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Modular Coordination—Architectural Design Associated to a BIM Application

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Abstract

To optimize the design and execution of an enterprise, the first design solutions can be defined based on the concept of modular coordination associated with the interoperability and efficiency of BIM tools. The objective of this paper was to apply the concept of modular coordination associated with BIM in the architectural design process of a residential condominium, to explore the possibilities of project customization. To this end, two work fronts were adopted, the development of the design flexibility and customization process and the development of an application on the BIM platform. As a result, the modular coordination applied to the design and customization, associated with the customization of the BIM tool, proved to be viable, considering the expectations of the company studied about the rationalization of the design and execution processes. The customization of the space by the client added social value to the project from the beginning, and the predefinition of the finishing and construction system added economic and environmental value to the project. It was also verified that the use of modular coordination in the development of the architectural project of a residential condominium generated several benefits, highlighting the flexibility and customization of the project for each residence, the viability of using the BIM tool, and the rationalization of the construction process.

Keywords: modular coordination, architectural design, BIM

1. Introduction

The design phase refers to the planning of the enterprise project, which is defined by the owner and designers, based on the client and market's needs. It involves complex and distinct activities, to plan the execution and maintenance of the project, to perform feasibility studies and the potential of success of the enterprise. In these studies, it is estimated the product cost and the expected financial return. Therefore, it is necessary a basic technical planning, which is based on the first project solutions.

In order to optimize the concept and execution process of a project, the first project solutions can be defined based on the modular coordination process, which according to Barboza et al. (2011), allows relating the project measures to the production measures. Summarizing, modular coordination is a standardization system based on dimensional coordination system for sizing the building components and placing them within a reference system (Singh, Sawhney, & Borrmann, 2015a). It promotes benefits in terms of increasing communication and integration between the agents involved in the production chain, approximation of design and execution stages, rationalization of the construction and the increase of flexibility of physical arrangements of the same enterprise, directly affecting the designer's activities.

However, the involvement of designers in 2D drawings, in data processing and information exchange is still elevated, requiring unnecessary effort and time. According to Singh, Sawhney and Borrmann (2015b), when designers engage themselves in high value-adding tasks such as decision making, analysis of alternatives and experimentation with shapes, they are also responsible for low-value production-related tasks such as data processing, information retrieval, design-documentation and coordination.

Thus, the induction of BIM authoring tools has enabled the industry to mobilize its resources from production-oriented tasks to decision making tasks (RICS, 2014), allowing BIM's personalization through tool making process, making the design process more efficient and reducing the efforts expended by designers on

repetitive and redundant tasks. In this context, the aim of the presented paper was to apply the concept of modular coordination in the process of developing a residential condominium project, in order to explore the possibilities of customization of the project.

Therefore, the use of the modular coordination concept provides professionals with agility, efficiency, and productivity, resulting in the delivery of the final product in a shorter period, benefiting the companies where the method is applied.

1.1 Modular Coordination

There is no universal definition of modular coordination. Greven (2007), defined as "the ordering of spaces in civil construction". Also, conforming to Lucini (2001) is a "technique that allows defining and relating dimensions of materials and components in design and work, through modular measures organized through a spatial reference grid".

According to NBR 15873 (ABNT, 2010), modular coordination is defined as dimensional coordination using the basic module or a multi-module. The module is the basic unit of measurement for the dimensional coordination of components and parts of the construction, which consists of the smallest linear unit of modular coordination, represented by the letter M, whose normalized value is M = 100 mm.

For Baudalf (2004), the module performs three essential functions:

- Common denominator of all ordered measures;
- Unit increment of all and any modular dimension so that the addition or the difference of two modular is also modular;
- Numeral factor, expressed in units of the adopted measurement system or the ratio of a progression.

The modular measure guarantees that each component has sufficient space in the construction work without invading the modular measure of the adjoining component (Lucini, 2001), these components of a modular project are called "modular building components" (ABNT, 2010). Based on this modular measure, modular coordination makes it possible to reduce the variety of measures used in component manufacturing, reduce cuts and adjustments of components and constructive elements, increase component interchangeability, and increase cooperation among the various agents of the construction production chain (ABDI, 2009).

According to NBR 15873 (ABNT, 2010), modular coordination applies to the project of all types of buildings, to design and production of all types of building components and the construction of buildings. Thus, according to ABDI (2009), modular coordination presents potential for the optimization of the compatibility of construction elements and components, to achieve the rationalization of building construction.

It can be generally considered that Modular Coordination aims to rationalize construction. Specific objectives include: promoting dimensional compatibility between building elements (defined in building designs) and building components (defined in product designs of the respective manufacturers), in addition to particular or restricted production arrangements. Also, modular coordination influences the constructive process from the design phase of the components to the phase of application in the buildings. According to Panet et al. (2007), in the design stage, modular coordination allows a clear systematization in the conception and execution through the rational ordering of spaces and its components. In the execution stage, modular coordination brings benefits to the constructability, influencing waste reduction, increase productivity and qualification of the construction industry (Greven & Baldauf, 2007).

Another relevant aspect is the possibility of using modular coordination associated to BIM, which according to Romcy (2012), promotes benefits such as: automatic generation of projects in accordance with its rules, through the insertion of proper parameters; facilitating the visualization of how modular coordination can be employed, since the parametric model allows the anticipation of the execution process in a virtual simulation; and the creation of a collaborative environment, which would encourage the inclusion of all agents involved in the construction work to adopt such dimensional referential.

1.2 Building Information Modeling—BIM

The National BIM Standard (NBIMS, 2007) defines BIM as a digital representation of physical and functional characteristics of an enterprise. For Krygiel and Nies (2008), it is the creation and use of coordinate and consistent computational information in the design of a building—parametrical information used in the project's decision-making process, production of high-quality documentation, prediction of building performance, cost estimative and construction planning.

Suermann and Issa (2009) point out that BIM represents a process of information sharing about an enterprise, forming a reliable base for decisions during the life cycle of the enterprise. Which means, the BIM is the process of generation and management of the enterprise data throughout its life cycle (Lee, Sacks, & Eastman, 2006), which approach the building as a tridimensional model, integrating cost and deadline issues, from the conception phase, through the execution and maintenance phases as well as providing tools to the interaction of all those involved in the process.

It is a fact that the construction sector, as well as the architecture industries are always seeking cost reduction and, allied to this, aim to increase productivity, product quality and reduce project delivery time. According to Eastman et al. (2011), the tool in question has the potential to achieve such goals, since computer programs are used to generate models of varying dimensions, which simulate the planning, design, construction and operation of a facility. Also, according to the author, besides bringing great efficienty, the tool provides, it provides harmony among professionals, who previously saw themselves as adversaries.

It has been reported that BIM was first used to minimize spatial conflicts and shortly thereafter to enable construction project management. Several authors then combined BIM with location tracking, augmented reality, gaming technologies, and virtual prototyping technologies. Later technologies and new construction methods were developed, the aim of which was to improve safety management throughout the project life cycle. In this way, it is indicated that BIM is the technology that raises most in the construction sector. Despite being a new approach technology in design, construction and facility management, it facilitates the exchange of information and data across computers (Eastman et al., 2011).

Through BIM technology, the entire construction process can be simulated during the planning period. Spatial matters, lighting, operation and layout of installations, quality of materials, constructive process, among others can be visualized. According to Sabol (2008), BIM can provide the exact and automated quantification of the enterprise, collaborating in the significant reduction of the cost estimative.

BIM interferes directly in the traditional design process, where the architect is primarily responsible for the conception of the enterprise, passing on responsibility of the subsequent stages to other planners. It is a relatively new technology in a traditionally conservative sector. This is a substantial change from the traditional use of computational tools to support the design process, as it offers a dynamic virtual information model, used by the project team. It includes drawings, contract details, environmental conditions, project delivery processes and other specifications to the overall quality of the construction (Vasconcelos, 2013). Corroborating this information, the authors Carmona and Irwin (2007) state that BIM is a virtual process that encompasses all aspects, disciplines and systems of an installation in a single virtual model and enables the collaboration of all team members, more effectively compared to traditional processes. Therefore, at the same time as the model is created, team members constantly adjust their parts according to project specifications and changes to ensure an accurate model prior to physical initiation.

Additionally, the information of the BIM allows a database capable of making the management process better and more consistent, even after the fulfillment of the building project (Romcy, 2012). From the development of a 3-D or n-D model, according to the level of information inserted in the model, it is possible to generate an automatic updating of complementary projects, decreasing the work time of project teams and possible failures (Pereira, 2015).

The compatibilization from a 3-D model is more advantageous than in the 2D model, since it is possible to overlap different projects, such as hydraulic, electric and structural installations, and analyze if there are any conflict points. Failure anticipation allows the study of solutions still in the planning of the construction work, avoiding unnecessary costs (Scheer, 2007). The BIM tools allow the design team to incorporate the domain of specific knowledge to ease the modeling process. The parametric modeling feature enables the user to create geometrical constraints and easily manipulate the design alternatives within a set of standards. Various options to adjust the parametric values make the modeling process more flexible (Singh, Sawhney, & Borrmann, 2015b).

Thus, it is known that modular coordination main strategy is interchangeability, characterized by the compatibly between elements and constructive systems, due to its multiple dimensions of a module (Greven & Baldauf, 2007). Furthermore, the BIM is characterized by the use of parametric modeling and interoperability, and the integration from BIM and modular coordination strongly influences the optimization and systematization of information at different levels of the production chain.

2. Research Methodology

This paper is a case study in which the application of modular coordination in the design phase of a single-family

residential condominium project was analyzed, associated with the customization of the BIM tool. The methodology followed the steps illustrated in Figure 1.

Figure 1. Methodology following steps

Initially, a research was made in the scientific literature, through papers in journals, thesis, dissertations, technical standards. References that deal with modular coordination, architectural designs and application of BIM technology were analyzed.

The second step was the selection of a project to be built. The project selected is a is a high standard residential condominium located in the municipality of Camaragibe-Brazil. The construction company sells only the plot of land, or or the plot of land and the built house, the latter being the focus of the study.

The condominium is surrounded by an Atlantic Forest reserve. The development presents itself as an ecological condominium, aiming at interaction with the environment without compromising the regional ecosystem. It has 215 lots ranging from 600m² to 900m². The building system chosen was structural masonry, construction technique construction system in which walls perform as partition and structural elements, with prefabricated blocks and in standardized dimensions, in order to facilitate the modulation.

Once the project was chosen, it was necessary to calculate the maximum construction areas for each land in compliance with the restrictions of the municipality's legislation. For this, the conditions were the obligatory setbacks and the maximum occupancy rate. A set of space arrangements was prepared, the size of the house and consequently the occupation of these spaces will be determined by each client.

After defining the location of the spaces on the ground, a team of architects was responsible for developing the flexibility and customization of the architectural project. Possible layout options were developed from the development and combination of modules, considering the maximum construction area. Aiming to meet the different needs of buyers in relation to the environments of future homes, the third step is the flexibility of spaces with the creation of proposal of different combinations of environments through 96 modularly coordinated spaces.

To operationalize the customer's choice of project, a BIM application was developed, integrated with Autodesk Revit ™ software, by the professional's team. The layout of the houses is assembled similar to a "puzzle", where it will be possible to make the choice of the project in a didactic and dynamic way. Through the proposed software, it is possible to select the type of finishing and architectural style of the house, with three options for selection. By the end of the project selection, all the architectural designs and the work quantitative table will be prepared with their proper budget worksheet.

The entire process was followed and monitored by the researchers in collaboration with the company. Having concluded these steps, a discussion was held to evaluate the advantages of the new process using the BIM platform with the proposed software combined with the modular design coordination in comparison with the traditional methods previously practiced by the construction company.

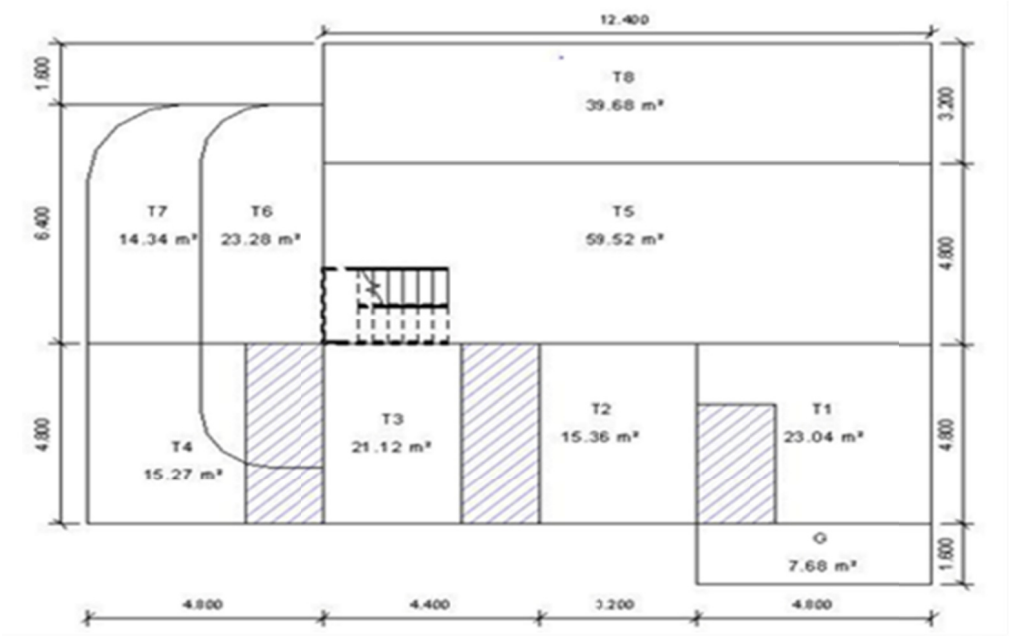
3. Results

3.1 Flexibilization and Customization of the Architectural Project

According to research performed in the launch of the studied enterprise, it was observed different characteristics and lifestyles among the target audience. Therefore, flexibilization and customization of the architectural project was necessary, in order to meet the needs and desires of each customer.

In that matter, it was elaborated a "grid" of modularly coordinate spaces to be occupied by the construction. It is important to emphasize that it was considered the maximum area of construction allowed by legislation, and the typologies for one or two floors. Figure 2 represents the spaces of the ground floor and Figure 2 represents the

spaces of the upper floor.



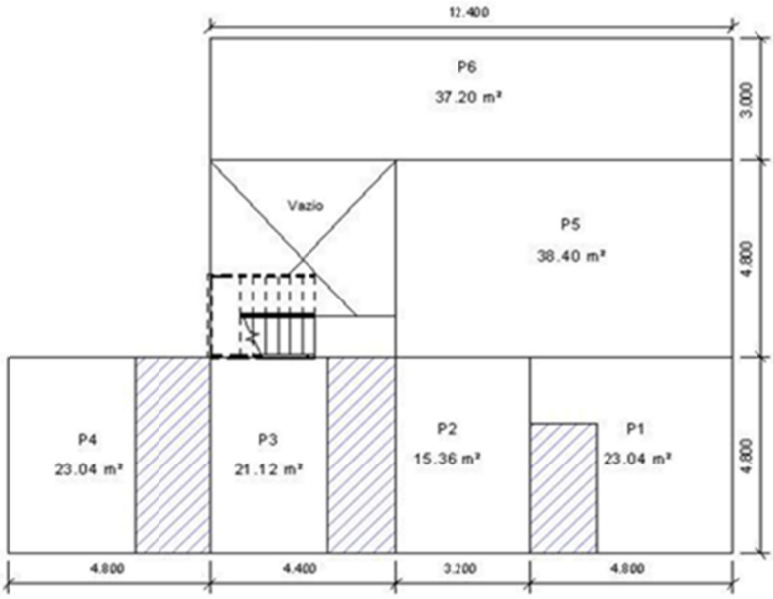


Figure 2. Spaces on ground floor and 1st floor

These spaces allow a large quantity of environment combinations, relying on customer's choice, resulting in a customized plan for each client. In a given space, it is possible the choice of the environment, whether is an office, a room or the extension of a suit, as an example.

After the definition of these modular coordinate spaces of the lot, a team of architects elaborated 96 environments, corresponding to modules. The modules combined in the spaces generate numerous combinations of different plans. It is worth mentioning that a space holds specific environments that "fit" into its shape. Each environment was designed in a way that the flexibility of the projects will be guaranteed in an orderly manner, so that there is no incompatibility in the execution process. Figure 3 illustrates environments to be embedded in the

spaces of the first floor.

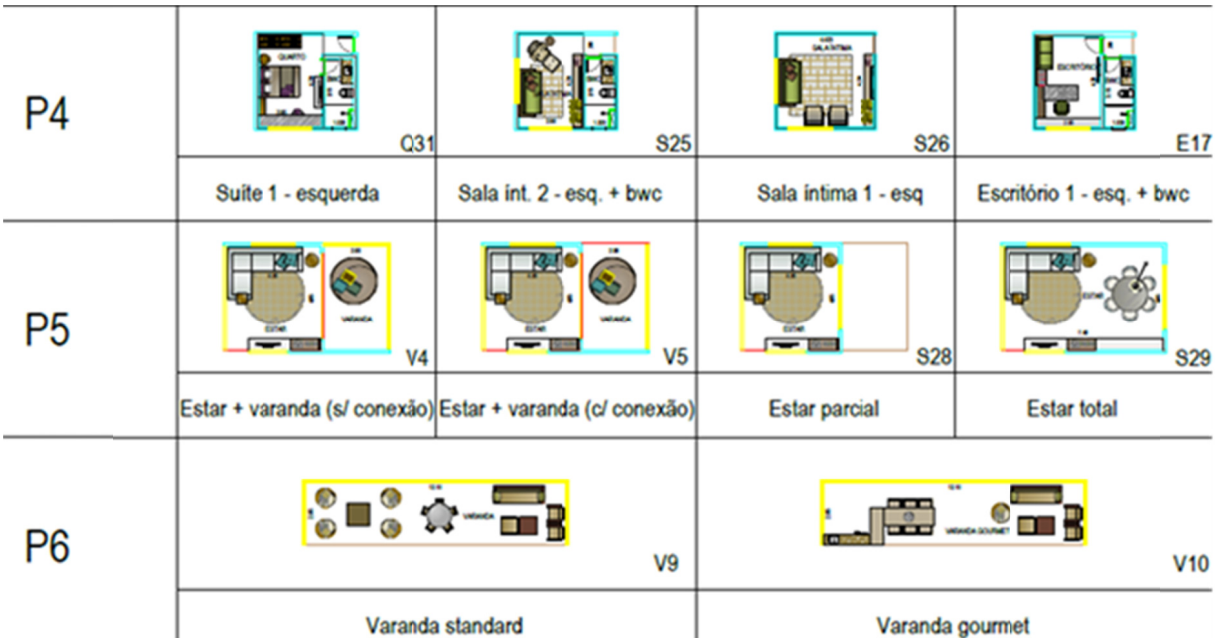


Figure 3. Environments of the 1st floor

Source: Archives of the construction company.

Environments Q31, S25, S26, and E17, as an example, are specific for the P4 space, as well as environments V4, V5, S28 and S29 for the P5 space, and so forth. Each space has several environment options in varied layouts. Environments that occupy more than one space are called special environments. Figure 4 illustrates independent environments and their integration in the space.

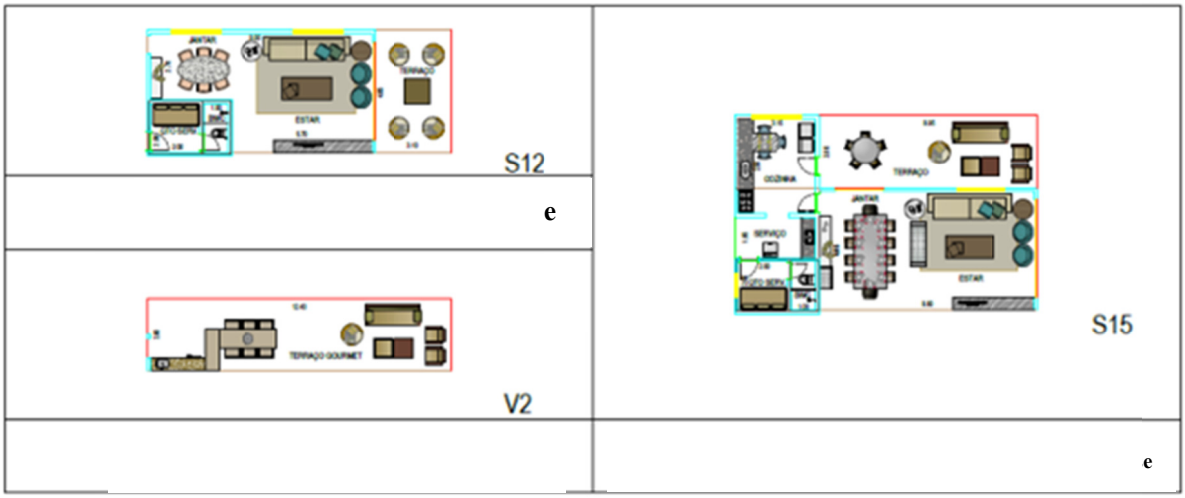


Figure 4. Environments of the 1st floor

Source: Archives of the construction company.

It is noteworthy that project modulation is directly related to the constructive modulation, based on the structural masonry system, in order to rationalize not only the project process but also the constructive process.

3.2 BIM: Personalized Application

In the application, the floor plan of the residence is "assembled" similar to a puzzle, in which it is possible to choose the project in a didactic and dynamic way. The floor plan is fragmented, so that when clicking in one of the spaces, compatible environments are presented. As the process was developed in the BIM platform, when finalizing the project choice, the client visualizes the entire architectural project, as well as the quantitative table of the construction work, according to the budget.

Initially, each client who owns a plot in the condominium had their access registered. Upon access, the customer is questioned about the residence style, if rustic, classic or modern, that have their particular finishes. Figure 5 illustrates the phase of choosing the residence style.

Figure 5. Residence style choice.

Source: Archives of the construction company.

Once the style is chosen, it is presented the space "mesh". Clicking on the spaces makes it possible to visualize the environments that fit in each space. This stage of the process is responsible for defining the area of the residence, which spaces will be occupied and, consequently, which environments will compose the spaces and whether or not there will be a swimming pool.

The building area is displayed during the project selection, so when filling the spaces with the chosen environments, the area is updated. When exceeding the maximum construction area, the user is notified, and the project is saved only by respecting this parameter. Figure 6 illustrates a screen example of project choice.

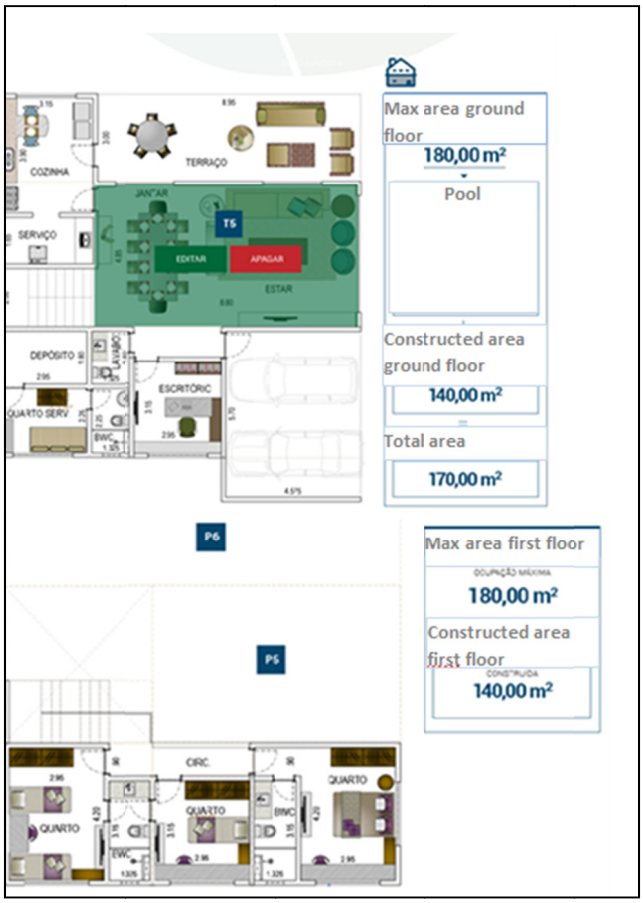


Figure 6. Example of project choice

Source: Archives of the construction company.

Once the floor plan is defined, the finishes choice phase begins. Three finishing groups are offered for each of the three previously mentioned styles. Each finishing group involves specification of floor covering, wall topcoat, lining, internal coating/painting, sanitary ware and metals. It is a type of floor covering, façade finishes, window frames, roofing, staircases, and porch structure. Each residence style combined with a finishes group generates a different option for the client, which also differs by their costs.

Once the finishes are chosen, the user is lead to a summary screen, in which the overview of the construction work is presented. The summary contemplates all the project's environments and its respective floor plan, the total of constructed area, with the description of the ground floor area, first floor, and swimming pool, if any. It is also presented the residence style and the type of finishes that were chosen. After confirmation of the initial project customization in the summary screen, all the data selected by the user is sent to the construction company, being the basis for the architectural design generation and construction budget.

4. Discussion

Modular coordination applied to the development and customization of the architectural project, associated to the BIM tool personalization, proved feasible, meeting the expectations of the studied company, regarding the rationalization of the design and execution processes.

Since the company can build houses on 215 lots, it would not be economically feasible if each condominium client carried an individualized project, elaborated by a different designer, since the project process would be extensive and the activities management would act punctually way in many different work fronts. To achieve that, a partnership was established between the construction company and the architects responsible for the design of the constructive modules, so that any necessary adjustments were foreseen in the construction cost. Thus, new hiring of architects for each project is avoided which gains time in the design phase and reduces workload for project management, since a single team designs the projects.

For the project customization, corresponding to the beginning of each individualized project, the user uses the BIM application, which later, the architectural team aligns the project defined by the user to the specific technical information for legal approval and obtainment the necessary licenses for the construction activities. Also, to optimize the design process and less costly to the company, it is offered to the user a wide range of customization options, through an interoperable application. Space personalization by the customer promotes its identification with their future house, adding social value to the project from the beginning.

Concerning the construction system adopted and the predefinition of finishes, the company reduced the use of different coatings used in the construction work and used the structural masonry in a rationalized way. Thus, the phase of purchase of the material was reduced, since the purchase of a certain type of material in large quantity means money saving on freight and waste reduction in the execution of the construction work, adding economic and environmental value to the real estate development construction.

Finally, it is intended to use this case study as a basis for new applications, in an improved way, with to develop a standard process structure for the development of architectural and engineering designs, with a modular coordination approach, applicable to the construction sector. However, understanding that modular coordination presents amplitude, the present study was limited to the purpose of customizing the architecture design.

5. Final Considerations

Although modular coordination in Brazil is still not widespread for all practical purposes, the present paper substantiates that the identity parameters can be associated with the construction objects, through BIM tools, in order to optimize the design and construction processes. It was verified that modular coordination and the BIM platform could act together in a positive way in the integration and optimization of data while allowing a flexibility of elements and measures combinations, facilitating the generation of new solutions and adaptations.

The results of the present study verified that using modular coordination in the development of the architectural project of a residential condominium generated several benefits, highlighting the flexibilization and customization of the architectural project of each residence, the feasibility of the use of BIM tool and the rationalization of the constructive process.

As the public of the enterprise is very diverse, the company's proposal to encourage project customization allows the best adaption to the lifestyle of users. The more involved the clients, the greater value can be added to the final product. The use of BIM, in a personalized way, was necessary to operationalize the flexibilization and customization of the architectural project. Through the information generated by the tool, the company was able to optimize the project process. The rationalization of the constructive process was possible through the choice of structural masonry and the pre-setting of finishing materials by the client in the phase of customization of the architectural project.

Considering that modular coordination can be present from the design phase of the project to the execution phase, this research believes that modular coordination can considerably improve the design and execution processes, directly impacting technological, economic and environmental aspects. Modular coordination associated to the BIM tool contributes to the increase in productivity, improving integration of projects team, increase communication and marketing, avoiding improvisation and re-work and reducing waste.

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