A framework to facilitate an interdisciplinary design process using BIM

Patricia Schneider-Marin[1] and Jimmy Abualdenien[2]

[1]Institute of Energy Efficient and Sustainable Design and Building· Technische Universität München · Arcisstr. 21 · 80333 München · E-Mail:p.schneider@tum.de
[2]Chair of Computational Modeling and Simulation · Technische Universität München · Arcisstr. 21 · 80333 München · E-Mail:jimmy.abualdenien@tum.de

A formalized building design process assumes that the design process is essentially linear with increased detailing of the design without essential changes or loops back to earlier design variants. BIM models follow this logic, i.e. they are used as if the model is increasingly detailed but not changed. However, the building design process is becoming increasingly an interdisciplinary, iterative process to account for the numerous legal and client requirements such as sustainability, fire safety, structure, etc. To facilitate this process, BIM models should include an indication of the maturity of the overall building model and the reliability of the included information.

Our work introduces the Building Development Level (BDL) concept as a measure to formalize the maturity of an entire BIM model. It is used at the beginning of the design process as a framework for the design team to define consultants' requirements on the model for analyses to be performed. The BDL structure is linked to the design process by first outlining the formalized design stages of different countries and subsequently showing how BDL provides a more precise subdivision of the traditional early design phases.

The concept is applied to a case study, showing the potential of a BIM process in combination with the BDL concept allowing for an extended analysis.

Keywords: Building Development Level (BDL), Level of Development (LOD), interdisciplinary design process, sustainable design, early design phase analysis

1 Introduction

Buildings provide us with a controlled environment where we can live and work in sheltered conditions. To construct them and the related infrastructure we use a large share of natural resources and to heat and cool indoor environments we consume unsustainable amounts of fossil fuels and and globally emit about 19 % of global greenhouse gas emissions (Lucon et al., 2014). However, there is a great potential for improvement in the building sector for more efficient use of materials and energy. To realize this potential, it is essential that building projects are diligently developed under environmental aspects in an interdisciplinary process. Especially in early planning phases designers have the opportunity to put a building project on a more environmentally friendly path, often without a long-term economic disadvantage (Schneider-Marin et al., 2019).

The introduction of Building Information Modeling (BIM) offers a chance for the building industry to enrich the design process with additional information as a basis for design decisions. The information a BIM model contains can and should be used in early design phases to analyse the design's qualities with regard to the related disciplines such as structural engineering, life cycle engineering etc. As the early design phases focus on the whole building rather than single components, the BIM model's information content that can be extracted with a defined certainty needs to be known. Currently, to define the information content of building components, the term level of development (LOD) is used. As this term should per its definition (BIMForum, 2019) not be used for the entire model, it cannot be used to define overall model requirements for analyses.

2 BIM in the design process

2.1 Formalized Definitions of the Design Process

Internationally, the Architectural Design Process is either linked to a fee structure for architects and engineers or to the respective contracts. Table 1 and table 2 show the definition of design stages in different countries. Only early design stages are listed, for this work defined to be the design stages before construction documents are prepared.

Two important facts can be seen at first glance: Firstly, a definition of the phase preceding actual design services, e.g. the definition of the general strategy of a project, is only included in the UK and in Switzerland. In other countries, architects and engineers are not involved at this stage per the official documents. In reality, there should be and often is a designer involved in the strategic definition even though fees for this work are undefined.

Table 1: Formalized early design stages of buildings 1

Country	UK	USA	Germany	Switzerland
Title	RIBA plan of work	American Institute of Architects	Scale of Fees for Services by Architects and Engineers	SIA 102: Structure for Architects' Services and Fees
Source	(Sinclair, 2013)	(AIA-TN, 2018)	(Springer, 2013)	(SIA, 2014)
Latest version	2013	no formalized version	2013	2014
Purpose	organization of building projects	defining architects' scope	defining fees	defining fees
Phase 0	Stage 0: Project Definition			Strategic Planning
Phase 1	Stage 1: Preparation and Brief	Step 1: Programming (Deciding what to build)	Service Phase 1: Basic Evaluation	Pre-Studies
Phase 2	Stage 2: Concept Design	Step 2: Schematic Design Rough Sketches	Service Phase 2: Preliminary Design	Project Development Preliminary Project
Phase 3	Stage 3: Developed Design	Step 3: Design Development	Service Phase 3: Design Draft	Project Development Building Project

Table 2: Formalized early design stages of buildings (continued)

Country	Austria	France	Belgium
Title	Fee Information Architecture	The Complete Assignment	Architect's Tasks Project Stages
Latest version	2008	2017	2017
Source	(BAIK, 2008)	(*Contrat mission complète*, 2018)	(*L'architecte et ses missions*, 2017)
Purpose	Definition of services	Definition of architects' tasks	Definition of tasks and stages
Phase 0			
Phase 1	Project Preparation	Preliminary Studies	Preliminary Studies
Phase 2	Design Phase: Preliminary Design	Pre-project Studies	Schematic Pre-project
Phase 3	Design Phase: Design Draft	(Project Studies after Construction Documents)	Detailed Pre-project

Architects therefore can be faced with a completed strategy although their input would have been valuable and could have led to a more efficient and sustainable concept. Also, information about alternative solutions considered can become lost in the process. Secondly, it is evident that the design process is divided into three stages of continuing precision. The design process per these definitions is essentially linear with increased detailing of the design without essential changes.

Generally, the official definitions are of rough granularity as they cover a wide range of project types. On the positive side, this means that there is flexibility in the exact subdivisions of the early stages of design. But this can also have the negative effect of communication problems between architects and engineers due to differing expectations as to when information has to be communicated and if it has to be final and precise.

2.2 Designing with BIM models

BIM models follow the linear logic of the design process, i.e. they are used as if the model is increasingly detailed, subsequently reaching milestones. Currently, the most common term classifying the stage of detailing is the American BIM Forum's "level of development" (LOD) (BIMForum, 2019) which indicates the level of geometric and semantic maturity of individual building components, but explicitly not the overall building maturity.

However, the building design process is becoming increasingly an interdisciplinary, iterative process to account for the numerous legal and client requirements such as energy efficiency, fire safety, structure, etc. This iterative process is not linear but involves multiple design loops, especially when requirements are contradictory, such as energy efficiency favoring a light construction for better thermal insulation versus sound proofing for which heavier construction materials would be advantageous. To arrive at the best synthesis taking into account consultants' analyses it is vital to agree on the quality of the information exchange within a team.

To facilitate this process, BIM models lack an indication of the maturity of the overall building model, describing the expected elements to be present, indicating how far design decisions are final or if the building design and its elements are still in flux and contain uncertainty. Also, project-specific flexibility and a framework for early stage analysis should be provided to allow an interdisciplinary process.

3 Building Development Levels

3.1 BDL definition

To allow for clear guidelines in early design phases and a framework for interdisciplinary design, we introduced a new concept, Building Development Level (BDL) (Abualdenien and Borrmann, 2019), to describe the overall building refinement in five levels (BDL 1 - 5), as can be seen in figure 1. BDLs subdivide the design process into intermediate stages with BDL 2 and 3 allowing for a two-stage analysis and decision process during the preliminary conceptual design, and BDL 4 and 5 during the more developed draft design. The exact information content and related design vagueness can be varied between projects and should be agreed on as part of the project definition at the very beginning of the design process.

Overall, the BDL concept provides a framework for consultants to communicate their requirements for analysis and the exactness of the results of analyses, thereby facilitating communication between architects and engineers.

3.2 BDL in the interdisciplinary process

The interdisciplinary process relies on close communication between architects and engineers to enhance design concepts by engineering input and vice versa (König et al., 2009). In order to arrive at sustainable design solutions, consultants in various fields provide their expertise. This expertise needs to be coordinated in such a way that input is dealt with simultaneously and not one after another as a linear design process would imply. Otherwise it could happen that decisions are based on one field that would be very unfavorable from another standpoint. For example, the structural engineer's analysis might advise for concrete to be used as a structural material for exterior walls whereas the energy consultant favors a curtain wall to avoid thermal bridges and provide flexibility for the size and position of openings. Both analyses happen at BDL 3 after the general volume has been agreed on and the advantages and disadvantages of each solution can be evaluated.

The BDL provides some room for flexibility tailored to the individual project. For example, the legal framework often asks for a certain number of car parking places. If the site is easily large enough to provide these above ground, the detailing of the site around the building can be decided on in BDL 4 or 5. Otherwise, underground parking or a layout of the parking lot needs to be included at BDL 2 as it influences the shape of the building. Another example is the presence of development plans asking for certain materials or finishes. In one past case study (Lang and Schneider, 2017), the development plan required plaster finish of the facades, therefore starting from BDL 1 the exterior walls already included this information.

4 Application

4.1 The sample project

Our sample project is the FTmehrHaus of Ferdinand Tausendpfund GmbH in Regensburg, Bavaria. It is a three-storey office building on a large site that houses also the company's building material storage. Despite the size of the site, only a small choice of buildable area was available for the office building because of logistics and parking requirements. There were also floor area and cost requirements and the idea to test different exterior wall materials on the project.

As shown in figure 1, multiple design variants are explored during each of the design stages and evaluated to support making informed decisions towards the design intentions. Accordingly, as the project goal is to develop a sustainable building, life cycle assessment (LCA) was performed in conjunction with energy and structural calculations and fire safety considerations to evaluate the variants. The decisions taken in each BDL are taken into consideration and preserved for the subsequent BDL.

4.2 BDL in the design process

In the process leading to the completion of BDL 1, the consultants receive information about the site, the functions and floor area of the building, the building footprint and legal and client requirements. In turn, they complete the requirement set, e.g. the energy consultant works with the client to agree on a desired energy standard, the fire safety consultant adds performance criteria and the life cycle engineer provides his evaluation framework and goals, in our case to minimize the use of non-renewable primary energy and greenhouse gas emissions.

To arrive at a model of BDL 2, several variants investigating possible building volumes are generated. All are checked for compliance with the BDL 1 information, e.g. the gross floor area or the building footprint. To consider these variants for analysis, they have to comply with the BDL 2 geometry and information requirements: To perform an energy analysis they contain all exterior surfaces (at a defined vagueness) and interior zoning. In addition to this information, the life cycle engineer needs the energy engineer consultant's output and information about the general material concept. The fire safety consultant provides information about the respective building classes based on the building's volume and use information. The analyses are performed based on the provided BDL 2 models and provide a basis for decisions. Here, the most compact shape is chosen, as it provides the best energy and life cycle performance and is of building class 3, having less strict fire safety requirements. This decision is stored and the respective BDL 2 model is used for further detailing.

Starting from this BDL 2 model, variants for floor plates and internal space configurations are added, such that also a structural analysis is enabled. The structural engineer provides several options for each variant, which are then evaluated by the other consultants. Following the BDL concept enables this process to happen smoothly, as it is clear that only the additional information needs to be considered, such as the position of interior structural elements, e.g. floor slabs, walls, columns.

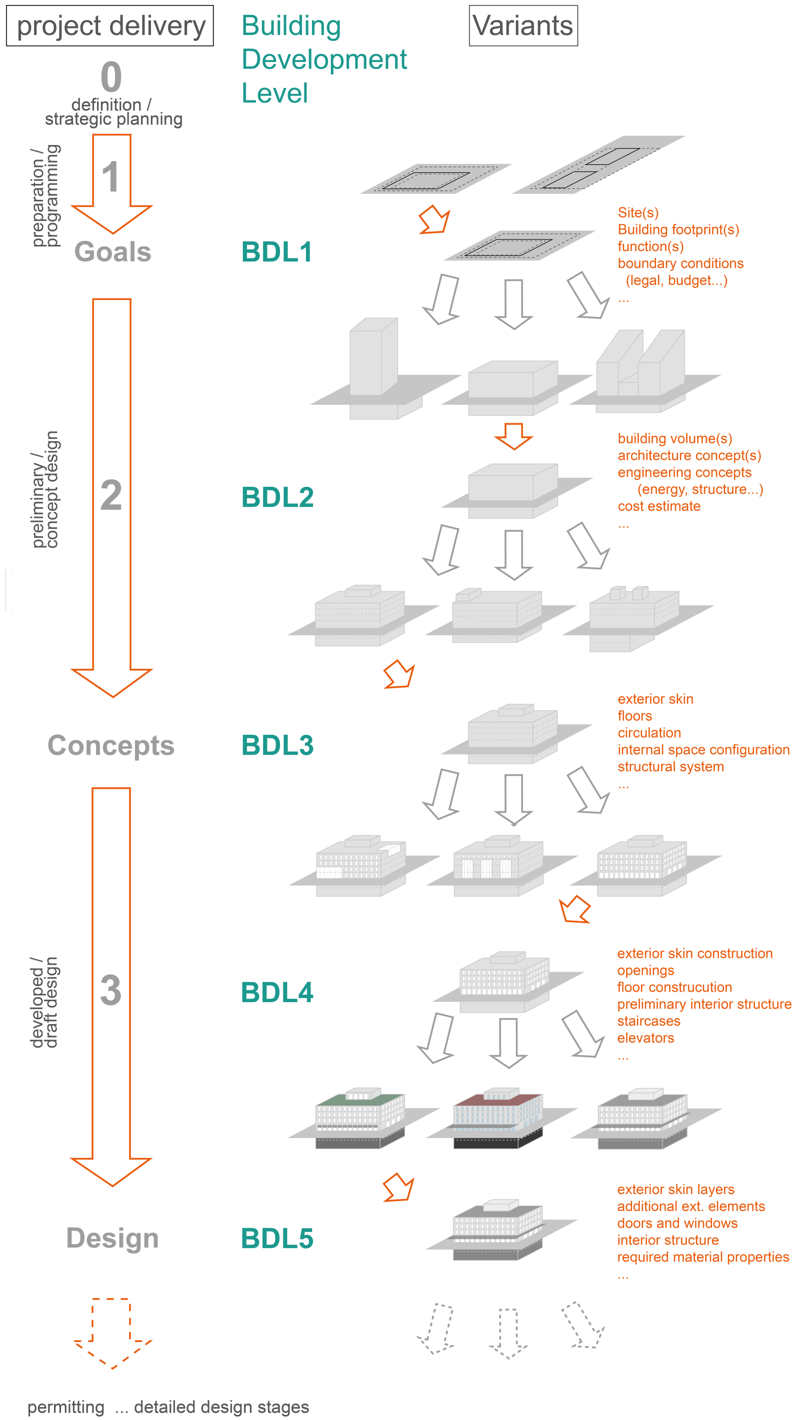

Figure 1: Project delivery and BDL

Compliance with the BDL 2 model entails the interior space configuration to reflect the zoning from the previous phase. If these do not match, the BDL 2 model has to be reconsidered. In reality, this happens frequently and is part of the nature of an interdisciplinary design process. The advantage of using the BDL concept is that these loops happen at the earliest possible moment avoiding late changes due to non-compliance with earlier project agreements or assumptions.

The BDL 3 model will contain more detailed information about the exterior skin, the structural system and vertical and horizontal circulation. The latter is primarily analyzed by the fire safety consultant to ensure compliance with existing regulations. Once all consultants have provided their input, a BDL 3 model is agreed on. The central vertical circulation with one core and a 3-storey layout with continuous floor plates is chosen.

The BDL 3 model is further developed and varied by adding material information and openings in the exterior skin, detailing the structural system by providing geometry according to the structural concept and adding stairs and elevators. All consultants analyze the models in parallel and determine if their requirements are met. The structural engineer and the energy consultant are in our case advising against very large openings. The fire safety consultant determines that his requirements are met by each variant and also provides feedback about possible detailing challenges in case of the use of combustible materials for the exterior walls. The LCA engineer evaluates the different options for the exterior wall construction determining that the wall type wood frame emits the least greenhouse gases at a small margin if the entire life cycle including the use phase is considered. The BDL 3 model with the most regular facade is chosen to provide equal conditions on each floor. For the exterior wall, the three different wall types to be tested are chosen.

For BDL 5, an exterior roof cover for the ground floor is added, as well as exterior wall layers with material group information (e.g. concrete, insulation, plaster), interior and exterior doors and windows are varied based on the BDL 4 model. As this is the last early design stage model, all information allowing for the permitting process to begin has to be contained.

5 Conclusion and future work

BDL offers a framework to facilitate communication in the interdisciplinary design process as requirements for analyses can be communicated at the beginning of the design process. Architects and engineers agree on certain elements to be included in the model for analyses to happen. If any of the earlier stage agreements are not met at a later stage, the design loop has to go back to the respective earlier BDL enabling changes to be evaluated more quickly and easily. BIM levels of development can be used as a basis, as they determine the maturity of elements contained in the model. BDL adds to this by defining which elements have to be present at which BDL and thereby provides an easy to understand concept for all consultants defining the overall maturity and exactness of the model and provides a framework for collaboration. The case study is used to illustrate the BDL concept in more detail and provide examples for collaboration between the architect and engineering consultants.

Our future work will apply the BDL concept during design processes to collect data and feedback and adjust the concept accordingly. Additional analyses will be performed, including life cycle costs and sound proofing. Definitions of design vagueness at each BDL will be tested, such that differences in analysis results for different variants can be more clearly distinguished. The BDL will be used as a basis to enable information included in a model of higher BDL to be transferred to models of alternative designs of lower BDL's.

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