An historical study on temporary and emergency post-disaster housing

Stefano Cascone, Giuseppe Russo, Nicoletta Tomasello

Highlights

Functional characteristics of emergency houses of each significant period have been analysed. Optimizing the architectural design of the temporary buildings in terms of energy, functionality and configuration. Improving thermal environment inside temporary housings has attracted considerable research interests worldwide.

Abstract

During recent years, the number of natural and non-natural disasters has drastically increased, due to the climate change, causing great damages on buildings and a high number of homeless people. However, post-disaster temporary housing solutions seem to have sustainability problems. Through a historical excursus, this work aims to analyse the steps that led to the current idea of temporary housing, in order to evaluate its functional and constructive characteristics. Finally, some considerations on improving thermal environment inside temporary housings are discussed.

Keywords

Temporary, House, Shelter, Prefabricated, Disaster

1. INTRODUCTION

Crisis management after natural and non-natural disasters – defined as an unforeseen and sudden event that often cause great damage – is a global critical concern for governments and population. Due to the current climate changes, the number of natural disasters has drastically increased in the last decades, having a considerable impact on the built environment: from fewer than 50 disasters reported in 1950 to more than 400 disasters in 2010 [1]. Besides human casualties, one of the most visible effects of any major disaster is the damage of houses and the high numbers of homeless people [2]. Therefore, housing provision plays a crucial role on the reconstruction programs since it...
is one of the most important needs for people and their well-being [3]. Temporary housing is defined as an object having the function to shelter people during the period since the disaster occurs until they are resettled in a permanent place to live [4]. Most of temporary house solutions are prefabricated, mass-produced and standardized, and they are classified into two main groups: ready-made units and kit supplies. The ready-made units are housing solutions totally made up in factory that just need to be transported to the site where the disaster occurred. The kit concept also benefits from prefabrication, although the only elements that make up the housing unit are made in factory and then transported and assembled on site. The second solution, compared to the first, eases transportation and assembly, since the elements are small, light and easy to handle. However, post-disaster scenarios have factors that can lead to inadequate solutions, mainly due to the need for a rapid and large-scale action under chaotic conditions; previous studies have presented many problems related to post-disaster housing [4]. Through a historical excursus, this work aims to analyze the steps that led to the current design of temporary housing, in order to evaluate its functional and constructive characteristics. Therefore, the final objective of the study is to provide the historical knowledge to optimize the architectural design of temporary buildings in terms of energy saving, functionality and configuration.

2. THE BIRTH OF “LIVING IN EMERGENCY”

The birth of the house addressed to emergency is connected to the necessities of the nomadic people who, having to move from one place to another, needed adequate shelter during the trip. These were initially represented by makeshift places – such as caves – and later by temporary housing units. Based on geographical area and climate, nomadic people advanced different shelter solutions, using the available resources for structures that, although temporary, have properties similar to permanent ones, such as stability and resistance to climatic conditions. These shelters also had to possess qualities that would allow easy transportability and assembly, such as the lightness and ease of connection of the components. The earliest forms of shelter can be identified in the Paleolithic age with the Aurignacian huts, which take their name from the Aurignac cave, located in France. This hut had a self-supporting structure. The basic element of the dome conformation was represented by the branches, which were fixed in the ground following a circular distribution, with the upper ends curved towards

1. INTRODUZIONE

La gestione delle crisi in seguito a disastri naturali e non – definiti come eventi imprevisti e improvvisi che spesso causano gravi danni – rappresenta una seria preoccupazione a livello globale per gli Stati e la popolazione. A causa dei cambiamenti climatici in atto, il numero di calamità naturali è aumentato notevolmente negli ultimi decenni, con un considerevole impatto sull’ambiente costituito: da meno di 50 disastri segnalati nel 1950 a più di 400 disastri nel 2010 [1]. Oltre alla perdita di vite umane, una delle principali conseguenze di un qualsiasi grave disastro è la distruzione e/o il grave danneggiamento degli edifici e il derivante incremento del numero di senzatetto [2]. Pertanto, all’interno dei programmi di ricostruzione post-disastro, la fornitura di alloggi svolge un ruolo fondamentale, essendo connessa con le necessità più importanti per le persone e per il loro benessere [3].

L’alloggio temporaneo è definito come un oggetto che ha la funzione di accogliere le persone durante il periodo che trascorre dal disastro fino al re-insediamento in un’abitative permanente dove vivere [4]. Le maggior parte delle soluzioni di case temporanee sono prefabbricate, prodotte in serie e standardizzate, e si possono classificare in due tipologie principali: unità già assemblate e unità fornite sotto forma di kit. Le unità già pronte per l’uso sono soluzioni abitative interamente realizzate in fabbrica e che, quindi, devono solo essere trasportate nel luogo colpito dal disastro. Anche il concetto di kit trae beneficio dalla prefabbricazione, sebbene i soli elementi che costituiscano l’unità abitativa vengono realizzati in fabbrica e successivamente trasportati e assemblati in loco. La seconda soluzione, rispetto alla prima, ha il vantaggio di facilitare il trasporto e l’assemblaggio, poiché gli elementi sono piccoli, leggeri e faciliti da maneggiare. Tuttavia, gli scenari post-disastro presentano una serie di fattori che possono comportare soluzioni inadeguate, principalmente a causa della necessità di un’azione rapida e su larga scala in condizioni caotiche; a tal proposito, studi precedenti hanno evidenziato i problemi connessi con l’edilizia post-disastro [4]. Attraverso un excursus storico, il presente lavoro si propone di analizzare i passaggi che hanno portato all’attuale concezione di alloggio temporaneo, al fine di valutarne le caratteristiche funzionali e costruttive. L’obiettivo finale dello studio, quindi, è di fornire una approfondita conoscenza storica degli alloggi temporanei per l’emergenza al fine di ottimizzarne la progettazione architettonica in termini di risparmio di energia, funzionalità e configurazione.

2. LA NASCITA DELL’”ABITARE IN EMERGENZA”

La nascita dell’abitazione destinata all’emergenza è connessa alle esigenze dei popoli nomadi che, dovendosi spostare da un luogo all’altro, necessitavano di adeguate forme di
the center and linked together; the coating, often realized with leather, covered the frame [5]. The Aurignacian hut, dating back to approximately 39,000 – 21,000 years ago, was followed by the Maddalenian hut, which takes its name from the La Madeline cave in Tursac, in Dorgogna (France). The structure was also in this case made of wood, with a double-pitched roof, central stiffening obtained thanks to poles and stitched leathers covering [6].

Paleolithic housings have inspired the most popular nomadic dwellings, i.e. tents. Made with a framed supporting structure covered with fabrics or leathers tended by tie-rods, the tent had to adapt to different climates, although it presented structural variations characterizing different populations. Among the most widely used types of tents, the Yurt – used until today – was technically more advanced from lightness and prefabrication points of view [7]. This type of shelter was originally used during the trips by the Turkish and Mongolian tribes [8]. The Yurta structure was self-supporting on a circular plant, with a diameter ranging from four to ten meters and a height of about three meters. The basic frame was composed of a trellis of curved elements arranged in a lozenge and tied together. This conformation allowed a “pantograph” lock, so a rapid dismantling of the structure, a reduction of the encumbrance during transport and an easiness in assembly. The ends of trellis elements culminated in a covering ring, left open to obtain the escape of the heat. During the night or in the coldest periods, this ring could be closed by curtains. The average weight of a Yurt was around 250 kg and the entire structure could be divided in five or six groups of components to ease the transport, supported by waggons or animals [9]. Yurta materials, chosen according to the available resources, were originally the flexible willow wood for the structure and the vegetable wicker or the felt for the covering, respectively during summer and winter. The internal microclimate was controlled thanks to technical measures designed to ease the convective motions of the air; the chimney effect generated by the described hole avoided the presence of smoke in winter and allowed ventilation in summer.

3. THE MODERN EXPERIENCES

The economic evolution following the first industrial revolution led the society to leave the agricultural-artisanal system, leading to a considerable urbanization and the transition to a modern industrial system, in a process that could be associated with an “industrialization of society”. In this period, there were an increase in well-being [10] and a widespread of technological innovation, which also affected the building sector. In those years, prefabrication was born, a process consisting in the preparation, in a different place compared to
the final one [11], of the structural elements, then transported and assembled in the final location.

Building industrialization involved a considerable increase in the productivity of the sector. The main advantages introduced by the prefabrication process was the reduction of construction time, use of manpower and processing waste, with a consequent increase of the building construction performance. In general, the prefabrication intrinsically involves the simplification of the single elements and the subsequent reduction in the number of associated process phases. It is based on “closed” or “open” cycle systems; the components, in the two cases, are respectively produced for a single building system or for different systems. Due to the versatility of the component, the second technique involves an economic convenience that most “justifies” a series production.

The prefabrication in the building sector – traditionally based on framed systems, systems with load-bearing panels or on three-dimensional cells – entailed numerous solutions to the needs of this historical period, characterized by the search for housing addressed to the working class, to the colonies and to the displaced people due to war. These needs had in common the necessity to obtain, in a brief time and with low costs, comfortable homes for temporary stay. Therefore, the construction to be built – for reasons related to its use – necessarily implied the intrinsic prefabrication [10].

3.1. WORKERS ACCOMODATION AND HOUSING PROBLEM

The increasing industrial activities resulting from the technical revolution of the nineteenth century led to a considerable migration to the city of people lured by factor work. The effect was considerable: this migration involved a malfunction of the services and a reduction of the hygienic conditions as well as the need to find housing solutions addressed to the workers and their families; the housing problem was born. In this scenario, new building rules – addressed to guarantee the satisfaction of minimum spaces as well as the achievement of adequate conditions of physical and moral well-being [12] and comfort – spread out. These rules provided for an increase in open spaces and for the use of suitable openings, in order to improve natural light and air changes.

In these years, some utopian theories became popular, such as the model hypothesized by E. Howard who, with the Garden city proposed in 1898 [13;14], solved the overcrowding of cities and the migration from the countryside, combining the advantages of city life and the relationship with nature in a
single housing model [15;16]. The single-family residences had green area and were connected to each other by commercial and/or administrative areas.

In the United States, the use of prefabrication techniques based on the construction of preassembled housing units caught on; an alternative to this process was the decomposition of the unit into different components to facilitate transport, although it went to the detriment of a rapid assembly. The Americans associated to the prefabrication the concept of modularity, intended as a repetition of basic components that, properly connected, allowed a “reasoned” development of the structure. American housing units, in accordance with the predisposition of this population to avoid a permanent stabilisation [17], could be dismantled and rebuilt in different places through simple operations. Symbolical examples were undoubtedly the units produced by Roebuck & Co. of Chicago, which sent by mail “assembly kit” for the construction of houses, correlated by the instruction manual [18]. Differently, in Europe, mobile or semi-permanent housing was preferred: an example can be found in the Italian Hoepli manuals that, in 1910, reported a mobile home proposal [19], consisting of a single-family house developed on one floor and made with parts that can be transported on wheels. According to the same principles, in those years Le Corbusier conceived the Maison Voisin, which reconciled the characteristic of minimum housing with those of the automobile. In 1929, these theories led to the design of the Ma Maison (Fig.1a), whose realization occurred in 1940 with the MAS, maisons montées à sec (Fig.1b), a two-level unit addressed to one family and conceived with different solutions that included or not the use of reinforced concrete.

Figure 1. a) Ma Maison b) M.A.S., maisons montées à sec. (Images from www.fondationlecorbusier.fr)
In this project, the prefabrication had a double importance, as it was used both for the elements of the frame and for vertical and horizontal closures. Both mobile and removable homes were mainly intended for working-class families who were forced to move from one place to another due to their work-related needs.

Prefabrication, modularity and transport possibilities – key issues in resolving the problem of housing for workers – are characteristics linked to the building industry for emergencies and to the resulting needs.

3.2. COLONIAL HOUSING

Numerous experiments involving emergency housing, holiday resorts or colony were carried out between the nineteenth and twentieth centuries. The field of colonial housing, as in the case of housing for workers, required functional living prototypes. This need occurred in Italy in the 1930s, following the expansionist policy of the Fascist regime, which took place in East Africa [20].

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The colonial settlements, intended for workers and technicians migrated to the colonized territories of Eritrea and Africa, had different characteristics compared to those illustrated. The most important challenge was represented by versatility: in fact, they were addressed to different climates. Therefore, the prefabricated housing unit had to be suitable for many weather conditions, often extreme. Moreover, light materials were omitted and replaced by materials that communicated not precariousness but stability, in order to transmit an image of “solidity” of the regime.

During the V Triennale di Milano held in 1933, Luigi Piccinato exhibited his prototype of Colonial House (Fig. 2). The development of the house – equipped with living room and study-library – took place around a closed court, “heart” of the house as it served as a hallway for the rooms. This court was intended for outdoor activities and was complete with aviary and tropical plants. The rooms were on one level, except for service rooms and guest rooms, located respectively in the basement and in the first floor.

I.T.A.L- Pumice materials were used for both the load-bearing masonry and the masonry for filling the reinforced concrete frame. The pumice, coming mainly from Lipari, was chosen for its lightness and for its thermo-acoustic insulation.

montaggio. Alla prefabbricazione, gli americani associarono il concetto di modularity, intesa come ripetizione di componenti base che, opportunamente collegati, permettevano uno sviluppo “ragionato” della struttura. Gli alloggi da loro concepiti, in accordo con la naturale predisposizione di tale popolazione all’evitare il permanente radicamento in un posto fisso [17] presentavano inoltre il vantaggio di poter essere smontati e ricostruiti in luoghi differenti mediante semplici operazioni. Esempi da annoverare di stampo americano sono senza dubbio le abitazioni prodotte dalla Roebuck & Co. Di Chicago, che spediva per posta “kit di montaggio” per la realizzazione di case, correlati da relativo libretto di istruzioni [18]. Differenmente, in Europa si prediligevano alloggi mobili o semi-permanenti: un esempio di questo è riconoscibile nella maquette la italiana Hoepli che, nel 1910, riportava una proposta di casa mobile [19], consistente in un’abitazione unifamiliare sviluppata su un unico piano e composta da parti trasportabili su ruote. Sulla scia dei medesimi principi, in quegli anni Le Corbusier ideava la Maison Voisin, che conciliava le caratteristiche dell’alloggio minimo e di massa con quelli dell’automobile. Tali teorie porteranno, nel 1929, alla progettazione della Ma Maison (Fig. 1a), la cui concreta realizzazione è da collocare temporaliamente nel 1940 con la M.A.S., maison montées à sec (Fig. 1b), unita su due livelli destinata a una sola famiglia e pensata con differenti soluzioni che includevano o meno l’utilizzo del calcestruzzo armato. La prefabbricazione rivestiva qui una duplice importanza, in quanto adoperata sia per gli elementi del tettoio sia per le chiusure verticali e orizzontali. Sia le case mobili che quelle smontabili erano prevalentemente destinate alle famiglie operaie costruite a spostarsi, per esigenze legate al loro lavoro, da un luogo a un altro. Prefabbricazione, modularity e possibilità di trasporto – tematiche chiave della risoluzione del problema dell’alloggio per gli operai – costituiscono caratteristiche indissolubilmente legate all’edilizia per l’emergenza e alle necessità che ne scaturiscono.

3.2. L’HOUSING COLONIALE

Numerose sperimentazioni aventi come oggetto abitazioni destinate all’emergenza, alla villeggiatura o agli insediamenti coloniali furono condotte a cavallo tra il XIX e XX secolo. Il campo dell’housing coloniale, così come accadeva per gli alloggi destinati agli operai, necessitava di prototipi abitativi funzionali. Tale esigenza si presentava in Italia negli anni Trenta del XX secolo, a seguito della politica espansionistica propria del regime fascista, che ebbe luogo in Africa Orientale [20]. L’emergenza abitativa fu affrontata in maniera rapida da parte del governo italiano, che predispose la realizzazione degli alloggi necessari in breve tempo (R.d.l. 17 maggio 1938-XVI, n. 701, relativo a provvedimenti per un piano di colonizzazione demografica in Libia.).

Gli insediamenti coloniali, destinati a operai e tecnici che
Some measures were adopted to face the tropical climate: to the south, the house had a wall almost without openings because of the presence of the sunlight and the “ghibli”. Materials and components were carefully selected according to both the living conditions and the climates of tropical countries: the window frame, metallic and composed of special shaped profiles, were equipped with hermetic closure and openings that allowed the ventilation of the highest areas; the wooden doors had compensating reticular frames to cope with the deformations caused by high temperatures; the floor, covered with linoleum, had a smooth pumice underlay, which increased its insulation both in the case of cold and heat [21;22;23].

3.3. THE ACCOMMODATIONS INTENDED FOR WAR AND POST-WAR EMERGENCY

In the building field, the war emergency led to the development of technological solutions to be used in “shelter units”, which required a comfortable, safe and of rapid execution construction. These constructions also had to be cheap, because of the economic restrictions of the period. To meet the first requirement, these units – residential or addressed to first aid – were made with few materials and components, therefore with a limited and simple steps, in order to reduce construction time and to employ unqualified workers.

In this period huts were born, mobile emergency buildings mainly intended to accommodate military troops. During the First World War, the American
military forces developed the *Nissen hut* (Fig. 3), experimented in 1916 by Peter Norman Nissen. The supporting structure was made up of metal arches able to react to the deformations due to the acting loads; these arches have a diameter of about 5 m and were arranged on a rectangular plan, variable according to the use of the hut. The construction's resistance was also due to the use of two layers of metallic and modular panels, characterized by small undulations. The layer of air between the two panels thermally insulated the structure.

The *Nissen Hut* was used with additional devices and with more performing techniques and materials even during the Second World War. The evolution of the typology was the *T-Rib Quonset-Hut*, which was equipped, at the base of the arch structure, of 1.20 m tall vertical walls, making the spaces more livable. The entire structure, composed by metal profiles lighter than those of the original one, could be stored in 12 boxes and built in one day by 10 not-specialized men.

The post-war experiments moved in the field of mobility and flexibility to meet temporary needs, based on the simultaneous occurrence of the housing crisis and the increase in population. In 1947, Carl Koch built the *Acorn Folding House* [24] for the families of soldiers returning from the war. Produced in series and cheap, this accommodation was transportable – as reducible to a volume of 2.40×6.90×2.70 m³ – and assembled by even non-specialized workers. In the destination site, after excavation and positioning of the foundation plinths in concrete, the parts were opened, connected by hinges and joined together by screws at the contact points.
4. EXAMPLES OF CONTEMPORARY HOUSING

The current research direction of temporary housing addressed to face the emergency is to use prefabricated structures able to combine the usual temporary requirements, assembly speed and transportability, to the recent environmental sustainability approach [25].

In the last few years some experimentations have been carried out. Among these there is the More with Less prefabricated living system designed by Cibic&Partners (Fig.4). It is a wooden module with standard dimensions of 4×4 m on plan, with two bedrooms, a kitchen area and a bathroom with shower; the module can be horizontally or vertically joined with others, creating different spaces configurations. The possibility to expanding the housing with the addition of other basic modules allows to customize them according to the needs of the users.

The load-bearing structure of the module is made of laminated wood and is internally covered in wood and externally with an insulating layer made by natural materials, in order to give to the home the necessary thermal insulation. The external finish can be chosen among wood, plaster or turf. The roof can be plane and practicable or inclined, with the possibility in both cases to apply green cover systems to hold inside heat in the winter and cool during the summer. The radiant floor heating system and the hot water system can be connected to solar thermal panels, biomass and geothermal plants, therefore reducing the use of non-renewable resources. The houses also provide for the recovery of rainwater in special tanks, systems for water saving and water purification and systems for the waste sorting.

More with Less is an example of modular housing characterized by the ease and speed of construction, which can be used as a post-emergency housing solution. The design concept – i.e. the use of ready-to-use modular homes – also characterizes ZenKaya. Designed by Eric Bigot, this house can already be configured allowing to different housing solutions; the smallest has a surface of 3.4×6 m and is composed of a single open space which includes the bedroom and the kitchen, as well as the bathroom with shower accessible by a sliding door. The largest module, on the other hand, has an area of 3.4×15 m and includes two bedrooms, a living room-kitchen and a bathroom with bath tub. The structure of these apartments has a high level of thermo-acoustic insulation, obtained through structural panels composed by a polystyrene layer of 75 mm covered on both sides with a metal sheet of 0.5 mm, or through wooden panels insulated with aerolite layer of 50 mm covered internally with an OSB panel of 9 mm and externally with a metal foil of 0.5 mm. The module

La Niessen Hut venne impiegata – con accorgimenti aggiuntivi e con tecniche e materiali più performanti – anche durante la Seconda guerra mondiale. L’evoluzione della tipologia fu rappresentata dalla T-Rib (Quonset Hut che, rispetto alla versione originale, venne dotata alla base della struttura ad arco di pareti verticali alte 1,20 m che ne permettevano l’inalzamento, rendendo maggiormente vivibili gli spazi. L’interna struttura, che presentava profili metallici più leggeri rispetto a quelli della struttura originaria, poteva essere riposta in 12 casse e montata in un giorno da 10 uomini non specializzati. Le sperimentazioni del periodo post-bellico si susseguirono nel campo della mobilità e flessibilità per far fronte a esigenze temporanee dovute al verificarsi in contemporanea della crisi abitativa e dell’aumento demografico. Anche in questo contesto, le strutture prefabbricate dimostrarono la sua capacità di essere pieghevoli a 2,40×6,90×2,70 m – e montabile da personale anche non specializzato. Arrivate in loco, successivamente allo scavo e al posizionamento dei piloti di fondazione in calcare, le parti venivano aperte, collegate per mezzo di cerniere e solidarizzate reciprocamente per mezzo di avvitature in corrispondenza dei punti di contatto.

4. ESEMPI DI ABITAZIONI CONTEMPORANEE

L’attuale direzione di ricerca delle residenze temporanee destinate all’emergenza è quella di utilizzare strutture prefabbricate capaci di coniugare i requisiti temporaneità, velocità di montaggio e trasportabilità alle recenti politiche di sostenibilità ambientale [25].

Negli ultimi anni sono state condotte alcune sperimentazioni, tra cui il sistema abitativo prefabbricato More with Less di Cibic&Partners (Fig.4). Si tratta di un modulo in legno avente dimensioni in pianta standard 4×4 m, dotato di due camere da letto, un angolo cottura e un bagno con doccia, che accostato in orizzontale o in altezza dà luogo a diverse configurazioni spaziali. La possibilità di espandere l’abitazione con l’insersione di altri moduli consente la personalizzazione degli alloggi in funzione delle necessità degli utenti. La struttura portante del modulo è in legno lamellare ed è rivestita internamente in legno ed esternamente con un rivestimento a cappotto con uno strato isolante realizzato con materiali naturali atti a conferire all’abitazione l’isolamento termico necessario. La finitura esterna può essere scelta tra legno, intonaco o tappeto erboso. La copertura può essere piana e calpestabile o a falde, con la possibilità in entrambi i casi di adoperare sistemi di copertura verde per trattenere il calore nel periodo invernale e rinfrescare durante quello estivo. Il sistema di riscaldamento radiante a pavimento e l’impianto dell’acqua calda possono essere collegati a pannelli solari termici.
is assembled directly at the factory and carried on-site ready for use. These houses are designed according to the concept of “module”, in fact it’s possible to combine two or more housing modules in order to create houses of different sizes. The dwellings are based on sustainability criteria since, within their construction process, renewable and reusable materials were used at the end of their life cycle, such as wood [26]. Since the entire production process is in the factory, quality and waste of raw materials can be carefully controlled, with benefits in terms of time and costs. A further advantage deriving from the use of this design solution is the high performance of living comfort of the module, an essential element for post-emergency housing.

5. CURRENT RESEARCH ON TEMPORARY HOUSING

Global sustainability need to be ensured in all the characteristics and stages of the temporary house life, “from cradle to grave”: in the choice of materials, in the ease of installation, in the energy consumption during life and the environmental impact of disposal.

Over the years, improving comfort conditions inside temporary houses has attracted considerable research interest worldwide, as shown by the studies reported below.

Obyn et al. [27] discussed the difficulties in achieving a realistic thermal model of lightweight structures taking into account the air permeability of materials, their light transmission and the use of several elements into the building envelope.

Figure 4. More with Less by Cibic&Partners – Modulo 4x12.
In order to improve the thermal environment of the temporary prefabricated house, Wang et al. [28] developed a model using Energyplus® dynamic simulation software and validated it by comparing the simulated data with the measured data obtained from a purposely built experimental prefabricated house. The research results suggested that adding a thin movable fabric layer of 0.9 reflectance to the walls and roof and external window blinds lead to a very high percentage reduction in energy consumption.

In [29] an experimental study on the indoor thermal conditions into a temporary prefabricated building located in the subtropics is reported. The measured thermal environments inside the experimental house clearly demonstrated that the comfort conditions inside temporary prefabricated houses are unacceptable for long-term occupation and that appropriate measures should be taken to improve the thermal environments. The study results suggested that the air temperature inside the experimental temporary house was very high at daytime in summer and very low at nighttime in winter. In addition, the variation of the air temperature inside the house appeared synchronously with that of outdoor air at daytime in summer, suggesting insignificant thermal mass of envelope to store solar heat gain.

Barreca and Tirella [30] proposed a prototype of a building module composed of wood and multilayer agglomerated cork panels as an environmentally sustainable shelter that can be assembled in situ. This module takes advantage of the characteristics of cork – such as acoustic and thermal insulation, fire resistance, resistance to molds and microorganisms – and shows high thermal performance.

Nemati et al. [31] introduced a modular non-reinforced foam-filled system for rapidly assembled buildings, using pneumatic formwork, and analyzed its structural performance as a post-disaster housing system. For this purpose, the authors presented a numerical analysis using finite element modeling on the foam-filled modular units, together with a set of experimental tests on the bearing elements.

Finally, in [32] a life cycle energy and cost analysis of two common types of post-disaster temporary houses constructed in Turkey was carried out. The authors studied whether it is more convenient to use prefabricated or container houses in post-disaster reconstruction projects. The results expressed that prefabricated houses have 25.1% and 29.7% lower life cycle energy and cost requirements respectively.

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