Digitalization of user-oriented demand planning through Building Information Modeling (BIM)

S Theißen¹, J Drzymalla², J Höper¹, E Liermann¹, R Wimmer¹, A Meins-Becker⁴, A Henne², N Kloster², M Lambertz¹

¹TH Köln (University of Applied Sciences), Research Area Green Building, Cologne, Germany
²TH Köln (University of Applied Sciences), Institute of Building Services Engineering, Cologne, Germany
³TMM Group, BIM, Böblingen, Germany
⁴University of Wuppertal, Chair of Construction Management & Economics, Wuppertal, Germany

sebastian.theissen@th-koeln.de

Abstract. Digitalization is accelerating and changing much in our lifestyles and ways of working. In the construction and building sector, this phenomenon is currently gaining acceptance through the Building Information Modeling (BIM) method. As an integral planning method for improving the quality of planning, construction and operating processes, BIM requires a starting point that is defined by demand planning. This paper focuses on recording demand planning digitally and generating it autonomously for basic planning. The aim is to provide planners with a BIM model that is generated early from user-oriented needs with in-depth information and enables considering sustainable and health planning aspects in the future. As a result, BIM and the open BIM data exchange format Industry Foundation Classes (IFC) are used to create a BIM-Model (3D Model) based on user needs, which are recorded by a web application. Thereby planners will be provided with a valuable starting and orientation basis that considers important user requirements. In doing so, maximum user satisfaction and quality will be achieved. Furthermore, communication and participation of users in the planning process will be promoted.

1. Introduction

BIM will completely change the processes from planning to operating a building in all trades. As a digital tool and integral method for improving the quality of planning, construction and operation processes, BIM requires a starting point that is described by the demand planning [1].

For example, requirements planning, which records the requirements of a project concept with the participation of as many stakeholders as possible, e.g., in accordance with the 10-point action plan of the Federal Ministry of Transport and Digital Infrastructure (BMVI) [2] and DIN 18025 [3] or sustainability certification systems [4, 5], must definitely be integrated into a project at an early stage and repeatedly checked over the building life cycle.

However, while cost security and adherence to schedules are usually the main focus of project management [6], structured, comprehensive demand planning in terms of sustainable, health and comfort relevant development has so far been a challenge [7]. For example, fine dust pollution is rarely or not at all taken into account in ventilation concepts for indoor spaces. Aspects such as heat stress [8], indoor air quality and the sick building syndrome, triggered by climate change, urbanization [9] and
higher workloads in a performance-oriented society, are also not considered in building planning. These psychological, biological and social factors, in their interrelated consideration as bio-psychosocial factors [10], play a decisive role in ensuring the health, performance and thus the well-being of future building users [11].

However, according to the current state of the art, such aspects are rarely considered in construction practice, although they influence user satisfaction and thus user behavior in building operation. This predicament can in turn have an impact on economic, ecological and physical parameters and thus on the overall performance of the building. Provided that comprehensive demand planning is implemented, adequate, safe and affordable living and working spaces can be generated and the risk of building-related diseases reduced [1].

If this is not done, this often results in insufficiently defined requirements and processes, which lead to subsequent improvements, various change requests or incorrect execution. Planning and construction processes become more difficult, cost and time schedules can no longer be met as planned [2]. As a consequence, there are misplanned designs and implemented concepts in operation that do not meet the specifications of the builder/user on the one hand, and on the other hand have usually only been subjected to energetic rather than holistic optimization. The result: A high quality of the building, described by the implementation of the qualitative and quantitative requirements of the owner and user, is not given [12].

This paper presents a solution approach that enables the requirements of the building owner and building users to be captured as digital planning parameters in a web application, enriched and made available in the BIM process via the IFC data format.

For this purpose, a workflow is presented that creates a "translation" of the requirements of the building owner and building user into digital planning parameters and their transfer into the BIM process. The presented workflow was validated on the basis of a prototypical implementation of the web application in an exemplary case study.

2. Literature review

2.1. Potential of BIM for enhancing user-oriented demand planning and design

It is often assumed that the life cycle of a property begins with planning. In fact, however, it begins much earlier - with so-called requirements planning [13, 14]. Before an initial building plan can be developed, the essential needs and objectives of the client and future users as well as the general conditions of the project must first be analyzed and recorded in a structured manner. Such methodical requirements planning is the basis for qualified planning decisions in project development [15]. It specifies the goals from the client's or user's point of view at an early stage and thus enables the ongoing comparison of the fulfillment of goals in the design and in the execution [16].

While methods and approaches to digitize demand planning have been in existence for 30 years, classical methods, such as those used in Germany, are often still used. Thus, user requirements and wishes are often collected, clustered and finally documented in workshops or questionnaires and interviews. Requirements planning results in a report that should be used by architects and specialist planners as a starting point. Although the file formats, mostly PDF and table formats of spatial arrangements, allow a clear presentation of the recorded information of the demand planning, these have to be searched again manually by the different disciplines and prepared and interpreted for further subject-specific planning processes [17]. The use of digital tools has so far primarily been seen as an aid to the simpler, more structured and complete recording of information. For example, electronic devices such as SmartBoards make written content directly usable as digital text format. The main purpose is to make it easier to manage the large amount of information from the many people involved in demand planning [18]. This has advantages over traditional demand planning, since there is less risk of inconsistent data storage and information breaks compared to manual processes.

Based on this, the networking of the BIM method as a holistic and cooperative working method, in addition to 3D modeling, enables an increasing depth of information or intelligence of the digital building models in a very early planning stage [19]. Thus, BIM offers the possibility of completely recording requirements in a structured and consistent manner and at the same time, to involve the
building owner and later users at an early stage [20]. For this purpose, data must be exchanged continuously during the individual lifecycle phases of a building, e.g., among project participants in an adequate form. If this data is incomplete or contains errors, good cooperation cannot be guaranteed. The typical use of different software programs considerably increases this risk. For this reason, the structured exchange of data from the building data model, in addition to the model-based graphical representation of the building, is a central component of BIM.

Here, BIM offers the possibility to structure the data captured in the model in the open and manufacturer-independent standard format Industry Foundation Classes (IFC) according to DIN EN ISO 16739 [21]. In the IFC standard, the building structures and components (e.g., opening, wall, floor, building, window, door, elevator) as well as associated properties (attributes) and geometries are mapped. The standard is also supported by numerous software systems (e.g., Autodesk Revit, Graphisoft ARCHICAD, Nemetschek Allplan) for exchanging building data and is defined by buildingSMART International to enable successful development, application and dissemination.

2.2. Consideration of user-oriented design aspects and participation of user in demand planning

In the field of standardization for requirements planning, "ensuring health, comfort and user satisfaction" is defined as a sub-goal at the international level in ISO 19208 [22] or at the German level in DIN 18025 [3], but there is no more precise specification for achieving these sub-goals. This is aggravated by the fact that demand planning, e.g., in Germany, is rarely implemented as defined in the standard [1, 6].

A further point is that the collection of user-centered parameters and thus the integration of users, especially during building operation, only takes place in the context of post-occupancy evaluation.

Numerous methods have been established for this purpose, which serve to a varying extent to collect user data, usually by means of interviews or questionnaires [23]. Although the knowledge gained is helpful for maintenance purposes, it has no direct influence on the planning of a building.

Thus, on the one hand, there is a general lack of application of a fully comprehensive demand planning system in which the user is integrated. Another complicating factor is that the standardized contents do not take into account all the complex cause-and-effect principles between people and buildings, e.g. with regard to biopsychosocial factors.

3. Framework and Workflow for the Digitalization of User-oriented Demand Planning through Building Information Modeling (BIM)

The basic framework for achieving a "Digitalization of user-oriented demand planning through Building Information Modeling (BIM)" is divided into five process steps, which are briefly described below and summarized in Figure 1.

2.1. User Input enabled by web application

Demand planning usually starts with the identification of client requirements and building user needs. The first step in the method is therefore to set up a web application for the structured entry of the building owner requirements and building user needs. In this process, building owners and users should be able to enter their requirements and wishes in the demand planning process, or be specifically queried. In this way, general and individual requirements can be considered equally. Via the web application, for example: Building use, type and number of required areas and rooms (area requirements depending on the function, necessary room heights), quality and equipment (e.g., lighting, devices, furniture, communication systems), organizational and operational boundary conditions (e.g., transport routes, coherence of areas) or technical and legal boundary conditions (e.g., radiation exposure, sound insulation) can be entered via the web application. In addition, basic requirements for the room, functions, and equipment of a room by specifying personnel functions and room profiles can also be defined.

A minimum amount of information has to be queried, which is necessary to enrich further data for the upcoming comparison with a database. For example, if the building owners state that they are planning an office building at a certain location. The users also express their wish to work in an office in pairs at the most.
2.2. Database of building segments

In the second step, the information now available in digital form is evaluated and compared with a database. With the exemplary information given on the type of use, number of occupants and location, etc., a profile can now be created that is compared with identical or similar profiles from the database. After successful matching, the most appropriate profiles are assigned to the project. The database required for this purpose requires not only a very large database consisting of real project data, standards, benchmarks, statistics, etc., but also suitable structuring. This structuring is achieved by segmentation (modularization, typification) of a building.

**Figure 1.** Proposed Workflow to digitalize user-oriented demand planning through BIM

**Figure 2.** Exemplary schematic representation of a building segment with digital planning parameters
This segmentation of building data is very important so that the data can be divided into individual areas of the building, i.e., into identical or similar segments depending on use. VDI 3813-1 [24] has already defined such structuring. For example, from a functional point of view, this defines the smallest unit of a building as a segment. Accordingly, rooms can consist of one or more segments. Figure 2 shows an example of an individual office that consists of one room and also contains one segment. However, segments can also be combined to form larger systems. One or more rooms can be functionally grouped into an area, one or more areas into a building, one or more buildings into a property and several properties into a property portfolio.

With the assignment of the profile, depending on the user input, the necessary planner-specific information can now be added. Based on the example in Figure 1, the profile can be enriched with information about the minimum area, standard temperature for an office, air exchange rate, illuminance, energy demand per area, etc. The profile gains in information content and becomes more intelligent.

2.3. Mapping to Industry Foundation Classes
To prepare the profiles as feedback for clients, users or as a starting point for the BIM process, the information contained in the profiles is mapped using the open IFC data format. The IFC data model is structured in such a way that it allows dynamically expandable data sets. Based on this IFC extension schema, information sources can be assigned to the objects or properties of the data model, which can be linked to each other. So far, the extensions address material data (e.g., thermal conductivity) and business aspects (e.g., time and cost planning). They are also suitable for mapping more complex relationships, e.g., in the context of sustainable and health-related planning parameters.

2.4. Generation and Export of the IFC model
An additional plug-in has been developed especially for Autodesk Revit that enables planners to communicate directly with the web application. This allows the BIM model to be imported directly into the web application and simultaneously checks the fulfillment of the information request from the previously defined BIM profiles. Using intelligent BIM mapping, the relevant information (attributes) from the BIM model is transferred to the right places in the web application and is available there. The IFC standard can thus be used to generate a digital, usable data format for the BIM planning process, which can also be displayed as a 3D model for the user for initial visualization using an open source viewer.

2.5. Visualized BIM Model
Once the demand planning is available as an IFC file, it can be used for visualization purposes and feedback for the client and users. After iterative processing and adjustment of the demand planning, it can be used as a starting point for the BIM process after completion.

4. Validation – Case study
In the following, the described procedure/workflow is tested on the basis of a case study using an exemplary application. The prototypical implementation of the demand planning tool from the industry partner company eTASK was used for this purpose. Construction projects can be created via the web application and subsequently enriched with individual requirements.

| **Table 1. Exemplary input for demand planning** |
|-----------------------------------------------|
| **Type of building** | **Type of room** | **Number of employees** | **Max. occupancy rate** | **Job position** |
| Building owner | Office | Open space | 62 | 6 | Researcher |
| User requirements | Office | Single room | 62 | 2 | Researcher |

Figure 3 shows the web application in which a construction project was created based on previously determined requirements/desires (see Table 1). For validation purposes, the requirements profile "office
"building" was created for an arbitrary construction project. Two different room requirements "individual office" and "meeting room" were then added to the requirements profile and supplemented with individual user entries. Since the building segment library described above is currently still under construction, no profile comparison was carried out.

For test purposes, the requirements were therefore analyzed manually and stored in the web application.

The required space was determined manually, based on the required room types, number of employees and occupancy rate. In the future, this process will take place automatically and generate a proposal that can be changed. The proposed room requirement of 25 rooms results from 22 individual work centers per 2 employees and 3 meeting rooms per 6 employees. An assignment in the form of room matchcodes must also be made. The room matchcode defines room types on the basis of usage types, areas, room reservations and personnel functions. After the number of rooms and the room matchcode have been specified, a requirements room book is also created. This book contains all room codes, numbers, descriptions, types, matchcodes, and departments.

![Image](https://example.com/image1.png)

**Figure 3.** Screenshot of web application eTASK (demand planning tool)

After the requirements capture or entry via the web application has been completed, a coupling with Autodesk Revit is made via a plug-in. The previously created requirements room book must then be selected and imported within the Revit environment.

![Image](https://example.com/image2.png)

**Figure 4.** Generated demand model in Autodesk Revit (a) and visualized in eTASK BIMexplorer (b)
To import the demand room book, generation settings must first be made in the Revit plug-in. The required settings include the floor distance, the room distance and the columns per department. After the successful generation of the demand model, the Revit project can be opened, which now becomes a demand model. Both a Revit and an IFC file can be generated.

The requirements model generated in Revit is shown in Figure 4, which shows the 22 individual workstations (15 m²) and 3 meeting rooms (18 m²). Within Revit, the model can be modified as desired and can be populated with additional information. It is also possible to view the requirements model within the web application in an integrated BIMexplorer. Similarly, the generated IFC model can be opened via an external IFC viewer, giving the user a direct visual presentation.

5. Results and discussion

In its prototypical implementation, the developed web application creates a first possibility to query the users in a structured way or to document individual wishes.

The results of the demand planning can be communicated to the planners in the correct, required subject-specific formats without loss of information. Potential conflicts can thus be identified and resolved even before the first planning draft. The finished demand planning can thus be used as a basis for the first planning drafts of the architect and specialist planners. Its creation can also be supported as a visual representation of the demand program in the form of room cuboids, thus promoting interaction and participation with the client and users at the earliest possible point in time before the planning of a building begins.

The basis for this is the translation and enrichment of the input information into subject-specific required data. For this process to succeed, the development of a database is necessary. In order to build up a comprehensive building segment database and to supplement or convert profiles based on simple user input, a large amount of real building data is required. Only when a solid database is available can user input be supplemented with the necessary, subject-specific parameters for planning, e.g., by comparison with standards or benchmarks. For example, a series of room templates could be created in which requirements for number, size and equipment, as well as for room climate, sound insulation or energy and resource requirements are entered. However, much research work is still to be done on this point, although the brief presentation of the method provides concrete guidance on how it can be set up and used in conjunction with a web application.

Furthermore, a complete mapping of all information in IFC format is not yet possible. In this sense, IFC proves to be a comprehensive data model that is able to cover a high information demand and complex processes. However, many attributes, entities and properties are not yet supported [25].

6. Conclusion and outlook

The methodology shown primarily presents, within the scope of the technical possibilities available to date, how digitalized demand planning can be combined with the help of the BIM method and the IFC data format in order to use the demand plan more intelligently for demand carriers and planners.

Secondarily, the depth of information at a very early stage of planning is increased by directly preparing and enriching information from the recorded requirements. The results of demand planning can be used in the IFC data format in a variety of ways for the BIM planning process and for interaction and visualization with building owners and users.

In the future, further complex relationships between humans and buildings will be researched, taking biopsychosocial aspects into account, in order to specifically include BIM design planning. The integration of these factors aims at increasing the health, performance and thus the well-being of the building users, while effects on building performance are already shown in the (pre) design process.

The authors see great potential in the use of the BIM method in order to implement the requirements defined in demand planning in a more targeted manner and thus to enable construction planning, processes and especially operation to the highest satisfaction of the client and user. In order to ensure that in the future, design aspects of sustainability, health, comfort, etc. are increasingly anchored in demand planning right from the start, the potential offered by digital design must be more fully exploited.
Acknowledgement
This work was conducted within the research project “HUMind” in cooperation with TMM Group, University of Wuppertal, eTASK Immobilien Software GmbH as well as other associated partners.

References
[1] M. Hodulak and U. Schramm, *Nutzerorientierte Bedarfsplanung: Prozessqualität für nachhaltige Gebäude*, 2nd ed. Berlin, Heidelberg: Springer Berlin Heidelberg, 2019. [Online]. Available: https://doi.org/10.1007/978-3-662-58652-5
[2] Bundesministerium für Verkehr und digitale Infrastruktur, Ed., “Reformkommission Bau von Großprojekten: Komplexität beherrschen – kostengerecht, termintreu und effizient,” Endbericht. Accessed: Oct. 8 2019. [Online]. Available: https://www.bmvi.de/SharedDocs/DE/Publikationen/G/reformkommission-bau-grossprojekte-endbericht.pdf?__blob=publicationFile
[3] *Bedarfsplanung im Bauwesen*, DIN 18205, 2016.
[4] Deutsche Gesellschaft für Nachhaltiges Bauen – DGNB, Ed., “DGNB System - Marktversion 2018: Kriterienkatalog Gebäude Neubau (3. Version),” 2018.
[5] Bundesministerium für Umwelt, Naturschutz, Bau und Reaktorsicherheit (BMUB), *Bewertungssystem Nachhaltiges Bauen (BNB) Neubau Büro- und Verwaltungsgebäude: Prozessqualität: Projektvorbereitung*. [Online]. Available: https://www.bnb-nachhaltigesbauen.de/fileadmin/stockbriefe/verwaltungsgebaeude/neubau/v_2015/BNB_BN2015_511.pdf (accessed: Dec. 20 2019).
[6] W. Alda and J. Hirschner, *Projektentwicklung in der Immobilienwirtschaft: Grundlagen für die Praxis*, 5th ed. Wiesbaden: Springer Vieweg, 2014. [Online]. Available: http://dx.doi.org/10.1007/978-3-658-02019-4
[7] Bundesministerium des Innern, für Bau und Heimat (BMI), Ed., “Leitfaden Nachhaltiges Bauen: Zukunftsfähiges Planen, Bauen und Betreiben von Gebäuden,” 2019. Accessed: Jan. 6 2020. [Online]. Available: https://www.nachhaltigesbauen.de/fileadmin/pdf/Leitfaden_2019/BBSR_LFNB_D_190125.pdf
[8] R. Basu and J. M. Samet, “Relation between elevated ambient temperature and mortality: A review of the epidemiologic evidence,” *Epidemiologic reviews*, vol. 24, no. 2, pp. 190–202, 2002, doi: 10.1093/epirev/mx007.
[9] T. Schmidt, I. Maras, B. Paas, J. Stienen, and M. Ziefle, *Psychophysical observations on human perceptions of climatological stress factors in urban environment* (accessed: Nov. 5 2019).
[10] J. W. Egger, *Integrative Verhaltenstherapie und psychotherapeutische Medizin: Ein biopsychosoziales Modell*. Wiesbaden: Springer, 2015. [Online]. Available: http://dx.doi.org/10.1007/978-3-658-06803-5
[11] K. Vimalanathan and T. Ramesh Babu, “The effect of indoor office environment on the work performance, health and well-being of office workers,” *Journal of environmental health science & engineering*, vol. 12, p. 113, 2014, doi: 10.1186/s40201-014-0113-7.
[12] H.-P. Achatzi, W. Schneider, and W. Volkmann, *Bedarfsplanung in der Projektentwicklung: Kurzanleitung Heft 6*. Berlin, Heidelberg: Springer Vieweg, 2017. [Online]. Available: http://dx.doi.org/10.1007/978-3-662-55626-9
[13] A. Heidemann, T. Kistemann, M. Stolbrink, F. Kasperkowiak, and K. Heikrodt, *Integrale Planung der Gebäudetechnik: Erhalt der Trinkwassergüte - Vorbeugender Brandschutz - Energieeffizienz*. Berlin: Springer Vieweg, 2014. [Online]. Available: http://dx.doi.org/10.1007/978-3-662-44748-2
[14] Klaus Aengenvoor, *BIM in der Bedarfsplanung: Startschuss zum modernen Lebenszyklus einer Immobilie*. [Online]. Available: https://www.etask.de/2017/12/07/bim-in-der-bedarfsplanung/ (accessed: Jan. 3 2020).
[15] W. Peña and S. Parshall, *Problem seeking: An architectural programming primer*, 5th ed. Hoboken, NJ: Wiley, 2012.
[16] R. Sonntag and A. Voigt, Eds., *Teil D: Planungssystematik*. Stuttgart: Fraunhofer IRB Verlag, 2011.
[17] J. McDonnell and P. Lloyd, “Beyond specification: A study of architect and client interaction,” Design Studies, vol. 35, no. 4, pp. 327–352, 2014, doi: 10.1016/j.destud.2014.01.003.
[18] H. Sanoff, Methods of architectural programming. Abingdon, Oxon: Routledge, Taylor & Francis Group, 2016.
[19] A. Koutamanis, “Briefing and Building Information Modelling: Potential for integration,” International Journal of Architectural Computing, vol. 15, no. 2, pp. 119–133, 2017, doi: 10.1177/1478077117714914.
[20] BIMiD-Konsortialführer (Fraunhofer IBP), Ed., “BIMiD-Leitfaden: So kann der Einstieg in BIM gelingen,” Holzkirchen, 2018. Accessed: Mar. 2 2019. [Online]. Available: https://bim-cluster-rlp.de/pdf/BIMiD-Leitfaden-2018.pdf
[21] Industry Foundation Classes (IFC) for data sharing in the construction and facility management industries - Part 1: Data schema, ISO 16739-1:2018-11, 2018.
[22] Framework for specifying performance in buildings, ISO 19208, 2016.
[23] P. Li, T. M. Froese, and G. Brager, “Post-occupancy evaluation: State-of-the-art analysis and state-of-the-practice review,” Building and Environment, vol. 133, pp. 187–202, 2018, doi: 10.1016/j.buildenv.2018.02.024.
[24] Building automation and control systems (BACS) - Fundamentals for room control, VDI 3813-1, 2011.
[25] E. Petrova, I. Romanska, M. Stamenov, K. Svidt, and R. L. Jensen, Development of an Information Delivery Manual for Early Stage BIM-based Energy Performance Assessment and Code Compliance as a Part of DGNB Pre-Certification. [Online]. Available: http://www.ibpsa.org/proceedings/BS2017/BS2017_556.pdf (accessed: Nov. 28 2019).