases have been constructed (see chapter 3.2). For each use case, the input, the work process with the database and the outcome which is expected have been considered. In order to evaluate the database, the following two methods have been implemented. For the process development, the interviews with use cases have been carried out. In the interview guidelines each use case has been briefly described and test users have been asked regarding the functionalities of each use case. For the technical implementation, test users have been asked to perform basic tasks and they have evaluated the usability. At the end of both methods, the qualitative evaluation has been carried out with discussion of evaluation clusters.

3.1 Roles in the D4E technology database

The relevant stakeholders for the use cases presented in this report are described in the following section. The roles are specifically derived from the context of the practical tests with the BIM tools and the according technology database developed and described in the reports D3.1 to 3.3. The roles commonly existing in the building industry are the building coordinator respectively the client, the project manager, the IT-manager, the process manager, the technical employee, the architect, the engineer, the energy expert, the economic expert, the electrical engineer, the BIM-manager, the technology developer, the BIM-coordinator, the HVAC designer, the building technician and the facility manager. When it comes to using the database for productive work there are some overlaps between the generally defined and commonly known roles in the building industry and the activities they perform in interaction with the database and in BIM. In order to get a clear understanding of the different types of interaction and responsibilities of the roles concerning the technology database, these have been clustered. The generally known roles are assigned to these clusters in a non-exclusive way. These clusters are described in detail in the following section and are named the BIM-Database-Manager, the BIM-Database-Operator, the Technology-Information-Provider, the Analyst, the Conceptual Designer, the Technical Designer and the Client.

BIM-Database Manager

Stakeholders that can interact in this role or cluster of roles are the project leaders as well as IT and process managers. Their main task is the implementation and process organisation. They have a lot of experience in working with tools that make interaction with the technology database easy and comfortable and can therefore save a lot of time and money in working with the technology database. Based on their experience, they are able and supposed to implement technology databases in their companies. Another task is to define standards in terms of the use of technology database and the according data formats and to control the compliance with these defined standards.

BIM-Database Operator

This role is occupied by IT and process managers and technical staff. BIM-Database Operators are generally uploaders of technologies and their main tasks contain data maintenance and the collection of information. They are responsible for the model based communication.

Technology information provider

The role of the Technology information provider describes Technology experts as well as Technology providers which make information on technologies such as building components or energy systems available according to the requirements of the data sheets. The role can be occupied by developers of technologies and by providers of technical data. Both stakeholders provide information about products and solutions based on developed technologies in the technology database. The task of this role can be summarised in the participation in an exchange of experience and in expert networks.

Analyst

The role of the analyst can generally be occupied by persons with specific knowledge and skills concerning the evaluation of technology and concerning decision making such as energy experts, economic experts, engineers and architects. Their task is the energetic and economic evaluation of building models, building components and energy systems. In combination with the use of the technology database these analysts can, for example, provide realistic thermal simulations for design approval as well as an analysis concerning the energy demand at building level and an analysis concerning the energy matching at neighbourhood level.

Conceptual designer

The role of the conceptual designer can be occupied by architects or engineers. In the phase of the conceptual design, the building model has a low level of detail. The tasks performed in this stage are optimisations such as the optimisation of heat loss or the choice of the best fitting building envelope and fenestration. The conceptual designer is supported by thermal building simulations based on the digital sketch model (BIM) in evaluation of the relevance and performance of his architectural and technical choices.

Technical Designers

The role of the technical designer can be occupied by architects, building technicians, engineers and HVAC designers. In the phase in which technical designers start their work, the building model already has a high level of detail. The main task of the technical designers is the design of technical components according to the existing building model and the given specifications. They, for example, design HVAC machinery, piping and connections, renewable energy sources and in-built equipment related to required environmental certificates.

Clients

Generally, clients are recipients of buildings and technologies developed and built in the corresponding projects. Possible stakeholders that can occupy this role are builders, building owners and users of HVAC technologies who buy the HVAC constructions or database contents and apply them to other construction projects. These stakeholders are supported in meeting decisions by the possibility enabled by the technology database to virtually change the configuration of walls and windows of a specifically modelled building, e.g. thickness of walls or materials.

3.2 Functional Overview of the Technology Database

In the following Figure 2, the functional overview of the technology database is given.

The technical process overview is designed to support the functionalities of the technology database. It especially shows the information flow from the point of unstructured technology data or unstructured technology information over the process of structuring to the result of machine compatible output for further works such as analysis and simulation.

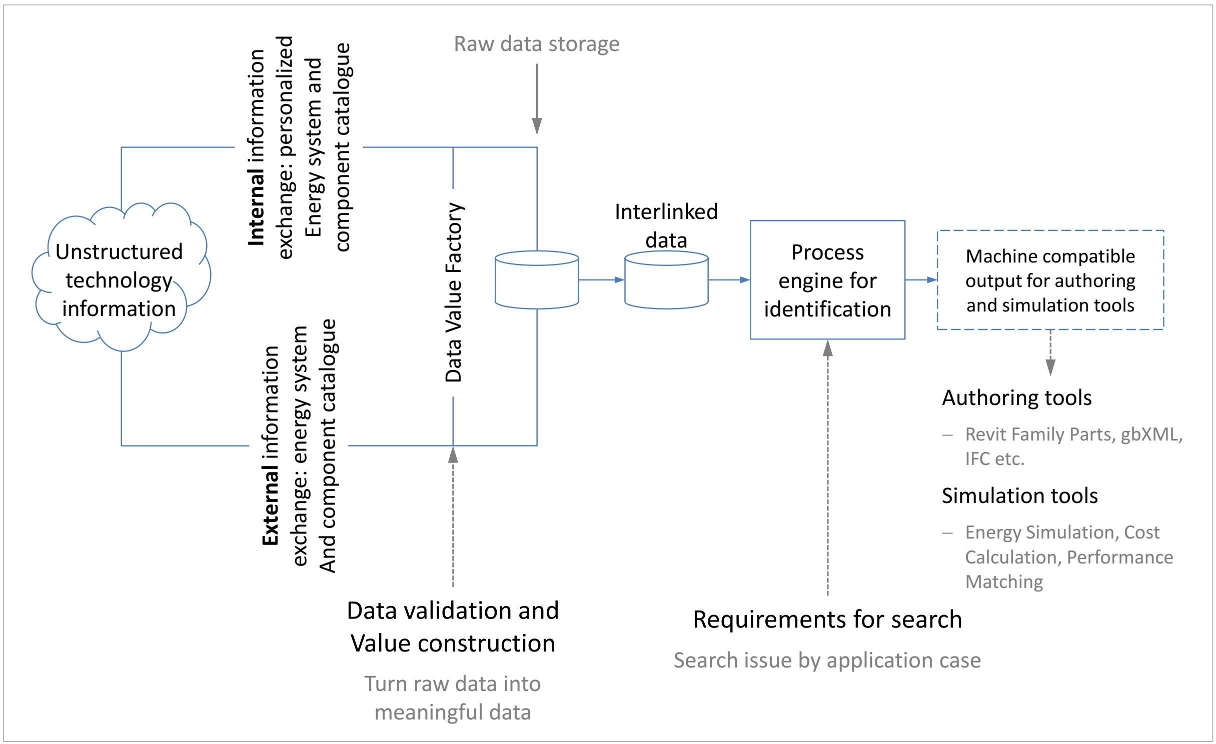


Figure 2: Logical information process design of technology database

The following list gives an overview about the functionalities on both a technical and a business level.

- Creating a user and assigning rights
- Create new objects, such as searchable energy system technology and enrich it with already researched data
- Perform search for function-based technology application cases by the given requirements
- Perform search for technologies with given performance demand
- Brows the database for database items such as technologies, components or buildings, and review performance data or information relevant for decision making
- Guidance in the graphical user interface for the database structure (design and usability)
- Dynamic, multifactor visualization for decision making
- Interfaces for authoring tools
- Security and process reliability
- Automated generation of simulatable gbXML-files
- Simulation of building models with building components selected and generated from the database
- File repository for components
- Methodology of technology management in construction industry
- Support of cost simulation
- Classification of building components

3.3 Description of Use Cases

The use cases are designed in a bottom-up approach. In the following, the use cases are described. Figure 2 shows an overview of the use cases. There are ten use cases and the use cases are divided into three groups according to their functionalities. The first functionality, namely technology management, includes technology adaption, technology sourcing and technology configuration. As the second functionality, e.g. internal and external collaborative data storage for innovation and product design, the technology database works for sharing, discussing and reviewing data with customers and partners. Additionally, the technology database has a further function, namely data storage and interface for analysis and decision support tools. It helps to calculate and analyse the whole building and to simulate alternative solutions. The produced data can be integrated into the decision support tools. Each use case is evaluated by test cases and interviews. The evaluation approach comprises the evaluation with respect to technical requirements and the evaluation with respect to business requirements. The technical requirement evaluation is based on a quantitative and qualitative evaluation of the functional requirements based on the test cases. The business requirement evaluation relies on the user's estimation based on the interviews.

Technology management

- Use Case 1: Technology adaption (for communication, development, as innovation source)
- Use Case 2: Strategic decision support (technology monitoring)
- Use Case 3: Technology sourcing (manufacturer and expert management)
- Use Case 4: Technology configuration

Internal and external collaborative data storage for innovation and product design

- Use Case 5: Selection of building components for building design
- Use Case 6: Interfaces to product development and authoring tools (CAD)
- Use Case 7: Common repository with customers or partners

Data storage and interface for analysis and decision support tools

- Use Case 8: Support for energetic calculation and evaluation of energy system technologies or products
- Use Case 9: Economic evaluation of products or technologies
- Use Case 10: Export of simulatable standard files

Figure 3: Overview and categorisation of the Use Cases

3.3.1 Technology management

The functionality of the database described in this section includes technology adaption, technology sourcing and technology configuration. The use cases described are showing the possible interactions with the database concerning the gathering of technology related information in terms of strategic decision support, support for technology sourcing decisions and as a replacement for consultancy.

3.3.1.1 Use Case 1: Technology adaption (for communication, development, as innovation source)

This first Use Case presents the use of the database for the adaption of technology at company level and at the level of an individual architect. At company level the knowledge about the application of a specific technology is documented and distributed within the company which enables early identification and evaluation of technologies. The knowledge can then be used for development and as a source of innovation. At the level of individual architects the database can replace the need for a technical consultancy as it provides insight into the available technologies and their application in products. The architect can browse the specific building components or energy systems that he or she needs for his building project and will get the information over the latest technologies. For the architect the database is an information system that provides all relevant data. This helps shortening the learning curve of the architect. Additionally, information about application barriers and about advantages and disadvantages of a specific technology help preventing potential fault planning in advance. The outcome of this use case is specific knowledge about the relevant technology at company level as well as at the level of an individual architect. The information can be structured as a data sheet, as a technology radar or as a technology portfolio. As the information is based on the application of a technology in a real product, it will enable comparisons with other technologies and show potentials for possible future optimisations of the application in products. Helpful information provided by the database for this use case can be summarised in data concerned with the application area (data about the environment such as temperature, etc.), data concerned with the application requirements (e.g. energy consumption, etc.), data concerned with functional and economic restraints (e.g. error frequency, material fatigue, etc.), data concerned with advantages and disadvantages (characteristic performance parameters such as a particular low weight), data concerned with lifecycle behaviour (e.g. estimated life time, loss of performance over time, etc.), data on complementary technologies (e.g. further technologies through which added value can be achieved) and data on the level of development (e.g. maturity of a certain technology, indicators like the amount of products available, etc.). Figure 4 shows the relevant data, the process steps and the results of this use case.

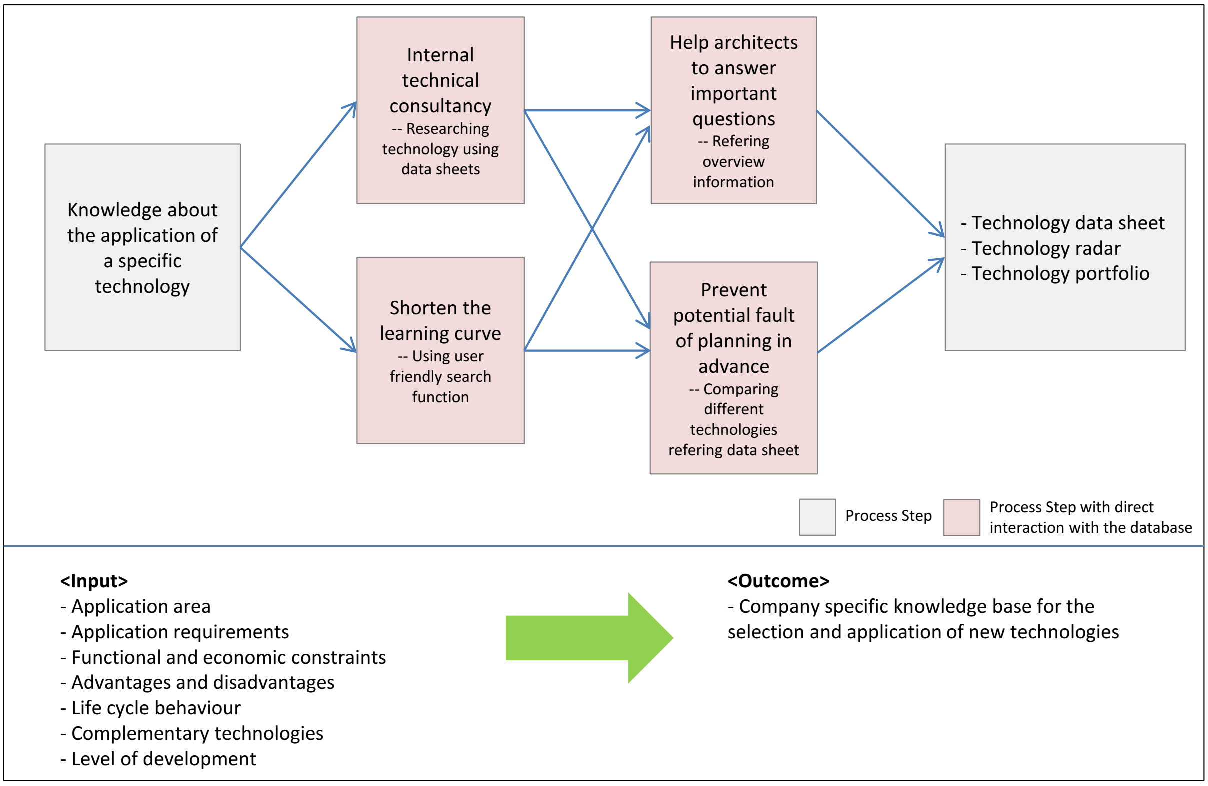


Figure 4: Detailed visualisation of Use Case 1- technology adoption

3.3.1.2 Use Case 2: Strategic decision support (technology monitoring)

This Use Case describes the use of the database as support for strategic decision. The database enables an overview of technologies and the according information that is documented from former research, evaluation and application. The database can generate complex graphs, provides user friendly interfaces and search functions which provide the base for a strategic view on these technologies. The reports can be structured such as technology radars or a technology data sheet. The most relevant step to be taken for this use case is to accumulate the knowledge and information about technologies in the database over time. The sources of information for the database are Committees and associations, Databases (patent, statistics, etc.), Events, (conferences, seminars, etc.), Experts (researchers, engineers, etc.), Internet (company websites, news, blogs, magazines, etc.), research institutes, scientific publications, Clients, Suppliers, technology studies, experience from former projects. The relevant stakeholders for this use case are technology providers, manufacturers, energy experts, architects, HVAC engineers and electrical engineers. The output provided for the addressed stakeholders is detailed information about the current situation for every building and energy system related technology represented in the database. Based on this information the related users are able to identify and evaluate technologies at an early stage and to do strategic decisions on technologies. The provided data can be summarised in different categories. The first category is performance related information (e.g. heating and cooling capacity of HVAC systems, annual produced energy, etc.) the second category is efficiency related information (e.g. operating efficiency of energy generator, operating efficiency of HVAC systems, etc.) the third category is ecology related information (e.g. CO2 emission of energy generator, CO2 embodiment, Life expectancy of building components, degradation of building components, etc.) the final category is related to economic data (e.g. investment cost of energy or HVAC systems, investment costs of building components, etc.). Figure 5 shows the relevant data, the process steps and the results of this use case.

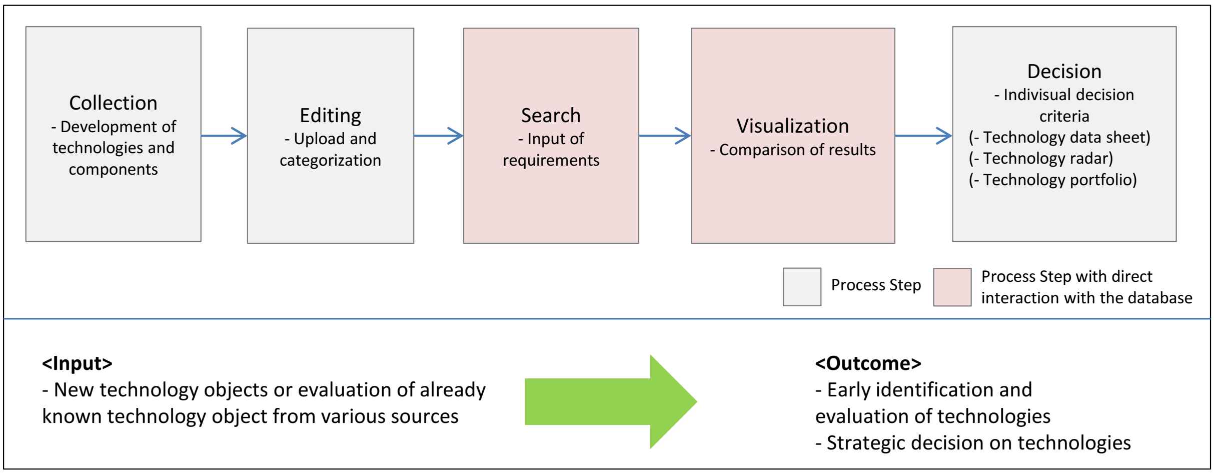


Figure 5: Detailed visualisation of Use Case 2 - strategic decision support

3.3.1.3 Use Case 3: Technology sourcing (manufacturer and expert management)

This Use Case describes the use of the database as a source of technological knowledge for companies. The sourcing of technological knowledge is a major concern for innovative companies. When making a decision on technology sourcing, the main task is to gather information on and the evaluation of manufacturers, experts and partners. The technology sourcing decision is made by companies and engineers. The database can serve as a tool for gathering information about the available manufacturers, experts and partners. The possibilities for visualisation of the information (e.g. technology radar) can help to get a quick overview over the relevant information and support the evaluation. The output of the database and the process described in this use case is the information about the best fitting manufacturers, experts and partners for the sourcing of technological knowledge. Figure 6 shows the relevant data, the process steps and the results of this use case.

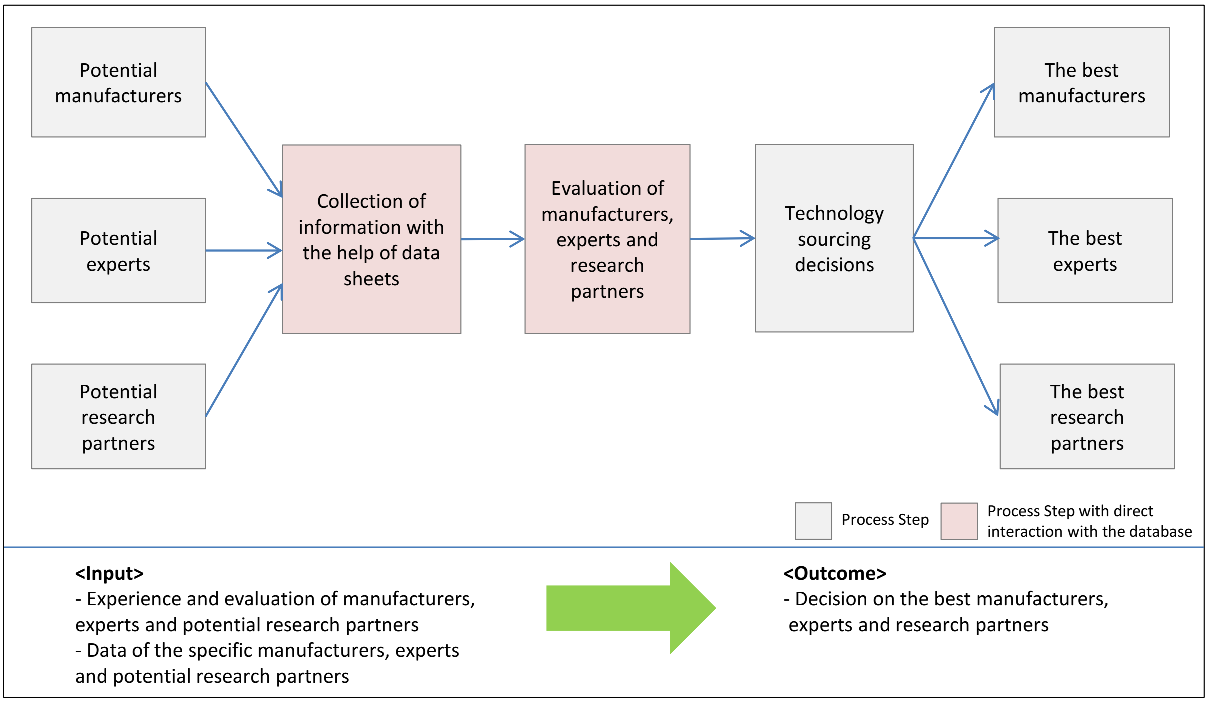


Figure 6: Detailed visualisation of Use Case 3 - technology sourcing

3.3.1.4 Use Case 4: Technology configuration

This use case describes the selection of building components, especially energy systems, based on the defined framework conditions for the current project and current project phase. The involved stakeholders depending on the according project phase are the client, the architect, the BIM manager and the design planner. The tasks in this use case that are supported by the technology database are the selection of energy solutions and building components, the consideration and evaluation of different solutions and the determination of requirements of the delivery objects. The steps to be taken are first the research on the framework conditions of the building and the neighbourhood as well as the calculation of costs, energy demand and heating demand of the whole building. Based on this information, in the next step a selection of fitting energy solutions and building components is done. This selection forms the base for the consideration of alternative solutions which is again supported by the technology database. The data acquired from the database can be described as semantic and ontological knowledge about the functionalities of technologies and components. Based on the gathered information, the determination of energy solutions and building components can take place. The needed input for using the database efficiently is the energy and heating demand of the whole building, information about the solutions in the neighbourhood, legal requirements for the neighbourhood and information about the framework conditions such as energy supply and heat supply of the district. The output of the process of this use case is detailed information about the performance data of the selected energy and HVAC solutions, the investment cost for the selected solutions and information about the amortisation. Figure 7 shows the relevant data, the process steps and the results of this use case.

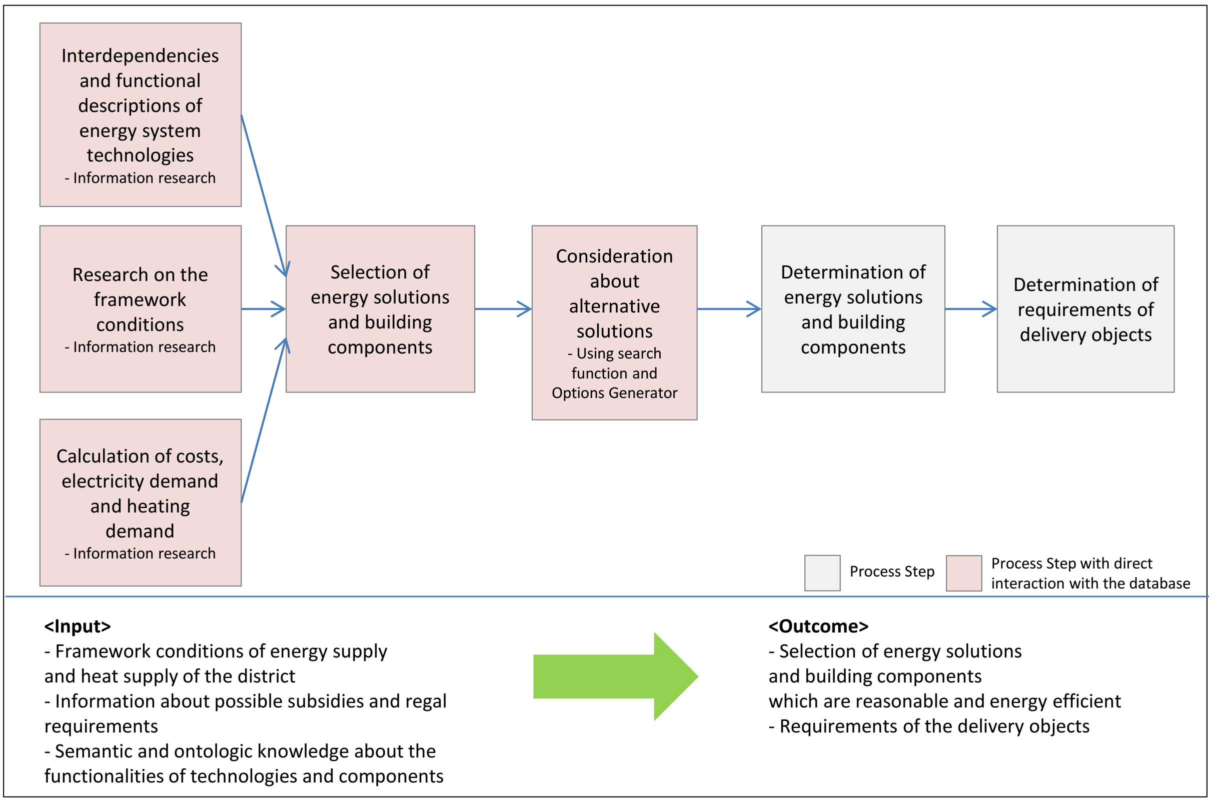


Figure 7: Detailed visualisation of Use Case 4 - technology configuration

3.3.2 Internal and external collaborative data storage for innovation and product design

The functionality of the database described in this section is related to data storage and collaboration in closed groups. It describes the use of the database as a platform for collaboration in closed groups for discussion and review of building models and building components. It also describes the use of the database as a repository in combination with other sources of information.

3.3.2.1 Use Case 5: Selection of building components for building design

This Use Case describes the use of the database as support for the selection of building components for building design in terms of energy efficiency. In the early planning phase the client defines the room allocation plan. The architect designs the building and the according components to fit the requirements defined in the room allocation plan. Therefore he uses the database. The BIM manager can use the database again to check the planned building components and energy systems for their efficiency in accordance to the requirements defined by the client. The information that is required for the check of the building components and energy systems is the heating and electricity demand which can be derived from the defined usage of the individual rooms. The data that is provided by the database to support the BIM manager in the evaluation of the components can be divided into energy based information (e.g. u-values, heating capacity, etc.) and information related to cost-efficiency (e.g. operating efficiency of energy systems, annual produced energy of energy systems, etc.). The output of the described process is an optimised energy efficiency of the whole building. Figure 8 shows the relevant data, the process steps and the results of this use case.

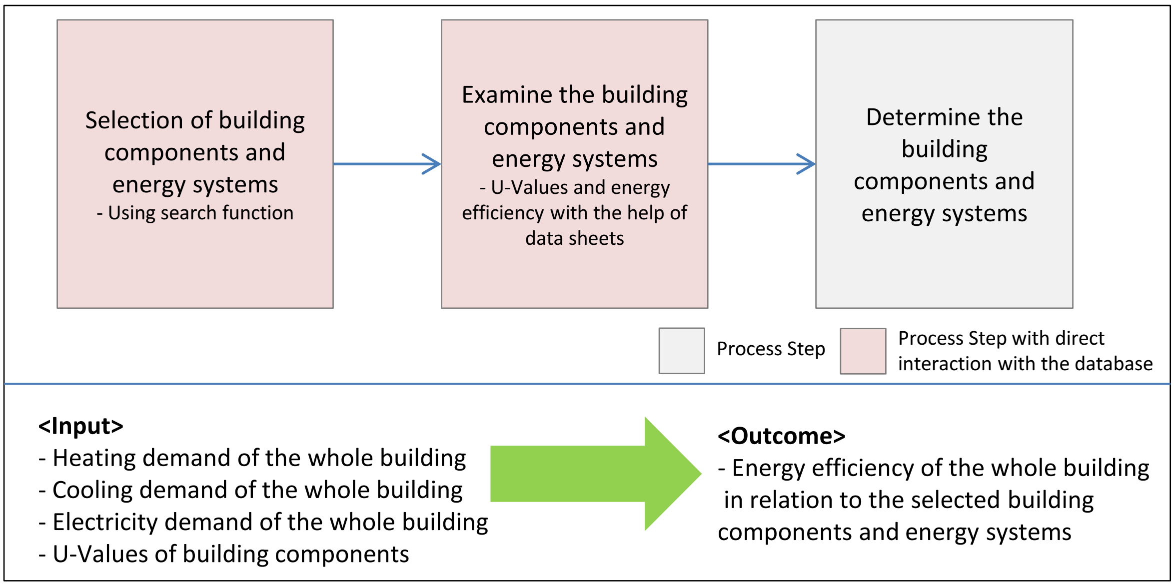


Figure 8: Detailed visualisation of Use Case 5 - Selection of building components for building design

3.3.2.2 Use Case 6: Product development and authoring tools (CAD)

This Use Case describes the use of the database as a repository for files that are used frequently in authoring tools. The focus is thereby on providing according interfaces to and integration into the according authoring tools. The first relevant process step is the collection of building components with the help of the database. Additionally and in parallel a collection of other building components from product catalogues and external libraries is executed. Based on the gathered information the product development and authoring with CAD and other CAx tools is done. In the next step a Failure Mode and Effect Analysis of the building components is carried out. Based on the generated information, the best fitting components for the building in relation to costs, U-Values and design can be determined. The data that is provided by the database and that is relevant for this process is energy related information (e.g. heating and cooling demand of the whole building, etc.), component based information (e.g. dimensions of building components, U-Values of building components, etc.) legal information (e.g. permissible range of building components, etc.). Figure 9 shows the relevant data, the process steps and the results of this use case.

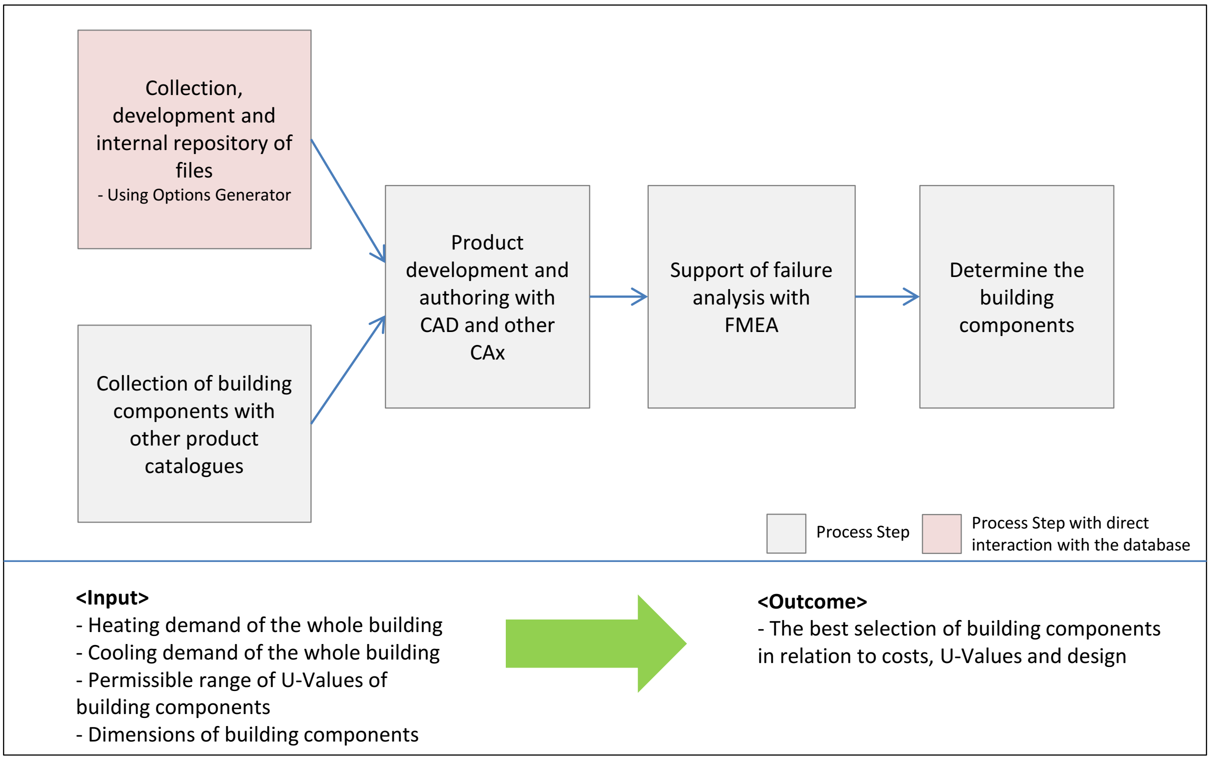


Figure 9: Detailed visualisation of Use Case 6 - Product development and authoring tools (CAD)

3.3.2.3 Use Case 7: Common repository with customers or partners

This Use Case describes the use of the database for sharing, discussion and review of data for the building together with customers. The database helps integrating the customers in the discussion and review of the building models, building components, energy systems and technology concepts. This use case includes the client, the architect and the engineers. At first the collection of the data of building components and energy systems and the development of building models and technology concepts is being executed. Based on the developed data and the use of the database as a platform for information sharing, the client is included in the review and discussion of the developed solutions in a closed group. The result is a decision that is based on data sheets of building components and energy system for the whole building. Thus, it is better coordinated and agreed on. The data that is provided by the database and that is relevant for this process is energy related information (e.g. u-values, heating and cooling supply of the HVAC system, annual produced energy of the energy generator, etc.), economic information (e.g. operating efficiency of the energy generator, investment cost of all components, life expectancy of all components, etc.). The output of this process provided by the database consists of datasheets of building components and energy systems and according gbXML files. Figure 10 shows the relevant data, the process steps and the results of this use case.

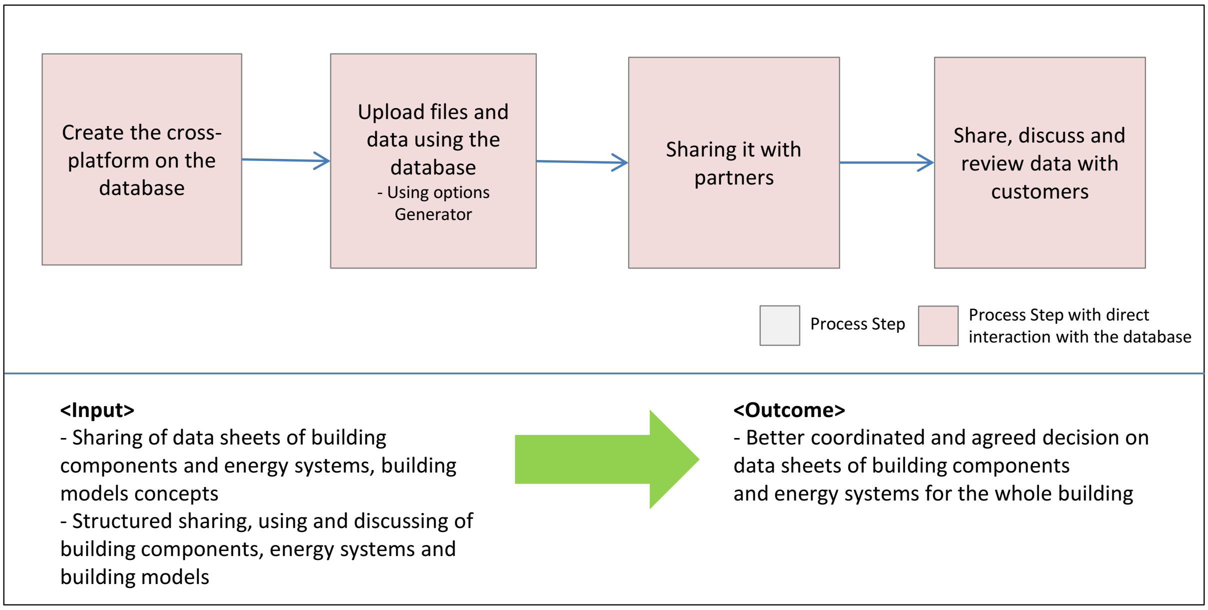


Figure 10: Detailed visualisation of Use Case 7 - Common repository with customers or partners

3.3.3 Data storage and interface for analysis and decision support tools

This section describes the functionality of the database as a support for economic and energetic evaluation of building components, products and technologies. Based on such an evaluation the database provides information to support the selection of the best fitting solution or component. This section additionally describes the use of the database as a support for the design, simulation and optimisation of HVAC systems.

3.3.3.1 Use Case 8: Support for energetic calculation and evaluation of energy system technologies or products

This Use Case describes the energetic calculation and evaluation of energy system technologies or products supported by the technology database. The goals to be achieved in this Use Case can be summarised as support of the analysis of energy matching at neighbourhood and building level and support of the design and simulation of energy generators, HVAC systems and lighting systems. To gain insight into these measures BIM is used to simulate and compare alternative solutions. The different possible simulations that are supported by information from the technology database are the calculation of the energy demand of the whole building, research for the energy supply data (e.g. annual produced energy, operating efficiency, etc.), analysis of energy balance of neighbourhood and, on building level, design of energy generators, HVAC systems and lighting systems for the building with the database and with BIM. The data used for this analysis can be categorized as specific performance parameters such as Photovoltaic Panel Efficiency, Annual Degradation Rate in Panel Efficiency (Estimated Lineal Degradation), Annual Energy Yield, Dimensions or Weight, which are relevant for simulations eg. In Energy Plus. The output of the subsequent steps consists of simulation and analysis criteria such as Energy supply data of energy systems, annually produced energy of energy systems, operating efficiency of energy systems, energy balance of neighbourhood and energy balance on building level. Further subsequent steps deliver concrete decisions such as selection of HVAC system, energy generator and lighting system. The result of this Use Case is the determination of the best HVAC systems, energy generators and lighting systems for the building. Figure 11 shows the relevant data, the process steps and the results of this use case.

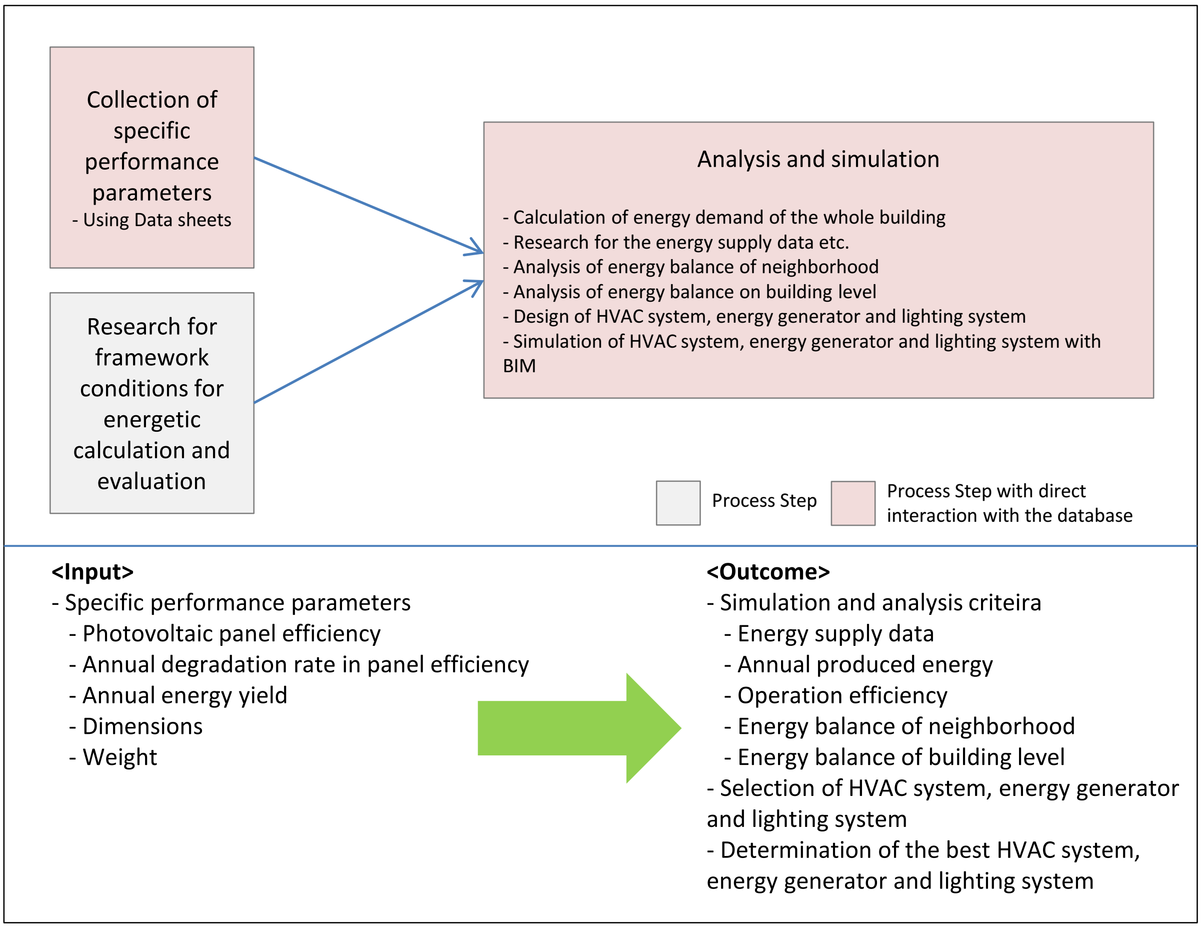


Figure 11: Detailed visualisation of Use Case 8 - Energetic calculation and evaluation of energy system technologies or products

3.3.3.2 Use Case 9: Economic evaluation of products or technologies

This Use Case describes the use of the database for a cost-benefit analysis and as a source for KPI calculation. The cost-benefit analysis can be done with the decision support tool by LU, the KPI calculation can take place by VTT's KPI tool. The stakeholders described in the following are using the database for economic evaluation of products or technologies. In the conception phase the design planner is supposed to evaluate alternative design solutions (Process step 59). He can use the database to gain the formation needed for the simulation about the alternative solutions. After finishing the simulation he can communicate the results to the architect who has to detail the architectural model (Process step 90). This action is supported by the optimized planning concept delivered by the design planner and supported by simulations based on information provided by the technology database. The architect has to do a cost evaluation of the different solutions in the planning phase (process step 63), an activity that is supported by the database which provides information for cost estimation on alternative design solutions. For this cost estimation the BIM manager has to check the plan of variants by simulation. He is supported in doing this by information provided by the technology database. Other possible uses without a direct link to a stakeholder that are supported by the database are the emission calculation for embodied CO2, external air CO2 schedule, thermal degradation of materials and systems, or utility rates and the selection of materials and walls for a building, linking of the material data with the building model, forecasting of costs and energetic properties, simulation of the building model and analysis of the energy consumption at building level.

The data that is necessary to execute the process steps described above are information about subsidies, energy related information (e.g. heating, cooling and electricity demand of the whole building) and legal limitations (e.g. permissible range of U-Values of building components). The results that are generated by the economic evaluation are the cost-benefit balance, measures of KPIs, results of economic comparison of alternative solutions, embodied CO2 and embodied CO2 schedule, thermal degradation of building components and energy systems, utility rates. Based on all this gathered and generated information, the engineer and designer is empowered to select the best fitting and performing energy system and building components for the planned building. Figure 12 shows the relevant data, the process steps and the results of this use case.

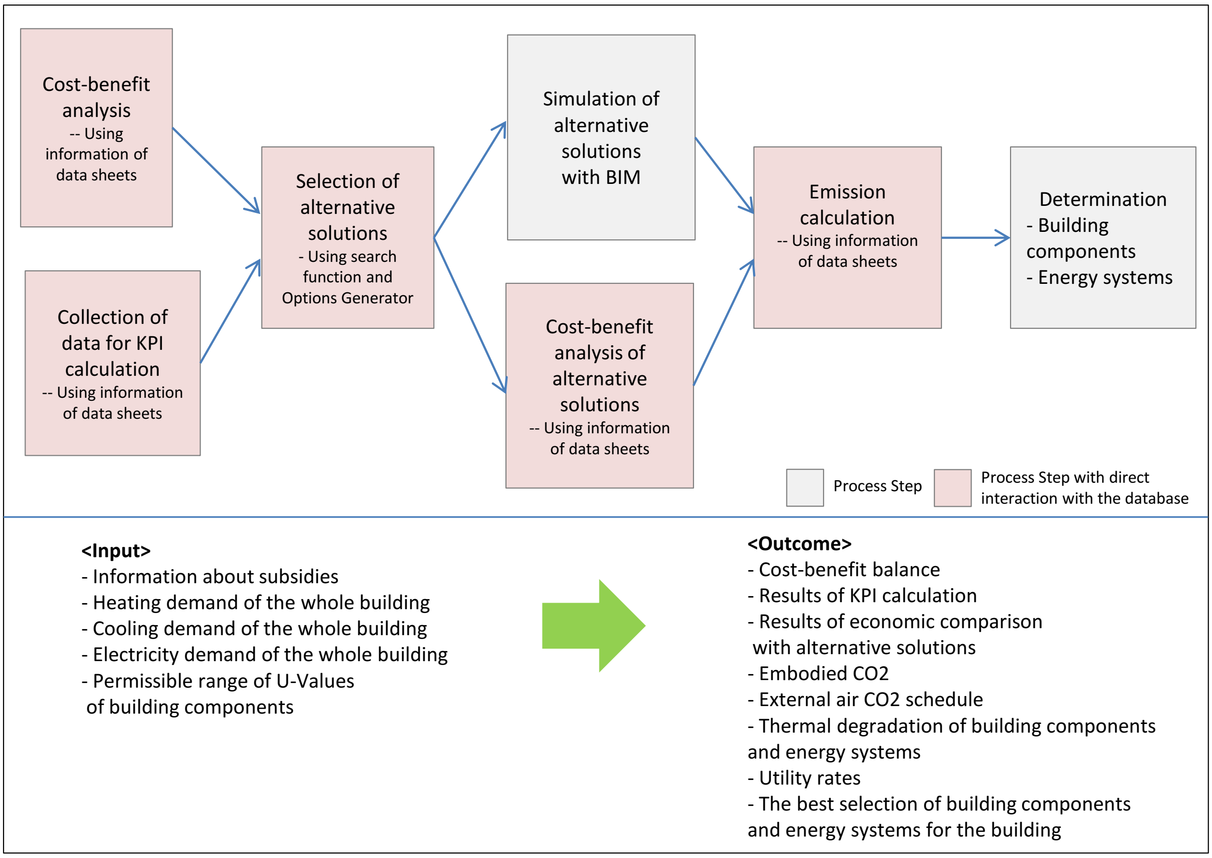


Figure 12: Detailed visualisation of Use Case 9 - Economic evaluation

3.3.3.3 Use Case 10: Design of HVAC systems

This Use Case describes the use of the data of the building components for the development and simulation of HVAC systems. Based on the simulation the design, the HVAC system can be improved and the results can be integrated into the BIM. The first step in the process of this use case is the calculation of the heating and cooling demand of the whole building. The next step is the simulation of the developed HVAC system in a model that contains the information about the building from the database. Based on the simulation of different designs of the HVAC system, the best fitting solution in terms of performance, energy efficiency and needed space can be determined. The final step is the integration of the solution that shows the best fit into the BIM. The data used to run the simulation is building based information (e.g. heating and cooling demand of the whole building, size of rooms, etc.) and component related information (e.g. u-values of building components, size of the components, etc.). The result of the process of this use case is a tailored to fit the HVAC system that shows the best efficiency possible for the designed building in relation to cost and energetic properties for the building. Figure 13 shows the relevant data, the process steps and the results of this use case.

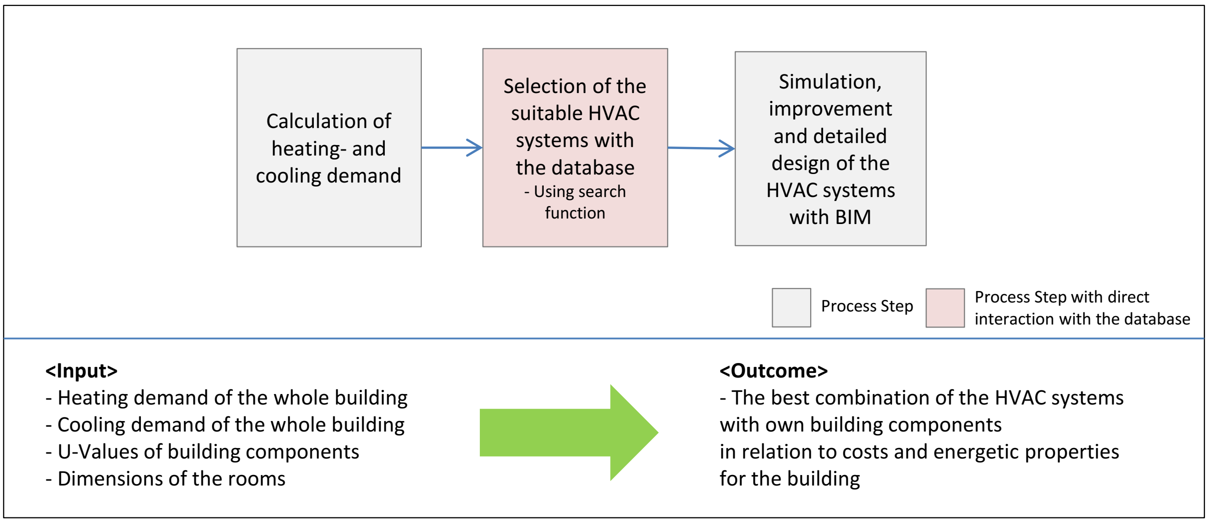


Figure 13: Detailed visualisation of Use Case 10 - Design of HVAC systems

4. Feedback and Evaluation

This chapter deals with the evaluation of the technology database. The feedback from user tests and interviews are summarized; the technical as well as processual performance of the database system is discussed in terms of the main requirement clusters. Especially the practical user tests lead to implications in usability improvements and bug fixing.

4.1 Feedback from Application Users

This testing part was conducted through practical testing based on tasks the users were given.

The sources for user feedback are twofold. Firstly, architects, engineers and energy experts within the consortium gave frequent and direct feedback throughout the project and development phase. Secondly, to reach the relevant stakeholders for testing and validation along the value chain and to gain feedback from user tests most efficiently the potential users were confronted at several occasions such as conferences and other dissemination events. After testing the users were anonymously asked in an interview specifically on the aspects listed in Table 2. In total about 11 tests with interviews from project-external stakeholders could be achieved. The internal feedback is then included in the results.

The following Table 2 gives an overview on the resulting evaluation of technical functionalities of the technology database.

Technical functions	**Relevance (0 to 4) and fulfilment of results (0 not fulfilled - 4 excellently fulfilled)**				
	0	**1**	**2**	**3**	**4**
Register on the platform					X
Create user profile					X
Create a new, searchable energy system technology with the researched data				X	
Perform search for function-based technology application cases by the given requirements				X	
Perform search for technologies with given performance demand					X
Review the database for technologies, components or buildings					X
Support of the cost simulation			X		
Dynamic, multifactor visualization for decision making			X		
Interfaces for authoring tools			X		
Guidance in the graphical user interface and design				X	
User rights					X
Security				X	
Automated generation of simulatable gbXML-files					X

Classification of building components					X
File repository for components				X	
Methodology of technology management in construction industry					X

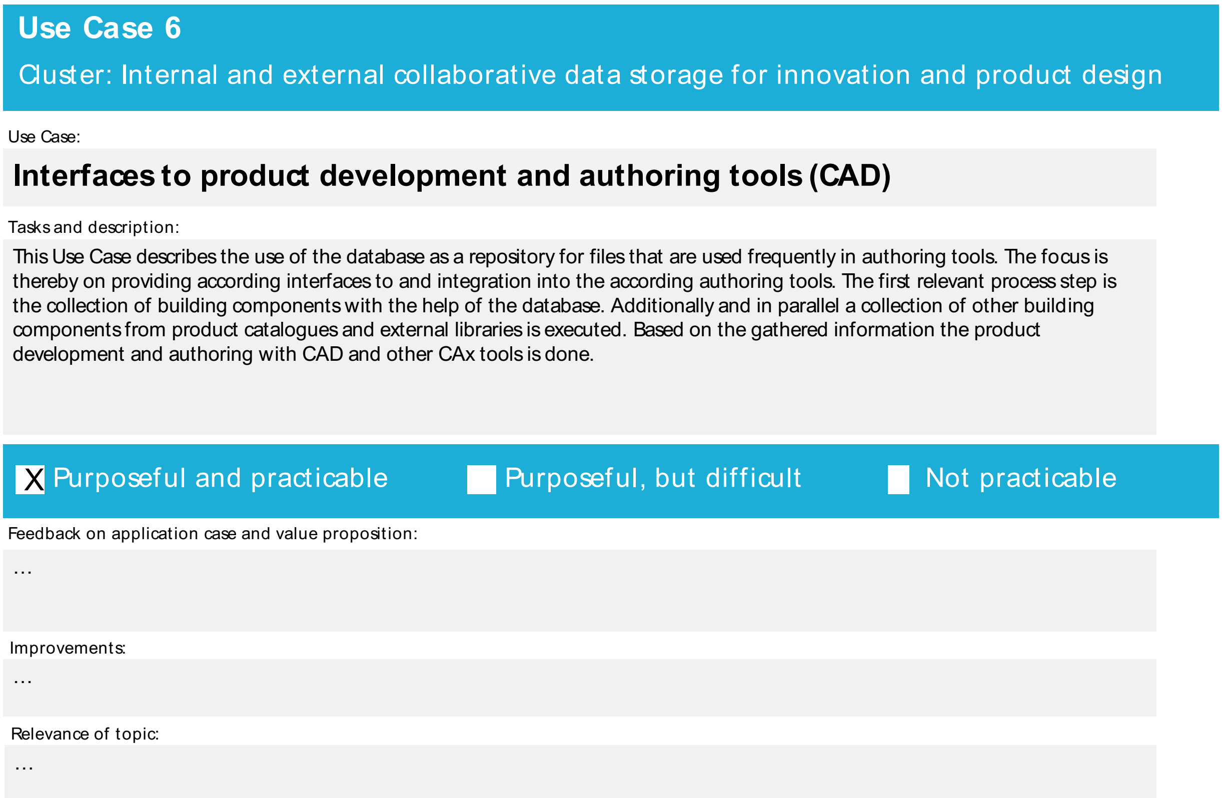
Table 2: Evaluation of technical functions

More detailed descriptions of improvements of the technical implementation can be taken from chapter 4.3.

4.2 Feedback from Use Case Evaluations

The test scenarios are split into the three clusters and ten use cases as described in the previous chapter. The following Table 3 gives an overview on the resulting evaluation of the use cases.

For the use case evaluation, next to the feedback from project partners, additional five interviews with external engineers and architects were conducted. Therefor the following interview structure was derived from the use case descriptions in chapter 3.3 and used as seen in Figure 14. The evaluation is the average of the user feedback.



Use Case 6

Cluster: Internal and external collaborative data storage for innovation and product design

Use Case:

Interfaces to product development and authoring tools (CAD)

Tasks and description:

This Use Case describes the use of the database as a repository for files that are used frequently in authoring tools. The focus is thereby on providing according interfaces to and integration into the according authoring tools. The first relevant process step is the collection of building components with the help of the database. Additionally and in parallel a collection of other building components from product catalogues and external libraries is executed. Based on the gathered information the product development and authoring with CAD and other CAx tools is done.

X Purposeful and practicable ☐ Purposeful, but difficult ☐ Not practicable

Feedback on application case and value proposition:

…

Improvements:

…

Relevance of topic:

…

Figure 14: Structure for interviews, examplary use case 6

The main issues why use cases failed to work without problems are the difficult capture of reality and realistic circumstances. A manufacturer and expert management is a very important task of e.g. an HVAC engineer. However the characteristic of the construction industry is the changing constellation of stakeholders, project participants and manufacturers. The decisive factor is the tendering phase. Due to this varying project constellation, technology providers have to be estimated newly and data and information about used technologies have to be investigated as if for the first time.

Use Case			**Evaluation**		
No.	**Name**	**Description**	**Useful and feasible**	**Useful, but difficult to implement**	**Not practical**
1	Technology adaption	For communication, development, as innovation source	X		
2	Strategic decision support	Technology monitoring		X	
3	Technology sourcing	Manufacturer and expert management		X	
4	Technology configuration	Determination of requirements of delivery objects		X	
5	Selection of building components	Determination of energy solutions and building components		X	
6	Product development	Interfaces to product development and authoring tools (CAD)	X		
7	Customer integration	Common repository with customers or partners	X		
8	Energetic calculation	Support for energetic calculation and evaluation of energy system technologies or products		X	
9	Economic evaluation	Economic evaluation of products or technologies		X	
10	Design of HVAC systems	Export of simulatable standard files	X		

Table 3: Evaluation of Use Cases

More detailed descriptions of improvements of the technical implementation can be taken from chapter 4.3.

In general the TechDB is considered a very useful concept especially by Engineers. What is frequently emphasized is the integrated way of managing data and information streams in the early design phases. This refers to the integration of further tools, CAD data, performance data and the support of decision methodologies.

4.3 Implementation of Improvements, Suggestions and Bug Fixing

This chapter gives a short overview of the problematic areas in bug fixing, improvements in usability and functionality and suggestions for further implementations.

Improvements for building databases

The market offers for components libraries are numerous. However, little or none fulfil the requirements of current BIM engineers. Big challenges have to do with the quality of built components. Success factors are the built quality, completeness of additional parameters and parametrization. This is especially important for the fast and IT-supported design process and furthermore for reliable simulation.

Deeper technical integration

An important success factor of integrating data into the workflow of engineers and designers is the deep integration into the used design tools. Interfaces should not only exist on the side of the database but as a plugin, e.g. in Revit, which is the design tool mainly discussed in this project.

In terms of feasibility and due to distributed development of the platform, more than two different web application technologies are used to create the technology database in D4E project. The use of different interfaces was criticised to be lowering the user friendliness.

Open source-readiness

Open source characteristics are frequently mentioned requirements by engineers and IT developers. A major reason why the TechDB web technologies were used for the project is open source availability. It is the aspiration and demand of the project to produce output that can be used and further developed by an open source community. The coding guidelines for platform extensions demand a certain methodology and structure of the implemented modules. In order to fulfil this, the implemented code has to be cleaned up in terms of implementation logic and documentation. Further functionalities have to be transferred that are implemented into external web application technologies. Also the implemented code has to be adapted to the latest platform version.

Energy Systems in simulation through gbXML

There is a big research field that deals with the simulation of energy systems. The data is provided in the developments in this project. However, further work could provide better support for generating machine compatible file output for the simulation of energy systems. Generating a new file type and integrating it over diverse software tools were a challenge common to the business of data standardization. However, the creation of gbXML components showed big interest among engineers due to a simple, understandable and fast creatable file type that could help with problems in the area of integrating CAD systems to simulation tools.

Interconnection for technology configuration

The technology database provides as solid set of demonstration technologies. In terms of further cultivation of the data, more intelligence can be provided to analyse the technology performances.

Advanced functionalities for user rights

The current version of the database provides a sophisticated management for user rights adapted to the needs of the roles in the construction industry. However it is required to develop towards an easier configuration of the company specific user management. The intended functionalities demand higher security standards. This is especially valid for a commonly built up component library among different companies. This is a higher demand than provided by a common, open source web platform.

Application interfaces as a challenge

The technology database depends on an open source platform, which can be used, maintained and further developed by an open source community. This platform has predefined data types and MySQL data tables. In some cases especially regarding the interface between the media wiki and the gbXML-creator some additional value checker functionality could bring an added value.

4.4 Review and evaluation of the tools for decision support and generation of retrofit alternatives

To review and evaluate the set of tools for decision support and generation of retrofit alternatives, a focus can be made on at least four aspects. If, compared to conventional practices how is the architect's creativity affected; how reliable is the outcome in relation to the input information; to what degree are user requirements taken into consideration; and how friendly are the tools to the end user? More details are provided in the following.

4.4.1 Architecture creativity

Formerly, building design was a more stable practice that evolved slowly, with each new building slightly modifying previous versions. The prevailing creative part of the general design process was often considered to be one without methodology, but an intuitive mechanism of "learning by doing" that could not be explained in words.

For the thermal energy analysis, defining relations between rooms and building elements by using space boundaries that are needed to ensure water-proof space enclosure which is essential for a correct computational thermal model, too. Therefore, once a need for improvement is confirmed the geometry of the building is often altered. In retrofitting, there is an element of disturbance to the architectural aspects; therefore the intuitive creativity of architects needs to be preserved while an automated decision support tool is employed.

4.4.2 Quality and quantity of data in database

The decision support tool, together with the option generator, need to rely on a dynamic and rich database. The quality of the decision is dependent of the quality and size of the database. Therefore, one can evaluate the performance of both tools from the information type, quality and size in the database.

4.4.3 Satisfying user requirements and building occupants

Furthermore, it is questionable how much the taken decision does satisfy the target sets by the owner and designers. The optimisation for a best solution is more or less mechanical taking into account both the desires of the building owner and occupants as well as the designer and complying with benchmarks. This often leads to making compromises, which otherwise in conventional practices could be compromised to deliver to a higher degree the occupants' proposed targets.

4.4.4 User friendliness

The database supports the decision support tool in a prototype version. Therefor the option generator is designed for functionality rather than to user friendliness. As it is the design package is less attractive and easy to use by designers and architects. More work is needed at the D4E platform to ensure the end user will appreciate the potential of the tools and make good use of it.

5. CONCLUSIONS

Feedback from the technical evaluation shows important challenges in the implementation of technology databases as well as the major merit of it. New versions based on the findings, feedback and improvements of this report, and further more mature concepts will lead to highly valuable and applicable technology databases that improve the design process of buildings many times over.

The focus of the TechDB was to demonstrate the possibilities of new data models and design processes, which it fulfilled greatly. However, to really go into depth with technical functionalities and integration in other tools is a big new field for futures efforts. On this way many practical issues of engineers and architects were discovered and help to design technology database in big steps.

Also the industrial exploitability of the results came clear. The technology database of this report has 3 main applications. The first application is technology management which helps companies to obtain the company specific knowledge base for the selection and application of new technologies. It enables companies to identify and evaluate technologies at the early stage, decide strategic on technologies and it also helps to decide on the best manufacturers, experts and research partners. Secondly, the technology database makes a contribution to the internal and external collaborative data storage for innovation and product design. With this application, companies are able to decide on building components and energy systems regarding to energy efficiency, and it enables companies to share, discuss and review data with customers and partners. Finally, the technology database plays a role as data storage and interface for analysis and decision support tools. This application helps companies to calculate costs and emission, to analyse cost and benefit and to simulate alternative solutions.

The results of the evaluation of the database based on the test cases and interviews have shown significant value for the architectural, structural and methodological design of the companies' technological knowledge and therefor the design process. The valid design requirements according to the concrete use cases enable companies to build a robust information management with data consistency. It helps companies to make a strategic decision and aims to show the success factors for a dynamic and reliable database. It is also an important value of the database to assist analysis and simulation for the whole building and to integrate the results.

6. Acronyms and terms

API .... Application program interface
BIM .... Building Information Modelling
CAD .... Computer-aided design
COP .... Coefficient of Performance
CSV .... Comma-separated values
D4E Desgn4Energy
DB .... Data base
DHW .... Domestic Hot Water
gbXML .... Green Building XML
HTTP .... Hypertext Transfer Protocol
HVAC Desgn4Energy
IAI .... International Alliance for Interoperability
IAQ .... Indoor Air Quality
IFC .... Industry Foundation Classes
ISO .... International Organization for Standardization
LCC .... Life cycle costs
MEP .... Database
OWL .... Web Ontology Language
PV .... Photovoltaic
RDF .... Resource Description Framework
REST .... Representational state transfer
SMW .... Semantic MediaWiki
SOAP .... Simple object access protocol
TechDB .... Technology Database
W3C .... World Wide Web Consortium
XML .... Extensible Mark-up Language

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