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Sustainable building information modeling in the context of model-based integral planning

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Abstract. Solving complex issues of energy-efficiency – at the building as well as urban level – requires a holistic, integrated approach. The energetic behavior of a system should not only be considered in individual processes or phases, such as operation. A holistic optimization should rather consider the explicit energy flows as well as the material fluxes including the associated gray energies over the entire system life cycle. The realization of such a holistic integral planning process implies an integrated planning-accompanying evaluation and optimization of the planned object. The early use of LCA tools and sustainable building assessment systems (SBA) provides an important basis for assessing planning decisions at a conceptual level for their impact on the entire lifecycle of a building and for ensuring good sustainability performance.

In practice, however, it is currently evident that the non-standardized and inadequate connection of simulation and balancing tools (e.g. LCA) to BIM authoring tools and the resulting high time expenditure for data acquisition and LCA application counteracts with a targeted stronger penetration of the market.

For realizing a consistent integral planning process – especially in early planning phases – an IFC-based interface is being developed for the connection of LCA tools to BIM models (data input) and the preparation and configuration of the LCA result data for the designated use in different SBA. In this contribution, from the interface specifications for different levels of granularity and concretization in the different planning phases that are developed by means of norm-based processes of model standardization in an underlying research project, parts regarding the early project stages will be presented.

1. Introduction

In the field of sustainable building measurable ideas have grown up in recent years that enable a viewpoint shift by taking into account holistic lifecycle-oriented assessments of the environmental impacts of a building. Up to now the provided sustainable building assessment (SBA) systems are only used after the building is realized. Thus, great potential for optimized sustainable building design lies in the possibility to shift SBA alongside with accompanying tools as f.i. lifecycle assessment (LCA) upstream in the planning process. By showing to the decision maker and designer the consequences of their design decisions the environmental performance of the later building can be significantly enhanced.



Within the framework of a research project the question is pursued of how this can be achieved with regard to design methodology. Here, as a starting point a holistic phase model was developed for an integrated planning approach that is required for solving complex questions regarding energy efficiency and sustainability of buildings [3]. Rather than examining the energetic performance of the system in single phases only (e.g. use and operating phase), for an overall optimization all flows of explicit energy and matter together with the respective grey energy throughout the lifecycle have to be taken into consideration. In turn, a holistically integrated planning process implies a consistent accompanying evaluation and optimization of the planned object. Early application of lifecycle and sustainability assessment tools in the process constitutes an important basis in order to support decision making already during the first development of concepts for the building.

In the core of the approach stands the provision of a process-accompanying data basis for building information as needed for respective LCA. To facilitate a dynamic concretization of the building information consistently through the design process, a systematic has been developed for a gradual transformation and enrichment of an initially fuzzy and rough area-based building description towards a more and more detailed element-oriented specification (cf. fig. 1). Thus, the approach depicts multigrain information structuring for the level of development according to the project phases.

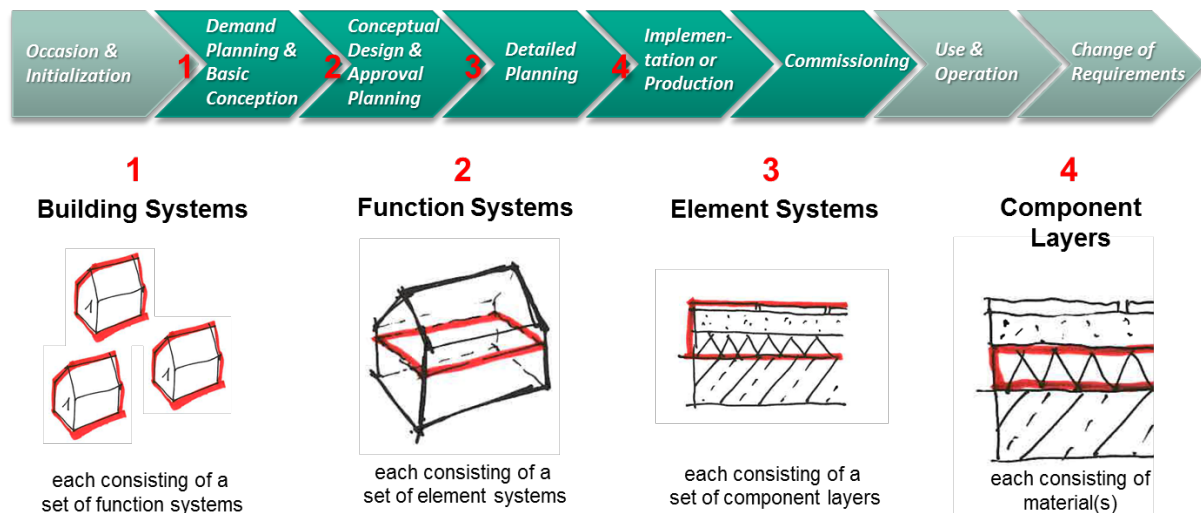


Figure 1. Multigrain information structuring approach for depicting the level of development.

At the beginning of a project, the strategic project development, a more abstract LCA-based description of targets, demands and their impacts is depicted. Successively, this building information can be enhanced to area- and shape-based descriptions, and then on to a detailed element-oriented model with references to materials and specific quantities. This granular concept will be implemented in the data model and the business logic of the IT-based tool chain from BIM to LCA and further to the SBA (c.f. [2] as well as [3]).

In this contribution we highlight norm-based methods applied in the research project in order to build a (technical) foundation regarding the data level from which shifting lifecycle and sustainability assessment tools into early planning stages can be accomplished (c.f. [1]). In order to provide model-based facility for early planning stages the information needs of two scenario-based use cases were thereby considered. As norm-based basis for specifying an appropriate data interface [4] these use cases will be presented following the short introduction to the background they are formally described in.

1.1. Foundations for norm-based generation of specific model view for sustainable building data

Within the digitalization in the field of planning and construction of the build environment a shift towards model-based methods on side of data can be observed. Thereby the established open virtual

building model standard Industry Foundation Classes (IFC) plays an important role in cooperative planning as a neutral base for BIM-based software overarching data exchange. In order to specify certain agreements toward which information has to be exchanged among partners, e.g. in the framework of Employer's Information Requirements (EIR), the model standard offers the accompanying Model View Definition (MVD) Standard. Since it is important to also clearly describe the context, namely the sender resp. receiver of the information, the exchange process and (further) considered framing conditions, (technical) MVDs are specified with regard to comprehensively compiled norm-based Information Delivery Manuals (IDM).

Beside an introductory part, IDMs basically consist of two parts of definition. Process-related depictions of the exchange scenario are compiled on the basis of the Business Process Management Notation (BPMN). In this first part concerning the process diagrams the indication of where the information is to be exchanged (data transfer point) between which stakeholder is important. To each of the thereby indicated transfer points corresponding tables containing the respective one by one information demands have to be prepared in the second part of the IDM.

2. First Use Case: Assessment in Phase 1

The use case regards to sustainable building aspects as well as outlining respective coarse targets in an initial design brief prior to starting a respective project. In a first subchapter the side of process is introduced that is situated in the first phase of an underlying phase model [3] Here, actors and their specific parts in the (data) exchange are elaborated. In the following subchapter the corresponding data structures and contents regarding the data transfer points that are stated in the process are described.

2.1. Initialization phase: sustainability target corridor as part of project inspiration

A so called (initial) "design brief" document facilitates the initial information regarding sustainability in this use case. Within the document different aspects of the project to-be-initialized are compiled in a balanced way. As explicit ground work, it summarizes all initial ideas that were made in the first phase and supports the main decisions at the end of the phase – whether or not to pursue a project (and successively realize the building). If moved on from here, the initial design brief besides a documented decision support can set a first guideline on project generation and on what to (in a coarse manner) consider for this.

Fig. 2 shows a generic process of compiling the contents for the initial design brief exemplarily on behalf of the consideration of sustainability aspects. As with every thematic field that is entered into the design brief, the starting point is within the role of the initiator. This role will then finally – if all themes have been iteratively weighed carefully against each other – consume the resulting design brief alternatives as a basis of the decision making. Thus, finally one alternative with which to move on with a respective project is chosen (cf. "swim lane" at the top of fig. 2). At the beginning of each thematic field more or less information exists on side of the initiator. For the field of sustainable buildings a first set of requirements could be the basis of a first discussion with a sustainability advisor consulted by the initiator, such as coarse information on function/usage and ideas on building dimensions. Besides reiterating these initial set of requirements in terms of whether they are sufficient (or can be reduced already), the outcome of the consultation could be a task for the advisor to fix alternative inputs to the design brief. These could be based on broadly discussed alternate sustainability objectives for the project that are illustrated by the consultant on behalf of sample buildings to the initiator. Samples are thereby chosen from a benchmark database by taking into account the initially outlining requirements together with first coarse targets, e.g. a high energy standard. With these more or less structured inputs the consultant can now prepare a first set of exemplary sustainable objectives pointing to respective benchmarks or existing sample buildings that frame alternative archways of how to include sustainable aspects in the framework of the aspired project. The iterative process for generating these alternative target sustainability corridors as input to an structured BIM-based design brief is shown as interaction of the middle (executive role) and the bottom (operative role) swim lanes in figure 2. In the lane between them the data transfer points are

defined where the model-based information firstly handed over to an actor in the LCA domain containing characteristics to the aspired project as well as specifier to different sustainability objectives. Secondly, after these incoming model-based information has been used to enhance the model with respective LCA-specific data in the bottom lane, it is handed back featuring the alternatives. The received models from the expert side can now be checked whether they are complete (and if not reiterated to the expert for completion) and finally, decorated with additional information characterizing them as parts of a design brief regarding sustainability, handed over to the initially requesting role of the initiator. With a decision for one of the handed in alternatives and merging its contents in the general BIM-based design brief the initiator finishes this process.

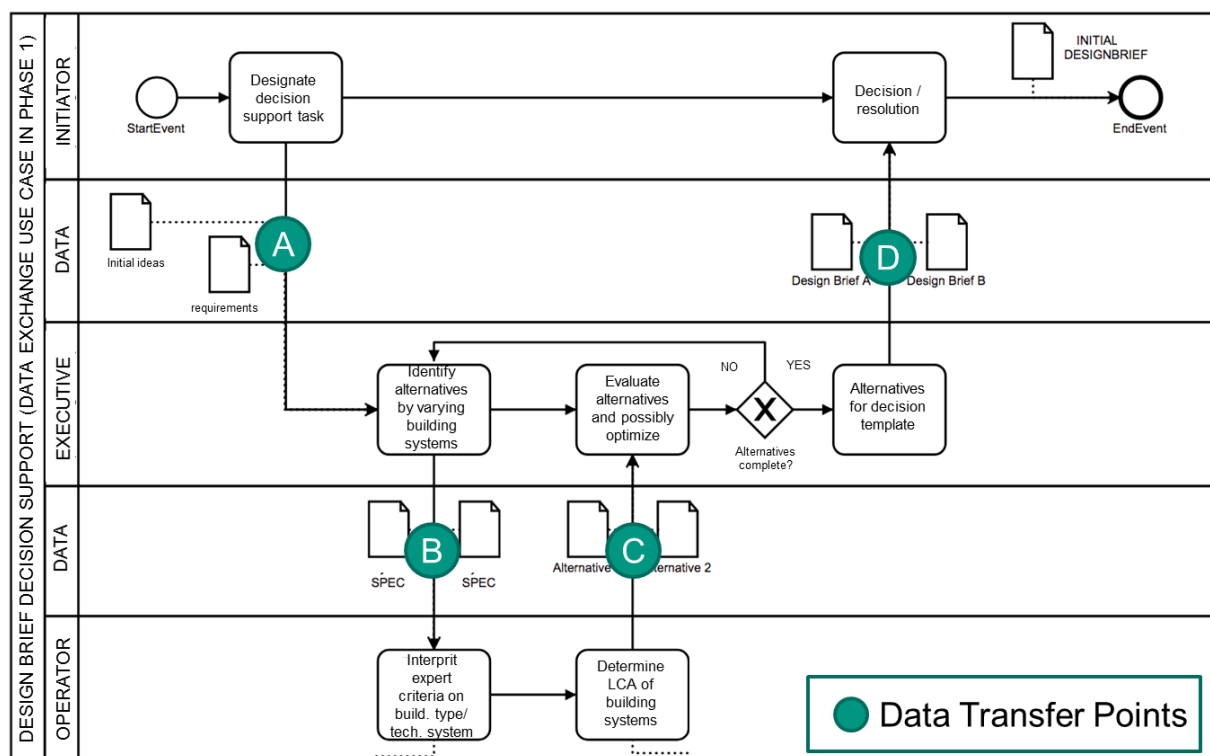


Figure 2. BPMN process map depicting a use case in the first phase.

2.2. Proposed data set of a BIM-based design brief

Different data might stand at the beginning of the above described process. The spectrum can range from a napkin with pinned down initial thoughts for a project up to (ideally) a well formed data base containing BIM-based design briefs of already realized buildings from which a template can be chosen. However, with the first (structured) data exchange between the executive role and the operative role (cf. fourth swim lane) a BIM-based model as structural base of the exchanged information is obligatory in the scenario set up. For the information systematic regarding concretization and maturity of the planned object (already published in the research project framework cf. fig. 1 and [2]), an instance of the class *IfcProject* with connected instance(s) of the class *IfcBuilding* builds the proposed base for depicting the most coarse representation stage of a „building system“.

Data transfer point A – At this very early stage – prior to the manifestation of a project – especially the knowledge on sustainability on side of the initiator marks the deepness and granularity of respective involved information. For example, if the potential builder is completely new to the matter of sustainable building on the one hand side some exemplary buildings as whole (building system) where f.i. the focus is set to achieving a similar environmental performance of the hull can be

feasible. Whereas on the other hand side an experienced builder might go much more into detail f.i. using benchmarked values of built samples to define concrete to be achieved boundaries while setting the outlines of his sustainability targets. Here, an example for such a systematic approach can be seen in the holistic system of Leitfaden Nachhaltiges Bauen/BNB. Although it is not obligatory yet, the early assessment of how to achieve to the most extend a sustainable building its guidelines advises the public builders to take into account can be seen as first step to respective required early goal setting.

Since the data involved in this stage is mostly generic, its central depiction concept is a linked data approach. Instead of adding information directly to these early BIM model instances, they are held as web based catalogs where the data can be referenced multiple times by respective references. In order to prepare the model instance with coarse characteristics (cf. above process description) as well as further specification of an initial target direction, e.g. by pointing out an energetic standard to be achieved, firstly the created building object is extended with a set of properties called „Sustainability benchmarks“. In this, properties can be added with a respective URL based catalogs referencing. By doing this for the added building object, all input information needed for the side of the LCA expert is already prepared. In order to precisely specify further objectives on the prepared building instance another property set “Sustainability target” can be added to the project object. Here, the specific objectives are then specified, f.i. „at least hull performance of sample building 1 and performance of technical system of building sample 2“ or „performance shall lay with in the average of building type 1 and type 2“.

Data transfer point B – By following the catalog references given in the handed-in model the expert gathers the arguments for filtering his data base. The results are then added to the corresponding building objects by extending them with a property that holds the respective value. Thereby, if the environmental performance data as CO₂ equivalent value that is filtered by the arguments given in the adjunct property set shall regard to the average of all buildings that meet the criteria instead of only one single sample building this has been indicated in the building object by setting its attribute „CompositionType“ to “COMPLEX” (as opposed to “ELEMENT” that regards to a single building).

Data transfer point C – The model-based data returned by the expert now holds the requested LCA-information, which can be checked whether it completely covers the requested sample/benchmark data. Now, by further specifying sustainability aspects through f.i. a range that is depicted by referencing the environmental impact of the hull of two returned example buildings, the advisor in the executive role can prepare the alternatives that he had earlier discussed with clients. By adding this information to different model files, explicit variants of target corridors can be specified as a decision basis.

Data transfer point D – Thus, the underlying alternative LCA-parts of a designated design brief model is finally handed back to the initiator. Here, the decision is supported by consuming the model-based information, by e.g. generating tables from its contents to visually compare the received alternatives that can also finally be used to explain in a transparent way the chosen variant. Through its standard-based depiction the chosen alternative design brief builds the (referenceable) root instance for a BIM-based data handling in the to be initialized project.

3. Second Use Case: Assessment in Phase 2

Thematically the use case regards to an implementation road map for the sustainability targets on behalf of respective project objectives. Thereby, compiling sets of strategic functional systems stands at the core of the road maps. In the first subchapter the side of process is described. The use case is situated at the end of the second phase „initialization and basic concept“ (cf. fig.1, Rexroth 2018). Here, it marks the final stage of the phase in which a respective project has been initialized by assessing and compiling the core requirements as a basis of decision whether all parts of the project are checked in terms of investment security. For this on side of data a derived set of evaluated objectives regarding sustainable building that is carefully considered in a basic concept can build a frame for the design task to be delegated to a respective planning team.

3.1. Requirements planning and basic design: support for investment security

The process shown for the previous phase involved an actor in the role of an initiator (usually a builder, or a resp. department of an institutional investment organization) that decided to move on and initialize a project on behalf of first ideas that were compiled in the frame of a model-based design brief (cf. chapt. 2). As input to the following phase, the design brief can help to set up the framework for initialization of the project e.g. by the designation of a suitable planning team to develop the design. Especially as a guideline to discussions on sustainability aspects in the requirements planning, it can thereby help to explicitly form concrete objectives derived within the initially set target corridor.

Instead of directly placing the followingly described use case at beginning of the second phase and use the design brief as direct input it was intentionally shifted to the end of the phase. By doing this the manifold and therefore difficult to generalize possible ways of how these concrete objectives are formed in different situations can be better taken into account. The end of the second phase is thereby determined by the process of the builder who wants to assure prior to kick starting the project that all contents have been carefully considered in a comprehensive investment security effort. Thus, before delegating the design to designated planners, this common decision situation is given where it should be decided upon whether all requirements of the potential builder are (explicitly) determined and respective investments are safeguarded.

Regarding the sustainability objectives within these requirements the process depicted in figure 3 shows a possible involvement of an respective sustainability advisor. After the conclusion of all requirements from the initiator the advisor is designated with the task to develop alternative setups of concrete sustainability objectives. Each of them should thereby be bound in a basic implementation concept that sets a (feasible) road map on how to achieve the expressed goals during the construction of the building. Here, it is crucial to set the right anchors for achieving the aspired sustainable building quality in order to e.g. get a specific SBA label as needed for a designated added value when placing the building in the market. Therefore, in this context the initiator delegates the task of offering alternatives on how to explicitly set project objectives regarding the building sustainability within the tender terms for respective design work to an advisor. Placed in this decision situation of the initiator, who is advised with alternative strategies that help him safeguarding his investments (cf. top process swim lane in process map), the subprocess of data exchange is furthermore embedded between the sustainability advisor and an expert LCA discipline (cf. swim lanes in the middle as well as the bottom).

Although it is not obligatory that the advisor as an input to his task of preparing the alternatives is handed over already structured (model-based) data, in an ideal case the initial design brief is at least given to build up upon in order to continually update the data in context of the project in a holistic manner. By having this single source of truth in a singleton document also all data at the basis of decisions along the lifecycle of the building can be process-accompanying captured. However, for the requirement-driven planning concerning the sustainability objectives the advisor prepares an according requirements model as a basis of the information on the environmental impact to be added. Since at this stage only coarse information is given, the modeling effort focusses on strategic building components. These are the parts of the building depicted by so called “functional systems” in the framework of the systematic on step-wise concretization of the planned object as developed in the underlying research project (cf. fig.1). In a first step based on expert knowledge regarding which of these building components are “the most relevant ones” on behalf of the advisor’s experience alternative roadmaps are considered. For these building components as in early cost planning, e.g. based on methods like the German Baukostenindex (BKI), with respective functional systems provided as items in a catalog voids of information can be filled as different kinds of construction are given based on typological data. This, together with the data that can be derived from coarse information, builds the modeling base of the requirements model. Here, for the rough information e.g. on office usage and on the coerture of the building by taking into account statistic data already default measures e.g. mean floor areas can be approximated (Rexroth Bausim 2018). In order to assess the modeled sets of (strategic) functional systems, the prepared requirement model is then in a second

step enhanced with respectively characterizing information. As an example different building elements are added to the modeled alternatives each one holding a set of characteristics, e.g. medium standard equipped wood frame light weight construction, which addresses a particular item in the catalog. This model is then handed over to the expert in the role of the operator (cf. fig.3 bottom swim lane in process map) for further detailing.

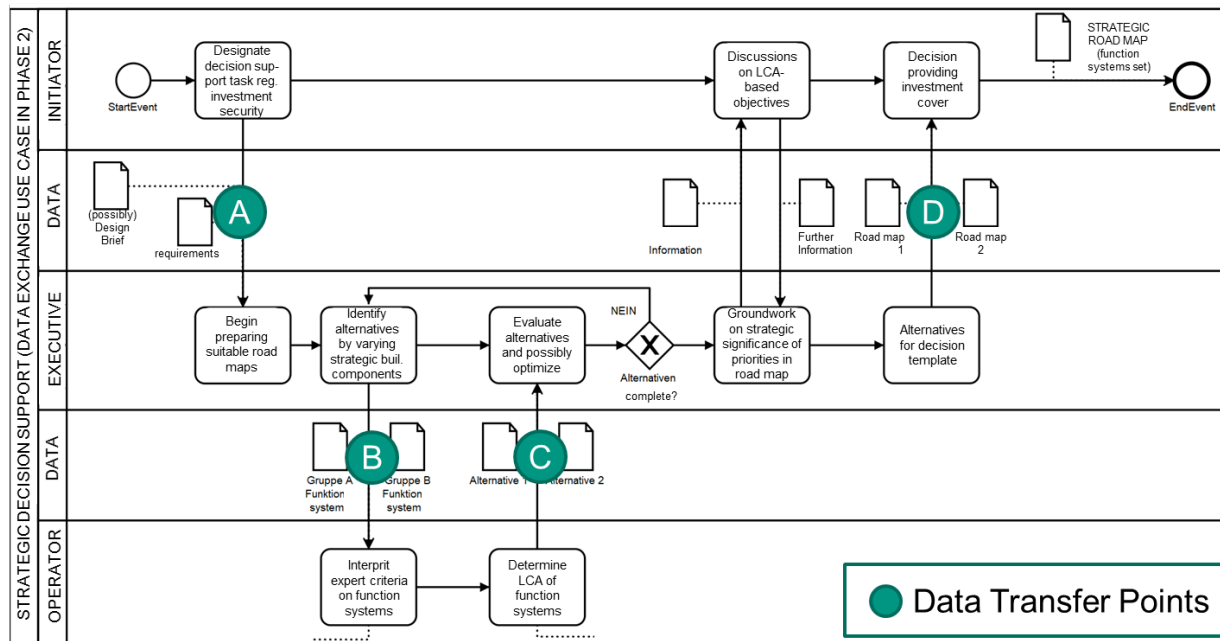


Figure 3. BPMN process map depicting a use case and data transfer points in the second phase

Once obtained the characterized model-based functional systems as well as their (approximated) measurements as an input, the environmental impacts can be added. Therefore, firstly the characteristics of each functional system of the handed in models are used to extract the according items from the catalog database. Then the required value, e.g. the environmental impact as CO₂ equivalent is calculated by taking into account other metadata like the usage that has been populated in the model. As a result, the models depicting the building requirements that have been further enhanced with the LCA-based impact information are returned to the advisor as different weighted alternatives. Here, they are checked whether they are complete and, if not, iteratively exchanged with the expert (cf. process map in fig. 3). Once the advisor approves the completeness of the prepared alternatives he can use them in further discussions with the builder about the objectives regarding sustainability to be pursued. Ultimately the alternatives are handed back to the builder that uses them as basis for his decision which strategic path to follow in the project. The chosen alternative depicting the LCA-based weighted requirements that from the view of the experienced advisor have been considered in terms of investment security can then be used downstream as basis of tender terms for respective design work.

3.2. Proposed data set for capturing the requirements planning regarding the sustainability objectives

The data exchanged in the above described process is based on IFC 4. For this a MVD is further enhanced that already contains the specification needed for the information demands regarding the first use case (cf. chapter 2.). For preparing a requirements model an instance of the class *IfcBuilding* is used. Thus, by adding a building element as complementary model for the later to be added planned object (that will reside in a separate building instance), an appropriate concept builds the base of the depiction concept for requirements information proposed in this contribution.

Data transfer point A –If an design brief was issued in the first phase (cf. chapter 2.), there has been already instantiated an enveloping project object (instance of the *IfcProject* class). This, in terms of the proposed MVD is maintained as single instance throughout the building lifecycle and can

thereby help to ensure uniqueness of all the data involved. So besides the building instance(s), that represent sample (benchmark) buildings and might have already been added as design brief to the model in the first phase, another building instance is added and characterized as requirements model. In order to accomplish a consistent data exchange throughout the following described data transfer points (as indicated in the above process), different copies of this one building are the base for differently alternatives populated within it. As the first step all meta-data regarding e.g. usage or coverage that is needed in the framework of an LCA are added to this common building object.

Data transfer point B – For the different alternatives the respective copies of the base model are added with instances of derivations of the *IfcBuildingElementType* class that represents the corresponding type for a functional system. As an example, an *IfcWallType* instance is added in order to depict all building elements of the buildings' hull. This added object is then decorated with attributes and properties that characterize it in the way it corresponds to one item in the catalog of functional systems on the side of the LCA-expert.

Data transfer point C – For each object representing a respective functional system the according characteristics are extracted from the input model and used to match the environmental impact value in the catalog. This catalog value is then aggregated to the concrete value of all respective building elements, e.g. the outer walls or the roof etc., by taking into account the meta data that is stored in the building element. Finally all building element objects are enhanced with the requested information, as e.g. their environmental impacts, in the copies of the building model that represent the alternatives. Furthermore the environmental impact of the whole building can also be added before returning the resulting models to the advisor.

Data transfer point D – By adding further arbitrary information to the LCA-weighted alternatives the advisor can document certain aspects regarding the requirements as further discussed with the initiator. These could include f.i. scheduling, implementation steps or further details, e.g. regarding materials needed to be taken into account. The final prepared IFC-based information models are then returned to the initiator. As well documented basis of his decision the chosen alternative holds all relevant data concerning the involved requirements that are depicted with strategic building elements that enable for achieving the targeted sustainable building quality. Thereby the concrete objectives for that quality are also stored as the environmental impact value of each building element.

4. Summary and outlook

In this contribution we proposed a BIM-based data handling of sustainability information in the initial stages of a construction project. In the framework of two use cases a IFC-based depiction concept was thereby presented that enables for starting with BIM already with the first ideas to a project. Here, major decision that have the greatest impacts on the sustainability of the later building are made. Thus, as also emphasized by the paradigm of integral planning the transparent depiction of all data involved in decision making at these earliest stages comes along with benefits of being able to optimize the environmental performance of the building before (design) decisions are made that hinder this in a (cost) effective way. The presented use cases with their interrelated data exchange scenario are thereby contents of an general IDM for the context of BIM and SBA. A therefore proposed MVD is being further developed in the underlying research project. Thereby following the systematic in figure 1, it will be extended with contents of the data exchange use case: design tools to LCA tools and further to SBA systems.

5. Acknowledgments

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