USING BIM FOR MODELING CLIENT REQUIREMENTS FOR LOW-INCOME HOUSING

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ABSTRACT

Client requirements management aims to improve value generation of construction projects through a systematic process of capturing requirements, processing this information, and making them explicit to the product development team, as well as controlling whether these are properly balanced. This is particular important when resources are limited, such as in low-income housing projects. This process involves a large amount of qualitative information, and need to consider the diversity of requirements that usually exist among different stakeholders. This paper aims to propose a method to model client requirements in social housing projects with the support of Building Information Modeling (BIM). This method was devised to support both the decision-making processes during early design stages, and also the evaluation of projects that have already been delivered. This article is focused on some of the activities involved in the process to model requirements: exploring different ways of modeling client requirements, and identifying and structuring client requirements. One of the main contributions of this article is concerned with the identification and structuring of generic requirements that can serve as a basis for developing new low-income housing.

KEYWORDS

Client requirements management, low-income house-building projects, product development, modeling client requirements, BIM, value generation.

INTRODUCTION

With the goal of reducing a housing deficit estimated at 5,546 million homes (Ministério das Cidades 2011), the Brazilian government has set up the Programa Minha Casa Minha Vida (PMCMV) [My House My Life Program]. Created in 2009, the initial goal of the PMCMV was to build one million homes for low and lower-middle income families (up to 10 minimum salaries), in partnership with state and local governments, and the private sector. This program, managed by the Ministry of the Cities and operated by Caixa Econômica Federal (National Savings Bank), has a target of financing another 2 million homes by 2014.

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Besides the need to reduce the country's housing deficit, it is important to improve value generation in the development of low-cost housing projects through the improvement of the design quality, in order to increase the level of satisfaction of the users of social housing projects. In the Lean Construction community, value generation has been a topic of several papers. The value generation is considered as a process in which the customer value is generated by meeting their requirements (KOSKELA, 2000). This process is carried out in a cycle where customer requirements are captured and converted into a product or service delivered to the customer (KOSKELA, 2000). The cycle of value generation and related principles (KOSKELA, 2000), therefore, exposes the need for managing requirements throughout the product development process. The aim of client requirements management is to define, analyze and translate requirements in a systematic way during the product development process (Kamara et al. 1999). By making them explicitly available, it is possible to support design decision-making, as well as to control whether those requirements have been properly balanced in the design solution (Kamara et al. 1999).

Due to the large amount of qualitative information involved in client requirements, Kiviniemi (2005) suggested that it is essential to develop IT tools to provide some degree of automation for requirements management. In fact, Kamara and Anumba (2001) suggest that IT can support the creation, communication, documentation and management of briefing information. However, the use of IT in that task poses important challenges, such as he difficulty of capturing both implicit and explicit requirements, maintaining information up to date, and storing different requirements from distinct stakeholders throughout the product development process (Leinonen and Huovila 2001).

The use of Building Information Modeling (BIM) seem to be an attractive alternative for supporting clients requirement management, since it is capable of connecting different types of information to product models. BIM, among other things, aims to streamline processes, present construction information in an accessible and common way (Hooper and Ekholm 2010), reduce the possibility of missing or clashing information (Hooper and Ekholm 2010, Eastman et al. 2008), ensure optimized project coordination (Hooper and Ekholm 2010), and facilitate simultaneous work of several professionals involved in the design and production of the project (Eastman et al. 2008)

Nevertheless, there have been very few applications of BIM in client requirements modeling, particularly in early design stages (Koppinen et al. 2008). Koppinen et al. (2008) suggest that BIM can support not only the management of technical requirements at the detailed design stage, but also at early design stages by manipulating information on space requirements.

This paper reports the results of a research project which aimed to devise a method to model the requirements of social housing projects' clients, supported by BIM. The main goal of the method is to support the decision making process in the product development process, for the professionals involved both in the design process, as well in the assessment of project proposals, from the perspective of the funding agency. This paper emphasizes some of the activities involved in the requirements modeling process: exploring different ways of modeling clients' requirements, identifying and structuring the client requirements. Moreover, this paper explore the use of this technology for managing requirements in social housing projects, which is a type of project that has not received much attention from the BIM community.

MODELING CLIENT REQUIREMENTS

A number of ways for modeling requirements is suggested in the literature, although none of them has been widely used in the construction industry. Three of those approaches have been investigated in this research project: Quality Function Deployment (QFD); Tree Diagram; and Requirements Model Specification, proposed by Kiviniemi (2005). These all have in common the emphasis on the requirements structuring stage.

QUALITY FUNCTION DEPLOYMENT

Quality Function Deployment is a widely known tool for processing clients requirements which can be used for understanding and tracking requirements, and improving the communication and horizontal integration among product development team members (Kamara et al. 1999). It allows the representation of the requirements through the matrixes, as well as documenting, communicating and providing the requirements to those involved in the product development process. However, the application of QFD in construction has been very modest, and there is only a limited number of examples in the literature on construction management (Dikmen et al. 2005).

In the context of social housing in Brazil, Lima et al. (2008) has used QFD for the analysis and structuring of requirements based on data collected directly from final users. Lima et al. (2008) pointed out some difficulties and limitations of the application of QFD in social housing: (i) it is time consuming to process this information, particularly if the proportions of the matrix become very large, (ii) it is not easy to involve product development team members in the processing stages that are necessary to produce the matrix.

Although there are limitations and difficulties in the application of QFD in the context of social housing, it is important to stress that this tool has played an important role in this study, since it has strongly influenced the development of other tools, such as ClientPro, which is based on the CRPM[4], and the EcoProp[5].

TREE DIAGRAM

The tree diagram is a tool that allows the systematic mapping at different levels of detail of the entire range of paths and tasks that must be undertaken in order to achieve a main objective and each related sub-objective (Anjard 1995). This diagram is used in a top down way to break down the objectives and needs of clients into requirements to very detailed levels, making it possible to connect them to the product attributes (Kwong and Bai 2002). It can also be used to provide a graphical representation of requirements, so that these can be better visualized and structured.

[4] Client requirements processing model (KAMARA & ANUMBA, 2001)
[5] Software developed by the VTT Technical Research Centre of Finland (http://cic.vtt.fi/ecoprop/ecoprop_web_site/Mainpage.html).

REQUIREMENTS MODEL SPECIFICATION (KIVINIEMI, 2005)

Kiviniemi (2005) devised a method to establish connections between requirements and building product models, which aims to support client requirements management in the design process. This model is based on the idea that it is necessary to structure (or model) requirements in order to connect them to the product model. Through the requirements modeling developed by Kiviniemi (2005) it is possible, among other things, to visualize the relationships between the project's requirements and design objects through direct and indirect connections, as well as to make that information available to the stakeholders. Moreover, Kiviniemi (2005) points out that the models offer the opportunity to manage and connect information so that it is not necessary to have a document-based environment.

Kiviniemi (2005) emphasizes the need to record and structure requirements so that these can be compared to design solutions. When conflicts between requirements and solutions emerge, it should be easy for the design team to visualize and manage problems (Kiviniemi 2005).

Requirements management tools can potentially contribute for the improvement of product quality since these: (i) create a formal structure for modeling requirements; (ii) enable the creation of requirement templates, which may contain a large amount of information, being possible to define sub-sets of requirements for different types of projects; and (iii) store data that can be compared not only with design solutions but also with maintenance information throughout the building's life cycle (Kiviniemi 2005).

REQUIREMENTS STRUCTURING

The structuring and decomposition of requirements in a hierarchical way can facilitate the understanding and tracking of requirements (Kott and Peasant 1995, Ulrich and Eppinger 2008). It usually starts at the highest (primary) level and goes down to an increased levels of detail at lower levels. Kiviniemi (2005) points out that only a broad structure of a set of predefined requirements will allow a useful connection between requirements and design models.

Nevertheless, Kiviniemi (2005) argues that it is not possible to standardize the different types of requirements due to the existence of several types of projects, which may have some common requirements, but also a large number of specific requirements. In fact, Kiviniemi (2005) proposed a framework, named the requirements specification model, which aimed to identify a set of requirements which would allow the addition of specific requirements to adjust to a particular project (Kiviniemi 2005). In this model, the structuring of requirements is based on five construction programs, two widely used requirement hierarchies (WBFS[6] and EcoProp) and spatial requirements from the IFC[7] specifications.

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[6] *Whole Building Functionality and Serviceability* (ICF 2000 *apud* KIVINIEMI, 2005). ICF 2000 - International Centre for Facilities: ASTM Standards on Whole Building Functionality and Serviceability. Second Edition. American Society for Testing and Materials 2000. ISBN 0-8031-27340

[7] The IFC (Industry Foundation Classes) is an international standard for the exchange of data on building projects between different computer programs. It offers new oportunities of data exchange and interaction between all types of applications involved in the construction process. (http://www.buildingsmart.com).

According to Kiviniemi (2005), the requirements hierarchy can be organized in two ways: (i) functional categories, such as safety requirements, lighting and acoustic requirements; and (ii) levels of detail of the building product, such as design, site, and space requirements. These two ways offer different forms of visualizing the organization of the requirements, providing a basis for the interface with users for requirements management.

Kivinemi's hierarchy (2005) is formed by 300 requirements in 13 main categories, such as location requirements, service requirements and 35 subcategories, such as, for example, site requirements and infrastructure requirements (belonging to the location requirements category). This hierarchy has a large amount of requirements, making it possible to adapt it to several types of construction projects. This was the starting point for the structuring the requirements of social housing projects.

RESERCH METHOD

The first step of this research project was to understand the overall characteristics of the *Minha Casa Minha Vida* program (PMCMV). A set of interviews was carried out with the stakeholders involved in this program, as well as with professionals involved in the design review process, which is performed by *Caixa Econômica Federal* (National Savings Bank), the funding agency. Interviews were also conducted with the technical team of a construction company that develops and builds social housing projects. Those interviews led to the identification of list of minimum requirements established by the Ministry of the Cities, as well as specific requirements determined by the bank. Those requirements were used to structure the clients' generic requirements. The requirements structure proposed by Kiviniemi (2005) was adaptated to the social housing context. The revised structure was then assessed by the technical staff of Caixa involved in the design review process, as well as project managers from a construction company.

In the second phase of the study, the set of requirements were input in the dRofus[8] software, which was chosen for requirements modeling. This is a BIM software that use of the IFC open standard, making it interoperable with most other BIM tools. It allows, among other things, to structure and organize the requirements, make it available to the design team, control and track, and also to check specific requirements. In addition, the software allows the creation of requirements templates for different types of buildings, enabling the management of a large set of requirements.

This software was used for modeling requirements and connecting this information to the BIM model of a specific social housing project. Based on this case study was carried out a method to requirements modeling. The aim of this method is to support both the decision making process during the early design stage, and the evaluation of projects that have already been delivered. Two possible users of this method were identified: (i) companies involved in the development of social housing projects; (ii) funding agencies and local authorities, which are responsible for assessing social housing projects, and sometimes also carry out the inspections during the construction phase. From the perspective of the government agencies, the method

[8] Available on http://www.dRofus.no

can improve the design review process, allowing a more consistent evaluation of projects, based on a well-organized set of expected results. For construction companies, the method can be useful by supporting the organization of information about different types of requirements, such us from final users, legal requirements, and also from other stakeholders.

PRELIMINARY RESULTS

DIFFICULTIES IN THE DESIGN PROCESS

The interviews conducted with stakeholders and professionals from the funding agency led to the conclusion that the process of checking the conformity of the design of social housing projects with the demand or with the characteristics of the program have some difficulties: (i) the assessment of proposals may take a long time, especially due to the large number of design mistakes that need to be corrected; (ii) the design review is usually carried out in a very idiosyncratic way by different technical staff; (iii) the lack of consistent criteria sometimes creates mistrust from the proponents, generating many complaints about lack of clarity in the definition of requirements; (iv) significant part of the information is qualitative and this results in subjective evaluations by the funding agency professionals; (v) visualize the information, due to the existence of different documents and incompatibility between them; (vi) lack of requirements organization, (vii) making the requirements available for designers; and (viii) lack of requirements changes control during the design process of low-income housing.

That provided additional evidences for the need of systematic client requirements to support the assessment of project proposals, both to facilitate the verification of MCMV’s minimum specifications, and to standardize the submittal of proposals.

THE REQUIREMENTS MODELING PROCESS

The requirements identified in the minimum specification list, as well as the specific requirements set by the funding agencies were used in the structuring of the requirements. In order to limit the scope of the work, only the categories of requirements that are typically verified during the process of assessment of proposals, Some of the categories and subcategories had to be adjusted and others were added, as shown in Figure 1.

With regards to the category Location Requirements, only the subcategories Infrastructure requirements (subdivided into Project’s infrastructure and Public infrastructure), Site Design Requirements and Systems requirements were considered (Figure 1b). The Site Design Requirements (Figure 1a), which are related to the geographic location, type of soil, etc., are checked in the preliminary analysis of the social housing projects. Representatives of the funding institution visit the site and do an overall assessment of the site in terms of slopes, drainage, etc. In this analysis they check the access to electricity, water and sewage services. Transport Requirements (Figure 1a), such as, for example, the distance to public transport, are considered in the preliminary analysis of the social housing project. The subcategory Existing Site Limitations (Figure 1a), which includes, among other things, the existing vegetation, existing buildings to be preserved or demolished, are analyzed during for the approval of the project according to the laws of each municipality. The funding agency may demand technical reports for the approval of the afore-mentioned existing site limitations. Finally, the subcategory Site Requirements for Building, which includes, for example, requirements related to the buildings' height and area, are also analyzed by local authorities, according to the existing Master Plan and are, therefore, not considered in the structuring of requirements.

Category	Subcategory
A CONFORMITY REQUIREMENTS	
A.2 Location Requirements	
	A.2.1 Site Requirements
	A.2.2 Infrastructure Requirements
	A.2.3 Transportation Requirements
	A.2.4 Site Design Requirements
	A.2.5 Existing Site Limitations
	A.2.6 Site Requirements For Building
	A.2.7 Site Requirements For Systems
A.3 Service Requirements	
	A.3.1 Service Requirements
A.4 Space Requirements	
	A.4.1 Space Program Instance
	A.4.2 Space Program Type
	A.4.3 Space Program Fixtures
B PERFORMANCE REQUIREMENTS	
B.1 Indoor Condition Requirements	
	B.1.1 Indoor Climate
	B.1.2 Acoustics
	B.1.3 Lighting
B.2 Service Life Requirements	
	B.2.1 Service Life Of Building
	B.2.2 Service Life Of Techical Systems
B.3 Adaptability Requirements	
	B.3.1 Flexibility Of Building
	B.3.2 Flexibility Of Technical Systems
	B.3.3 Flexibility Of Space

Category	Subcategory
B PERFORMANCE REQUIREMENTS	
B.4 Safety Requirements	
	B.4.1 Safety Of Site
	B.4.2 Safety Of Building
	B.4.3 Safety Of Technical Systems
	B.4.4 Safety Of Storey
	B.4.5 Security Of Space
	B.4.6 Accident And Catastrophe Risks
B.5 Aesthetic Requirements	
	B.5.1 Visual Requirements
B.6 Accessibility Requirements	
	B.6.1 Building Accessibility
	B.6.2 Storey Accessibility
B.7 Circulation Requirements	
	B.7.1 Circulation Area
	B.7.2 Circulation Systems
C COST REQUIREMENTS	
C.1 Life Cycle Cost Requirements	
	C.1.1 CostRequirements
D ENVIRONMENTAL REQUIREMENTS	
D.1 Sustainability Requirements	
	D.1.1 Energy Insulations
	D.1.2 Energy Requirements
	D.1.3 Environmental Pressure

Category	Subcategory
CONFORMITY REQUIREMENTS	
Location Requirements	
	Internal Infrastructure Requirements
	External Infrastructure Requirements
	Site Design Requirements
Space Requirements	
	Functionality requirements of the spaces
	Requirements for quality of construction and finishes
Electrical System Requirements	
	Electrical System
Plumbing System Requirements	
	Plumbing System
PERFORMANCE REQUIREMENTS	
Safety Requirements	
	Safety Of Site
Aesthetic Requirements	
	Visual Requirements
Accessibility Requirements	
	Common areas Acessibility
	Housing Accessibility
Circulation Requirements	
	Circulation Systems

CATEGORIES NOT USED

SIMILAR CATEGORIES

CATEGORIES ADDED

(a) (b)

Figure 1: requirements structure. (a) requirements categories (adapted from KIVINIEMI, 2005) (b) requirement categories adapted to social housing programs.

In the structuring adapted to the social housing projects (Figure 1b) only requirements related to the tangible products were used: housing unit, common use areas and surroundings. Requirements that are related to intangible products like services (social project and use management), presented in Figure a, were not considered in the requirements structure, since those requirements cannot be verified during the project's feasibility analysis. The verification of the service requirements may occur during the occupation of the project through evaluations conducted with the final users.

The category Space Requirements was considered in the structuring, but with changes in the names of the subcategories: Space Program Instance, Space Program Type, Space Program Fixtures (Figure b).

Although Kiviniemi (2005) does not consider structures and systems requirements, the categories Electrical System Requirements and Plumbing System Requirements (Figure b) were considered in this study. The insertion of those categories is due to existing electrical and plumbing installations requirements verified in the projects during the social housing project analysis process.

With regards to performance requirements, the category Indoor Condition Requirements (indoor climate/environment, acoustics and lighting) was not considered in the scope of this study (Figure a). For this category it is necessary to use specific software to simulate and measure the performance of the building's indoor conditions.

The categories Service Life of Building and Service Life of Technical Systems, as well as the category Adaptability Requirements (flexibility of the building, of technical systems and spaces) (Figure 1a) were not considered in the structuring, as no specific requirements were defined for those categories. However, requirements related to the service life might be relevant for the operation and maintenance of the project. The adaptability requirements are also important and should be considered by public policy. An example of that is the current production of projects in structural masonry, hindering the flexibility of the spaces. Flexibility can be important, for example, for a family that have a member with special needs, since it is necessary to make alterations on walls to reduce one space and extend another.

From Safety Requirements, only the subcategory Safety of Site was considered. However, there are specifications such as the installation of a door phone and the planned installation of lightning rods that could be, respectively, in the subcategories Safety of Building / Space (control of access) and Safety of Building. These two examples are present in the category Electric Systems Requirements by choice of this paper's author.

Accessibility requirements were considered, but the names were altered in order to adjust to the social housing product. Therefore, the subcategories are named Common Areas Accessibility and Housing Accessibility (Figure b).

The last category considered in the structuring of the requirements is Circulation Requirements, which include the requirements of the circulation system, like elevators, for example (Figure b).

The categories Cost Requirements and Environmental Requirements were not considered in the structuring of the requirements (Figure a). There is a guide to produce more sustainable constructions, named *Selo Casa Azul*, created in 2010 by Caixa Econômica Federal. However, it is only rarely used by construction companies. The requirements in this certification are not required by the *Minha Casa Minha Vida* program and for that reason they are not in the scope of this study.

Figure 2 presents the detailing of the Location Requirements. It is possible to see that it is divided into four columns: (i) level 1, formed by the main category of Location Requirements; (ii) level 2, formed by subcategories of requirements; (iii) level 3 includes a description of requirements and attributes; and (iv) column 4 lists the attributes and minimum specifications of the *Minha Casa Minha Vida* program and CAIXA's specifications.

Requirements category - Level 1	Requirements subcategory - Level 2	Requirements description / attributes - Level 3	Attributes / specifications of PMCMV - Level 4	Product object
Location Requirements	Project Infrastructure Requirements	Site lighting	Plant lighting technique favoring energy efficiency	Site
		Site drainage	Drainage	Site
		Gas Supply Infrastructure	Individual metering of gas (not required for metropolitan area)	kitchen
		Water Supply Infrastructure	Elevated reservoir of potable water	Coverage
			Provide the reservoir enclosure with protection for pumps	Site
			Individual measurement of water	Site
		Sewage Supply Infrastructure	Solution sewage	Site
	Public Infrastructure Requirements	Electricity network and lighting	Public Electricity network and Public lighting	Public area
		Sewage Supply Infrastructure	Public sewage	Public area
		Water Supply Infrastructure	Water supply system	Public area
		Road Infrastructure	Paving of sidewalks, guides, gutters	Public area
	Site Design Requirements	Min. Bike Parking Spaces	Bike Parking Spaces	Site
		Min. Motorcycle Parking Spaces	Motorcycle Parking Spaces	Site
		Min. Car Parking Spaces	Car Parking Spaces as defined in municipal legislation	Site
		Min. Green Site area	Provide grass in places not paved	Site

Figure 2: location requirement structure of social housing projects

The last column, Product Object, indicates with which product objects (parts of the project) the requirement information is related. This relationship is important when all the requirements have been entered in the requirements management software, dRofus, and connected to the product model (Figure 2).

Figure 3 illustrates some of the information that was represented in the software dRofus. Level 1 (requirements categories) is the content of RDS (room data sheet), while the other levels of requirements and specifications are inserted in those sheets.

Once the requirements and specifications have been included in dRofus, a connection can be made between those requirements and the product model (the architectural design modeled in Autodesk Revit). This product is a specific housing scheme. The connection between requirements and the product model allowed a comparison to be made with the initial design.

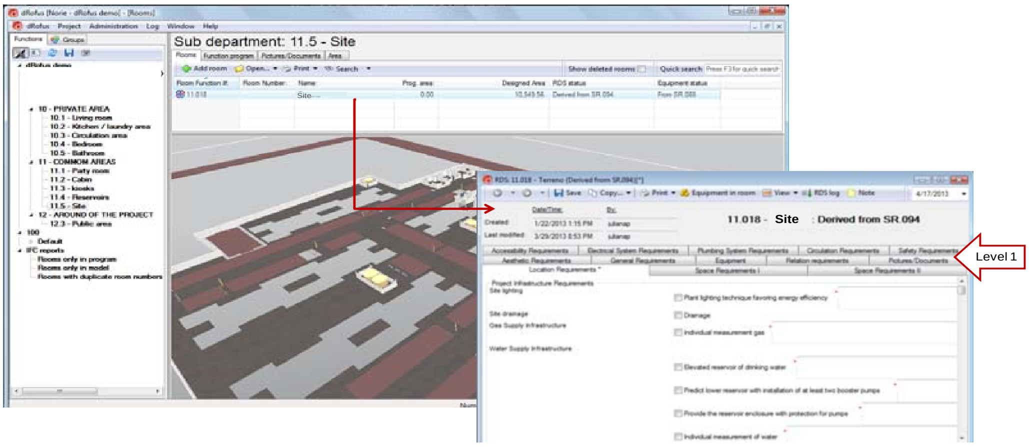

Figure 3: requirements stored in dRofus

CONCLUSIONS

This study highlights the importance of managing social housing clients requirements in order to assist decision making and allow the development of better design solutions. In order to do that, the modeling social housing clients requirements with the support of BIM has been proposed.

This modeling pointed out several utilities: (i) assist the design evaluation process standardization, (ii) increase the evaluation criteria scope, (iii) facilitate the requirements availability to designers, (iv) reuse of information in different social housing programs, (v) control the requirements evolution, and (vi) assist the requirements visualization and organization. However, the requirements modeling application in social housing is a complex task because it involves the need to purchase BIM tools and training the professionals. Moreover, the funding agency should require designs in IFC standard.

The requirements modeling process involves a stage of identifying the clients' requirements, structuring, as well as connecting the structured requirements with the project's software, which represent models of the building product. Through the modeling of clients requirements it is possible to make available, control, track and check the requirements with the design solutions adopted, and thus assist the decision making of the different stakeholders involved in the development process of social housing projects. The use of the requirements modeling can help to generate value for the social housing project by meeting the needs and expectations of the final clients.

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