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A Research Methodology for Mitigating Climate Change in the Restoration of Buildings: Rehabilitation Strategies and Low-Impact Prefabrication in the "El Rodezno" Water Mill

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Abstract: New environmental challenges, coupled with the fact that 80% of the residential buildings that will exist in Europe in the year 2050 have already been built, mean that rehabilitation and restoration must be prioritised over new buildings. Construction is one of the largest generators of CO_2. Using prefabricated and industrialised products and systems can help to mitigate its harmful effects thanks to the greater control and environmental evaluation that can be carried out on these products from their manufacture until the end of their useful life (LCA). In the county of the Sierra de Cádiz (Andalusia, Spain), there are 85 water mills, many of which are derelict and in disuse, which, due to their location, size, and characteristics, are ideal for rehabilitation and restoration for residential use. Taking the "El Rodezno" mill as a case study, this paper proposes rehabilitation strategies using prefabricated industrialised elements that have a low environmental impact. The methodological discussion takes as its starting point the process of design and testing that Alvar Aalto applied in 1940 and from subsequent studies that have confirmed a research structure based on the project design and the built project with the appropriate field of study and confirmation of the applicable strategies and solutions. To this end, this article is written on the basis of the two main phases of Alvar Aalto's method, using the same terms that the Danish architect defined: *Scientific Observation*, for the study of preceding works and projects in light prefabrication and for the analysis of certain construction products and systems that, based on other research, have evaluated their LCA, and *Construction Period*, for the rehabilitation strategies of the "El Rodezno" mill, considering the studies and analyses of *Scientific Observation*. For the roof solution, we took as an example the rehabilitation of the roof carried out with the same methodology, construction criteria, and prefabricated products analysed in this article and used in the intervention strategies in "El Rodezno". The paper concludes with the validity of the methodology applied to test the starting hypotheses that lead to intervention strategies that confirm the environmental and economic advantages of industrialised prefabrication, the importance of the design and synergy that results from combining different construction systems, and technologies that improve the acceptance of prefabrication by the inhabitant and boost the circular economy.

Keywords: heritage regeneration; water mills; sustainable prefabrication; local industry; housing; climate change

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1. Introduction

Productive rural architecture refers to various types of buildings: granaries, silos, other grain stores, farmhouses, estates, or mills [1]. They are anonymous constructions that were built prior to the technological advances that resulted in industrial production. The move from craftsmanship to industrialisation entailed the loss of use and later abandonment of these buildings, which were built taking into account the resources available in the area, creating a system in balance with the environment. It must be recalled that these constructions, due to their size and the function they served, were architectural works that required strategic positioning and recognition in an area to fulfil a very well-defined productive methodology for which there were few alternatives.

In the Sierra de Cádiz, there were 85 water mills on the banks of the rivers and streams that used to flow through the region [2]. The Sierra de Cádiz, with a pronounced orography, has a significant water network, supplied in a natural manner by the high rainfall in this region. Roads and paths, along with rivers and streams, established an infrastructure network superimposed on the territory that linked mills, riverbanks, crop areas, other diverse architecture, and settlements. Therefore, the mills were an essential part of the land, the topographical conditions that define it and its landscape, understood as identity values of the region (Figure 1). Its adaptation to the environment was also reflected in its relationship with the communication infrastructures that facilitated its accessibility and habitability. Additionally, along certain riverbanks, in mills and fields under cultivation, the water infrastructure was shared, creating a water recirculation system. Once the water had been used by mills and fields under cultivation, any that was left over returned to the river, recycling a natural resource as valuable as it was scarce [3].

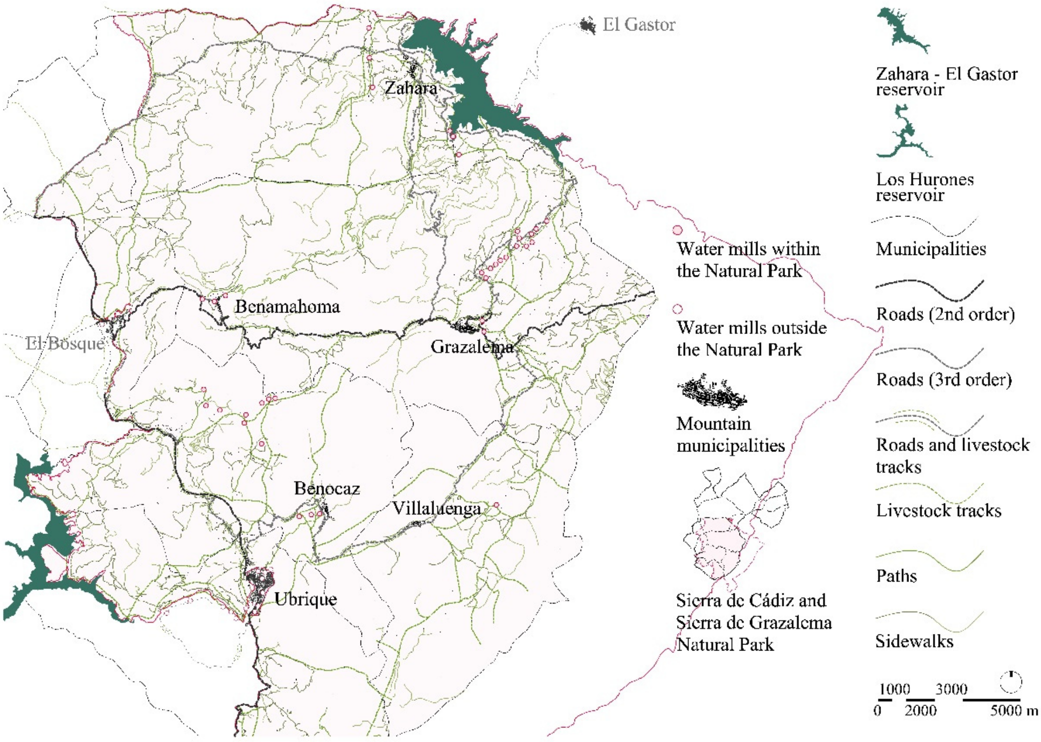


Figure 1. Current communication infrastructures of the Sierra de Grazalema Natural Park (Sierra de Cádiz). Source: prepared by the authors.

These mills are of a very basic type with a small and simple volumetry, which is usually very rational, without excessive pretensions. The inclusion in certain cases of the miller's own dwelling makes them more similar to the residential classification than the industrial classification, due to which transfers including the dwelling are believable. The knowledge that arises from traditional construction, the artisan trades that made it possible, results from the logical application of the materials [4] and the law of the "maximum internal economy" [5]. Despite their inherent values, these constructions had not been studied in the academic or institutional field until a few decades ago, and there has been even less reflection on the potential of their restoration and on the modus operandi in which their rehabilitation and re-habitation could be carried out.

It is important to bear in mind that 80% of the buildings that will be used for residential purposes in Europe by the year 2050 have already been built and, until that date, an annual increase of 1% is forecast. However, the restoration and rehabilitation of the residential housing stock will mean a larger percentage, which may reach 3% [6] and possibly increase, as the awareness of the need to recycle the existing architecture is greater and is supported by public institutions. Proposing the rehabilitation of existing architectures for residential use would also be consistent with the European Union's strategic guidelines and its policy of Comprehensive and Deep Renovation of residential buildings [7].

Construction is the cause of a third of CO_2 emissions, including generated waste, and 40% of energy consumption, which is why it is the goal of the Paris Agreement to minimise these two indicators. The use of industrialised prefabricated products makes it possible to better assess and control the environmental impacts that are generated, from their manufacture to the end of their useful life, following the cycle of recycling—manufacturing, function, and new recycling—that also boosts the circular economy.

Describing and contextualising a specific situation, this article starts from the hypothesis that these mills constitute an experimental field that serves to verify the validity of intervention strategies for the restoration and rehabilitation of these heritage architectures and, given their small size, their adaptation to family homes.

This article aims to explore the possible restoration of these architectures with new construction products and technologies that meet basic environmental criteria regarding recycling, lightness, flexibility, and modulation in the design of construction and structural systems that allow for self-assembly, facilitating the inclusion of unskilled labour, boosting the local economy, reducing greenhouse gases, and diminishing energy consumption. It also aims to verify the viability of certain strategies and solutions for the restoration, rehabilitation, and protection of these architectures which, due to the simplicity and viability of the strategies, can be transferred to the rehabilitation of dwellings of a family scale.

2. Methodology: Discussion and Rationale

In addition to research on the eco-efficiency of prefabricated products that must be used and the evaluation of the environmental impact throughout their life cycles, the design on which, to a large extent, the optimisation of materials depends, reducing waste or facilitating the total dismantling of what was built, plays a vital role. For this reason, the methodology that this study follows is based on the analysis and observation of the results of projects and built works. In the same vein, one of the most well-rounded methodologies was the one pioneered by Alvar Aalto during his time at MIT, Cambridge, USA, in 1940, in which he proposed a laboratory for researching prefabricated solutions for dwellings that were communal as well as individual [8] (pp. 173–186). Aalto distinguished three phases in his method: after the first one devoted to the construction of different types of houses that were the basis of the study, he continued with the phase that he called *Scientific Observation*, which was aimed at assessing the proper functioning and acceptability of these prototype built houses. The studies, analyses, and results derived from this phase should, in Aalto's opinion, be published "for academic and scientific use". To this end, he included the collaboration of universities and technological institutes with the intention of obtaining an objective assessment of what was designed and built. Aalto called the last phase the *Construction Period*, and its objective was to involve private companies.

The value of Aalto's method lies in its commitment to applied research that had to conclude, first, in a project design and then in its implementation. This means that the research that stems from the project or the architectural intervention requires its own methodology which, nonetheless, considers the advances on construction products or systems that contribute individual or one-off solutions to construction. Aalto's method also had the novelty of involving university research centres and faculties with technical and scientific capabilities to participate in the construction of the project and private companies with links to the construction sector, which would force one to consider, in the design phase, aspects such as profit and return on investment: a process that is, firstly, one of research and, subsequently, participatory (Figure 2).

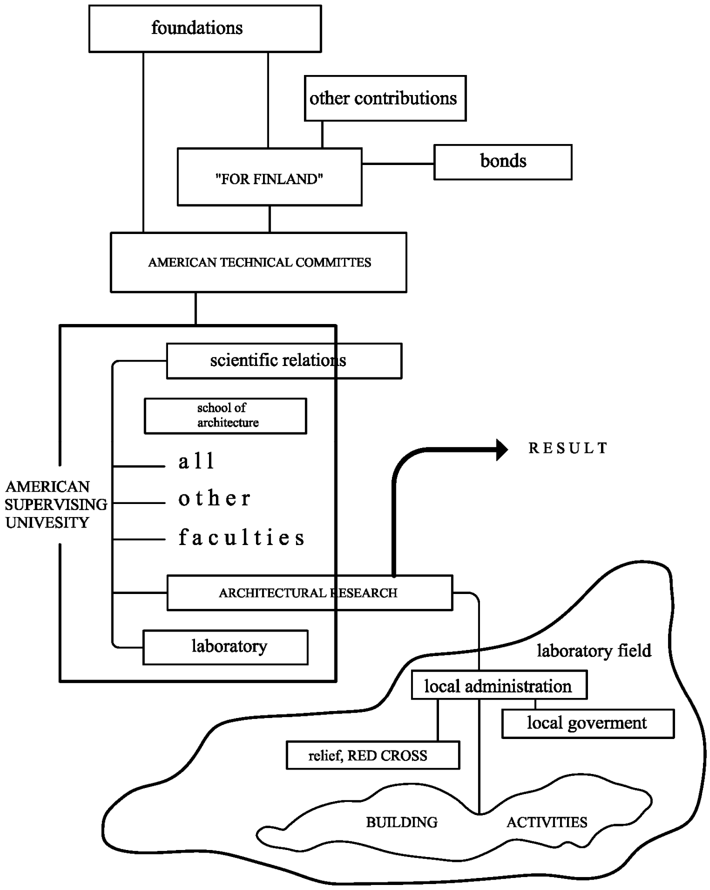


Figure 2. Organisational and participatory scheme of the project. Alvar Aalto 1940 [8] (p. 181).

In 1948, Richard Buckminster Fuller, during his time at Black Mountain College, applied a similar work method, albeit a much more simplified one. On this occasion, it was the construction of a geodesic dome with the assistance of students that turned out to be failure. He did achieve success, however, on his second attempt in 1949, thanks to the collaboration of a team of engineers who corrected the students' initial errors [9]. Aalto and Fuller′s experiences emphasise a methodology in which the project is proposed as a theoretical testing model that validates or refutes the hypotheses that bring forth the proposal. The specificity of each project means that the conclusions are, in principle, exclusive to each one of them, although there are always generalisable results. What they have in common is that they consider that an experimental project may lead to a prototype or a model from which it is possible to define a series of main lines of intervention for similar cases. One understands, then, that some years later, Leonardo Benevolo would advocate a scientific research process in architecture based on the immense amount of experience built and accumulated over the years, which forced our research to consider the preceding projects and works of architecture, evaluating their results to create "a web of inductions and deductions, invention and calculation, and not a homogeneous succession of deductive operations" [10]. Benevolo stressed that "all contemporary experience must be systematically compared with that of the recent past in order to find the thread or threads of research capable of growth".

Research and advancement processes of this kind can be recognised even before Aalto's proposal, and, in the modern period, we can cite the experiences of the Bauhaus, especially the Haus am Horn, designed in 1923 by Professor Georg Muche in collaboration with Adolf Meyer and Walter Gropius: a laboratory test that set out to systematically verify the benefits of a new way of living. Perhaps these cases of research based on a project and built work methodology do not seem to conform to an empirical model as proposed by Bruce Archer [11], but these presented cases, based on a project action, express a fundamental and specific form of knowledge. Professor Christopher Frayling distinguishes three ways of conducting research through the project or the built work [12], and in what he calls "through art and design", he places in this type of methodology those works where the practice serves a purpose of the research: a project from which useful and necessary hypotheses can be made to solve a problem and, in the process, prove useful to the research itself. This is the methodology that this team of researchers has been developing for several years, with the conviction that "in architecture, to test ideas and knowledge, there is still a need for theory and practice enunciated and demonstrated in projects and in works" [13].

Professor Jorge Torres Cueco [14] positively rates "inferential" methodology, a term coined by Michael Baxandall in 1985 [15], also termed "generic critique", in which the construction work is and must be the starting point from which one justifies the relations that need to be established, inverting the research process, which would lead from the work to the background.

At present, especially as a result of the financial crisis of 2007, it is uncommon to complete the Aalto method, and the methodology of this article is closer to the "through art and design" approach of Frayling and the method of Alvar Aalto than to Baxandall's inferential method, since Frayling and Aalto's approaches allow architectural works from different periods to support a prior knowledge necessary for a practical implementation that considers the results of other previous projects and research. This ensures a greater interaction between basic and applied research.

Consequently, this article is written in two sections that borrow the terms *Scientific Observation* and *Construction Period*, which Aalto used in 1940, because they are well suited to both the contents and the methodology followed.

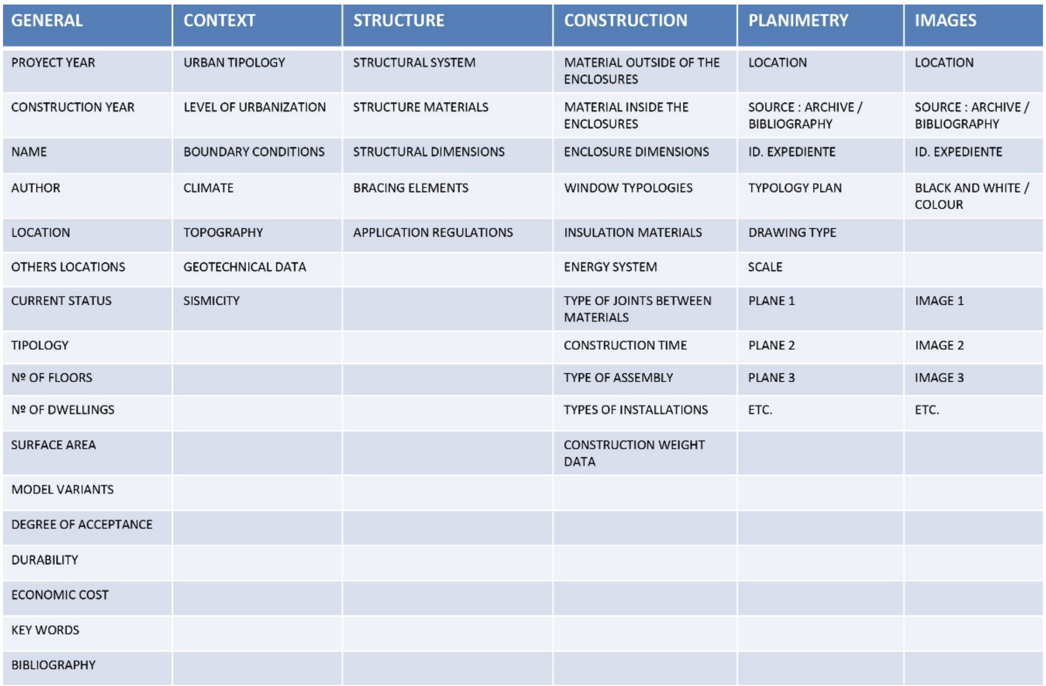
The first part, *Scientific Observation*, is intended to create a sufficient spectrum of architectures to support the purpose of the research. To this is added the analysis of certain products with which it is possible to create construction and structural solutions applicable to buildings on a domestic scale, *scientifically observed* from current environmental performance criteria that further strengthen the objective of affordable construction using local labour.

The second part, *Construction Period*, defines intervention strategies to restore a heritage site in poor condition that is reusable as a home and proposes a specific solution for covering the roof using, in both cases, materials with low environmental impact that help to mitigate the consequences of climate change and that have been analysed in this article.

3. Scientific Observation

3.1. Previous Architecture in Light Prefabrication: Values Applicable to the Proposed Intervention Strategies

The examples of architecture that we have studied with prefabricated systems are those that use light, prefabricated systems that comply with the conditions for recycling, the use of modules, and the standardisation of minimum dimensions that can be self-assembled. The result of this study has been sorted into a database that combines various information, considering not just the usual identification data that refer to its context (urban or rural location, climate, topography, access, etc.) but especially those that define its construction (data referring to the surroundings: materials, weight, dimensions, type of joints, implementation time or situation of the facilities, etc.) and its structural system (structural system, materials, dimensions, or bracing elements). The database also reports on whether there have been variants of the model, the degree of acceptance achieved, or its commercialisation, which are directly linked with its level of industrialisation (Figure 3).



GENERAL	CONTEXT	STRUCTURE	CONSTRUCTION	PLANIMETRY	IMAGES
PROYECT YEAR	URBAN TIPOLOGY	STRUCTURAL SYSTEM	MATERIAL OUTSIDE OF THE ENCLOSURES	LOCATION	LOCATION
CONSTRUCTION YEAR	LEVEL OF URBANIZATION	STRUCTURE MATERIALS	MATERIAL INSIDE THE ENCLOSURES	SOURCE : ARCHIVE / BIBLIOGRAPHY	SOURCE : ARCHIVE / BIBLIOGRAPHY
NAME	BOUNDARY CONDITIONS	STRUCTURAL DIMENSIONS	ENCLOSURE DIMENSIONS	ID. EXPEDIENTE	ID. EXPEDIENTE
AUTHOR	CLIMATE	BRACING ELEMENTS	WINDOW TYPOLOGIES	TYPOLOGY PLAN	BLACK AND WHITE / COLOUR
LOCATION	TOPOGRAPHY	APPLICATION REGULATIONS	INSULATION MATERIALS	DRAWING TYPE	
OTHERS LOCATIONS	GEOTECHNICAL DATA		ENERGY SYSTEM	SCALE	
CURRENT STATUS	SISMICITY		TYPE OF JOINTS BETWEEN MATERIALS	PLANE 1	IMAGE 1
TIPOLOGY			CONSTRUCTION TIME	PLANE 2	IMAGE 2
Nº OF FLOORS			TYPE OF ASSEMBLY	PLANE 3	IMAGE 3
Nº OF DWELLINGS			TYPES OF INSTALLATIONS	ETC.	ETC.
SURFACE AREA			CONSTRUCTION WEIGHT DATA		
MODEL VARIANTS					
DEGREE OF ACCEPTANCE					
DURABILITY					
ECONOMIC COST					
KEY WORDS					
BIBLIOGRAPHY					

Figure 3. Structure of contents in each record in the database. Source: the authors.

Based on these criteria, a selection was made of 78 examples of projects and construction works that begins with the Charles S. Ross House, by Frank Lloyd Wright, 1902, and ends with the Casa Garoza 10.1, by Juan Herreros, 2010. The structuring of the database enables the systematisation of solutions that are compatible in many cases with industrial production in the local area. Considering this condition, there is a greater probability of success both in the manner in which it is necessary to intervene as well as in the use of minimal modular elements that allow buildings to be habitable.

Following the methodology explained herein and based on the projects studied, it is useful to take note of some points that will later have bearing on the intervention strategies.

Firstly, and derived from the designs and projects for the Shingle Style carried out by Frank Lloyd Wright in the first decades of the 20th century, we must take note of the importance of the small-scale modulation employed in inward and outward-facing elements (porches and balconies) that were linked to more distinctive internal spaces and built with a single material. The Balloon Frame system used gives pride of place to the carpenter's craft as the basis of a highly adaptable construction system. In addition, in some houses, Wright used a floor grid that was modulated in accordance with the dimensions of the standardised wooden elements, such as in the Double Cottage for George Gerts (Whitehall, Michigan, 1902), using the "board and batten" technique (Figure 4) [16] under a 3-foot (91.44 cm) grid through which everything would be linked both in terms of space and construction. The use of a small base measurement restricts the maximum lengths of the materials to be used and establishes a proportional relationship among them.

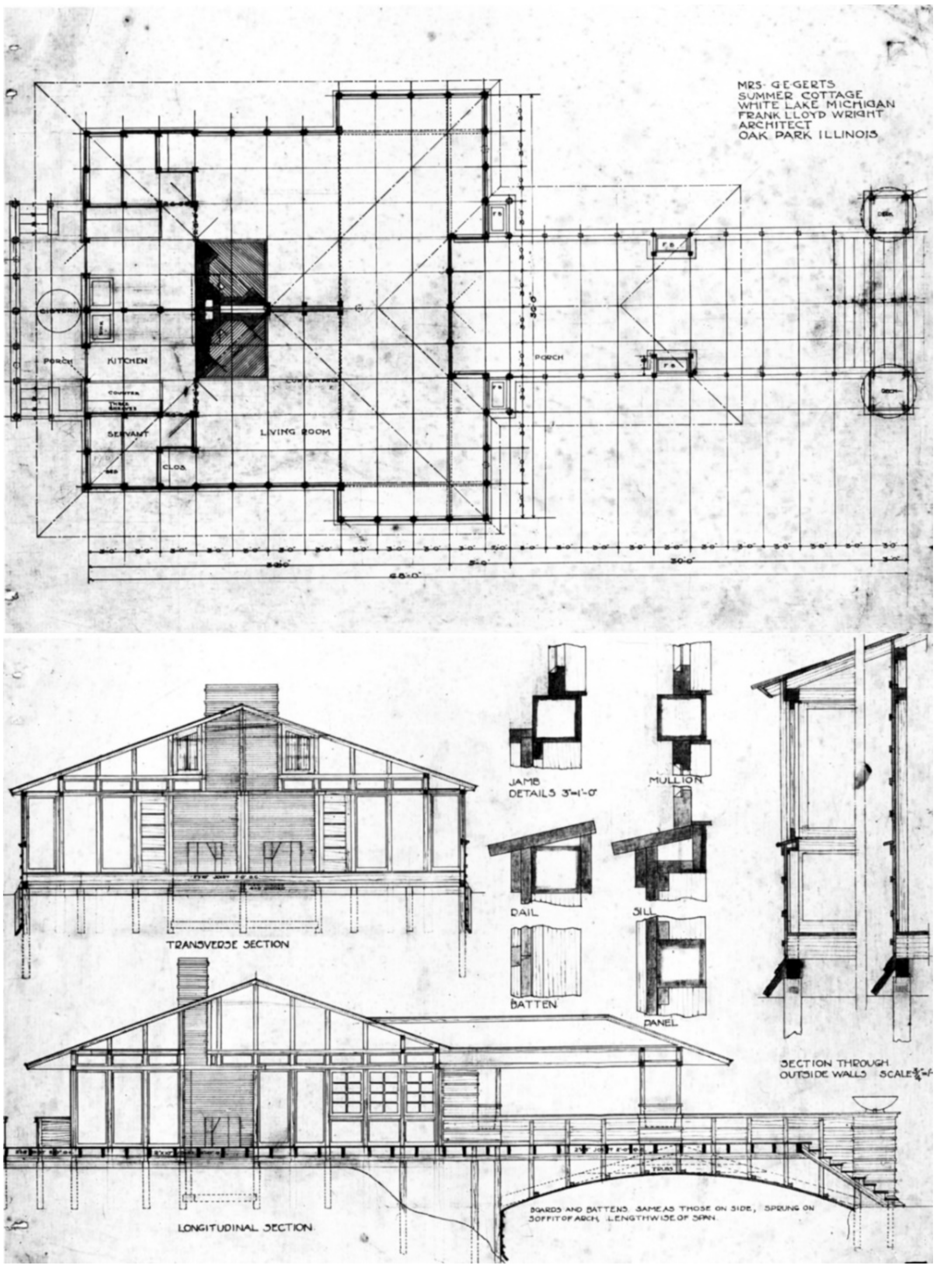


Figure 4. Doble Cottage for George Gerts (1902) Frank Lloyd Wright.

The grid as an instrument for control of the project has been widely used throughout the 20th century. Walter Gropius, in his houses numbers 16 and 17 built in the Weissenhof Siedlung (1927), used the dry assembly system—*Trockenmontage*—laying out a floor grid of 1.06 m × 1.06 m, the dimension of the standard door frame measurements. Additionally, well-known are the projects that the German architect developed in his American stage with the Packaged Houses.

Jean Prouvé also used a grid for his prefabricated houses, in this case a 1 m × 1 m grid. In addition to limiting the length of the prefabricated structural and construction elements, the condition was added that no item could exceed 80 kilos so as to ensure that all the components to be used could be handled by three or four workers. The aim was to facilitate self-assembly, a criterion that extended to numerous projects of his and was applied in various ways to all his designs. The engineer Léon Pétroff, who collaborated with Prouvé, patented an extendible system (1968) that consisted of a repeatable structural module that was adjusted to the dimensions of the grid (1 m × 1 m). Easy to transport due to its small dimensions and weight, it was also recoverable, as the joint between modules was bolted together. Prouvé used it in several of his works such as the Maison de Mme. Jaoul (Mainguerin, 1969) (Figure 5). This module is a braced box with which one can form a growing structure that works in a similar way to a spatial mesh, which enables one to conceive of other applications of this system, including as a linear and vertical structure in the same way as scaffolding, which would be easy to adapt to shore up unstable masonry walls. The prototypes with an axial doorway, sheet, and central nucleus that Prouvé designed were intended for housing but were also applied to schools with similar dimensions to the domestic scale. In some of them, such as that of Jules Ferry, built in the French town of Dieulouard (1952–1953), the prefabricated elements were combined with masonry walls, although it was still a new build [17], something that Prouvé had tried in the Meudon houses (1950–1952), in which, on masonry walls, a slab was deployed based on reticulated metal strips on which were mounted the prototype for the central doorway [18]. Prouvé designed the Maison Tropicale (1946–1949), also with an axial doorway, which, with a 2 m gallery and 1.2 m brise-soleil, he sought natural ventilation through an open gable that provided airflow, thus attempting to produce an architecture whose comfort and thermal control were based on incorporating passive elements [19]. In addition to providing a sustainable design, the combination of traditional construction techniques and prefabricated industrialised materials is feasible. This expands the possible intervention strategies in locations and architectures in which a mixed system is called for with apparently diverse building techniques. To put it another way, it also entails the inclusion of unskilled labour in the implementation of a project, without giving up the technology that the construction industry has to offer.

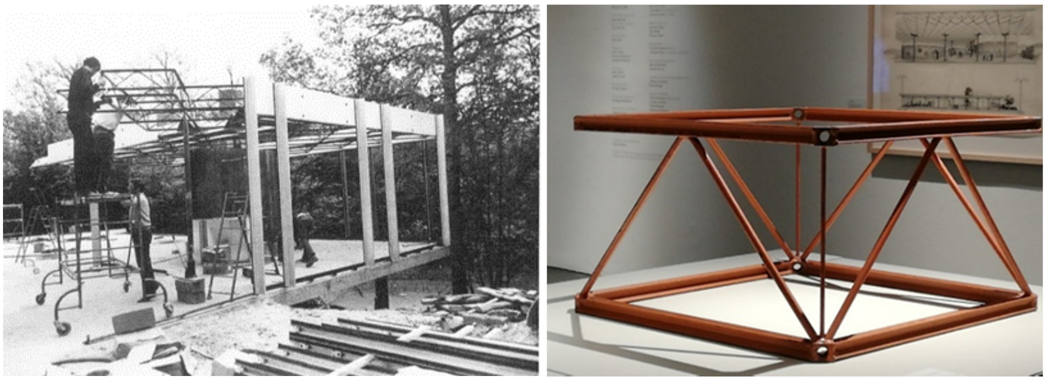


Figure 5. Maison para la Mme. Jaoul. Jean-Claude Drouin, architect; Jean Prouvé, consultant engineer; Léon Pétroff, engineer; Brisard, construction company (1969) [18]. Model of extendible module by Léon Petroff. Photography, authors.

The design of a module that could be repeated until it formed a larger whole has had very diverse variations, such as the Stadt Ragnitz designed by Günter Domenig & Eilfred Huth (1963–1969), the dimensions of which led to dense networks of prefabricated elements cable-stayed with diagonals. Additionally, the works of Eckhard Schulze-Fielitz are included, such as the Urban System, Research and Development (1965–1966), which was a cellular spatial system of 7.2 m × 7.2 m with four maximum elements in each node and screwed joints. He also proposed three types of climate control for the internal spaces: natural, semi-air-conditioned, and artificial, depending on the level of protection from rain, radiation, temperature, and wind [20] (Figure 6). Eckhard Schulze's proposal, which goes beyond the small scale of the home, alludes to a complex combination of and connection between residential units that would occupy each module measuring 7.20m × 7.20 m [21]. In this way, the rigidity that a grid apparently transfers, in this case in spatial terms, is converted into an adaptive and flexible system, depending on the number of modules this spatial grid will occupy. Each basic unit of the grid is understood as the container, and inside it, one conceives a free, clear space that allows for a diversity of uses or functions.

This idea would be of interest when aligning construction and structural systems that facilitate a flexible use of the interior when the external limits—the container—are rigid and unchangeable.

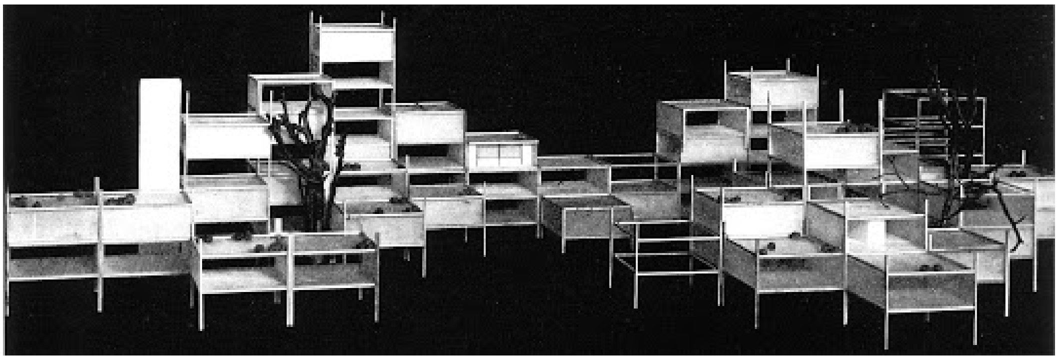


Figure 6. Urban System, Research and Development Company Ltd. Eckhard Schulze-Fielitz, 1965–1966 [22].

Lastly, it is interesting to cite the Naked House by Shigeru Ban (Kawagoe, Saitama, Japan, 2000). In addition to the wooden fibre-reinforced struts that support the trusses hidden by a false roof, the external casing is constructed with two panels of corrugated glass fibre-reinforced plastic [23]. The Ephemeral Pavilion for the Centro Andaluz de Arte Contemporáneo [Andalusian centre for contemporary art], constructed in Seville (2006) by architects Frank Mazzarella and Inma Donaire, is designed based on several walls that have an internal structure as a type of scaffold. The external casing is mini-wave panels of glass fibre-reinforced acrylic. These examples introduce new industrial materials and, above all, the combination of structural and enclosing systems of very different natures into the debate.

3.2. Prefabrication and the Construction Industry: Products and Systems Applicable to the Proposed Interventions

Prefabrication is a type of industrialisation of construction [24] that guarantees that the final product is the result of a process that is completely controlled and determined, in which it is possible to define the optimum conditions in which a construction element must be produced [25]. The exhaustive control of the dimensions, weight, mechanical characteristics, the possibility to choose the components, and the fabrication process distinguish it from other ways of manufacturing products that, without due control, may prove to be more environmentally harmful, contrary to the assessment of the impacts through the product life cycle and the circular economy [26].

Globalisation has meant a dislocation of industries and, with it, the atomisation of prefabricated components to form a final product. The case of cars is very illustrative, where the various mechanical components are made in various factories located in distant locations, ultimately to be assembled in a factory expressly dedicated to this function. In this international context, it is difficult to think of closed prefabrication, especially in construction, particularly when architecture is not well-suited to this idea of the final product, closed and repeatable at a quantity and with a fabrication and installation time similar to that used to produce a model of car. For architecture, the challenge consists of leveraging the advantages that industrialised prefabrication offers to generate different, innovative solutions [27] that, in addition to reducing environmental impacts, are energy-efficient and reduce building costs. Architectures can be created that comply with what Richard Llewelyn–Davies and John Weeks called in 1951 "socio-technological environments" [28]. The aim was that with prefabrication, one could define a way of building that would be accepted by its inhabitants, who normally rejected it. According to his theory, the image and prefabricated materials had to be visible in the new construction but compatible with the needs of the inhabitants in terms of function and space, spirit, and emotion. When this fails, the traditional architectural forms are imposed, and the reasons are forgotten as to why, in the 1960s, prefabrication and industrialisation were associated with a change in the paradigm of production in construction. At the end of the 1960s, Alexander Pike suggested some reasons why prefabricated architecture was rejected, reasons that still exist today [29].

- A greater presence of architects was needed in the production teams of companies involved in new materials and construction technologies.
- There was a lack of university education in the design of new technologies.
- There was a big difference in size and weight of the prefabricated products used in construction in comparison, for example, with what was happening in the automotive industry.
- The lifespan of a home was, at the time, approximately 65 years (today perhaps longer), comfortably exceeding the lifespan of a car or of any domestic appliance.
- A change in mentality was needed, both in the sectors and actors that participated in house building and in the people that were going to live in them.
- Products were needed that would be financially profitable and that could hold their own in the market for long enough to create companies and production plants engaged in prefabricated construction.

Prefabricated construction must be compatible with people's wish to be able to adapt accommodation to their needs. To the extent that the construction industry pays attention mostly to its sales rating, the way forward consists of designing systems that bring together both interests so that the construction industry fabricates products reducing energy consumption, minimising the carbon footprint, and driving the circular economy, to succeed in changing the current economic, social, and environmental model. Together with the choice of materials according to their life-cycle assessment, the design must achieve an optimisation of the materials and allow the space to be reconfigured so as to prolong the building's useful life until its complete disassembly for a new recycling. Nevertheless, it is difficult to foresee all the modifications that a building may undergo during its useful life, even more so in the case of single-family homes. For this reason, in 2003, some researchers proposed understanding the building as a container capable of adapting to different future scenarios, and so to assess its environmental impact, they proposed a dynamic life cycle assessment (DLCA) [30], studies that have been continued in other research; since 2013, LCA studies on the rehabilitation of single-family homes [6] have been more frequent, in which changes in the surrounding industrial and environmental systems have been considered [30]. This does not mean that prefabricated construction is not suitable, and, in fact, buildings built with conventional systems have been compared to those that have used prefabricated systems, concluding that prefabrication reduces environmental impacts by between 5% and 40%: it reduces greenhouse gas (GHG) emissions, energy consumption, resource depletion, and damage to ecosystems and is also 30% cheaper [31], although this figure varies depending on the geographic location, transportation, and labour costs.

Achieving widespread implementation of the industrial ecology continues to be a challenge [32], which translates the idea of natural ecosystems into construction: a continuous flow in which the waste from an activity, once exploited, is once again transformed and harmless to the ecosystem, enabling the cycle to begin again. The climate emergency has meant that industrial ecology seems current and innovative when, in reality, it dates back to the 1960s.

From all of this, we can obtain some keys and guidelines for our interventions that we can summarise as follows:

- The use of recycled materials or those that, after use, can be recycled.
- Considering the criteria for industrialised prefabrication, the number of different materials to be used must not be high.
- The commitment to an open system facilitates the substitution of elements and the adaptation of the construction for new uses.

- Implementing a circular economy in the construction process that returns to the environment near the project, using products, industries, and the workforce that are nearby.
- Encouraging the restoration and reactivation of pre-existing buildings as an engine for development, alternative to the global economic model.
- Based on these premises, the possibilities for using three prefabricated products are explored briefly. Due to their composite and environmental characteristics, as well as their modular nature and weight limitations, they would be suitable for our intervention strategies.

3.2.1. Laminated and Cross-Laminated Timber Panels

This product can be combined with others, also industrialised, creating construction systems with greater uses (sandwich panels of cross-laminated timber panels); therefore, it offers versatility in situations that require solutions suited to each requirement. Its widespread use also coincides with a suitable adaptation to the market due to its compatibility with other prefabricated products that follow a dry construction process, facilitating the disassembly and recycling of the products. It is important that it stays on the market due to the possibility of replacing it without causing obsolescence in the building.

The technical values confirm good thermal performance [33], with an insulating capacity up to three times better than that of a conventional enclosure, minimising energy consumption. In restoration, it would improve the function of the existing masonry enclosures, stone, bricks, etc., by lining with these products, increasing the insulating capacity of the whole resulting construction.

According to the study carried out by V. Tavares et al., in which the embodied, operational, and end-of-life energies have been compared, as well as the carbon emissions of products made with wood, these have the lowest impacts in all the categories, compared with the light steel structure or with conventional non-prefabricated solutions [31]. Given that it is possible to fabricate it using recycled materials, the waste generated is also reduced, nearly 60% in comparison to other traditional construction materials: reinforced concrete, ceramic, or metallic materials [34]. To this must be added the low effect of transport on the total impacts [35], as it is a product whose manufacture is widespread since it does not require high technology to produce it.

3.2.2. Industrialised Structural Steel

This section covers the structural profiles, bars and plates, and rolled steel parts, a wide range of elements that can be assembled in various ways using mechanical systems that enable their recovery, and therefore recycling, to a high percentage (90%).

To these elements is added extensive experience in the design of these construction and structural systems as evidenced in the examples selected and studied in the database of architectures referred to above in this article, which has also produced numerous patents for joining systems, anchors, and assemblies that increase the options for their use.

Its production system also enables it to be adjusted to any dimension without it requiring a modification in the production chain, i.e., a made-to-measure industrialised prefabrication. The current systems for controlling the dimensions through software and laser cutting increase the precision and expand the design possibilities of metal parts, regardless of the speed of production and their mechanical characteristics. On-demand production also enables the control of the dimensions and weight of the elements, aspects that are especially relevant for self-building.

In environmental terms, these structural steel products have also been analysed through an evaluation of their life cycle, above all considering the production stages of the product in a comprehensive way, from the extraction of the raw material needed to make it to the final deployment of the product for use in construction. As the study carried out by Pietro Renzulli et al. shows, the data vary not only between countries but also depend on the extraction and production systems of each factory. In any case, it is known that the steel production process is the most polluting part of its life cycle, due to the energy consumption required, to which we must add the waste it generates, although the slag produced by the manufacturing process can be reused as a fertilizer or for road surfacing [36].

Of the United Nations' 17 Sustainable Development Goals, it is important to guarantee the use of clean energy (goal 7), consumption patterns (goal 12), and climate action (goal 13), among others, for which controlling CO_2 emissions is required, goals that would also align with the European Union's Green Deal and the Paris Agreement. The production of these products with neutral steel would contribute to all of this.

3.2.3. Light Steel. Light Steel Framing

This system is the heir to the American *Balloon Frame* based on the construction of a network of elements that, due to the distance and deployment of their struts, take on a load-bearing function. Equally, there are numerous projects and construction works built with this system that give an example of its usefulness and the diversity that can be achieved.

Unlike the previous one, this system requires precise coordination between the elements and the other prefabricated products that complete the whole. In a certain way, as it is an open system in terms of components, its application is subject to the interdependence imposed by the framework of the profiles, but this can also produce an optimal result if the combination of these products is also based on environmental criteria. Some prototypes have been built and tested in accordance with this principle, such as the research carried out by Ornella Iuorio et al., which also compared the results with a wall built with traditional materials with the same thermal transmittance [37], with better results achieved by the prefabricated combination in almost all the categories in its LCA. Although each test shows that the results depend on the solution adopted in each project, there are mostly favourable conclusions in the construction systems combined with an LSF-based structural system, considering that the total restoration of the light structure is achieved at the end of its useful life. As these researchers indicate, the non-structural products of the ensemble can be replaced and reinserted into the life cycle. In addition to a better thermal behaviour, they would contribute to a greater implementation of the circular economy.

The distance between these profiles, which varies between 40 and 60 cm and reduces the dimensions of the elements to be used; the joining system between elements with recoverable systems; and its cold-rolled construction contribute to the lightness of the system, the ease of self-assembly, and its manageability.

4. Construction Period

4.1. Intervention Strategies in the El Rodezno Watermill

The 2030 Agenda and its Sustainable Development Goals, as well as the European challenge of the nearly zero energy buildings (NZEB), require the use of renewable energies: zero energy, in the operating systems of a building using renewable energies; zero emissions, using materials that do not emit substances that are harmful to the environment, are flexible and reusable or recyclable, and take into account the service life of the products used throughout the building's lifetime; and zero waste, in the use of construction solutions.

This approach was already included in the goals for *Horizon 2020* Cultural Heritage, Framework Programme, for the period 2014–2020 under the *Europe 2020* strategy, which is now in force in the new commitments that place the horizon in the year 2030 [38].

The goal consists of providing innovative solutions and knowledge, by means of strategies, methodologies, technologies, products, and adaptation and mitigation services, with a view to the conservation and management of the tangible cultural heritage of Europe that is exposed to risk due to climate change.

Of the 85 mills located, the scenarios are very diverse, and not all of them still have a sufficient wall structure to be recovered with light prefabricated systems, which would allow a habitability compatible with residential use. In fact, of the 37 mills that existed in the Sierra de Grazalema Natural Park, a region that is part of the Sierra de Cádiz, 13 of them still maintain a part of their construction that would make it possible to propose their restoration. Sixteen of them have already been converted into rural dwellings, without a clear intervention rationale: some have been completely replaced by a new-built dwelling, others with very extensive alterations that prevent their origin as a mill from being recognised, and in no case has an intervention been proposed based on sustainability principles. The remaining eight mills only present vestiges; some traces of their walls or part of the infrastructures that channelled the water to the mill remain [2] (pp. 507–508).

It is evident that any intervention in built heritage requires a deep formal, structural, and constructive study of its current state, so the strategies put forward here are merely suggestions that would require the subsequent verification and review of the proposed solutions. However, it must be considered that these mills are of a very common type, with one part devoted to the milling machinery that presents few variations in terms of construction and dimensions: a rectangular layout that ranges between 3.50 and 4.50 m, built with masonry supporting walls, using the materials from the area, with sand and lime mortar, usually around two feet thick. In less frequent cases, this base construction was extended with the miller's dwelling, giving rise to very variable combinations according to the family composition or the physical characteristics of the site, usually on a slope. The mills that included this house have been maintained better than those constructions intended exclusively for the production of flour, but they have also been the ones that have been transformed the most, precisely by including and maintaining residential use from the outset. In this research, the rehabilitation strategies for these rural architectures for residential use are applied only to the part that was devoted to milling because it is a replicable construction, with similar dimensions between different mills and, therefore, with a greater possibility of systematising the solutions that are proposed.

The "El Rodezno" watermill, located in Ubrique (Cádiz, Andalusia, Spain), is in a state of semi-ruin, retaining its structure of walls (Figures 7–9), so it lends itself well to a study of its rehabilitation with light prefabricated systems. This tests the adaptability of these industrialised materials and systems to the spatial and functional structures of existing buildings with or without heritage value. The symbiosis between tradition and innovation is also a field of exploration on the ability to comply with the general principles of a bioclimatic architecture, while the old walls that delimit the interior present an adequate thermal inertia. The new materials can provide an eco-efficient construction in addition to a rapid execution, reducing the energy consumption required during construction.

The mill has two floors, and its load-bearing walls are masonry constructed with stones from the area with a mortar of lime and sand, reaching a variable thickness between 60 and 65 cm. As in all mills, it had a gable roof, constructed with wooden elements and clad in Arabic tile: it is currently almost non-existent, as is the slab on the first floor (Figure 10). The floor does not have the regularity that it seems to show, which, apparently, could make the application of industrially prefabricated elements and systems difficult. The average dimensions of the bays are 4.30 and 3.30 m, dimensions that, however, would facilitate working with small, lightweight elements, avoiding the use of special machinery to assemble the prefabricated elements on the site.

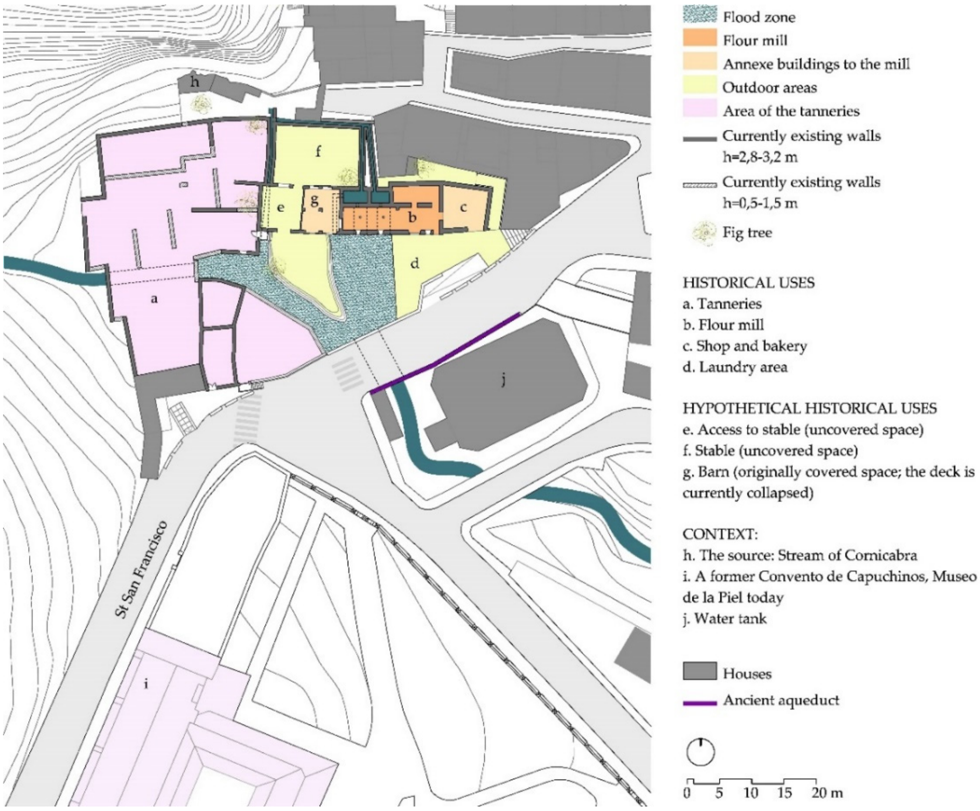


Figure 7. El Rodezno water mill. Current state. Ubrique, Cádiz, Spain. Plan of historic uses. Source: authors.

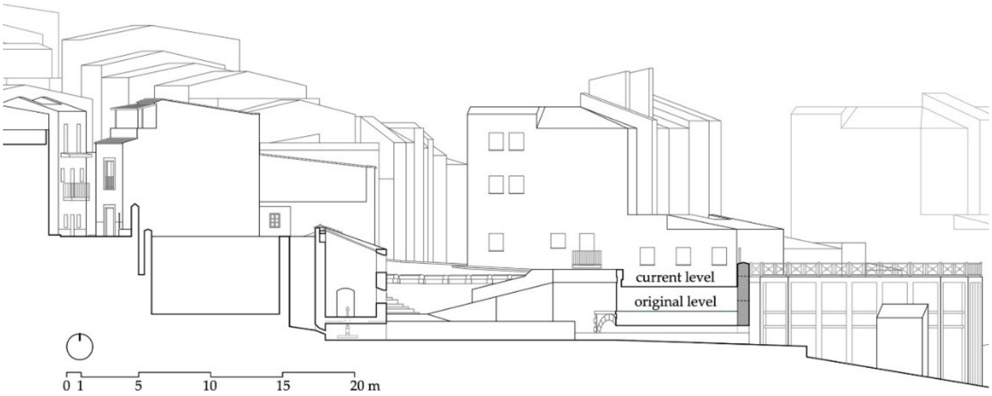


Figure 8. Cross section from Calle San Francisco. Source: authors.

Figure 9. Elevation from Calle San Francisco. Source: authors.

Figure 10. "El Rodezno" water mill, Ubrique, Cádiz, Spain. View from Calle San Francisco. Photography: authors, 2006.

The mill's current stability is due above all to the fact that it is a small construction and that the bonding between its different walls braces it as a whole. This way of building is of interest as it demonstrates the importance of the assembly between elements, necessary so that the overhauled structure as a whole can achieve stability and a light articulated structure that functions as a mechanism that can be inserted and that should form a solid structure with the existing walls, because, although these contribute by their own weight a certain structural stability, it is insufficient for the level of safety that is currently required in construction. This structural combination of walls and prefabricated structural elements would optimise the number and dimensions of the internal supports. An inspection of the pathologies observed in the masonry walls would also be necessary for their repair and/or consolidation and their stability or reinforcement, depending on whether what is required is an improvement in their base, in the wall itself, or in its crowning, following intervention criteria already analysed and studied in earthen walls in various conditions and of diverse natures [39,40].

There are various consolidation techniques for these types of walls, but their repair by composite reinforced coating applied on both their interior and exterior faces and in the corners guarantees stability and bonding at the weakest points without altering their external appearance. In addition, it also improves their ability to dissipate energy [41].

The improvement of the masonry walls can be an opportunity to rationalise their internal layout and thus achieve a better fit with prefabricated products. Something similar was done by Jean Prouvé in the Meudon houses (and in the Jules Ferry school) at the joint of the masonry wall with the sheet system whose roof protruded beyond the position of the wall. This solution avoided the encounter with a non-industrial or prefabricated construction element. Prouvé also built his houses on a reinforced concrete base executed on site, that is, a horizontal floor is needed for the assembly of the lightweight structural system. The reference dimension for the horizontal plane in the case of the “El Rodezno” mill would be the dimension +1.30 (Figure 9) where it is possible to resolve the accessibility from the outside.

Having said all this, the intervention avoids altering the external image without resulting in an excessive modification of the immediate environment, although according to article 20 of the Andalusian Historical Heritage Act of 2007 [42], any intervention on pre-existing architecture with heritage value must be acknowledged. In this regard, the internal intervention with the analysed materials respects this law and yet enables the recognition of the space occupied by the current semi-ruined status of the mill. The connection with the walls can be occasional given that the regular geometry of the new materials does not interfere with this approach, and, indeed, the slabs need not conform to the irregular contour they define, accepting the possibility of a physical and visible discontinuity between the walls and light structure.

The grid that must relate the different light elements must start from the dimensions of the industrialised products to be used. It is not a construction on a vacant surface where it is possible to start from a generic measurement, as Prouvé did with his 1 m × 1 m plot. The existence of a defined contour makes Gropius’s strategy at the Weissenhof more appropriate, which started from the measurement of one of the construction elements (the door frames). In this way, several modulations can be proposed until the one that best fits between the outer walls of the mill is achieved. The smaller the grid dimension (as in Wright’s houses), the greater the possibility of adjustment between construction systems as different as the artisanal and the industrial. The lower modulation extends the use of other possible prefabricated elements, which are also small and available on the market, to help resolve the encounters between different materials and different structural and construction systems. The panel that has been used repeatedly in the examples analysed in Section 3.1, and regardless of the dimension, shape, material used, or arrangement in the whole construction, indicates that it is an element that allows for adjustments and combinations and is the most suitable one for the basis of a modulation.

With this analysis, intervention strategies are proposed based on the use of prefabricated products that meet the criteria analysed in the previous sections, i.e.,

- Open systems, compatible with traditional construction.
- Frequently used products that guarantee availability in warehouses or rapid relocation.
- Products that correspond to production processes such as that of nearly zero energy schemes.
- Preference for local industrial production.
- Reduced number of materials.
- Dry assembly that enables the optimisation of implementation times, producing minimal or zero waste during the work.

- Systems that fabricate modular elements with small dimensions or that are easy to adapt to the construction site.
- Weight of prefabricated products limited to handling by two or three operators.
- Systems that enable the disassembly, reuse, and recycling of the prefabricated elements.

The systems and elements analysed in Section 3.2 may industrially produce linear products (beams and pillars), surface products (plates, boards, and panels that are self-load bearing or not), and spatial modules.

In the case of the mill, the use of spatial modules is not suitable due to the small dimensions, but the two first items were appropriate. The dimensions of the panels of the companies in the sector consulted (Thermochip for laminated wood panel and Egoin for cross-laminated wood panel) determine the structural modulation and the lengths of the linear elements. If we consider that the number of different materials to be used must be low, the options are wood or steel. In this case of restoration, wood seems the most suitable given the conditions of the environment in which the mill is located, its better environmental performance, and possible local production. As a result, to carry out the interior structural network, the following would be used:

- Laminated wood panels: *Thermochip* type. Dimensions: 550 mm × 2400 mm.
- Cross-laminated wood panels: *EGO_CLT* and *EGO_CLT MIX* panel type (with insulation). Usual dimensions (transport limit): 2400 × 10,000 mm.

A grid of wooden beams and pillars of 2400 mm × 1650 mm (Figure 11) sufficiently coincides with the dimensions of the panels chosen (Thermochip for the roof and EGO_CLT for the first-floor slab). A structure independent from the mill consists of 16 modules inserted between the pre-existing masonry walls. The connected modules would avoid the duplicity of pillars. To fill in the horizontal surfaces of the grid at "El Rodezno" (Figure 12), 48 Thermochip panels and 7 EGO_CLT panels of 2400 × 10,000 mm would be needed (each panel would be divided into three panels of 2400 mm × 3300 mm, filling in two modules).

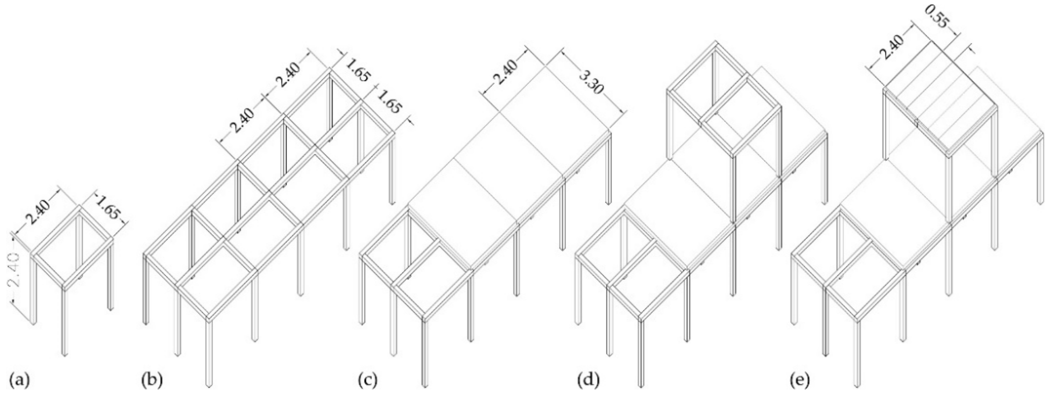


Figure 11. (**a**) Modular structure; (**b**) Addition of modules; (**c**) Placement of cross-laminated wood panel EGO_CLT panels; (**d**) Addition of modules at height; (**e**) Placement of Thermochip panels. Source: authors.

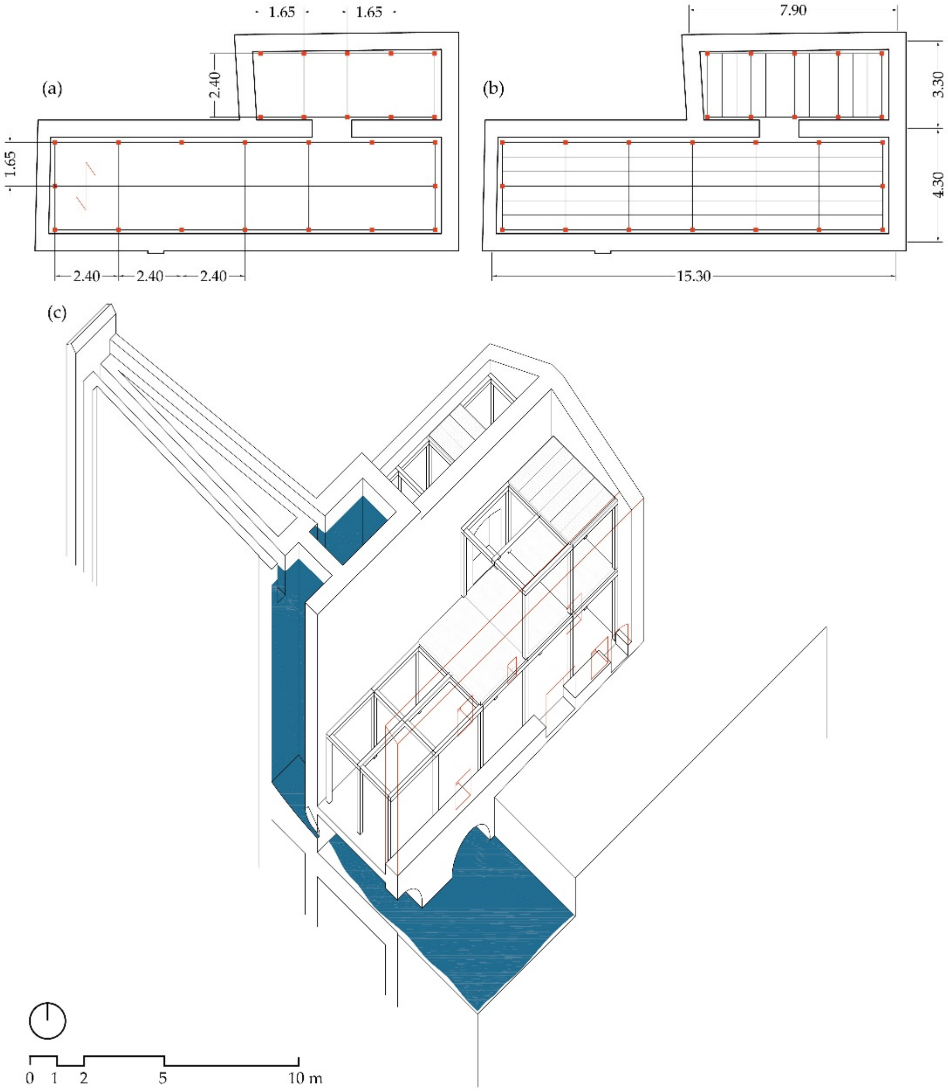


Figure 12. Insertion of the modular system at El Rodezno: (**a**) EGO_CLT panels; (**b**) Thermochip panels; (**c**) Floors and axonometry. Source: authors.

The columns and beams could also be made of industrialised structural steel, and the position of the columns in the contour of the mill could even be replaced by a framework of small profiles (light steel framing). In other words, the strategy of sizing from the panel not only allows the number of elements to be used to be optimised but is also highly compatible with the other two systems analysed in Section 3.2.

The small dimensions of the mill suggest a continuous and diaphanous interior with beams with a maximum dimension of 3300 mm. In this way, the pillars of the inserted lightweight structure are located next to the masonry walls, the slabs being resolved as a simple bay. The structural module delimited by beams and pillars is 2400 mm × 3300 mm in the main building and, in the smaller building, 3300 mm × 1650 mm, dimensions that are the result of subdivisions of the measurements of the wooden panels used. The final dimensions applied are suitable for the residential scheme. Thus, in a 2400 mm × 3300 mm (7.92 m^2) module, eliminating the slab panels, the staircase, and even a hoisting platform can be included to guarantee accessibility to all the floors of the house. The rest of the surface, five modules of 2400 mm × 3300 mm (39.60 m^2) to which would be added the surface of the second building, four modules of 3300mm × 1650 mm (21.78 m^2), allows different housing schemes to be developed. It is not a question of defining a solution or proposing various types of distributions but of facilitating a flexible and habitable space where the principles of Richard Llewelyn-Davies and John Weeks of the "socio-technological environments" are observed: the prefabricated light structure and its materials must be visible, and the designed spatial structure must be compatible with the functional adaptations, modifications, alterations, or divisions that its inhabitants wish to carry out over time. This is a frequent characteristic in the residential architectures that were included in the selective database of 78 works and projects in which continuous space and division with temporary or movable elements (furniture), built with different prefabricated materials and with very diverse shapes, forms, and volumes, are prioritised: Buckminster Fuller's Dymaxion House (1925); the Aluminaire House, by Albert Frey in collaboration with A. Lawrence Kocher (1930); the Canvas House by Albert Frey (1934); the Case Study House of Charles and Ray Eames (1949); the Zip-Up Enclosures of Team 4 (1968–1971); Shigeru Ban's Naked House (2000); the Maison Kerema by Lacaton & Vassal (2003–2005); or the Casa Garoza 10.1 by Juan Herreros (2010), among others.

Professor J. Terrados verifies that the progressive decrease in the size of houses is related to the way in which users assess the house's essential functions, prioritising the efficiency or the comfort of both the space and its construction [43] (p. 147), a view that fits with the approach of not carrying out a conventional distribution of the house.

It should be noted that the reduction of the surface areas also entails a proportional adjustment of the height of the interior space. Spatial continuity allows for many constructive resources, such as the one devised by Rudolf Schindler for the Schindler-Chace (1922), using a portico (*Schindler Frame*) that limited some elements to the height of 1.90 m so as not to interrupt the continuity of space, while the height of the house approached 244 mm, the standard dimension of the panels as sold on the market.

4.2. Construction of the Roof

One of the most important enclosing elements to be resolved is the roof. With laminated wood panels (Thermochip-type), they would maintain the same distribution as the wood panels used in the floors, optimising the number of construction elements. Its exterior location leads to the design of a coating that guarantees waterproofing and resolution with vertical walls. For this exterior cladding, using the prefabricated products studied in Section 3.2, the conditions of dry assembly, restoration of construction elements, lightness, and limitation of dimensions must be maintained to guarantee self-assembly and facilitate the transport of the products, and a simple solution that can be carried out by any kind of worker must be proposed.

Continuing the strategies analysed in the "El Rodezno" mill, the proposed solution is based on the cladding of a roof built in subsidised social housing where the methodology and construction criteria are those of the same research. In addition to the desired transfer between applied research and real construction, this solution is linked to the necessary rehabilitation of single-family homes that entail a functional and constructive improvement to increase comfort by reducing energy consumption and thus help to mitigate climate change.

The final finish by means of cold-formed light steel sheets makes it necessary to resize the external modulation based on the product's manufacturing limitations, also considering the design of the side edges of the sheet so that the union between elements is by overlapping and setting of materials, avoiding excessive handling, manufacturing, and the subsequent assembly processes [44] (Figure 13).

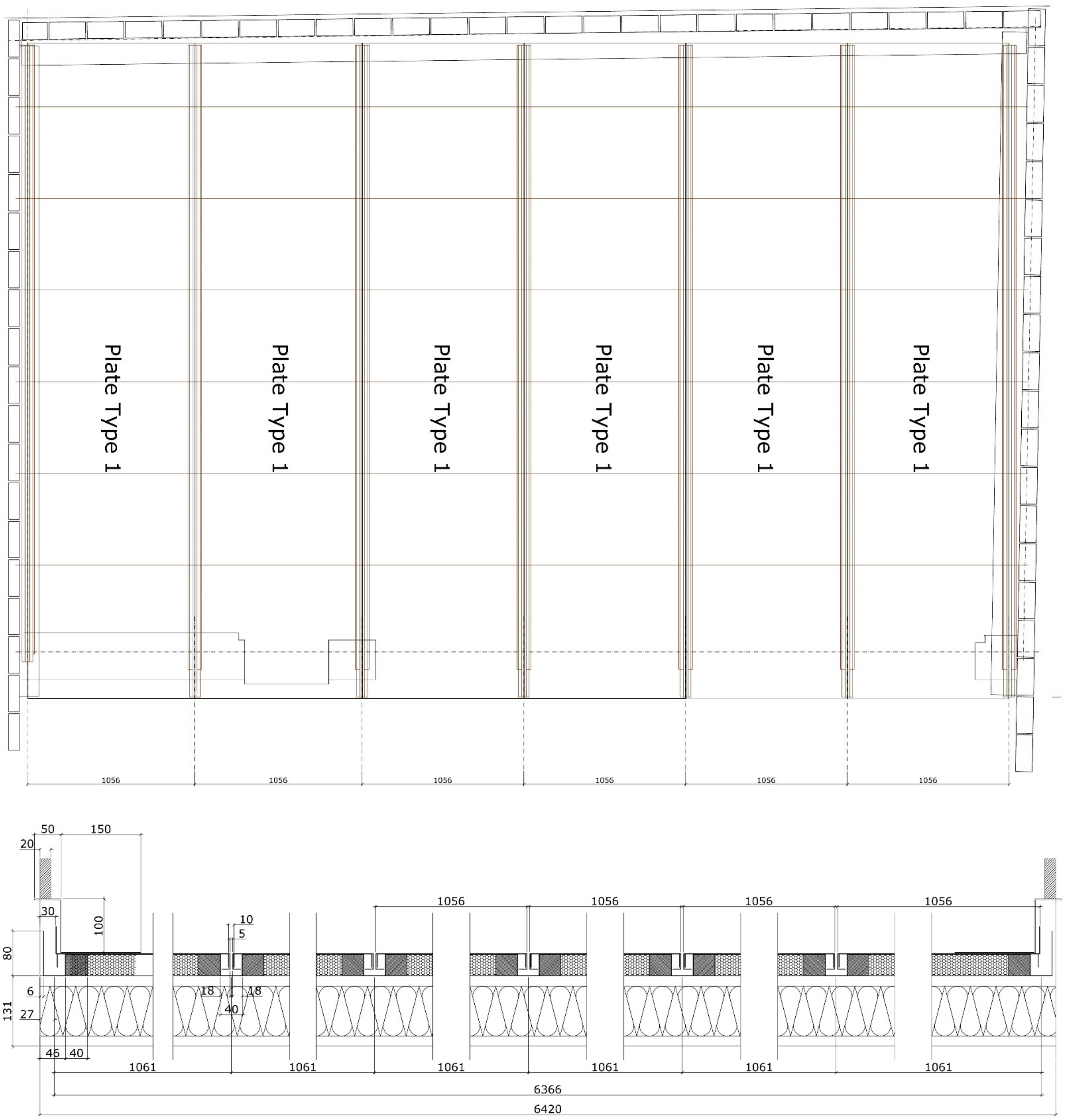


Figure 13. Roof plan and cross-section.: modulation of the guides and type of covering sheets.

Based on frequently used materials that are easily available on the market, such as pine wood slats and different profiles and light cold-formed steel sheets, a solution is designed where the union between materials is mechanical, by means of rivets, self-drilling screws, or guidelines where the outer sheets are fitted. These guidelines formed by the wooden slats and the cold-formed profiles are fixed to the Thermochip panels, and the gap that remains between the guidelines is filled with a light but rigid insulation so that the maintenance of the roof can be facilitated without having to pass through it, which would cause dents and deformations of the exterior cladding (Figure 14). The shape and dimensions of the steel sheets are digitally controlled, laser cut, and mechanically folded. Its ease of construction and the use of common materials that can be easily sourced make the generalisation of this solution viable.

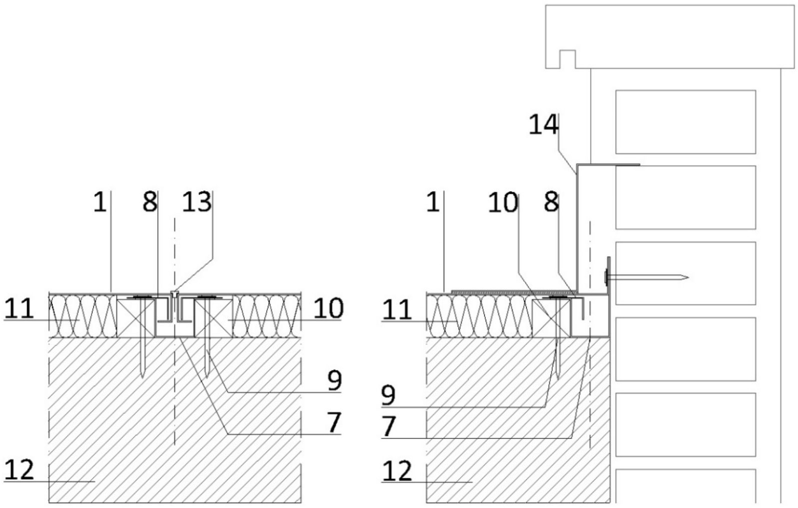


Figure 14. Detail. (**1**) Lacquered metal sheet thickness: 0.06 mm. Digital cut; (**7**) Profile W galvanized steel 40 × 40 × 40 mm; (**8**) Profile L galvanized steel 40 × 40 mm. Riveted joint with W profile; (**9**) Guide fixing screw to cover panel; (**10**) Pine wood strip 40 × 40 mm; (**11**) Lightweight insulating filler between guides. Thickness 40 mm; (**12**) Termochip slab panel; (**13**) Elastic sealing of the joints between sheets; (**14**) Lacquered sheet metal part. Thickness: 0.06 mm. For termination at the factory edge, sealed with the base plate.

The guidelines are hidden, achieving an external surface that is flat and consistent (Figure 15). This characteristic facilitates the solution of the front of the slab with the same material and types of profiles, as it is a continuous enclosure that can also continue along the outer side of the wall leaving the face of the slab concealed and insulated, where the joint occurs with the wall constructed with conventional resources. The solution can even be extended to the windows, also covering the darkening system, an area usually with significant energy losses (Figure 16).

Figure 15. Side edge and centre guides. Assembly process of the coating sheets. Factory-edged finish. Photographs: authors.

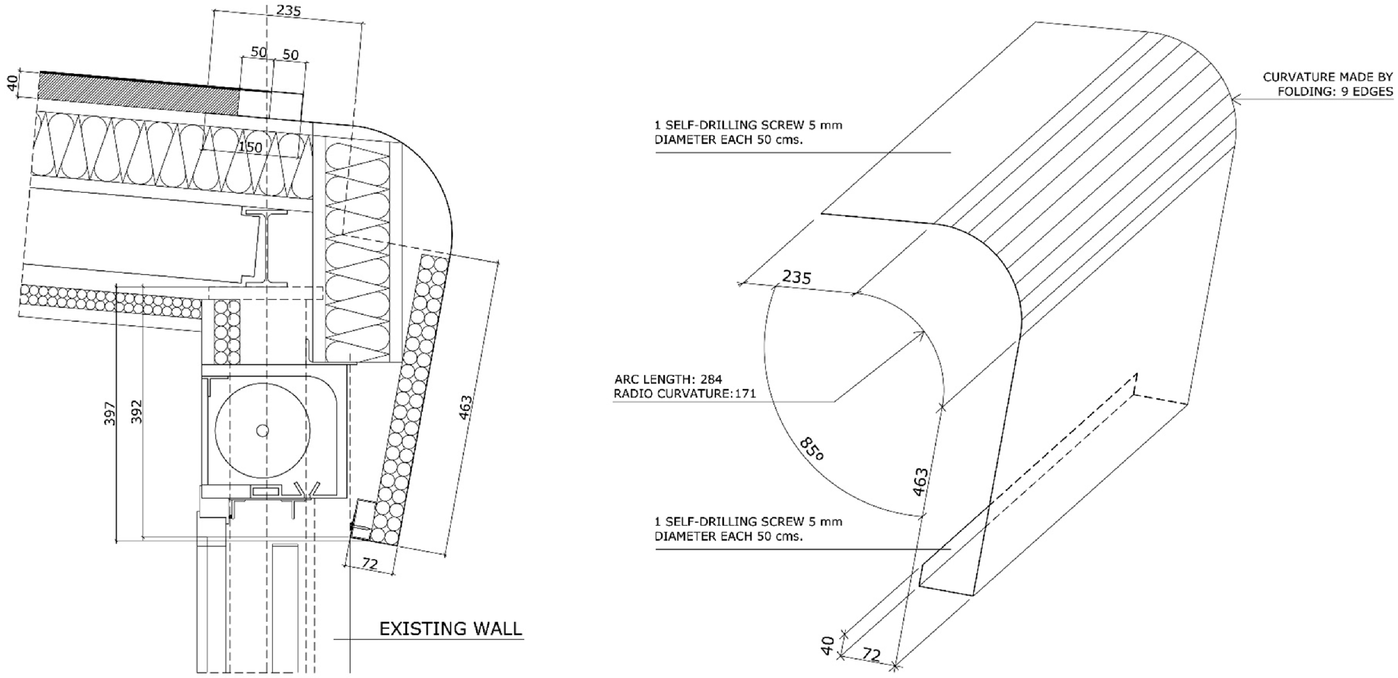


Figure 16. External casing of the front of the slabs and the darkening system. Source: authors.

5. Discussion of Results

The research methodology used, the intervention strategies in the "El Rodezno" mill, and the built roof model that, adjusted to the criteria of this research, are transferable to the studied mill architecture reaffirm the existing relationship between theory and practice that is a form of progress for architecture, thanks to the empirical value [45] provided by architectural designs and the critique that derives from architectural practice accumulated over decades. For this reason, the knowledge provided by the projects and the built works constitute a transfer between theory and practice that does not follow a chronological sequence, but rather constitutes a diachronic process of progress and improvement between theory and practice. From the built work, new solutions can be transferred to the strategies of a project, and vice versa, accepting that research in architecture is an open-ended process.

The research reveals the importance of small-scale renovations that need to be carried out with limited financial resources. This affects many homes, also considering that 80% of the housing stock that will exist in Europe in 2050 has already been built, necessitating both current processes for the comprehensive rehabilitation of buildings and urban environments, based on interventions that use non-polluting solutions and products [46].

The strategies proposed and the construction solutions implemented could be described as precision interventions in architectures with or without apparent value. These architectures are also transformed into an extensive field laboratory whose solutions lead to patents that can be marketed and, indeed, applied to constructions on a bigger scale.

We advocate compatibility between different construction techniques and technologies, even ones that would appear to be incompatible, such as industrial design and artisanal construction. This combination of opposing techniques would be along the lines of the "socio-technological environments" advocated by Richard Llewelyn-Davies and John Weeks. In this regard, the Frank Lloyd Wright buildings mentioned in Section 3.1 that were built in the early 20th century do not feature an industrialised exterior. Wood, in the different forms in which it is produced, prefabricated, industrialised, and widely marketed, conveys the idea of an artisanal construction linked to the carpenter's trade, and some researchers associate this circumstance with its greater acceptance [43] (p. 209). It also turns out that the environmental impact that derives from the evaluation of the life cycles of products made from wood are the lowest of those analysed in the literature and which have been mentioned in Section 3.2.

The dimensional and weight adjustment, which is a condition that characterises light prefabrication, is another factor that influences the acceptance of these construction systems, insofar as it allows the user to self-build and, in the process, to create a sense of identity and belonging in the home-dweller; "do-it-yourself" is the pleasure of doing it [47]. The sense of identity, of belonging of the dweller, is opposed to the idea of temporariness identified by A. Pike that is shown today, practically impossible for single-family homes, and more credible for those sectors of society that, due to their economic or employment situation, are more changeable, in addition to the humanitarian emergencies that occur frequently today for various reasons. Both situations convey a market need.

Modulating the house based on the basic products marketed by the construction industry results in a greater variability of interchangeable prefabricated components, enhancing the circular economy. This strategy is an old aspiration of prefabricated construction applied to housing, and it was already put forward by Walter Gropius in 1910 [48]. However, it did not succeed in gaining a foothold in the construction industry, which, in any case, was starting to focus its interest on reinforced concrete as a new building and structural system.

Prefabrication has generally been associated with innovation, creating new situations or solving problems with new forms. In housing, it has almost always generated interesting ideas, regardless of the different currents of thought with which it was associated or of certain circumstances that, during the 20th century (the lack of housing after the Second World War) or the beginning of the 21st century (natural disasters or migratory flows), have increased its demand and, with it, the interest of architects and the opening of numerous lines of research that address its study, optimisation, and consequences from the perspectives of various disciplines.

Regarding the roof solution, it should be noted that its implementation cost was EUR 18.49/m^2, including the auxiliary assembly elements, and is similar to the cost of covering a roof with traditional materials, which, under normal conditions, is around EUR 20.00/m^2 (valuation according to the Regional Government of Andalusia's construction price database, 2017). However, the labour yield of this lightweight cover is much better compared to a traditional one, taking 50% of the time it takes to complete a roof with traditional materials (compared to the time that was used in the implementation of the planned solution with the labour yields according to the construction price database of the Regional Government of Andalusia, 2017). It is not about defending the built solution but the validity of a research strategy aimed at looking for low-impact solutions combining materials that have been analysed in Section 3.2. To this is added profitability, thanks to its simplicity and the implementation by workers who do not have high qualifications. The economic competitiveness of construction without entailing a reduction in safety or comfort conditions is a factor worth considering for the acceptance by users of construction with prefabricated elements.

Finally, it should be noted that, together with evaluations of materials according to their life cycles and minimising environmental impacts, local climatic conditions are important, and, based on these conditions, incorporating passive solutions that are grounded in the experiences of the craftsmanship and knowledge that have proven to be useful in reducing energy consumption is equally as important. As Milagrosa Borrallo et al. state, "this allows us to decide on the type of actions in the field of architectural design, construction and management to include in the [evaluation] tool, based on the potential development of bioclimatic strategies in specific passive design systems" [49], a criterion which is recognisable in that the prefabricated light structure was implemented inside the masonry walls of the "El Rodezno" water mill.

6. Conclusions

Prefabrication can reduce impacts, the consumption of materials, and the generation of waste, promoting circularity within the construction sector. There are studies that quantify the reduction of environmental impact between 5% and 40%, in addition to economic savings around 30%, as opposed to traditional construction.

Assessments of the life cycles of industrialised products, which analyse and quantify environmental impacts, are essential studies to mitigate climate change and make necessary knowledge available to companies and architects. However, the intervention strategy in "El Rodezno" also demonstrates the importance of design, whereby the effects of climate change can be reduced by the choice and optimised fit of the products used. This factor, together with others of a social or cultural nature, should be considered in life cycle evaluation studies, so architectural projects need to follow a research methodology based on previous experiences on which they base their proposals.

In the rehabilitation of minor architectures located in rural environments, it is helpful to exploit those parts of the existing building made with manual means and artisanal techniques that can help reduce the energy consumption of the whole building. For the "El Rodezno" mill, it was also compatible with the objectives for the Cultural Heritage of Horizon 2020, now extended to 2030, and with Article 20 of the Andalusian Historical Heritage Act of 2007.

Wood-based prefabricated systems are those with the least environmental impact. Although they entail a greater increase in labour costs compared to other industrialised products, the user usually associates them with the manual and artisanal work of the carpenter. Solutions that hybridise prefabricated and traditional building systems, or use industrialised prefabricated products based on the use of wood, help to create a sense of belonging in the user and thus a better inclusion of industrialised prefabricated products in home renovation. Achieving a high degree of acceptance helps to change the mentality of users with regard to the use of this type of product and, in this way, to increase their demand, a factor that determines the profitability that justifies these products being available on the market for a sufficient time.

For the rehabilitation of minor architectures that can be adapted to residential use or the rehabilitation of single-family dwellings, the limitations of dimensions and weight increase the possibility of assembling, enlarging, piling, dismantling, or recycling all the structural and construction elements, with the resulting reduction in environmental impacts and a better evaluation of the LCAs. The use of products of these types that are usually available both in rural and urban environments boosts local employment and the circular economy, criteria that are compatible with the Sustainable Development Goals.

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