Online Platform for Home Design and Project Management in Modular Construction

Vinicius Belloli dos Santos
Instituto Politécnico de
Bragança
Bragança, Portugal
a52554@alunos.ipb.pt

Enzo Dornelles Italiano
Instituto Politécnico de
Bragança
Bragança, Portugal
a52549@alunos.ipb.pt

Paulo Alves
Research Centre in
Digitalization and
Intelligent Robotics
(CeDRI), Instituto
Politécnico de Bragança
Bragança, Portugal
palves@ipb.pt

José Eduardo Fernandes
Research Centre in
Digitalization and
Intelligent Robotics
(CeDRI), Instituto
Politécnico de Bragança
Bragança, Portugal
jef@ipb.pt

Fernando Alves Pimenta
CICon – Center for
Innovation in Construction
Vila Pouca de Aguiar,
Portugal
fernando@cicon.pt

Nelson Bento Pereira
Graniparalelo Construction
Vila Pouca de Aguiar,
Portugal
research@graniparalelo.com

Nuno Oliveira Ferreira
CICon – Center for
Innovation in Construction
Vila Pouca de Aguiar,
Portugal
nuno@cicon.pt

Abstract — **The construction industry is currently facing the challenges of intensifying global competition, increasing market volatility, increasing product differentiation, and shortening product life cycles. In this context, versatile production concepts with modular structures promise a better adaptation to these dynamic boundary conditions in terms of quantity production, product variety, and manufacturing location. Modular construction has significant advantages over traditional on-site construction in terms of material efficiency, safety, and sustainability. Therefore, specialized software for building design is one of the critical aspects of modular construction. This work presents the development of an online platform for the design of buildings using modular construction. The main features of this platform are the 2D home design with 3D visualization, using BIM approaches, the validation of architectural rules and system limits taking into consideration the design and legal framework, and the management of orders and workflows for sustainable construction. The validation of architecture rules and system limits allows the use of the platform by final clients to design their houses and obtain the budget and the construction viability based on modular construction. After, an architect can assume the final design and legal approvement of the project.**

Keywords – Modular construction; online project; home design; BIM; sustainability, digitalization in construction.

I. INTRODUCTION

Modular construction refers to a construction process where components are manufactured in a factory and taken to a construction site for installation. It offers significant advantages over traditional on-site construction, such as faster and safer manufacturing, better quality control, and lower environmental impacts, leading to sustainability benefits in terms of material efficiency, reduced on-site waste (up to 90%)[1], and improved working conditions [2,3]. The use of modular construction technologies can reduce construction time by 50% and cost savings by 20% based on a case study of current projects. The prefabricated house concept is not new, but its technology, economic needs, and changing mindsets have attracted an unprecedented wave of interest and investment. It is expected to supply a solution to the affordable housing crisis by making housing available quickly and for a lower budget [4].

Modular construction offers several advantages due to the controlled environment in which the modules are fabricated. This allows the modules to be built to precise specifications, using standardized components that can be easily assembled on-site. As a result, safety is improved, errors during construction are minimized, and there is greater flexibility in design and customization. In addition to these benefits, modular construction also enhances sustainability by reducing transportation emissions and waste during the off-site production process [2].

To fill in the gaps of specialized software for modular construction, the development of this project was necessary to develop an online platform that supports 2D design and 3D visualization and implements the rules and requirements necessary for modular construction.

This platform was developed in the context of MICADO Project - Modular Insulated concrete core - advanced and optimized panelized production system. MICADO proposes developing a new advanced production system for buildings, comprising components produced in autonomous manufacturing facilities and assembled on-site. Sustainable architecture and building rehabilitation are essential areas of application of new modular construction software with multiple functionalities to assist in designing, validating, and delivering components for this new construction area.

The document was divided into 6 sections so that it was possible to focus on some parts of the work more punctually and

objectively. Section II discusses related work and existing web-based home design platforms, section III addresses the requirements that the platform, section IV addresses the implementation details of the Frontend part of the application, section V discusses the details of the implementation of the backend and the section VI presents the conclusions.

II. RELATED WORK

In modular construction, Hořínková [5] presents its advantages and disadvantages, explaining the several factors of modular construction, its risks and gains, and how there is still a particular bias about modular construction by members of the construction community. The benefits of prefabrication and modular construction compared to the conventional method are the lower global impact on the environment, economy and society, and consequently on the sustainable development of construction.

Karthik, Sharareh, and Behzad [6] refer to the benefits and limitations of modular construction, dividing it into classification categories. The challenges in modular construction are also pointed out, as well as the mitigation of some problems found by the authors. On Building Information Modeling (BIM), Lu and Korman [7] state the advantages of using BIM in modular construction and how it can be helpful for process improvement.

Volk, Stengel, and Schultmann [8] argues that BIM can be seen from a narrow and a broader perspective. BIM in a narrow sense ('little BIM') comprises solely the digital building model itself in the sense of a central information management hub or repository and its model creation issues. Commercial BIM platforms offer integrated data management, component libraries and general functionalities. Widespread differentiations of BIM are 3D (spatial model with quantity takeoff), 4D (plus construction scheduling) and 5D (plus cost calculation).

Campbell [9] discusses implementing BIM in the construction industry and for the Web3D development community, explaining how the tool can help in integrating the fragmented industry, eliminating inefficiencies and redundancies, improving collaboration and communication, and enhancing overall productivity.

BIM, digitally representing the physical and functional information of construction projects, is essentially a shared database that can facilitate the whole process of managing the building life cycle. BIM has enabled the digital management of the full life cycle of buildings, including the design, construction, operation, management, and maintenance phases of construction projects, which can effectively improve the progress and efficiency of such projects, control their costs, and reduce risks [10].

Based on simulation and visualisation characteristics, the implementation of BIM technology has made a great contribution to improving the efficiency of the construction industry by increasing collaboration between stakeholders [11].

The digital building model is one of the most relevant components of BIM for the design of 3D model that contains detailed information about the physical and functional characteristics of the building. The use of web tools in the design of 3D models brings new opportunities for information sharing and collaboration. Some examples of web tools for the collaborative design of buildings are SketchUp, Homestyler and React Planner.

SketchUp is a dynamic software program that is used to quickly compile, modify, and construct 3D modeling image. SketchUp software were developed and marketed by Google and Trimble Inc. This software usually used in the fields of architecture, design and engineering [12]. SketchUp was the first web-based 3D modeling tool and is compatible with BIM using plug-ins.

Homestyler[13] is a platform developed by Alibaba and Easyhome New Retail Group. This platform allows the design of a home, including interior and external areas, using a wide range of components and textures with a modern design and many visualizations with light depending on the chosen environment. It is also possible to download rendered images from each area. The site has subscriptions to release more complex models and unlimited renders, and currently, the platform is not open source.

React Planner [14] is a drawer *React* component for buildings, developed by the Computational Visual Design Lab (CVDLAB) of RomaTre University. The platform allows a home design with a predefined catalog of ready-to-use objects, and a 3D visualization of the drawn plan. As a developer, it is possible to add more items to the catalog. The code is currently Open Source and has an MIT License.

As presented above the current platforms are not specific to the field of modular construction, bringing a challenge to validate the construction rules in this type of project. In this work, we propose the development of a web platform for modular construction based on React Planner and integrating BIM solely for the digital building model itself in the sense of a central information management hub or repository and its model creation issues, rules validation of the modular construction.

III. REQUIREMENTS

This section presents the requirements of the online platform MICADO, including the architecture, business rules, and functional requirements.

A. Architecture

The platform's architecture (Figure 1) is based on a REST API with a backend in Python and Frontend in Javascript. The selected database is a NoSQL database, since the objects of the 2D project design can be stored natively in JSON format, adding flexibility for object representation of dynamic components.

The backend has a rule-based system to manage the limits of the construction of the components and the architectural rules. The optimization algorithm for distributing components inside a container for transportation is also one of the backend modules.

The frontend has all the user interface components to interact with the backend, including the 2D project design, 3D visualization, budget, orders, and logistics. Based on the user's profile, the interface presents modules for the management of the platform with a back-office for company staff.
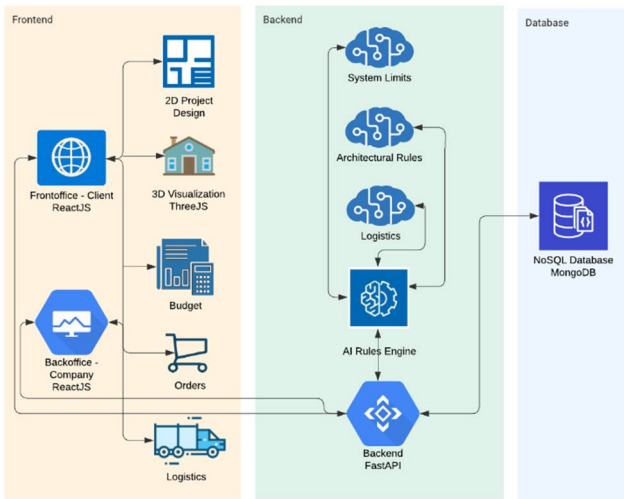
Figure 1. System architecture

B. Business rules

Business rules related to architectural restrictions derive from the general regulation of urban buildings in Portugal. Restrictions to minimum areas, wall distances, accessibility, number of rooms, and number of sanitary facilities are always validated before the construction project of the building is approved.

The properties of the material used in construction impose structural rules and restrictions. For example, the following rules need validation:

- The slabs cannot span more than x meters.

- In walls on which the slab rests, the sum of the openings in each wall must be equal to or less than x meters.

C. Functional requirements

There is a distinction between five different kinds of users, namely: visitors, customers, project technicians, sales technicians, and administrators.

Visitors must be able to find public information about the company (including contact methods), services available, modular construction, and project examples. They also must be able to register on the platform and be able to log in.

After registering, visitors become clients and must be able to manage their projects, draw buildings, submit for validation, visualize the building in 3D, request and consult the budget for the construction, and check the order status.

The project technician must be able to list projects waiting for validations, validate or edit a project, check order status, consult the budget and list required modules for the construction. The difference with the sales technician is that he is not able to validate or edit the project, instead, he must be able to confirm the order and get an optimized distribution of the modules for transportation.

The administrator must be able to manage the objects, such as equipment, furniture, modules, and materials, list projects,

consult budget and order status, and get an optimized distribution for module transportation of projects.

IV. FRONTEND

This section presents general considerations about the implementation of the frontend, as well as issues, challenges, and work realized.

A. Issues and Challenges

During the development of the project, several challenges and problems came up. One of them was how could be developed an efficient web platform for drawing plans for the modular construction area. The analysis of some possibilities was conducted to understand what will be the most viable solution, like using an open-source platform or creating a new one from scratch.

Looking for some alternatives, React Planner was the one that fit the proposal because it was already an open-source drawing software, allowing to change the platform according to the needs.

One of the first challenges and problems met after the choice of the platform was the process of understanding how the functionality worked and how it could be adapted. This led to a major study of the structure and code to get used to the original platform and to start developing the needed changes.

Another big challenge was the implementation of the new calculation functionalities, which was a challenge to get to a stable point for delivery and final implementation.

Later challenges were mostly related to adapting the platform to the new functionalities, such as calculation tools for the construction modules, intelligent validation tools, and new screens that the earlier system didn't have.

B. Work realized

Concerning the implementation of the Frontend, as it is an improvement of React Planner, the language in use is *Javascript* with *ReactJS*, which is a library for building user interfaces. It is widely used because it is simple to understand, it is possible to create personalized components, the time to render is faster than other libraries or frameworks, and other pros, which make *React* the best alternative for this project.

Included with React Planner, there is the library *ThreeJS*[15], which is a general-purpose 3D library that aims to be easy to use, lightweight and cross-browser. It uses WebGL to present animated 3D graphs.

It is interesting to highlight some features that were created and that are of interest to the client, such as allowing users to access the platform in a more controlled way, with login screens, registration, and dashboard that presents the features that each user has access to the system. Some users have higher permissions and can access areas that others cannot, as is the case of the system administrator, who can set some special system settings, such as the components available for presentation to the user.

React Planner was adapted to support modular construction (Figure 2), with the components that are necessary to design the structure of the house, including walls, windows, and doors. It

was added a new control panel for project validation and submission with the list of the components and their budget.
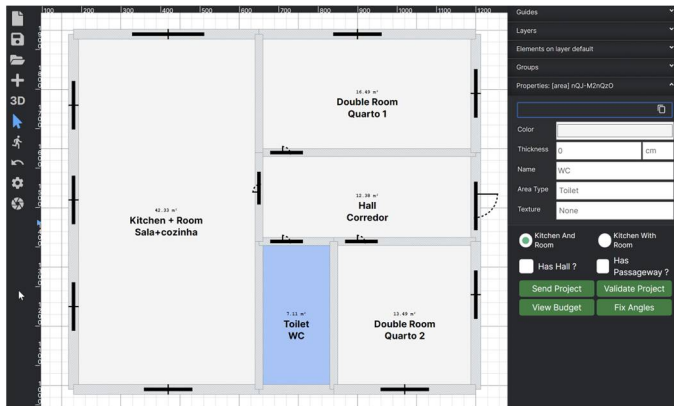

Figure 2.   2D project design

To create the floor plan, new elements were added to the existing library (Figure 3), with exterior and interior components. Interior components, like internal walls, doors, kitchen and bathroom items, and general decoration elements, are not based on modular construction. Exterior walls, doors and windows are automatically mapped to modular construction with an algorithm to calculate the necessary modules.
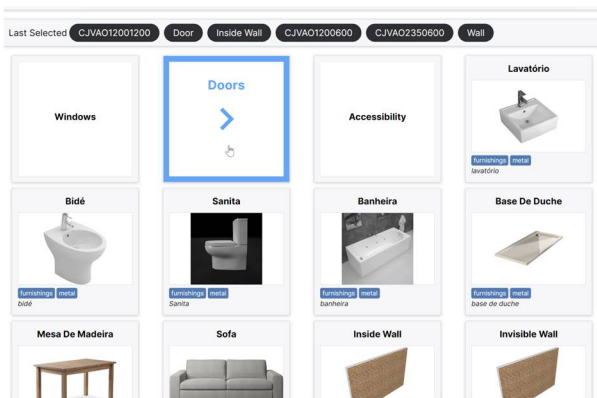

Figure 3.   Components for 2D design

An essential function in the system is the possibility of obtaining a budget based on the floor plan designed by the user. The presentation of this budget in a detailed way is the Frontend's responsibility. As such, when the user requests budget verification, the related floor plan is consulted, and the number of parts needed for the construction of his house will be returned.

One of the most essential features is the project's mandatory validation, which is done before submitting it to a technician. This part is important because it reduces the number of errors that the technician must adjust so that he/she only needs to focus on the most important details of the plant. Therefore it is the system's responsibility to have clear communication with the user so that he/she understands what needs to adjust in the design. An example of the errors returned to the user to make the validation can be seen in Figure 4.
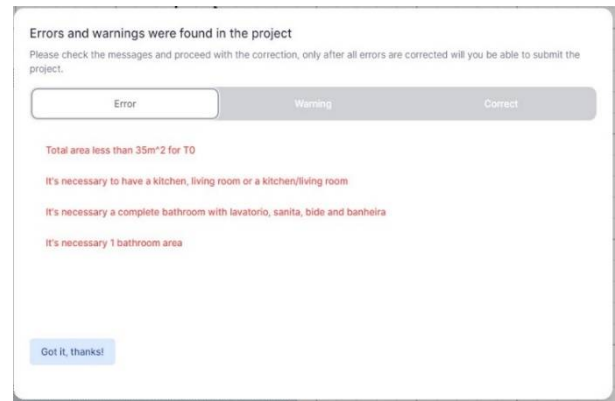

Figure 4.   Example of how validation errors are presented to the user.

For 3D visualization, it is used the ThreeJs component of React Planner, which uses WebGL for render the interior and exterior of the house with a 360 view (Figure 5).
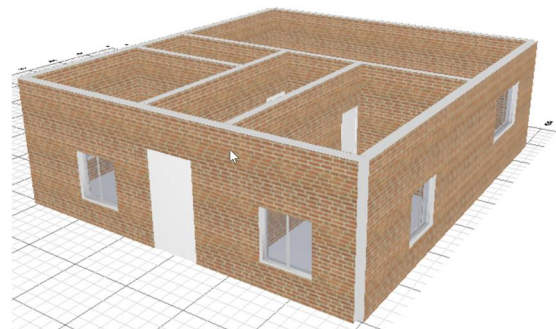

Figure 5.   3D visualization

One more of the important functionalities implemented is the calculation of the modules needed to build the residence. This calculation is based on information about the size of the pieces and the modules that can be used with these pieces. Based on this, a calculation is made and always gives priority to the biggest modules because they are cheaper.

The calculation generates a list that can be changed if the user puts doors or windows in a wall that causes modules recalculation and therefore keeping a precise pattern of what is needed to build the residence.

Figure 6 illustrates an example of how the modules are presented to the user in the system when selects a wall.
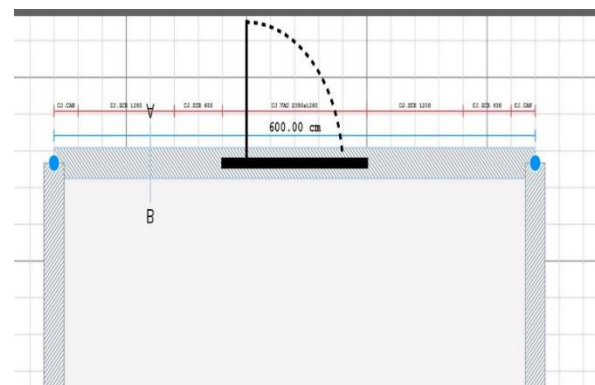

Figure 6.   Modules calculations for a single wall visualization.

V. Backend

This section presents general considerations about the implementation of the backend, as well as issues, challenges, and work realized.

A. Issues and Challenges

The development of the API was marked by two milestones. The first one occurred before the definition of a structure with pre-processed data, which would be used to validate the structural and architectural rules. At that time, only the most basic functional requirements were implemented, so the project was already operational. However, the data used in the project has a complex structure for the represented objects in the 2D design. After completing the basic components of the frontend, it was necessary to search for the best way for validate building construction rules.

The content with information about the building just gives data as geometry shapes, points, lines, and areas. Then, to validate the project, it was necessary to change this to a better format to do the specified calculations for each rule.

With the pre-processed data structure model established, the second milestone began. This allowed us to resolve most of the structural rules issues and challenges for all types of buildings. However, some remaining rules had to be validated by the project technician later, because some specific rules is not possible to be validated automatically. We consider the validation rules algorithm as an assistant that helps to reduce errors in project validation but still needs human final validation.

B. Work realized

The language chosen for the development was *Python*, version 3.10, a high-level general-purpose programming language with a large standard library that covers many areas that can be used, if necessary, in the project. The core library being used is *FastAPI*[16], a modern and fast web framework, that has all the features needed for the project.

FastAPI is a web-based Python framework that provides a layer for the 3D modelling web tool to deliver high performance and expose the functionality of the backend as a restful microservice. A novel approach to utilize the FastAPI technology is proposed such that the authentication system can handle approx. 9000 requests simultaneously. This is very fast when compared to Flask based solutions. This integration would add a strong layer of enhanced security that is entirely transparent and frictionless [17] and add an asynchronous architecture model for performance enhancement and non-blocking requests.

One of the libraries used along with FastAPI is *Shapely*. This library is used for validating the overlapping of objects by the polygon functions it has, so it is possible to create polygons for every shape in the project and then analyze the intersection of the points. Another library being used is *NumPy* which has many math functions and constants to simplify some calculations. A JOSE[18] (JavaScript Object Signing and Encryption) implementation for python is being used with *Passlib*[19] to hash the user password and store in the database.

The first tasks accomplished were related to code organization to make the coding processes faster. These tasks defined the folder structure, the design pattern, and the model of the database to be used during the whole project (Figure 7).
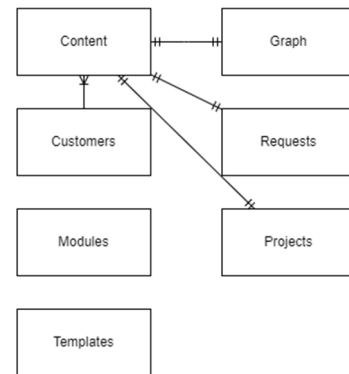
Figure 7. Simplified representation of the database collections

Afterward, the first common entities, constants, decorators, and functions were made, such as the connection to the database, endpoints for login, and token implementation to guarantee security to the system, as well as the main function to create a blank project on the database.

The data organization provided by the frontend is supported by a graph. The first idea was to create a graph to pass functions through the nodes and validate the necessary rules, but during the development other types of information were needed, making the structure lose graph properties and become a mix of a graph, linked list and simple pre-processed data.

Every vertex, line, area, hole, or item in the project has an id and it is used to locate its information in the graph. As it is a dictionary, the speed of locating a requested object is faster in terms of coding. This structure is used to validate building rules including systems limits and architecture legal requirements.

To validate the information about the building being constructed, it is converted into this graph structure which passes for some validations, e.g., number of rooms, area value, opening space for doors, walls distance, and other validations asked by the Decree-Law n.º 38382 of 7th August 1951 and its alterations.

The creation of the graph assigns the components to the graph and it is when the data is pre-processed, e.g., the direction of walls, horizontal or vertical, the angles between vertices, and the lines of the areas, becoming able to validate which walls are externals or internals.

The validation of the system consists of functions, one for each rule. Each function iterates through the keys of the graph to check the compliance of the value assigned with the underlying rule conditions. In case of non-compliance, it returns errors with changes that must be done by the person drawing the building.

All the rules were created to work for all types of houses, but some rules may not work properly if the user doesn't follow the instructions or pay attention to the platform since the calculations it does are sensitive to wrong information.

Beyond rules validation, there are other modules to complete the requirements asked, such as sending a project to review with the project technician and requesting the budget for the project,

giving the count of the pieces needed, the price, and a prediction of delivery times through the execution of the validation of the project, it is possible to verify the problems found and solve them by changing the project so that it follows the construction rules determined by the platform. If the project is not corrected it is not possible to submit it.

VI. Conclusions

Research work in modular construction tends to be more common and important, as the area has shown significant growth in recent years. It is important to support an area that can help to significantly reduce environmental impacts as well as construction costs and waste of materials.

During the development of this work, it was possible to verify the importance of the existence of a specialized platform for the modular construction area, allowing fine adjustments in the system to be compatible with the specific rules of this area. The development of this project aims to meet these goals and allow common users to have the freedom to design their own house.

This work, contributes to the research on web tools for modular construction and BIM. The developed modules of 2D home design with 3D visualization, the validation of architectural rules and system limits and the management of orders are essential for supporting sustainable and personalized modular construction using a common database.

BIM enables collaboration among varieties of stakeholders through data interoperability among different BIM applications. Currently, BIM applications involve every stage of a construction project, including conception, design, construction, and operation management. The MICADO project brings BIM framework concept to modular design, construction and management.

As future work we plan to add interoperability between MICADO platform and other BIM 3D design tools using open standards like IFC.

The delivery logistics module is being developed to optimize the transportation of pieces using containers or road transport, minimizing costs, speeding up the delivery time, and having a focus on sustainability.

The optimization of the system is in the process of improvement and operational tests are planned for the next milestone with different houses typologies will be designed and validated all the construction rules and processes.

Acknowledgment

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