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Creative Frugality as a Sustainable Circular Pattern in Architecture and Building Construction †

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Abstract: The global population growth and the imperative to achieve decarbonization goals suggest a re-evaluation of conventional building design approaches. A shift towards sustainability, guided by the Triple Bottom Line principle, becomes essential. In this context, a design paradigm rooted in frugality and creativity can be a promising alternative. This study delves into the role of creative frugality within affordable housing. Through case studies, we showcase technological solutions designed following frugality and creativity. These solutions demonstrate key research findings, such as the relationship between sustainability, circular practices, and frugal, low-technology buildings. These findings are enabled by the concepts of flexibility, adaptability, and disassemblability.

Keywords: sustainable construction; frugal architecture; low-technology construction; affordable housing; circular construction; frugal innovation; built environment

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1. Introduction

The world population is expected to grow significantly in the coming years. This projection emerges from the latest report by the United Nations [1], which indicates that the population will reach around 9.5 billion by 2050. As a result, there will be an increasing demand for houses that should be affordable to meet the needs of low-income people. The scenario depicted by this projection directly involves the construction sector. Addressing this issue requires all involved stakeholders to work towards achieving the environmental goals set by the Paris Agreement for the year 2050. The construction sector has a significant impact on the environment, as it represents approximately 40% of global operational energy consumption and process-related CO_2 emissions [2]. It is also responsible for over 30% of the extraction of natural resources and about 25% of solid waste generated worldwide [3]. To build affordable houses capable of meeting the increasing demand, a change in the design approach is imperative. The new approach should focus on low-technology design strategies capable of extending the building life cycle. This approach will also allow easy modification and adaptation of buildings to the needs of the occupants. It will enable them to have an active role in managing their houses, promoting self-maintenance and self-construction, and reducing operational costs. Relying on local materials is also crucial both to stimulate the local market and labor force and to reduce the embodied energy of the materials used [2]. How can this new design pattern be achieved? To answer this question, it is interesting to delve into the concept of frugality. It could provide a possible design pattern to counteract population growth with environmentally, economically, and socially sustainable buildings. The concept of frugality is strongly connected to sustainable development. It promotes the idea of making more with less. In recent years, frugality has spread across various industries. In mass production, a new tech paradigm called frugal innovation (FI) has gained traction among academics, even if it is less prevalent in construction [4]. In this field, it could promote innovative affordable materials and

components. Notably, frugality connects to creativity. Their relationship allows for resource reduction and the blending of traditional wisdom with modern technology. This study aims to deepen the concept of creative frugality in the building and construction sector to highlight sustainable and circular design solutions. The following sections will provide an overview of the concept of frugality in buildings and the relation with FI. Subsequently, two case studies will be presented and discussed to demonstrate the role of creativity within the framework of frugality.

2. Materials and Methods

Frugality is a well-known concept in building construction and has been applied for a long time. Vernacular architectures serve as clear examples of frugality, featuring technical solutions that arise from resource-constrained contexts. This kind of architecture exhibits an adaptive attitude and complete fusion within the context. This adaptive attitude can also be observed in design solutions that improve the thermal performance of buildings in relation to specific climatic conditions [5]. Moreover, the need to rely only on locally available resources has allowed the establishment of a unique relation with the context and the consolidation of construction techniques over time through trial and error processes. A clear example of frugality in vernacular buildings is provided by Japanese joinery. It originated as a response to challenging environmental conditions, including climate variations and frequent seismic events. The apparent simplicity of the structural connections in Japanese vernacular buildings results from a complex synthesis process involving creative intuitions, trials, and errors. Therefore, while vernacular architecture showcases frugality in its forms, this frugality does not equate to simplicity. Instead, it represents a refinement that purges excess elements to adapt to the environmental, social, and economic context. The need to reduce the environmental impact of the construction sector, while addressing complex issues like sustainable affordable housing, indicates the exploration of new approaches in building design. Nowadays, an approach based on the concept of frugality warrants investigation. The concept of frugality has evolved in the contemporary context of globalization. It has adopted a sustainability-oriented connotation, aiming to promote the construction of buildings that feature good quality, cost-effectiveness, and low environmental impacts. This modern paradigm of frugality in architecture finds support in the French movement "Frugalité Heureuse et Créative", launched by D. Gauzin-Müller, A. Bornarel, and P. Madec. It has sought to formulate guiding principles that integrate frugality and creativity into the building sector. These principles are outlined in the manifesto for creative frugality [6], authored in 2018. Their main objective is to adopt sustainability principles while concurrently pursuing innovative approaches to design and construction. It is also perfectly in line with the UN SDGs, in particular 1, 3, 7, 11, 12, and 13. The manifesto outlines the concept of frugality across four domains of application: energy, materials, technology, and territory (Table 1).

Table 1. Frugality variations from the Frugalité Hereuse and Créative Manifesto.

Frugality	Features
Energy	Reduce the use of fossil as a source of energy; improve the use of renewable energies (solar, wind, etc.); adopt bioclimatic and passive design solution for climate adaptation.
Materials	Use local materials to shorten the supply chains and have environmental benefits; use low embodied energy materials; promote bio-based materials.
Technology	Design buildings that rely on low technology and low-carbon solutions which are easily reused and recycled; allow self-maintenance and self-construction operations.
Territory	Respect local culture; low soil usage; building adaptation to the context.

Frugality in energy highlights the use of renewable energies in building construction. It also advocates for the integration of bioclimatic and passive design solutions to ensure optimal thermal comfort and climate adaptation. Frugality in materials encourages the use of local, bio-based, and low embodied energy materials. This approach promotes technologies and labor which are typical of a region, thereby preserving cultural identity and supporting local economies. Additionally, local materials generally require shorter supply chains, resulting in reduced CO_2 and GHG emissions. Frugality in technology involves low-technology design strategies. This variation of frugality is especially fascinating. It serves to remove unnecessary elements from the building to make it more streamlined. Here, frugality is combined with creativity to promote innovative and sustainable design strategies, capable of achieving low carbon emissions, and incorporate circular economy practices, such as reuse, recycle, repair, and repurpose. Additionally, the role of low technology is central. It allows us to easily confer flexibility, adaptability, and disassemblability features to the building. These features also enable self-maintenance and self-construction, which foster active resident involvement in home management. Lastly, frugality in the territory seeks to encourage responsible land use and reduce ecological footprints. It also promotes the adaptation of the new building to the context. The frugality proposals from the manifesto encompass a range of activities. These activities, in some cases, are directly connected with circular economy (CE) practices. In particular, the use of bio-based materials and low-technology solutions can foster the application of CE practices.

Considering the variations of frugality explained in the manifesto, creativity is essential to drive innovation. In particular, it can prompt a bricolage process. This process reclaims existing solutions and repurposes them through aggregation and reinterpretation. This creative process is also at the basis of a developing technological paradigm known as FI, primarily in business and management sciences [7]. While a singular definition of FI remains elusive, its general outline is clear. It involves developing good quality solutions that are more cost-effective than existing products in resource-scarce scenarios. FI is gaining traction, particularly in low-income and less developed countries, to serve customers at the bottom of the pyramid [7,8], i.e., those with limited access due to low incomes. Within the building and construction sector, FI guides the improvement of material production and construction systems' sustainability, involving economic, environmental, and social principles. FI thrives on using minimal environmental and economic resources, fostering a design process that blends traditional technologies with bottom-up creative intuition in resource-constrained contexts. This approach can yield environmental benefits by relying on locally sourced materials to minimize transportation and costs, with an upsurge in bio-based materials. Among the frugality variations highlighted in the manifesto, frugality in materials and technology closely align with industrial production. This is the realm where FI is establishing itself. Conventional production processes for frequently used building materials come with dual negative effects, emitting substantial CO_2 and depleting global natural resources. To make them more sustainable, a frugally creative approach to foster innovation and ensure more sustainable processes and products should be adopted. In prefabricated building systems, FI offers valuable insights, optimizing system components and utilizing local and bio-based materials. These insights extend beyond environmental considerations to encompass economic and societal dimensions.

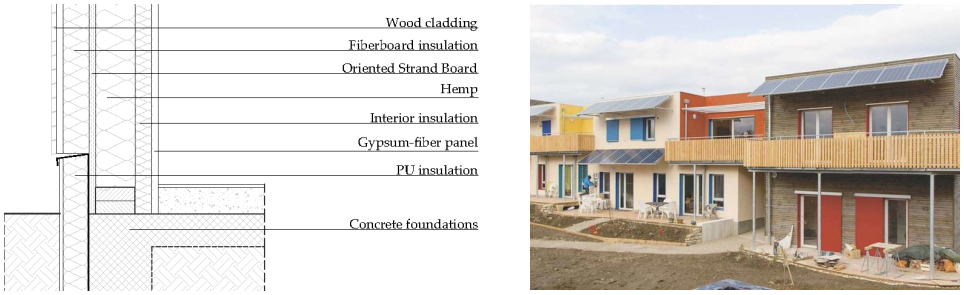
To further elucidate the concept of frugality in buildings, the next section presents two case studies. These provide examples of frugal design and construction solutions.

Case Studies

The case studies presented here feature two contemporary buildings built on frugality principles. Both of them are residential buildings and showcase frugal and creative design solutions. The selected projects are as follows:

- "Les Colibres" [9], in Forcalquier, France, finished in 2017.
- A detached house in Ban-sur-Meurthe Clefcy, France, completed in 2022.

Les Colibres is a participatory housing project promoted by an association of 31 members, spanning ages 2 to 80. Atelier Ostraka and Sylvie Detot guided development, engaging continuously with the association during design phase and construction. This teamwork tailored the building to future residents' needs. The complex holds three structures: two with private residences and the third accommodating public spaces. These shared areas feature a communal hall, laundry, guest rooms, storage, and deposits. They are collectively managed by members. The design of all three buildings focuses on local materials and bioclimatic principles, aligning with frugality's core. While most structures use local timber, specific parts of the residential buildings incorporate steel, like the terraces (Figure 1). Examining the technical details (Figure 1) highlights the pattern's simplicity.



(**a**) (**b**)

Figure 1. (**a**) Technical drawing of the exterior wall of the buildings (Source: Authors' drawing). (**b**) The steel structure used for the terraces (Source: cahiers-techniques-batiment.fr (accessed on 18 May 2023 [9]).

The buildings are designed for self-construction by the association members; only the concrete foundations have been built by a construction company. To enable self-construction, a dry construction system is used, incorporating timber, gypsum fiber panels, and primarily bio-based insulation. Hemp fills the wooden structural frame, while fiberboards act as exterior insulation. Dry connections and construction systems enhance the adaptability and flexibility. Low-technology building systems play a vital role in reducing construction costs. The entire project costs about EUR 1.37 million (excluding taxes), approximately 1400 EUR/m^2. Passive thermal solutions and solar energy integration minimize operational costs and emissions. The second frugal building reported is a detached house designed by the French-based firm, Studio Lada. The project's design draws inspiration from the barn architype. Inside, the building is organized on two floors. Frugality guides material selection and local labor usage. Sawn wood is the primary material, promoting local businesses and reducing environmental impact. The wooden frame, prefabricated locally, is filled with straw for insulation (Figure 2) and then transported to the construction site for assembly.

(**a**) (**b**)

Figure 2. (**a**) Detail of the assembly of the wooden structural frame; each element is filled with straw. (**b**) A picture of the granite blocks and the concrete trusses that constitute the foundations (Source: studiolada.fr (accessed on 15 April 2023)).

A spruce cladding covers both the exterior and the interior faces of the envelope. Foundations consist of twelve local granite blocks, each 50 × 50 × 50 cm (Figure 2). Blocks are interconnected using concrete trusses, which are required due to the area's seismic vulnerability; however, this structural design solution minimizes concrete usage. The building's interior extensively features wood, for partition walls, slabs, and furniture. The ground floor is clay, aiding thermal regulation. This case study also reveals dry and low-technology solutions. Despite the structural layer being much more constrained compared to Les Colibres, due to the prefabricated elements, the interior remains adaptable. Sawn wood partition walls offer impressive spatial and technological flexibility through their possible disassembly. Heating depends on a wood-burning stove integrated with radiators. This project is connected with FI. The production of prefabricated elements operates within resource limits, fostering a cost-effective, environmentally friendly construction system. The building's total cost is around EUR 250,000 (excluding taxes), for an area of 126 m^2, approximately 2000 EUR/m^2. The higher price, in contrast to Les Colibres, could be due to specialized labor instead of self-construction. Both of the case studies rely on optimized structural layers, mainly made of wood. According to Shelton [10], optimizing building structures by ensuring the right robustness reduces material use and lowers the overall costs.

3. Results and Discussion

The study reveals an interesting aspect: there is not a singular definition for frugality within the building and construction sector. Rather, it is a concept molded by the specific site. Shifting contexts bring forth different ways to attain frugality. This is particularly true for the building's design phase. Yet, frugality can be extended to the industry, as implied by FI. It can optimize construction material production and technology advancement. In other words, frugality in buildings is an attempt to use simple construction methods, integrating them with contemporary technologies, to produce innovation. The case studies presented underscore the role of creative dry, low-technology solutions, which drive adaptability, flexibility, and disassemblability. They can also simplify self-construction and self-maintenance, thereby reducing costs. From the designers' perspective, frugality involves considering the context in which they have to work. Frugal buildings result from an approach where designers address specific constraints, primarily economic and environmental. The study of the building's intended context is a priority. It enables a deeper understanding of local construction techniques, materials, labor, and culture. Subsequently, the designer synthesizes study outcomes to devise a viable design strategy meeting the owners' requirements. The designer aspiring to create a frugal building should recognize that the priorities lie in the needs of the future inhabitants and the surrounding context, rather than merely pursuing personal experimentation. This emerges clearly from the case studies presented. Designers in these projects aim to seamlessly integrate their projects into a specific context, addressing issues without affirming themselves. These issues could range from economic and social to environmental challenges. To tackle them, low technologies, local materials, labor, and green energies are crucial. However, achieving the integration of frugal elements like bio-based materials into building systems with recognizable architectural features requires creativity. This creative process entails the designer reinterpreting local peculiarities, as evidenced by the case studies. In this sense, creativity characterizes Studio Lada's choice to use granite blocks for foundations, driven by the will to employ local materials and expertise, thus exemplifying this principle. Similarly, Les Colibres was collaboratively designed with an association to simplify construction elements for effortless self-assembly. In a broader sense, creative frugality offers a valuable strategy which can effectively address challenges like sustainable affordable houses in developing and less developed nations, while catering to the demand for affordable housing in developed countries. The use of bio-based materials, such as straw, hemp, and wood, is central in frugal buildings. However, the incorporation of bio-based materials in construction is a hot topic among academics, particularly concerning methods to assess their environmental impact and what indicators

to consider. Furthermore, in a scenario of increasing demand, the advantages observed in situations of low demand could be offset by other factors. For instance, the intensive soil usage or the CO_2 and GHG emissions necessary for their production. This issue is largely exemplified by the sawn wood production process [11].

4. Conclusions

This paper aims to delve into the concepts of frugality and creativity in construction. It demonstrates that frugality varies with context; however, there exist some guidelines, given that there is not a standardized frugality for buildings. This is due to the fact that an approach based on frugality is a site specific one which considers the building as a unique object. It is the expression of local culture, which gathers local construction methods, labor skills, knowledge, and materials. Relying on local culture allows one to reuse traditional construction methods and innovate them via the adoption of new construction technologies. Most of these new technologies rely on prefabrication, modularity, and the use of natural or recycled materials, whose production requires industrial processes. These sometimes result in specialized labor and high costs. In this sense, FI can contribute to reducing the resources, energy, and pollution needed for the production of construction materials and systems, as seen in Studio Lada's project. Regarding the use of bio-based materials, it should be noted that despite frugal buildings use of bio-based materials being intense, further research is necessary to evaluate their true sustainability. In conclusion, frugality principles offer a valuable approach across different building typologies, especially residentials. This is particularly relevant considering the growing demand for housing and the pursuit of decarbonization goals. In the future, research could deepen the designer's role in building design, using both frugality and creativity.

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