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Method for the architectural design of wood houses in Portugal

Método para el diseño arquitectónico de casas de madera en Portugal

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ABSTRACT

The goal of this study is to propose a method for the architectural design of wood houses in Portugal. Construction and manufacturing companies were interviewed to understand the wood house market. A case study was developed by simulating four variations of a project, including different wood construction systems (wood frame, post and beam, logs, and cross-laminated timber). Based on the identified problems, a design method was defined by using decision support tables, lists of procedures and optimization strategies. A multi-criteria decision support process was proposed to assist in the assessment and selection of the “best” solution among the potential options. During the program phase, the use of a catalogue of architectural typologies with construction and formal systems promotes the process’ optimization. In the sketch design phase, the adoption of an assessment process, specific design procedures and pre-set strategies (durability, construction integrity, economy) aims to assure construction quality.

Keywords: *Wood house; design methodology; architectural design; typology; wood structure; multi-criteria decision.*

RESUMEN

Se presenta un método para el diseño arquitectónico de casas de madera. Se entrevistó a empresas de construcción y fabricación y se desarrolló un caso de estudio simulando cuatro variaciones de un proyecto, incluidos diferentes sistemas de madera (entramados ligeros, poste y viga, troncos, y madera contralaminada encolada). Sobre la base de los problemas identificados, se definió un método de diseño utilizando tablas de apoyo a las decisiones, listas de procedimientos y estrategias de optimización. Un proceso de apoyo a la decisión de criterios múltiples fue propuesto como una ayuda en la evaluación y selección de la mejor solución. Durante la fase del programa, el uso de un catálogo de tipologías con sistemas de construcción y sistemas formales promueve la optimización del proceso. En la fase de anteproyecto, la adopción de un proceso de evaluación, procedimientos de diseño específicos y estrategias preestablecidas (durabilidad, integridad de la construcción, economía) tienen como objetivo garantizar la calidad de la construcción.

Palabras clave: *Casa de madera; metodología de diseño; diseño arquitectonico; tipología; estructura de madera; Análisis Multi-Criterio.*

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1. INTRODUCTION

This research is addressed mainly to architects and aims to promote the qualified use of structural wood in Portugal. The motivations to propose an architectural design method are the environmental and aesthetical performance of wood, the natural association between wood and clean construction methods and the potential of the Portuguese forest (1, 2).

The Portuguese Forest Strategy (ENF) defined as one of its goals the promotion of forest products and its use by architects and designers (3). Additionally, the incorporation of local building materials is a criterion valued by various sustainable construction assessment systems (4).

In the national context various excuses are used to avoid the use of wood. While some of them are culturally biased, others are justified by rational arguments. The local conditions of climate and the current characteristics of the forest, as well as the local building culture and experience, are not as favourable to the use of wood as the conditions we can find in cold climates and in regions with a history of continuous use of structural wood.

The innovation in wood products, due to scientific research, market demand and architectonic experimentation, has provided answers to the mentioned concerns. Furthermore, codes and norms are being continuously updated to ensure safety and quality.

The use of wood in the construction of single-family houses has been the object of several studies concluding that there are advantages in its use (5, 6, 7). It is argued that the replacement of other building materials by wood components would lead to a reduction in carbon emissions (8). Other important arguments to consider are related to the high pre-fabrication level and the efficiency in construction time (9).

In Portugal, the process of designing a house was initially dominated by specialized companies, with very marginal intervention by architects. Recently, as reported in a first survey conducted within the context of this research (9), the situation started to change. Nevertheless, from an architectural point of view, the current design method in Portugal is not the most appropriate for the needs of wood houses. First, Portuguese architects do not have local vernacular integral wood construction references to learn from. Second, Portuguese universities did not offer architects a serious wood construction education. Finally, the codes related to wood construction are understood as an engineering domain. Therefore, the relationship between architecture and construction systems in wood, as well as the potential and limitations of each construction system, are not fully understood. Given these conditions, it is justified to propose an architectural design method.

The available literature combining the subjects of wood construction and design methodology usually does not adopt the unified perspective that architecture, as a discipline, requires. In Portugal, several master's and a doctoral thesis in particular (10), already focused on the theme of wood, framed by an architectural perspective. Different approaches may be found in these works: the comparison of systems, the development of solutions and the proposal of prescriptive manuals. In the area of project methodologies, we found national works in the themes of evaluation, quality and generative processes (11), but there are no studies that specifically put into question the traditional process of architectural design. The originality of this research rests in part on the singularity of the object itself, which integrates four main objects: methodology, architectural design, wood construction and single-family housing.

2. RESEARCH METHODOLOGY

To achieve the stated goals, a process was used where theory, surveys, interviews, empirical data and an architectural design simulation, were progressively integrated into conclusions that informed the definition of the proposed method. The following activities were carried out:

1) Review of relevant literature on Architecture, architectural design methodologies and construction systems.
2) Fieldwork, involving surveys and structured interviews, to identify the main problems associated with the wood house's market and architectural design in Portugal.
3) Definition of a case study simulating a schematic design of a single-family house with the integration of the four most relevant construction systems in wood.

3. THEORY

3.1. Traditions

The study of the tradition of wood construction was considered an important starting point to search for a reasoning inside the universe of all the different existing methods and technologies. Traditional wood construction and its evolution were systematized in a logical way using a division in four main categories: wood frames, post and beam, light walls and solid walls. The main driving factors triggering the evolution of form and technology were summarized as being the availability of raw materials, the environmental and climatic conditions, the cultural dynamics, the functional requirements, the search for durability, the technologic knowledge, and the search for economy.

3.2. National context / Portuguese particularities

Few precedents can be found to define a Portuguese tradition of integral wood construction. The cases of the Atlantic Central Coast and the Avieiros of Tagus River (12) are the exceptions. These are very basic solutions, corresponding to temporary shelters or contexts of low resources.

Reviewing issues pertaining to the national forest, climate and building regulations, allowed concluding that, while the forest shows a dormant potential, the climate with warm summers and wet winters justifies the historical fact that wood as an integral solution was never a standard choice.

In 2011, a first national market characterization was done by surveying the wooden house market. This survey received 25 responses and was published by the National Laboratory of Civil Engineering (LNEC) (9). The results showed that these companies built a total number of 3640 residential units for the national territory, plus 1195 units for export. There were a small number of companies with a robust structure, and a great number of companies with basic business structures often representing foreign companies. The total wooden houses built in Portugal correspond to 0.13% of the single-family dwellings built in 2011. As an obstacle to the increase in the demand for wood houses, the companies pointed to the prejudices of the people, the absence of the State's support and the lack of specialized technicians in Portugal.

3.3. Architectural typologies

To organize the study's contents, the long-standing concept of "type" was used. A type can be defined by a set of typological characteristics that refer to spatial and formal invariants and their frequent occurrence. A typological framework (Fig. 1) was defined according to which an "architectural typology" could be decomposed into two systems: the "formal" and the "constructive". Formal systems contain functional, spatial and symbolic types while construction systems consist of structural, envelope and partitioning types.

A classification of structural wood systems was carried out in order to overcome divergences in the terminology used by different authors, and a proposal was made (13), focusing on the vertical elements of the structure and adopting geometry and weight as the criteria for differentiation (Table 1). Thus, it was possible to distinguish between systems with components of predominantly linear, planar or three-dimensional geometries and systems with heavier or lighter components. Another level of classification was also considered grouping the systems into frames, post and beam, walls and panels, depending on the characteristics of the elements, as placed onsite.

Among the formal systems, the symbolic types are the most important (Table 2). As subtypes, traditional, contemporary and modern types were considered, distinguished by the characteristics of the roof and the details. The distinction was also set between open and closed subtypes defined by the greater or lesser dimension of the openings on the envelope. Finally, rustic and urban types were assigned depending on the type of finishes used.

3.4. Constructive systems description

Construction systems were named with reference to the structural types because these are the basis of all the other typological definitions. As objects of study, four structural

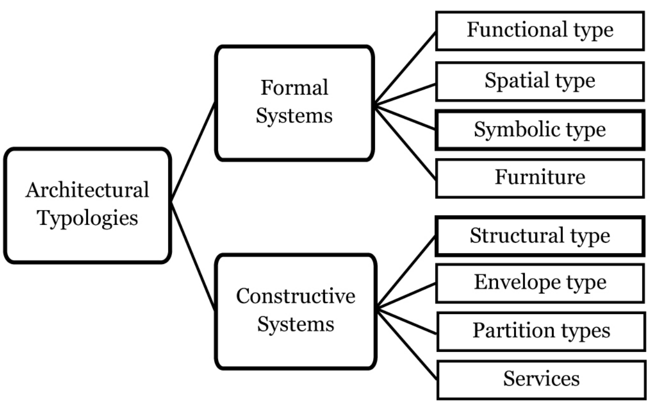

Figure 1. Typological framework.

Table 1. Structural types defined by geometry.

Structural types		Typological characteristics
	Selected types	**Element's geometry**
Light Frames	Wood Frame	Linear and frame
Post And Beam	Post And Beam	Linear and post and beam
Light Walls	-	Plane stacked - light
Light Panels	-	Plane assembled - light
Heavy Walls	Solid Log Walls	Plane stacked - heavy
Heavy Panels	Solid Laminated	3D - heavy
Partial Modules	-	3D - partial
Full Modules	-	3D - full
Light Mixed	-	Components – mixed, light
Heavy Mixed	-	Components – mixed, heavy

Table 2. Symbolic types defined by characteristics.

Symbolic types		Typological characteristics		
Roof / details	**Openings**	**Finishes**	**Roof**	**Details**
Traditional	Closed	Rustic	Sloped	Elaborate
		Urban	Sloped	Elaborate
	Open	Rustic	Sloped	Elaborate
		Urban	Sloped	Elaborate
Contemporary	Closed	Rustic	Sloped	Abstract
		Urban	Sloped	Abstract
	Open	Rustic	Sloped	Abstract
		Urban	Sloped	Abstract
Modern	Closed	Rustic	Flat	Abstract
		Urban	Flat	Abstract
	Open	Rustic	Flat	Abstract
		Urban	Flat	Abstract

types were selected: wood frame, post and beam, solid log walls and solid laminated glued panels (cross-laminated timber). The reasons for this selection were its diffusion and use in Portugal and the potential to provide a diversity of design features, when compared to each other.

The "wood frame" system is one of the most used systems and was the topic of a Ph.D. thesis (10), arguing that Portugal has the necessary conditions for its implementation. The "post and beam" system offers an alternative that is similar in its formal logic to the reinforced concrete solutions and is the second most used system according to the survey addressed to Portuguese companies. The "solid log walls" is the system where wood is presented in its most expressive form and is also offered by the majority of prominent companies. The solid laminated glued panels (cross-laminated timber) refers to the formal logics of slabs and walls of reinforced concrete and is contemporary and innovative.

3.5. Experience of Portuguese companies

The experience of national companies in the design process was considered relevant in comparison to the almost non-existent experience of Portuguese architects, so in 2013, a structured interview to 15 of 25 preselected companies was carried out. A summary of the conclusions was presented in a conference paper (14). The most important results concerning the design methodology were as follows (Figs. 2 to 5):

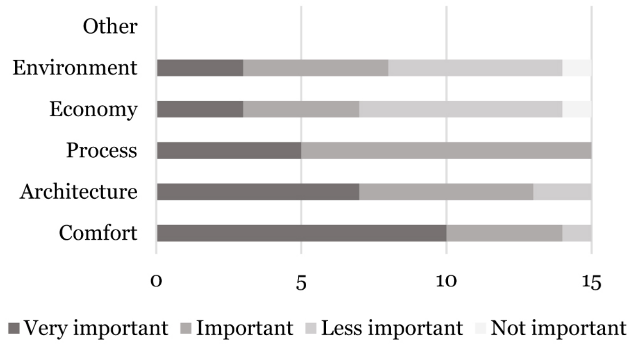

Figure 2. Arguments to buy a wood house.

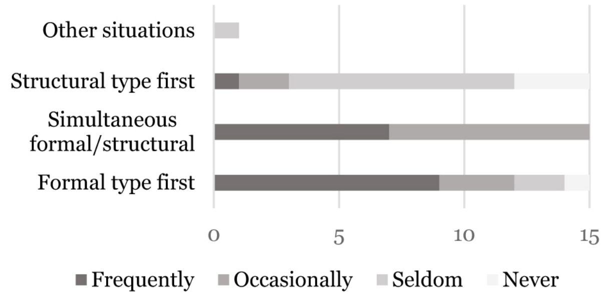

Figure 4. Process of structural type's choice.

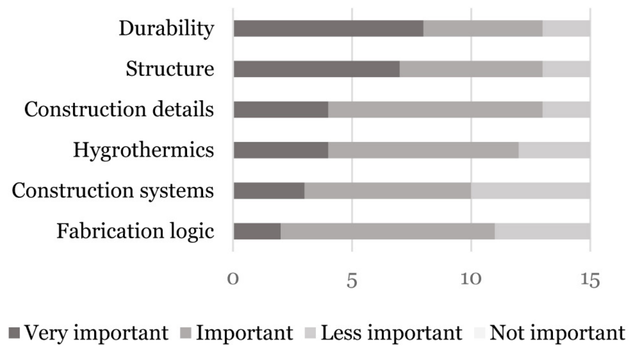

Figure 3. Architect's difficulties.

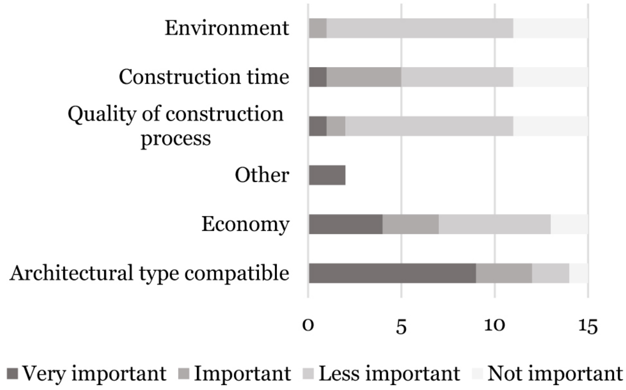

Figure 5. Important criteria to choose the structural type.

The arguments that led customers to choose a wooden house are first the comfort and then the architectural aesthetics, with economic and environmental factors being the least important. The typical client that visits the companies is the final-consumer, without an architect as a consultant. The form of presenting the "product" to the clients comprises the existence of customized solutions but integrates, in the majority of the cases, a catalogue of solutions used as a design reference. Companies regard an architect as a professional that demonstrates many or some difficulties in the process of designing wood houses. The aspects in which these difficulties are most relevant are related to the understanding of durability requirements. The choice of structural types is done, in most cases, after the choice of formal types. The simultaneous definition is also frequent. As the main criterion for the choice of the structural type, companies consider: "adequacy to the architectural solution", followed by "economy".

3.6. Case study

The case study aimed to simulate an architectural design process with the architectural integration of the four selected structural systems. The objective was to obtain information to define the procedures to be included in the design method.

Based on the average requirements of a Portuguese house, a solution was defined. Among the various symbolic types available, the "contemporary closed" symbolic type was chosen (Fig. 6). The choices, as well as the design process, were assumed by the main author while representing the architect and the client.

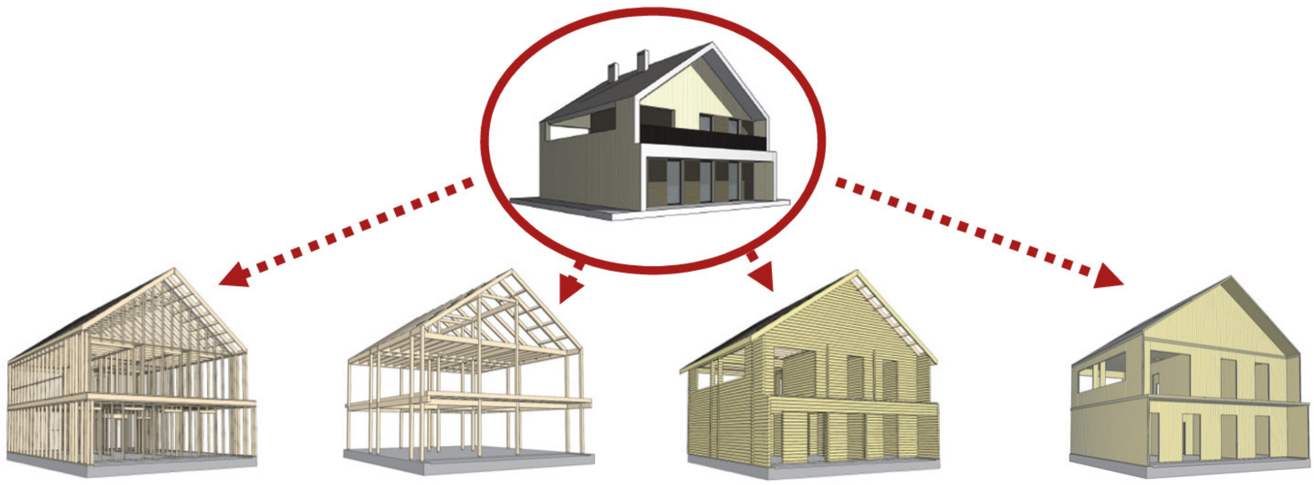

Figure 6. Selected symbolic type "contemporary closed type" and the four options to structural type integration (from letf to right: wood frame, post and beam, solid log walls, solid laminated glued panel).

The structural types were integrated into the solution after the definition of the formal type. To obtain support for technical decisions, some of the available manuals were seen. For the "wood frame" system, the "Canadian Wood Frame" manual was used (15), among other sources (16, 17, 18). The "post and beam" system was studied following the North American "timber-frame" approach, with the envelope filled with SIPs (Structural Insulated Panels). The technical solutions were based on varied manuals and sources (19, 20, 21, 22, 23). For the system of "solid log walls", mainly the project manual of Honka (24) and the document of homologation of the Rusticasa system (25) were considered. The solid laminated glued panel system (CLT) was tested within the Kreuz Lagen Holz (KLH) system (26, 27, 28) and with the support of its instructions.

4. THE METHOD

The design method was based on information collected from the national companies' survey and from the case study, but it was also a result of the analysis of the different ways in which current design processes take place.

4.1. The existing design process

For those wanting to build a wooden house, three main possibilities to choose from were identified. These three options are defined by the nature of the available offers made by architectural services (Fig. 7).

The first option is offered by wooden house companies and is the rational choice if one is searching for a predictable result. The second option is done by contracting an architect that is associated with architectural solutions containing a specific aesthetical "brand". If a customized service is sought, the third option consists of hiring an architect open enough to assimilating an effective contribution from the client. In the first case, Architecture is conceived as a "common product", pre-existing and available to be an object of choice. In the second case, architecture is seen as an artistic product that results from a creative process designed by a specific author. The third case - the most frequent - corresponds to an understanding of architecture as a service, offering support to the client's choices.

From the client's point of view, each process has its own advantages and its associated risks. The first situation offers a forecast of the costs, promotes the constructive quality and assures the efficiency of the process. The associated risks regard a lower formal quality, a lack of singularity and a dependence on the company to which the client is connected. The second case stimulates formal quality and singularity. The risks are the low client contribution and the higher project-construction costs. In the third case, the immediate satisfaction of the client should be obtained, the project costs should be lower than those of the second case and there should also be independence from the company. The associated risks are a lower formal quality when compared with the second case and higher project and construction costs and lower constructive quality, when compared with the first case.

4.2. The fourth and proposed method

The proposed design method ("architecture as a qualified service") was intended to be based on the most positive aspects of each possibility (Fig. 8). This method aims to support the

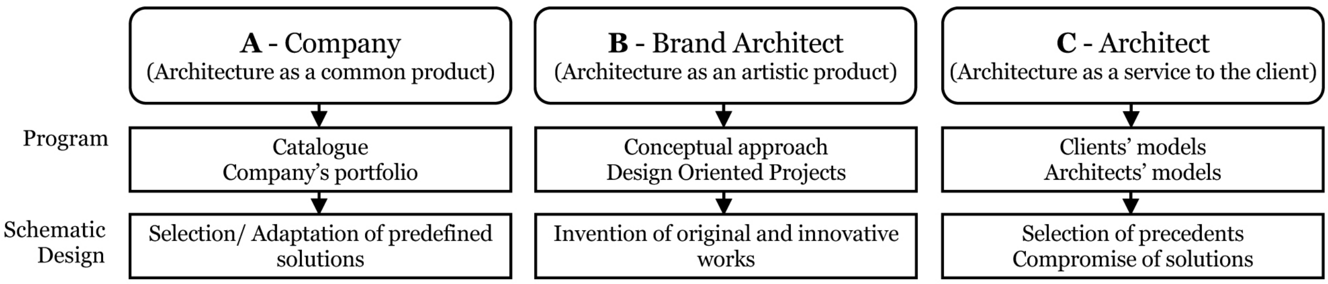

Figure 7. Models of the existing design process. Options defined by the nature of available offers made by architectural services.

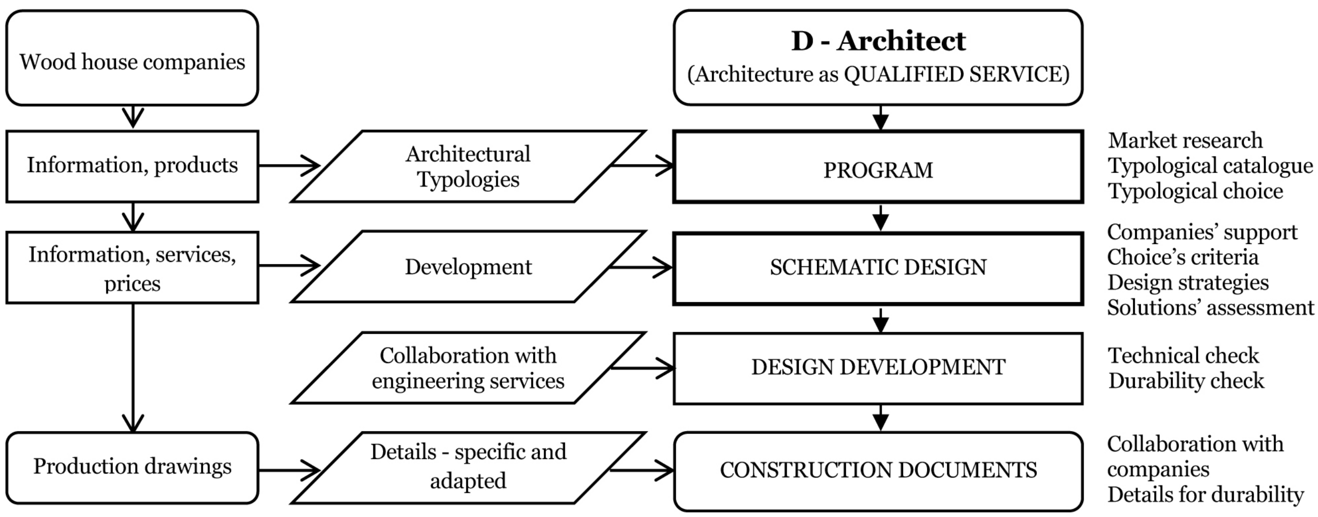

Figure 8. Proposed design process.

perspective of the client, who wants a customized project, while offering control over the total costs (project and construction). At the same time, there is the intention to promote design decisions regarding the constraints of wood construction and to support an understanding of the limitations and potential of different architectural types.

Advantages of the proposed method:

The final solution should match client's satisfaction, as in the first and third models, because of his or her participation in making choices. The formal quality of the solution should be the result of the typological approach, where each type assumes coherent architectural rules that relate to a specific formal character. Constructive quality is ensured, not only by the inclusion of procedures and project strategies but also by the involvement of construction companies, through indirect or direct collaboration. Nonetheless, this is supposed to be an independent process allowing architects to analyse a larger possibility of solutions and suppliers.

4.3. The program

The objective of the program is to systematize the design problem and to define, in a descriptive way, the typological characteristics of the solution according to project constraints and requirements. Thus, the functional, spatial and symbolic types are defined. The symbolic type will be defined based on a structured catalogue of types, illustrated with examples. Once the formal type has been defined, the choice of the structural type begins, involving an analysis of its suitability to the formal type and vice versa.

After the choice of the structural type is made, the process evolves to the definition of the building envelope and partition types. Once the construction system is finished, an architectural type is automatically obtained (Fig. 9).

When it is not possible to determine a satisfactory single symbolic type, alternatives are necessarily defined and considered. The same thing happens in the case of the structural type.

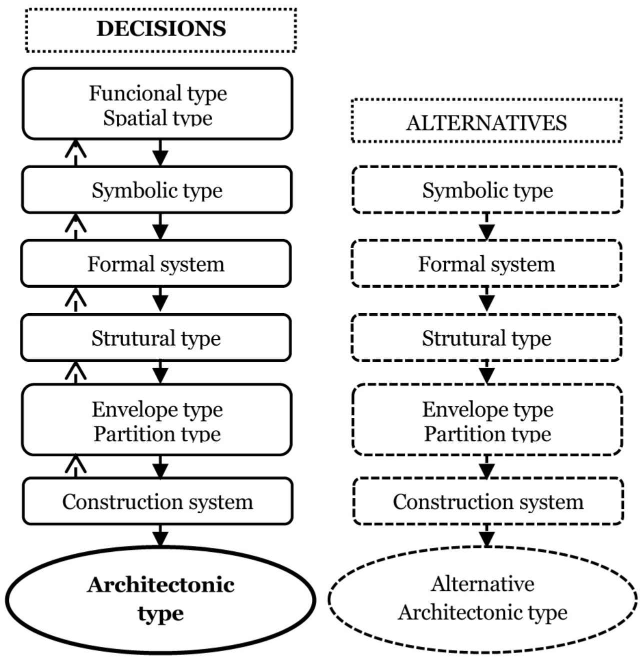

Figure 9. Proposed method - The Program.

The program - Symbolic type definition:

The process of choosing the symbolic type during the program must address the constraints of the project's scenario, as defined by the client needs. Thus, the use of a decision support table rationalizes the choices. For example, if a more durable project is desired, traditional types are recommended, or if the budget is limited, not only modern types but also open types should be avoided.

A reference catalogue must be built, assuming the form of an illustrated table, with examples of each defined type, showing external solutions and indoor environments. Additional information may be added, including in each symbolic type the diversity of applicable structural types.

The program - Structural type definition:

The choice of a structural type may be conditioned by previously defined symbolic types. Therefore, the use of a support table is proposed where logical connections are established between structural types and the characteristics of the symbolic types. For example, the characteristics of contemporaneity, modernity or traditionalism, point to solid laminated glued panels (CLT) in the first two cases and indicate types of solid log walls in the latter case. In addition, open types ask for post and beam, while closed types relate to other solutions. The use of decision support tools, using a simplified decision matrix, allows for the evaluation of alternative solutions based on pre-defined criteria and their weights. Using the MACBETH (Measurement attractiveness by category based evaluation techniques) method (29; 30), a straightforward evaluation and analysis is possible, facilitating the simulation of different weights. The most obvious criteria we can set are, for example, the suitability of the solution to the types previously defined, the architectural potential of the wood in the system or the durability of the solution.

Finally, the method calls for the listing of the various options available within each structural system. Depending on the constructive element considered (the exterior walls, the roof, the ground floor, the intermediate floors, and the interior walls), different types of solutions and components can be found.

4.4. Sketch design

The sketch design phase (Fig. 10) has three main objectives. First is the design of architectural solutions based on the types defined in the previous phase (program). Second is the assessment of alternative solutions. Third is the definition of the final architectural solution.

The design of the formal solution must be made within a framework of design strategies with the goal of addressing the requirements and priorities established by the architect and the client.

The constructive solution implies its combination with the formal solution, but it also requires the integration of information from companies and engineering consultants regarding the products and solutions used. Fundamentally, we put

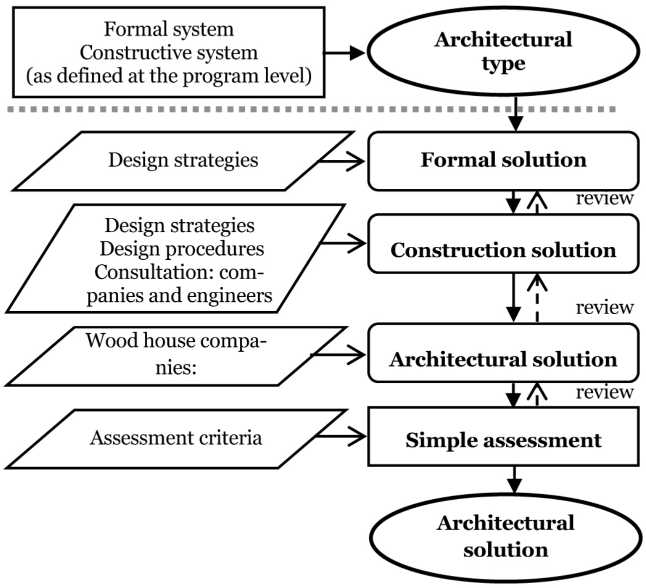

Figure 10. Proposed method - Sketch Design.

in place project strategies to address aspects of economy, durability and constructive integrity.

Considering that there is a need to develop alternative solutions, a careful choice of the best option must be made based on a multi-criteria assessment method that allows solutions to be ranked considering a sum of weighted criteria. The evaluation criteria to be used may belong to the following groups: Economy, Process, Quality, Architecture, Companies and Environment.

Sketch design – Design procedures:

The method assumes the adoption of procedures organized sequentially and formalized in a list of procedures and design questions for the definition of the constructive solution. The following list summarizes the procedures to be adopted:

1) Definition of the formal solution, including the gathering of information about available components, construction elements and companies offering specific solutions for each constructive element. It is also necessary to collect pre-dimensioning information useful for optimizing design dimensions.
2) Definition of a structural grid and its suitability to the spatial and structural solutions. In parallel, the basic structural floor plans must be drawn, especially when dealing with linear component systems.
3) Definition of the envelope's characteristics, checking its suitability to the structure and to the symbolic type.
4) Three-dimensional modelling of the structure and verification of potential problems of component's integrity, focusing on connections between components.
5) Identification of constructive problems can be carried out through the drawing of construction sections that point to questions about structural, thermal, acoustic and fire behaviour. This process requires consultation with engineering partners who are expected to analysis and review problematic situations.
6) Identification of durability problems, analysis and revision.
7) Definition of a temporary constructive solution for submission to the engineering consultants. This analysis may lead to a possible final revision.
8) Assessment of the solution or solutions.
9) In the final stage, consultation with the relevant company or companies allows obtaining a commercial proposal, possibly leading to a final refinement, after which the final solution is obtained.

Design strategies integration:

The development of formal and constructive solutions is regulated by the adoption of strategies of economy, durability and constructive integrity. Each construction system will be ruled by specific strategies, each one having different weights, depending on the criteria valued by the client and the architect.

Some of the economic strategies consist of common sense choices such as, for example, the selection of non-complex formal typologies, the implementation of more economical structural types or the rationalization of structural components. In addition, the use of modular and standardized dimensions or the choice of structural grids, compatible with the positions of the associated elements and constructive components, can lead to substantial savings.

Durability strategies include a list of specific wood construction concerns, organized by constructive elements, including generic measures for the construction phase, comprising the surrounding terrain and specific actions to avoid biological attacks. Durability strategies can be grouped in procedures directed for the use of durable materials (durable wood, protective alternative materials and treatments), drying measures, external drainage and protection of the components' exposure.

Constructive integrity strategies, also specific to wood construction, are related to the water content in the wood that causes its shrinkage or swelling, leading potentially to cracks, bends, warping and differential settlements. Some strategies will have general validity, but many of them are applicable specifically to one or only a few systems. It is fundamental to avoid connections between materials of different characteristics and geometries that lead to dimensional variations ruining the components' horizontality or verticality and their material integrity.

4.5. General synthesis

To sum up, at the level of the program there must be a definition of the architectural type, in a process that includes the use of information presented in a catalogue of types and the selection and definition of feasible structural types, using choice and evaluation criteria. At the sketch design level an architectural solution is generated following procedures framed by design strategies and supported by a weighted assessment of alternatives.

Although there is a focus on program and on sketch design, the design development and construction document phases should also include procedures to address the specificities of wood construction. Design development mainly consists in verifying the overall durability and integration of engineering projects since augmented scales always raise questions to be solved. The construction document phase is focused on designing durability details, preparation of a maintenance manual and integration of drawings for production.

4.6. Testing the method

The case study was developed first with the goal of informing the content of the method, not of testing it. The main author worked as an architect and client, as explained earlier. Therefore, it was decided to test the method by assessing the architectural solution using the methodology and the software M-MACBETH (29; 30).

Assuming that the process was in the sketch design phase and that the development of the constructive solution was accomplished through the defined procedures and strategies, there was already a solution to assess.

The evaluation of the architectural solution, based on the constructive solution (now with the price criterion added), was systematized with the following criteria: “Architecture” (assessing the suitability of the constructive solution to the symbolic type and the degree of the client’s satisfaction), “durability” (used in a broad sense of technical behaviour, joining structural, hygrometric and water tightness requirements), “price”, and finally “environment” (Table 3).

Architecture, durability and environment criteria were defined on a basis of comparison of qualitative levels of performance while the price criterion was defined assuming a base of comparison of quantitative levels of performance. For the first criteria, five qualitative levels were used, while for the price, minimum and maximum values were defined.

The scale of weights was defined using MACBETH software through an evaluation of the differences in attractiveness between each “global reference” (or criteria). Thus, the weights were automatically obtained through a judgement table with the following values: architecture 48, durability 32, price 16, and environment 4.

The definition of performances required the description of the expected response of all the options in each level of “performance” (Table 3). The levels of “good” and “sufficient” were first defined by setting the general requirements of each criterion. It was considered that the level “very good” would correspond to an answer higher than “good”. The level “weak” would correspond to a less satisfactory answer than “sufficient”.

Assessment of the architectural solution:

The evaluation was done by assigning to each option a level of performance that resulted in a score table (Table 4). The results favoured solutions with solid laminated panels (CLT) and post and beam. Both obtained the maximum score in the Architecture criterion. The wood frames and the solid log walls were penalized, not only because of the evaluation in the “Architecture” criterion but also because of the score obtained in the “durability” and “environment” criteria.

The test of theoretical variations of the criteria’s weights allows to conclude that, for example, a variation of 3.4% in the price criterion would make the post and beam to become the preferred solution instead of the CLT solution. The wood frames would be preferential with a weight of the price higher than 77.1% (the weight attributed to the price in the case study was only 16%).

Varying the scenarios (or contexts of the decision) will naturally change the results, so several scenarios were simulated. It started with the “architecture scenario”, in which it was considered

Table 3. Assessment of architectonic solution. Table of criteria and levels of performance.

Criteria	“Performance level”	“Performance”
Architecture	Very good	Structural/Construction solution exceeds expectations of required symbolic type Excellent architectural solution
	Good	Structural/Construction solution is adequate to the required symbolic type Balanced architectural solution
	Sufficient	Structural/Construction solution requires changes to the symbolic type, is satisfactory and can be improved
	Weak	Structural/Construction solution requires changes to the symbolic type Architectural solution is not satisfactory/acceptable
Price	Maximum level	186.890 Euros
	Minimum level	301.146 Euros
Durability	Very good	Structural/Construction solution have superior durability solutions
	Good	Structural/Construction solution minimizes the effects of shrinkage, minimizes the joints, avoid the contact of structural elements with the exterior environment, promotes efficient thermal behaviour
	Sufficient	Structural/Construction solution, presents some of the following problems (not all): Shrinkage and settlements, profusion of joints, structural elements exposed to the exterior environment, thermal behaviour issues
	Weak	Solution with all the problems described in the “Sufficient” level
Environment	Very good	Structural/Construction solution with superior environmental solutions
	Good	Solution contributes to the use of wood and carbon sequestration, contributes to the waste reduction (through prefabrication), optimizes envelope and reduction of energy consumption, avoids the need to the use of chemically treated wood
	Sufficient	Solution with “Good” behaviour only in some of the parameters.
	Weak	Solution without “Good” behaviour in any parameter

Table 4. Table of Performances and Table of scores according to M-MACBETH method.

Performance table - Evaluation of the architectural solutions					
		Architecture	**Price (euros)**	**Durability**	**Environment**
Wood Frame		Good	186.890	Satisfactory	Satisfactory
Post and beam		Very Good	195.380	Good	Good
Solid log wall		Satisfactory	187.920	Weak	Good
CLT		Very Good	246.290	Very Good	Very Good
Score table - Ranking of the architectural solutions					
Options	**Global**	**Architecture**	**Price**	**Durability**	**Environment**
[all upper]	100.00	100.00	100.00	100.00	100.00
CLT	91.68	100.00	48.01	100.00	100.00
Post and beam	89.81	100.00	92.57	75.00	75.00
Wood Frame	70.00	75.00	100.00	50.00	50.00
Solid log wall	50.86	50.00	99.10	25.00	75.00
[all lower]	0.00	0.00	0.00	0.00	0.00
Weights:		0.48	0.16	0.30	0.04

that architecture was the dominant criterion, and sub-scenarios were drawn where it was assumed that each of the constructive systems had a higher degree of suitability to the symbolic type than the others. In this case, it was concluded that inside the "architecture scenario", in each sub-scenario, the dominant preference falls under the constructive system that is considered preferential in association with the symbolic type.

Other variations were also tested, consisting of drawing three additional scenarios - Durability, Price, and Environment - in which each criteria (durability, price and environment) would become respectively dominant. Other sub-scenarios were also simulated, which were drawn in order to allow the Architecture criterion to be successively favourable in each scenario to each of the structural systems.

In contexts of decision where Architecture is the criterion with the greatest weight and the price is a secondary criterion, the structural option that collects the preferences in terms of adaptation to the architecture will be the dominant one. In a case where technical behaviour is valued above all, solid laminated glued panels (CLT) tend to dominate. If the price criterion is the strongest, wood frame solutions may become preferential. If the environmental criterion and the carbon sequestration are valued, the heavier systems such as solid laminated glued panels (CLT) and solid walls of logs can be favoured.

4.7. Final assessment

It is not possible to state abstract conclusions about the studied wooden systems because every evaluation is dependent on each context and each scenario. Nonetheless it is posible to describe the overall potential of each system and to characterize them in very simple and brief terms.

The "wood frame" system is the most generic, without presenting a structure from which an aesthetic expression is necessarily derived. It is suitable for economic structures, presenting great flexibility for the possible aesthetic solutions. The attributes found, for a basic classification, are "pragmatism" and "lightness".

The "post and beam" system is suitable for open spaces and dematerialized volumes. The appropriate attributes would be "elegance" and "spatial flexibility".

The "solid log wall" is the one that best expresses the true character of wood in its natural state. "Tradition" and "nature" would be fair attributes.

The "solid laminated glued panel" (CLT) system stands out for its robustness and for addressing technical requirements. It also allows for the setting of spaces where the expression of wood, even if in a modified state, is present. This system could be designated the one of "innovation" and "contemporaneity".

5. CONCLUSIONS

This research achieved optimization of knowledge, explored the requirements of main wood construction systems, and, more importantly, defined a design method that can be followed as a reference by Portuguese architects or can be adapted for application in other regions.

Architectural typologies were defined by dividing them into formal systems and constructive systems. This approach allowed for a systematization in which the formal and technical components, although conceptually separated, can be thought of in a unified and logical way.

The most significant project requirements from the architectural point of view for the main building systems were identified. The most relevant ones to be used at the national level were selected and focused on.

The knowledge of wood's behaviour in each one of the systems allows understanding that wood behaves differently depending on the system one is dealing with. Therefore, it is fallacious to use the generic term "wood construction". The understanding of the performance of each system allows the architect to consider a wider range of options and to match them with the clients' problem, thus defending their interests.

The proposed architectural design method is suitable for the characteristics of wood construction and is focused on the program and sketch design phases. This design method aimed at ensuring the overall quality of architecture in terms of wood construction, customer satisfaction, the formal and constructive quality, and, finally, the customization and independence from construction companies and manufacturers.

The innovative aspects contained in the method at the program phase are the procedures for choosing architectural types, based on typological catalogues, and the more precise definition of types, based on decision support tools. In addition, during the sketch design phase, the development of drawn solutions is supposed to be carried out following a set of procedures that simultaneously integrate strategies of durability, constructive integrity and economy. The method assumes the assessment of solutions with the use of tools of multiple criteria decision support. Finally, it proposes collaboration with construction and manufacturing companies because of the advantages that can be obtained in terms of experience and competence.

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