



## TECHNICAL EVOLUTION OF 3D MODULAR CONSTRUCTION FROM THE NINETEENTH CENTURY TO WORLD WAR II

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### ABSTRACT

3D Modular construction is poorly known and scarcely published in technical literature. In spite of that there are an increasing number of manufacturers offering their products in different countries. This method has largely evolved from early examples such as the American Gold Rush prefabrication in the nineteenth century, the Sears precut homes or Voisin's prototypes for modular homes, to the end of the first half of the twentieth century. In this period a non negligible number of attempts in 3D modular construction have been carried out, ranging from theoretical proposals to several hundred or thousand units produced. Selected examples of modular architecture will be analysed in order to illustrate its technical evolution, concerning materials, structure, transportation and on site assembly. Success and failure factors of the different systems will be discussed. Conclusions about building criteria shown in them and their applicability in current architecture will be drawn.

**Key words:** *modular housing, 3D modular building construction, prefabrication*

### 1 INTRODUCTION

Modular construction evolution has a close relationship with the prefabrication history. In spite of the repeated prophecy of the unstoppable arrival of prefabrication and mass production to architecture most building are today essentially hand crafted on site. Moreover, one of the most highly prefabricated methods of construction such as 3D modular accounts barely for a small share in the developed countries building market.

The reasons for success and failure of prefabrication methods can be clearly seen in its history an evolution during XIX and XX centuries. In the beginning, prefabrication has emerged as a need to transport a disassembled building to a destination where for some reason could not be built in a traditional way. Housing shortages, during colonial migrations, or post war periods fueled prefabrication industry occasionally. But only long term conditions, commercial opportunities and strategies, and customer acceptance have provided several systems survival as successful trademarks. The end of the Second World War could be taken as a turning point after which systems and techniques have evolved in a quiet peace-time competition with traditional building work, and additionally a time that has seen the birth of modern modular home industry. But "the how did it all begin" history starts as early as the seventieth century.

### 2 The nineteenth century

If it is true that several examples of prefabrication in Scandinavia, Japan [1], England or U.S. [2] [3], took place before the nineteenth century, but it was not until then when several companies began to market their off-site made buildings.



Wood construction has been involved in prefabrication from its very beginnings. Progress in sawmill's techniques led to a certain level of accuracy in lumber sizes that, for instance, allowed the development of the "balloon frame system" in the U.S [2].

By the time could be found a few examples of the early prefabrication of houses as the Manning Portable Colonial Cottage [3], in 1830, in England; the Fredrik Blom experiences in Sweden, in 1840 [1]; and the Gold Rush event in 1848, that brought California along an urgent demand of shelter for workers, receiving almost any type of prefab dwellings from every country that were able to produce them [4].

One interesting fact that characterized the last decades of the century were the emergence of the mail-order-from-catalogue selling system [4] being one of their earlier examples the Hodgson houses, whose catalogue appeared by 1894. Most of these buildings were essentially a set of precut lumber and light panels, broadly known as "Portable" buildings [4].

### 3 First half of twentieth century

Perhaps one of the best illustrative examples of catalogue houses in the U.S., though not the first, was Sears Roebuck and Co. (fig. 1), in 1910. Several companies offered their catalogue houses by the time in the U.S., accounting for the non negligible sales figure of 250.000 until 1943 [2].

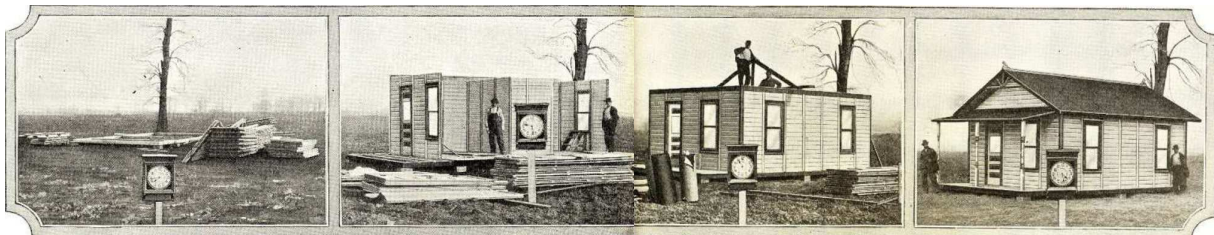


Fig.1. Sears Simplex, process of erecting in eight hours. Source: Sears Modern Home Catalog, 1921.

But in spite of portable houses were already a healthy business in the turn of the century, 3D modular constructions still were in an embryonic stage. Early attempts in this field can be found in Hennebique's concrete cabin for French railways by 1896 (fig. 3c). Post war periods and their associated housing shortages were to play a big influence in the development of new prefabrication systems. In this way at the end of World War One, a French airplane factory made 3D modular houses by 1919, Maisons Voisin, that was published by Le Corbusier L'Esprit Nouveau N° 2, in 1920. Although it was an industrial failure due to strong opposition of French building unions, it showed all the features of current 3D modular construction (fig. 2).

Many experiments and prototypes were planned in this period, from Edison's poured concrete houses in 1908 [1] (fig. 3a,b), Prouvé's panelized houses and bathroom module [5] (fig. 7e), Buckminster Fuller Wichita house and Deployment Unit [1], to Gropius and Wachsmann Packaged House [1]. Equally more and more elaborated and non wooden kit or panelized houses were produced as the enameled-iron Lustron house in 1948 [6] (fig. 4b,c), or AIROH house (Aircraft Industries Research Organization on Housing) in 1945 [7] (fig. 4a).

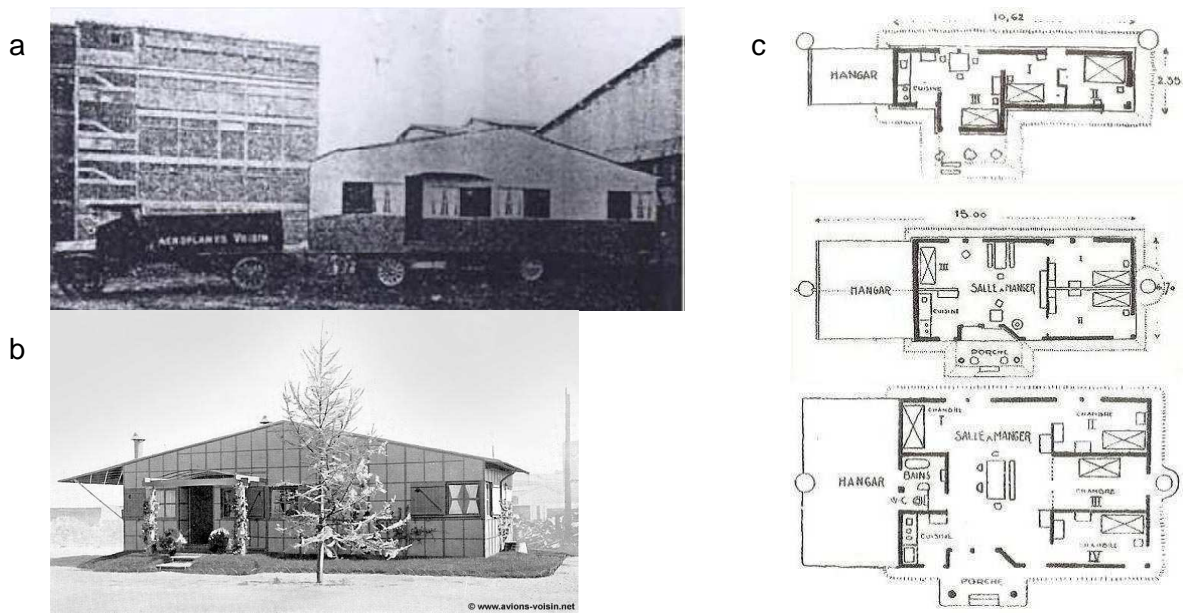


Fig. 2. a: Truck transporting the Maison Voisin, 1920. b: Final prototype [8]. c: 3 floor plan types Maisons Voisin of 400, 700 and 1.000 square feet [9].

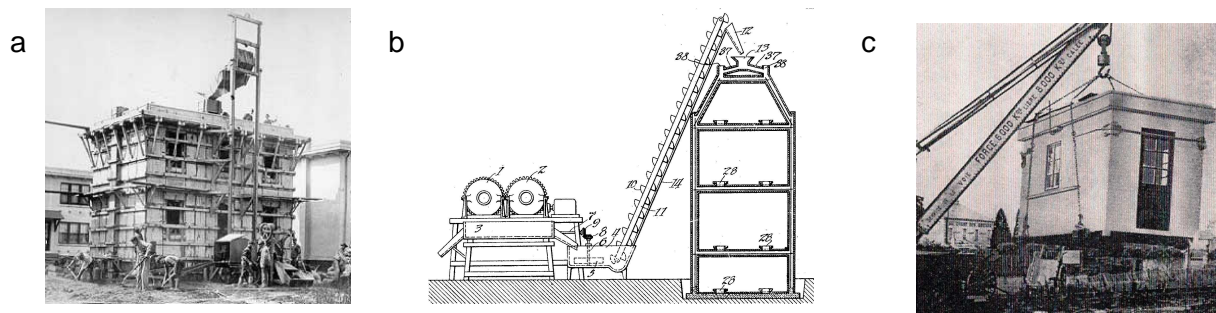


Fig. 3. a: Poured concrete houses, Edison, 1908 [10]. b: Patent houses Edison [11]. c: Concrete 3D module for the railways of France, 1896, F. Hennebique [12].

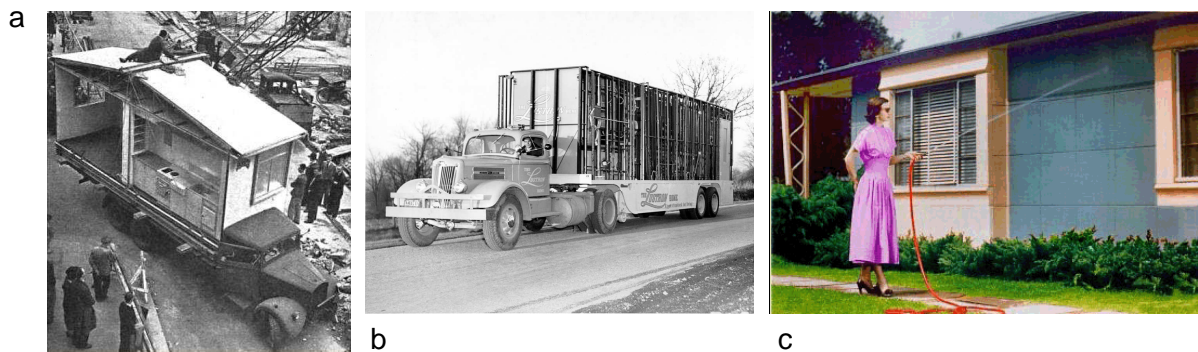


Fig. 4. a: Truck transporting the house AIROH, 1945 [7] b: Truck transporting the house Lustron, 1948 [6] c: Exterior house Lustron [6].

Another non-architectural industry was going to be the natural precedent of the American mobile home. We are talking about the trailer, that grew in size from 1919 to 1953 [13] (fig. 5). Mobile homes as the last evolution of the trailer even grow by duplicating its size with the double-wide versions. Very representative of this type of prefabricated 3D homes are the Tennessee Valley Authority double-wide mobile homes by 1942 in the U.S. [14] (fig. 6).

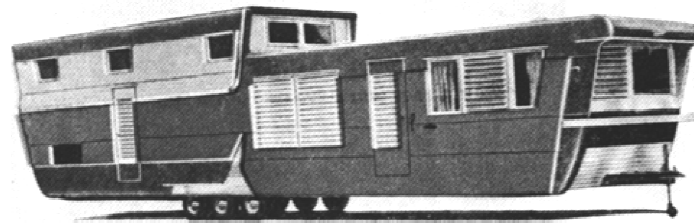


Fig. 5: Pacemaker Bilevel, 1953, had a double level that allowed to separate day zone from night zone [13].

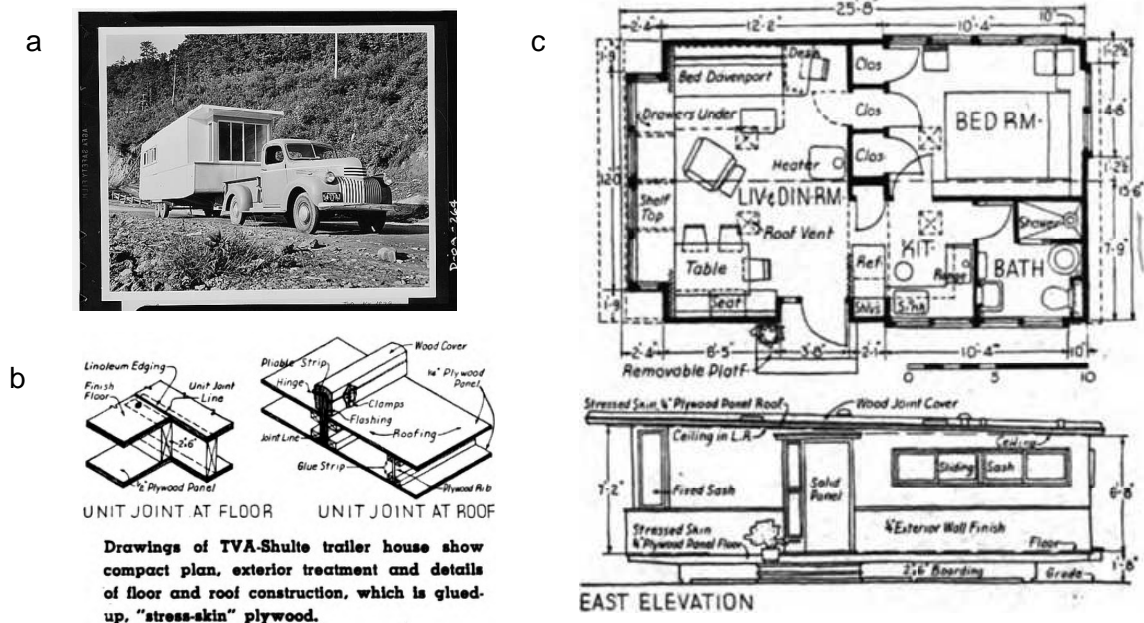


Fig. 6. a: Tennessee Valley Authority (TVA) [15] b: TVA floor and roof details [14]. c: TVA plan and elevation [16].

In 1979 the H.U.D. (U.S. Department of Housing and Urban Development) code would finally separate mobile homes from modular homes, changing their name from "mobile" to "manufactured" homes.

The aim of combining plumbing, electrical, heating, etc, inside a compact mechanical core was an engineer's concern. Several attempts in this field can be seen in this period such as B. Fuller prefabricated bathroom in metal [17] (fig. 7a) and his mechanical core integrating bathroom, kitchen, heating and lighting, in 1943 [18] (fig. 7b). Other examples are Gugler's crane mounted module, in 1936 [18] (fig. 7c), Ingersoll core bathroom and kitchen in 1947 [2] (fig. 7d) and Prouvé's kitchen-bathroom module for Abbé Pierre's house, in 1956 [5] (fig. 7e).

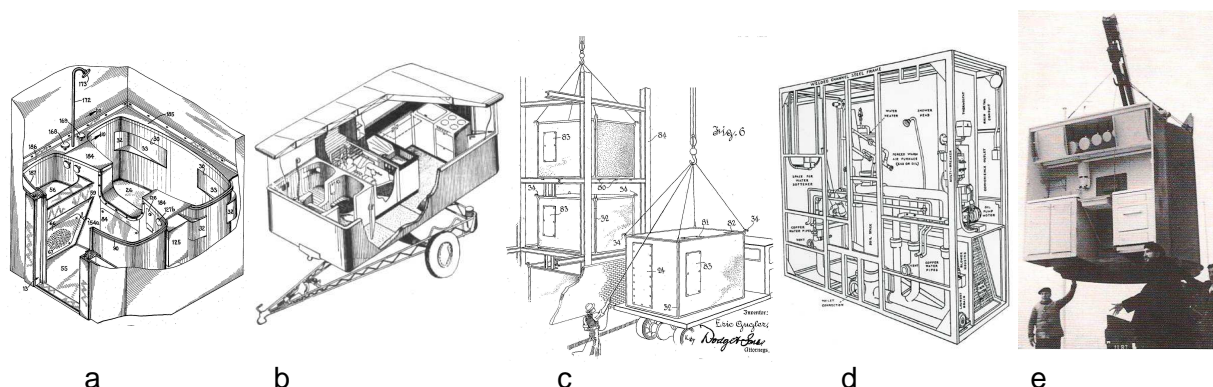


Fig. 7. a: Prefabricated bathroom, B. Fuller[17] b: Mechanical core (bathroom, kitchen, heating and lighting), B. Fuller [18]. c: Baño prefabricado en un módulo, Gugler [18]. d: Core bathroom and kitchen, Prouvé for the Abbé Pierre house [5].

#### 4 Discussion

As above described 3D modular houses were actually invented and factory made, yet in a short number, by Voisin in 1920. By the time, wooden houses prefabrication had already almost fifty years of tradition. Precut or Portable houses continue to be a healthy business along the twentieth century. Nevertheless it is true to say that prefabrication history has plenty of sound failures during the studied period. Successful experiences not always can be easily exported to one country to another. Wooden prefabrication success in the U.S. combined with the particular evolution of the bigger and bigger sized trailer seen to have originated the steel-chassis wooden construction factory made mobile homes. Almost the same building criteria, joint design, and construction detailing of double-wide mobile homes are used in today modular homes in the U.S.

#### 5 Conclusions

First documented attempt in actual modular housing construction is Voisin, although there previous partial experience, such as Hennebique in France.

Prefabrication has provided the technical basis for later development of modular housing construction with special attention to wood prefabrication.

Trailer development in the U.S. has lead to mobile homes and then to double-wide homes as a modular housing construction antecessor.

Precut or packaged, panelized and mobile homes are types completely developed in the studied period. 3D modular homes as an established type will not be a reality until second half of twenty century.

Several historic events that caused occasional increase in housing needs, such as post-war periods, fuelled house prefabrication industry, but only long term conditions as government support, customer culture and market viability have granted their survival.

Building criteria shown in this period, such as road transportation requirements, light timber or steel construction, single unit, double wide or multiunit arrangements, are currently in use in current modular house building industry. Same can be said about mechanical modules.



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