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DESIGNING A PARAMETER CATALOGUE FOR AN ALGORITHM-AIDED BIM TOOL

Sophia Pibal[1], Iva Kovacic[1], David Schuster[1]
[1]Institute of Interdisciplinary Construction Process Management,
Integrated Planning and Industrial Building,
TU Wien, Vienna, Austria

Abstract

By developing a digital tool for parametric planning based on algorithm-aided design and Building Information Modeling (Algorithm Aided BIM Tool: AABIM), we aim to support the design and evaluation of affordable and sustainable housing-specific BIM models. The overall aim of the presented research is to create a guideline for the design of an AABIM tool and to explore which parameters and requirements must be obtained as a basis. The explorative determination and cataloguing of preliminary housing-specific parameters, and preliminary specifications for the design guideline are the objectives of this study.

Introduction

At the same time as the digital transformation of the construction industry, industrial residential construction has also been revived due to the increasing demand for affordable housing. The potential of digital technologies has not yet been sufficiently integrated in the planning, construction process or management. The coupling of digital processes has the potential not only to accelerate the production of housing, but also to minimize costs and resources. In a Viennese context a vast number of multi-storey residential buildings are highly similar, yet every residential building is unique, adapted to its individual environmental conditions. Planners have to adapt their designs to different building sites and project conditions, and at the same time plan as efficiently as possible. For this purpose, they utilize often-used, tried-and-true elements (such as commonly room proportions, exterior walls, stairwells, building depth, openings, apartment sizes, etc.). Those must, however, be modified and reassembled iteratively to meet individual project requirements. The result is an extensive and time-consuming planning effort that often becomes a gauntlet between law, design, society, urban planning and site-specific regulations. In order to make deficits and potentials of the built environment comparable and assessable, a maximum number of investigations by means of variants and evaluations is required, especially in the early design stage. One way to support traditional planning services to support affordable and sustainable housing is to utilize parameter-based or algorithm aided modeling. The underlying idea is to generate models and variants of building designs by entering and adjusting descriptive qualitative or quantitative parameter values within an algorithm or script. However, purely parameter or algorithm-based design of a building information model relies on defined requirement specifications. The parameters and values required for algorithm-aided design must be defined. With the complexity of residential buildings, however, a large number of geometric and non-geometric parameters and related constraints inevitably arise. By parameters, we define non-geometric, technical, legal, normative and economic and environmental factors or requirements. The aim is the definition of a parameter catalogue and preliminary requirement specifications, as basis for the design of a semi-automated AABIM tool for the generation and evaluation of digital information models. This paper presents an extension of the research conducted within the funded research project “Housing 4.0” (Kovacic et al., 2020; Pibal et al., 2020; Pibal et al., 2021) where a digital platform for user-participation oriented BIM based planning for affordable and sustainable housing is developed.

Research Context

Within the funded research project “Housing 4.0” (Housing 4.0: Digital Platform for affordable housing FFG Austrian Research Funding agency, Project number: 873523), a framework for a digital platform was developed, enabling integrated, participatory design and construction process and data consistency along the value chain for sustainable and affordable housing - serving as basis for the presented research.

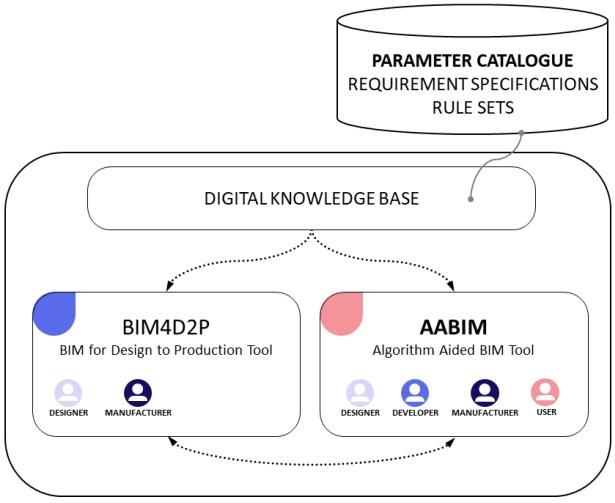

Figure 1: Research Context, Digital Platform Housing 4.0 with its Components: Digital Knowledge Base, BIM4D2P Tool and the Extension AABIM Tool and Parameter Catalogue

The “Housing 4.0” approach (figure 1) is extended by the development of an algorithm-aided BIM tool (AABIM). Our aim is to develop an algorithm (script) inside a visual programming editor, the Grasshopper plug-in for Rhinoceros (McNeel) which will be connected to the BIM software Archicad (Graphisoft) via a live-connection. AABIM tool should enhance modular off-site production in multi-story housing, enabling material, cost and time savings and thus affordable and sustainable housing design. The methodology of BIM-based integrated planning is missing in the planning practice and the processes for the development of industrialized construction production (off-site production, prefabrication). Thus, the overall objective is the development of an integrated methodology as well as the optimization of BIM-supported planning and construction processes by creating common data structures, open interfaces and the development of standards for the creation of common BIM object libraries for design-build-operate processes. The innovative contribution of the AABIM tool aims at the semi-automated generation of BIM models based on spatial, non-geometric, technical, legal, economic and environmental parameters.

Literature Review: Parametric Design, Algorithm Aided BIM and Housing

Feist (2016) defines parametric and algorithmic design as a design process in which designers create a script that creates the model or variants. These design variants further on can be examined by modifying the parameter values (Ferreira and Leito, 2015; Leito et al., 2012). These algorithms can be programmed in text programming languages or visual programming languages. Visual programming languages enable users to change geometry and computations using graphical commands rather than text commands (Máder et al., 2018). Parametric modeling (Haymaker et al., 2018) includes both Algorithm Aided Design and BIM, where parameters can be set within an algorithm or within an object. Humppi and Österlund (2016) refer to the combination of Algorithm Aided Design and BIM as Algorithm Aided BIM. The terms “Algorithm Aided BIM” (Humppi and Österlund, 2016), "Generative BIM" (Mirtschin, 2011) and "Parametric BIM" (Aish, 2013) are interchangeable. Although there is no fixed term, we refer to this approach as Algorithm Aided BIM in this paper. Algorithms are used to create parametric models with embedded metadata that can then be used in the design and construction process and for assessments. To a considerable extent, BIM and parametric modeling still need standardization. The integration of algorithms to support BIM in the built environment, as investigated by Rausch et al. (2020), shows that their performance can be helpful not only in complex design processes, but also in accurately identifying sources of error. Rausch et al. (2020) also emphasize the importance for future research to investigate potential applications of computational algorithms throughout the building life cycle. Furthermore, the study by Deng et al. (2021) explores various technologies that can facilitate the evolution of BIM into digital twin processes in the construction industry. This includes building lifecycle, operations, and management. Some studies point out the lack of effective links between parametric, generative and digital tools and processes and their sharing. (Fernando et al.,2012; Bosch-Sijtsema et al., 2021) Seamless connectivity can offset the fragmentation of the sector and make projects more targeted for all key stakeholders (Bosch-Sijtsema et al.,2021). In particular, Fernando et al. (2012) cite standardization of BIM-based parametric modeling as patchy. Dautremon et al. (2019) highlight the relevance of developing an effective combination of parametrics in BIM processes to determine building reuse assessment in more detail. A software solution proposed by Ferreira and Leitao (2015) shows an innovative combination of specific BIM tools and generative design programming environments. This should allow, through a user-friendly programming environment, to create portable programs that consider general BIM concepts and thus different BIM tools can be explored. These studies illustrate the potential of parametric approaches in terms of fast, dynamic and effective generation of variants within a parameter based or algorithm aided BIM environment. Nonetheless, a gap between the utilization of parametric and generative tools in research and practice exists. Pasetti Monizza et al (2018) have investigated the potentials and problems of parametric and generative design techniques in off-site production (mass production) in construction. The results show that improvements in manufacturing efficiency, as well as production efficiency, can be observed through parametric algorithms in manufacturing. However, due to the lack of Industry 4.0 approaches in the ordinary value chain, limitations also had to be considered. A study sponsored by the Vienna "MA 50 Wohnbauforschung" (2012) addresses the issue of low-cost housing and has identified design and planning parameters relevant to construction costs. Extensive studies on industrial housing, which include an overview of the different technologies as well as extensive case study collections of multi-story housing developments include Philip Meuser's handbook and planning guide on industrial residential construction (2019) and the publication "Prefabrication and Automated Processes in Residential Construction" by Jutta Albus (2018). In both studies, the topic of digitalization in planning processes is hardly dealt with. Albus focuses on automation in production without connection to planning, while Meuser points out the potentials of individually configured buildings using BIM, however, the use of parametric modeling is not systematically presented in the presentation of realized projects.

Research Design

This study intends to develop a parameter catalogue and preliminary requirement specification through an exploratory approach (figure 2) of analyzing use case related secondary data. In this section, we focus on the

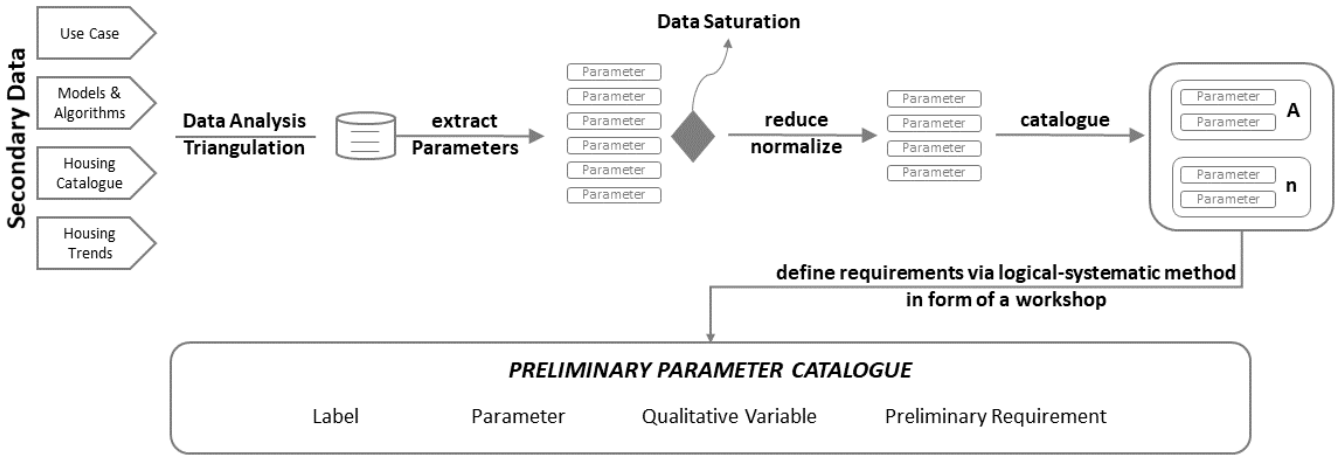

Figure 2: Research Design, from Secondary Data to Preliminary Parameter Catalogue

methodology, methods and materials of the exploratory parameter obtainment and cataloguing. This section is structured in the following: i) a description of the project specific use case and related secondary data and ii) the methods of parameter exploration and cataloguing.

Use Case and Secondary Data

In this section we present the use case and secondary data for the content analysis, extraction, reduction, normalization and cataloguing of parameters. The gathering of a large variety of data is essential to ensure diversity and versatility. The data generation has been performed prior to this study during the superordinate research project. Hence, a diverse set of modular multi-storey residential building related secondary data (table 1) has been available for the content analysis.

Table 1: Overview of Secondary Data, Formats and Content

Data	Format	Data Content
Use Case	Document	2d floor plans and sections
	Spreadsheet	spatial programm
	Document	project description
Algorithm	Grasshopper	8 design-scripts in visual programming language
BIM Model	Archicad Model	6 native files
	Revit Model	2 native files
	IFC	8 ifc files
Housing Catalogue	Spreadsheet	60 modular multi-storey residential building case studies
		23 catalogue characteristics/parameters
Study on Housing Trends	Document	collection of institutions, normative frameworks, actors, materiality, technical systems, digital technologies

Use Case: Joint Building Venture ("Baugruppe")

The legal construction common in Vienna today is that the members of a joint building venture (German: "Baugruppe") form an association that builds and owns the house and rents the individual apartments to its members. The members of such an association are thus simultaneously owners and landlords (as a group of association members) and tenants (as individuals or families or other residential constellations). During planning, the architects thus first work with the group to develop a basic concept for the house (development, apartment mix, common areas, etc.). This is followed by more detailed planning participation for the common areas and also for the individual apartments. There is usually an agreement on how many planning meetings are scheduled for each apartment. Of course, cost sets a framework for how much specific molding is possible in an apartment. Different groups see this differently; some specify a few types from which there can then be only minor deviations; others plan the individual apartments very individually. In many projects today, it is common to take into account in the design that relatively long changes can still be made to the apartment floor plans during the project development, so that members who join later can still adapt their apartment to their wishes. Other than that, the technical and architectural deviations from common residential buildings are minor, except that there is a larger proportion of common areas. This use case (table 2) is consistent with this model.

Table 2: Use Case Profile - Joint Building Venture

Use Case	Joint Building Venture (Baugruppe)
	Vienna
	2015 - 2019
	4000 m^2
	multi storey residential building: ground floor + 5 storeys
Type	funded residential home
Units	34 dwelling units

	2 guest/refugee apartments
	35-150 m^2 per unit
Common Areas	media workshop
	roof terrace: shared kitchen
	roof terrace: library
	roof terrace: sauna
	atelier
	fitness room
Outdoor Area	balconies (private)
	pergola (semi-private)
	roof terrace (semi-private)
Construction	ground floor: concrete
	storeys above ground floor: modular hybrid- timber construction
	interspersed apartments, modularly connectable to adjacent apartments
	slabs: cross-laminated timber and concrete
	exterior walls: prefabricated wooden box elements
	apartment partition walls: cross-ply timber

Algorithms and BIM Models: Through research led teaching the research projects use case has been re-generated as variants by interdisciplinary teams of architecture and civil engineering students over the course of one semester (Pibal et al, 2020). The data we obtained from research led teaching consists of 8 Design Algorithms inside Grasshopper plug-in for Rhinoceros (McNeel) and 8 BIM model variants inside Archicad (Graphisoft) or Revit (Autodesk) and 8 IFC files.

Housing Catalogue: The catalogue includes 60 case studies of modular residential buildings and tabulates their characteristics that include 23 building characteristics derived from the 60 case studies.

Study on Housing Trends: addresses institutions, normative frameworks actors, materiality, technical systems, and digital technologies as co-producers of the built environment.

Parameter Exploration and Cataloguing

The methodology of the parameter exploration and cataloguing is divided into following phases, which will be presented in this section:

- Data Triangulation Phase
- Content Analysis, Extraction of Parameters and Data Saturation Phase
- Reduction and Normalization Phase
- Cataloguing Phase
- Preliminary Requirement Phase

Data Triangulation Phase

The fundamental concept of the conducted triangulation is to combine several perspectives on an object of study into one overall result. Triangulation as a strategy originally comes from empirical social research, but has long since left its boundaries and is also established in other research areas. This data triangulation includes various data sources and formats of secondary data (table 1) to view the research subject from multiple perspectives. In this study we utilize the secondary set of data for the extraction of the housing specific parameters, described in the next subsection.

Content Analysis, Extraction of Parameters and Data Saturation Phase

Firstly, we intended to define the specific terms that need to be searched for in our set of data. Under the definition of non-geometric parameters, we summarize requirements, characteristics, functions and elements. To define these specific parameters, the generic term housing, is divided into 3 categories: i) the single room, ii) the independent dwelling unit, iii) the building unit. In an iterative process of data analysis, parameters were extracted from the secondary data and assembled into a non-clustered spreadsheet. Adapted from qualitative research methods, the extraction of parameters and qualitative variables was carried out iteratively until data saturation was reached. Here, the data saturation defines the phase of our qualitative data analysis in which we take samples and analyze data until no more new parameters emerge.

Reduction and Normalization Phase

Within the non-clustered list of parameters multiple mention of parameters occurred. Duplicates that have occurred are of the same or similar designation of a parameter. These were sorted, reduced and combined. The requirements for the individual pieces of information in a normalized table are independence, functional dependence and freedom from redundancy (Bühler et al., 2019).

Cataloguing Phase

In a further iterative phase, the normalized non-clustered parameters are catalogued in form of a spreadsheet with the aim to segregate groups with similar traits and relations. Within this iterative process, we have developed four levels within the catalogue. The i) Label, ii) Parameter, iii) Qualitative Variable and iv) Preliminary Requirement levels.

Preliminary Requirement Phase

The preliminary requirement phase has been conducted after labels, parameters and qualitative variables have been catalogued. The research team reviewed the use case data, discussed and formulated the preliminary requirements utilizing implicit expert knowledge. Adapted from systematic-logical procedures (Felkai and Beiderwieden, 2015), we applied a logical-systematic method in the form of a workshop. In this process, the general and independent characteristics (parameters, designations, variables) are identified, which were then assigned data-related preliminary requirements within the catalogue.

Results

The resulting parameters have been structured according to the levels: label, parameter, qualitative variable and were assigned preliminary requirements. The super-categories have been pre-defined during the extraction of parameters, i) room, ii) dwelling unit and iii) building unit. The resulting and catalogue parameters are shown in the following section of this paper.

Room Specific Parameters

Various rooms within a residential unit within a complex have diverse usage profiles and thus different parameters that characterize them. A number of parameters must necessarily be applied to all rooms, others are used only to a limited extent or in certain rooms. An excerpt of the room specific parameter catalogue is shown in in table 3.

Table 3: Room Specific Parameters, Qualitative Variables and Preliminary Requirements - Excerpt Parameter Catalogue

Label	Parmeter	Qualitative Variable	Prelminary Requirement
lighting	light source	natural	*must in mandatory room*
		artificial	*must*
area	floor area	aspect ratio	*design specific*
		spatial proportion	
		furnishing	
air	ventilation	natural	*must in every mandatory room*
		mechanical	*optional*
thermal	thermal comfort	heating	*must*
		cooling	*optional*
openings	structural openings	doors	*must in every room*
		windows	*must in every mandatory room*
		ventilation openings	*must if no window*
con-nections	power supply	/	/
	water supply		
	sewerage		
sanitary	sanitary facilities	quantity	*according to unit size and room count*
		equipment	/
surfaces	flooring	material	*design specific*
	ceiling		
	walls		

Dwelling Unit Specific Parameters

A dwelling unit consists of the combination of several rooms, different in their type and functionality, which in their interaction enable the use for residential purposes. The specific parameters describing a dwelling unit are shown in table 4. The size of dwellings varies greatly in terms of the number of mandatory rooms and supplementary rooms, and the size of the individual rooms. A division is made between mandatory and supplementary rooms. Through implicit expert knowledge mandatory rooms are required to enable, in their interaction, the use of the unit for residential purposes. Supplementary rooms are defined as additional rooms that expand the functions of the unit. An excerpt of the dwelling unit specific parameter catalogue is shown in the following.

Table 4: Dwelling Unit Specific Parameters, Qualitative Variables and Preliminary Requirements - Excerpt Parameter Catalogue

Label	Parameter	Qualitative Variable	Prelminary Requirement
mandatory rooms	room	room 1	*must have ≥ 1 room*
		kitchen	*must have ≥ 1 room + separate kitchen*
		room 1 + kitchen	*must have 1 ≥ room including kitchen*
	sanitary room	bathroom	*must have bathroom*
		toilet	*must have toilet*
		bathroom + toilet	*bathroom and toilet can be in one room if unit has ≤ 2 rooms*
	area between mandatory rooms	corridor	*mandatory rooms shall be accessable via corridor*
	entrance area	hall	*unit shall have a hall*
supplem. rooms	sanitary rooms	seperate toilet	*must if ≤ 2 mandatory rooms in unit*
		additional bathroom	*design specific*
		utility room	*design specific*
	functional room	starge room	*design specific*
		pantry	*design specific*
	non-mandatory /additional room	room 2	*according to housing mix and unit size*
		room 3	
		room n	
	outdoor area	balcony	*design specific*

		loggia	
		garden	
		sunroom	

Building Unit Specific Parameters

In addition to the residential units, the overall concept of the housing development also includes the development areas, possible general-use areas or rooms, and the technical building equipment, as well as the additional requirements associated with them. The determination of the parameters is deliberately supplemented only at this point by the planning and constructional aspects of the housing development planning. If one considers, for example, selected load-bearing systems, wall structures or ventilation systems, these always extend in the same way over several floors or even the entire residential building. They do not have to be redefined for each room or housing unit. The equipment and building physics requirements were deliberately not included as they are beyond the scope of this study. An excerpt of the building unit specific parameter catalogue is shown in table 5.

Table 5: Building Unit Specific Parameters, Qualitative Variables and Preliminary Requirements - Excerpt Parameter Catalogue

Label	**Parameter**	**Qualitative Variable**	**Prelminary Requirement**
general requirement	accessibility	/	*units must be accessible*
	circulation	staircase	*according to design and building regulations*
		access to units	
		lift	
	general areas	laundry room	*design specific*
		universal room	*design specific*
		private storage	*optional outside unit*
		bicycle room	*must*
		garbage room	*must*
		youth space	*design specific*
		stroller room	*must*
engineering factors	structure type	/	*design specific*
	components	load bearing	*design specific*
		non-load bearing	*design specific*
planning factors	fire safety	escape routes	*according to building regulations*
		material	*according to building regulations*
		compartment	*according to building regulations*
	housing mix	unit size and number of rooms	*design specific*
	building physics	vapour diffusion	/
		sound proofing	
		insulation	
		damp proofing	
	superstructure	wall	*according to structure type*
		slab	
		flooring	
		cloumn	
	building site	development	*according to building regulations*
		height	
		area	
technical building equipment	media	/	/
	sanitary piping	/	/
	ventilation	/	/
	power	/	/
	thermal	/	/
	shaft	count	*design specific*
		position	
		size	
	lift system	operating room	*design specific*
		shaft size	

Conclusion and Future Research

The objective of this paper was to define and catalogue preliminary housing-specific parameters, qualitative variables and preliminary requirements and define which parameters and requirements must be obtained as basis for the design guideline for an algorithm-aided BIM tool. Aiming to explore the parameters and requirement specifications utilizing secondary data of a specific use case. When utilizing an exploratory approach to qualitative data analysis, limitations regarding data saturation must not be neglected. A category is considered saturated when researchers have reached the point of data analysis where the inclusion of additional material cannot yield any new properties of a category. Only after this saturation is reached are further steps, such as a quantitative research, useful in determining variables. The objective of this study was not statistical representativeness, but rather to develop the properties of theoretical concepts and categories inside the catalogue. Nonetheless, the fact that the application of the criterion of data saturation is subject to interpretation and cannot be derived objectively from the data places legitimacy demands. The housing-specific parameters derived in this study have their limitations, of course. Since the analysed set of data has been developed during the research project and has a very specific scope, we suppose further research and especially analysis of normative, legal and technical sources for the definition of requirements and constraints. Which shall result in a broader quantity of housing specific parameters, qualitative variables and more detailed requirement specifications. Concluding, for

future research following questions must be met. How must requirements and constraints be formulated that deal with rules, conditions and limits of the identified parameters, values and preliminary requirements? How must developed constraints be utilized to create sets of rules that cover all elementary areas of design holistically, qualitatively and quantitatively? The goal is to prepare the constraints and parameter values qualitatively and quantitatively in such way that they make a concrete and, if possible, measurable statement that stands on its own. In doing so, they should meet the legally applicable conditions, the prevailing state of the art, the demands for high-quality residential construction, as well as specific requirements for semi-automatic model generation based on algorithm-aided design and BIM. In conclusion, this study presents a preliminary cataloging of housing-specific parameters and preliminary requirements that serve as a foundation for future research regarding the design guideline of an algorithm-aided BIM tool.

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