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METHODS AND INSTRUMENTS FOR PREFABRICATED HOUSING REFURBISHMENT: THE FRENCH CASE (1960-70)

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Highlights

This study focuses on analysing the front panels of two French patents (i.e. Balency and Camus): developed in the 60s, they were widely resorted to in Europe. The material, geometrical, and construction-related data led to implementing a BIM model that furthered the development of a methodology of digitisation of European prefabricated building stock, with a view to its upgrading, as far as architecture, environment and functions are concerned.

Abstract

The 60s and 70s housing blocks consisting of large two-dimensional prefabricated elements represent a sizable share of European building assets: their upgrading as regards architecture, energy efficiency, environment and social services is a priority for European Union aims by 2050. Prefabricated housing blocks total to such large numbers as to require new methodologies and technologies to be developed, in order to make upgrading technically viable and economically sustainable.

Keywords

Prefabrication, Refurbishment, French construction, BIM, Residential buildings.

1. INTRODUCTION AND OBJECTIVES

The 60s and 70s demographic and urban growth sped up industrialisation as regards construction, thanks to the massive resort to prefabricated reinforced-concrete elements. The urgency of EU [1] strategic objectives towards upgrading the existing building stock (namely 42% reduction of total energy consumption, 35% of greenhouse gases and of over 50% of raw materials); the need to improve the environmental, social and architectural features of many European neighbourhoods; the sheer number of such buildings (in Europe they average to 67%, in the most industrialised countries – such as France, United Kingdom, Germany, Scandinavia, and Eastern Europe – they peak to 95%) demand an innovative approach to upgrading both as far as planning and analysing are concerned, prior to tackling the project [2].

The objective of the present work – belonging to a broader project regarding upgrading European two-dimensional-elements -high-rise buildings – [3], has been the analysis of two of the main French patents (Balency and Barets), focusing on their construction-related and material features. We have started from front panels, since not only do they represent the signature features of the patents, but even the utmost complexity from a material, geometrical and construction-related point of view. This has allowed exploring even the potentialities of BIM (Building Information Modelling) in digitising prefabricated building stock. Starting from their digital reproduction, which contained all the information reporting their material, geometric, and construction-related features, perfect 3D models of such buildings have been implemented. Furthermore, thanks to the BIM potentialities, the models have been connected to the information for their graphic conversion (LOD), which has allowed the processed data of the current situation to be extracted automated. Thanks to this first step towards digital modelling, the bases have been laid for the next steps leading to upgrading, which is essential when taking into account both the number of prefabricated housing blocks and the urgency of curbing energy consumption.

2. METHODOLOGY

In order to lay down a suitable approach to building heritage, so as to streamline reclamation and upgrading plans, it is essential to analyse and thoroughly assess the technological and environmental system, as well as the building procedures it has implied. As regards upgrading existing buildings, the usual approach consists in laying down an upgrading project for an ad hoc case study that proves to be only partially capable of replication; general appraisals, on the other hand, may be formulated only after carrying out several works [4]. As far as blocks built by resorting to industrialised techniques (e.g. prefabrication) are concerned, instead, it is necessary to adjust the methodology, so as to make it fit to respond to the different logic of production. Building resorting to industrially-produced prefabricated elements has in fact followed project-and-production-based principles belonging to mechanical industry: namely a prototype was developed, then it was serially reproduced [5, 6]. That is why it is necessary to start from the general analysis of the construction systems before defining the upgrading project of individual case studies; only later will the global material and performance-related condition of the buildings be assessed. The technical characterisation (i.e. construction-related features, structural behaviour, energy performance) of the "according to project" building not only allows to spot its main flaws that may be made worse by disrepair but even to lay down the preliminary set of criteria regarding upgrading industrialised buildings; this approach will minimise the hazard of the renovation project, impacting positively on its economic sustainability.

Besides showing a particular interest in upgrading 1950-2000 housing – with the view of reaching its objectives by 2050 – the EU has been increasingly keen on finding the instruments allowing upgrading to be monitored and made technically efficient and economically sustainable. This is why Building Information Modelling (BIM) has been applied to this sector of construction, exploiting the opportunities offered by the modularity and reliability of prefabricated systems, allowing to obtain a detailed rendering of the existing technological systems, to which retrofit projects can later be connected.

3. PREFABRICATION IN FRANCE: MODELS AND CONSTRUCTION SYSTEMS

The know-how gathered up to the late 50s in the experimental yards sponsored by the *Ministère de la Reconstruction et de l'Urbanisme* (MRU) laid the foundations for the new public housing programmes developed by various bodies (HLM, Logecos) in the following ten years, based on *grands ensambles* policies [Fig. 1] and on heavy prefabrication [7]. Not only did this allow to reach the figure of 278,000 dwellings built by 1955, but even laid the foundations for the dizzy growth of the following years: 1,698,000 new units built in 1975, so as to peak to the 8,750,000 public and private buildings built during the *Trente glorieuses* [8]. As regards construction technologies and production structure, the heavy (*lourde*) or closed prefabrication was resorted to: it re-

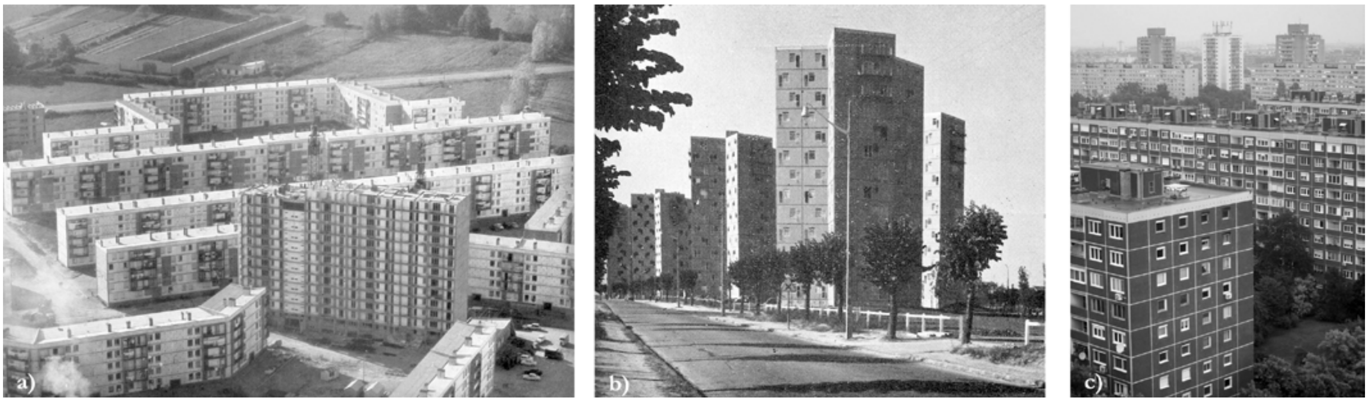


Fig. 1. *Heavy prefabrication and the new residential buildings in the 60s: Dreux (a), Savigny-sur-Orge (b) e Budapest (c).*

lied on reinforced-concrete- cast- in- formworks (*béton coulé*) panels, produced in specialised factories.

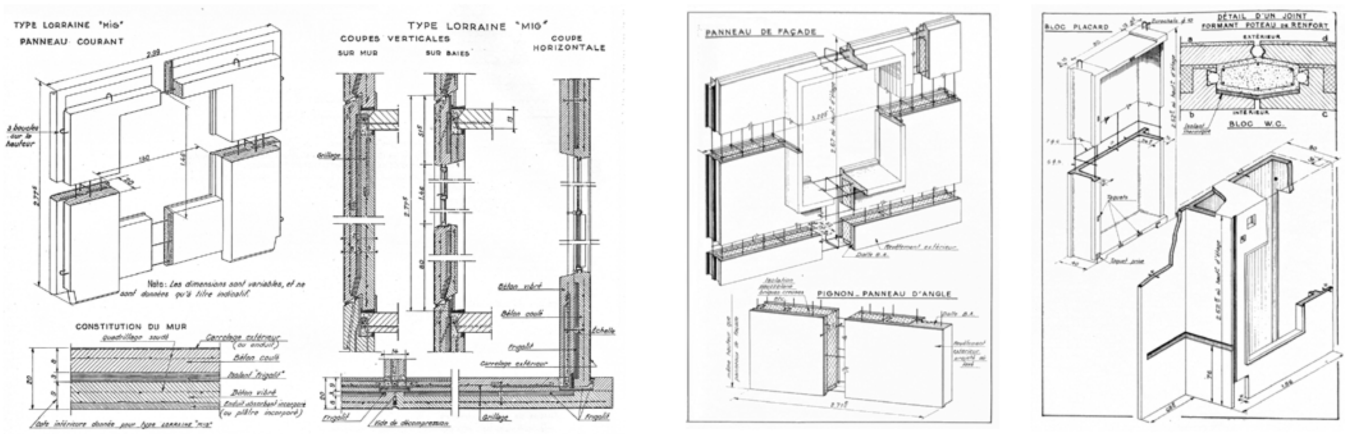
The main role in the MRU plans and in the 60s housing blocks development was played by the patents, which were the response of the French production system to industrialisation in the sector of construction. In the early 60s, various construction systems were introduced: they were mainly developed to realise high-rise buildings featuring weight-bearing front panels and both structural and partition walls, some of which derives from the first (Balency & Schul, Barets, Camus, Coignet) patents, and newly-conceived others (Costamagna, Estiot, Fiorio, Precoblin and Technove). In all instances, it was heavy or closed prefabrication: the reinforced concrete elements were industrially produced and were employed to obtain a complete high-rise building featuring weight-bearing both front and cross-sectional elements. There was a correspondence between room-sizes and front-panel-sizes, generally consisting in three layers (two weight-bearing external ones and an internal insulating one); the patents differed as far as the material employed for thermal insulation was concerned, i.e. cell-like material – such as Frigolit (expanded polystyrene) – [Fig. 2], or variously-sized, either brick or insulating-particles hollow elements [Fig. 2].

Among the systems belonging to the former type, the Camus patent enjoyed widespread success not only in the new French quarters but also in various European countries (Italy, Western Germany, Belgium, Great Britain and Austria) and non-European countries (Soviet Union, Algeria and Japan).

Filed in 1948 and developed until 1957, the Camus patent was essentially based on factory-produced large-size two-dimensional elements (such as walls and floors)

Patent	Year	Thickness (cm)	Stratigraphy (cm)	Materials
Balency & Schul	1959	21 + 1 (gypsum plaster)	10,5 + 3 + 7,5	r.c., insulating, r.c.
Camus – Lorraine	1962	19 + 1 (gypsum plaster)	8 + 4 + 7	r.c., insulating (Frigolit), r.c.
Camus – Serpec	1960	24	6 + 2 + 16	r.c., insulating (Frigolit), r.c.
Coignet	1961	25 cm	19 + 2 + 4	r.c., insulating (expanded polystyrene), r.c.
Barets	1956	23 + 2 (gypsum plaster)	5 + 18	r.c., hollow brick
Costamagna I	1956	25	3 + 18 + 4	r.c., hollow brick, r.c.
Costamagna II	1960	30	3 + 23 + 4	r.c., hollow brick, r.c.
Estiot	1958	22	3 + 2 + 17	r.c., hollow brick, r.c.
Fiorio	1963	20,5	2 + 17 + 1,5 cm	r.c., hollow brick, r.c.
Precoblin	1962	25 + 1 (gypsum plaster)	5 + 12 + 4 + 4 cm	r.c., hollow brick, empty, hollow brick

Fig. 2. *French main prefabrication systems in late 50s and 60s (layers are from exterior to interior).*



a) b)

Fig. 3. *Camus-Lorraine patent (a) and Balency & Schul patent (b).*

modulated according to the length of the room. The staple building that could be obtained resorting to the 60s-developed Camus-Lorraine and Camus-Serpec systems [Fig. 3a] consisted in 20-22 cm-thick front walls and 14 cm-thick weight-bearing cross-sectional walls on top of which full 13 cm-thick slabs and 7 cm-thick partitions were laid [9, 10].

The front panels featured two weight-bearing panels reinforced with 5 mm-thick metal rods and a Frigolit (expanded polystyrene) one; their edges were hinge-shaped, so as to house both the irons connecting one panel to the next and the insulating material making the seams tight [11]. Weight-bearing cross-sectional and partition panels consisted of full concrete slabs reinforced with one 5 mm-thick steel-rods mesh; their surfaces were smooth and could be either daubed with chalk-plaster or painted. Even in this case, the 10 mm-thick steel-rod connecting hooks protruded from the edges. The floors presented similar features; their upper edges were bevelled, so as to allow the curbs and the joints connecting the panels to be cast. The sanitary bloc featured a wall housing tubing and drain pipes as well as the brackets for kitchen appliances [9, 10].

The Camus system even provided for the panels to comply with finishing works: the window frames were embedded into the inside edge of the panels, in the same way as the metal door frames were encapsulated within the cast. The thin plastic laminate floors were glued directly onto the previously smoothed floor panels. The maximum weight of the elements reached 7t, so as to make their transport, handling and building-yard assembly easy [9, 10]. Through the 60s, the Camus system became the reference model for heavy prefabrication, even in Eastern bloc countries, where it triggered off various local developments [12].

The Balency & Schul system, on the other hand, belonged to the second – hollow elements – system., the patent, filed in 1950, envisaged 15-20 cm-thick Fibragloss insulating hollow panels, (Fibragloss is similar to Eraclit): their role being the weight-reducing and providing thermal insulation; the panels were placed in the moulds and cast concrete poured over them and over the window frames. Such panels could be employed by themselves in up to 3-4 storeys buildings, whereas in over 4 storeys buildings a reinforced-concrete framework was needed. Evaluations regarding production and the resistance of the panels themselves suggested that the hollow elements were to be substituted with insulating-material slabs (they were either 3-4 cm-thick expanded polystyrene or 6-8 cm-thick vermiculite-concrete slabs), as shown in the *agrément technique* issued by CSTB in 1956 (Fig. 3b) and by the addition to the previous patent applied for in 1966 [13, 14]. Vermiculite-concrete slabs, therefore, consisted of a 3 cm-thick external finish layer, a 5 cm-thick reinforced-concrete one, a 3-11 cm-thick insulating one, an internal 11 cm-thick weight-bearing reinforced-concrete one, an internal 1 cm-thick plaster one; this amounted to 23-31 cm-thick panels, depending on the thermal insulating performances required.

First in its kind, the Balency system introduced a weight-bearing vertical element named *bloc fonctionel porteur*, moulded in a seamless 5-10 cm-thick concrete block containing the landing general electric conduit risers, the meters, the conduit risers belonging to each flat, and the sanitary bloc. Resorting to such block allowed to build a two-dimensional uniform structure, so as to sizably reduce sanitary facilities fitting and connection times [10, 15].

Similarly to other prefabricated systems, the Balency system required resorting to weight-bearing cross-sectional walls that consisted of 8-15 cm-thick reinforced-concrete panels, and floors consisting in 13.5 cm-thick reinforced-concrete solid slabs, with the iron hooks of the reinforcing frame protruding so as to allow the slabs to be lifted and suitably connected together. As regards flat coverings, suitable 8 cm-thick reinforced-concrete slabs were produced; they had a 4 cm-thick expanded polystyrene insulating layer and were laid on the top ceiling. Though it did not enjoy the enormous commercial success of the Camus system, the Balency & Schuhl patent was reasonably popular in Europe: in Great Britain, it was introduced under licence from the patentees in 1964 and was resorted to in several housing blocs at Thamesmead, in Belgium and Ireland (1968), in Israel (1970) and in Italy (1964), where the MBM licensee company built several housing blocks in Milan.

4. DIGITISING THE REFURBISHMENT PROCESS

As explained in the previous paragraph, the preliminary study of prefabricated systems and their components has been essential in order to understand how houses built according to this technology perform adequately. The next stages of the analysis (i.e. surveying the "as-built" and project-related design of the buildings), with a view to their re-purposing and upgrading, will, in fact, start from the data gathered about the construction-related processes and assembly of their components. More specifically, as far as this particular sector of building stock is concerned, the analysis has been focused on the suitability of building information modelling (BIM) as the instrument of digital restitution regarding the "as-built" survey. Such an instrument allows the smart modelling of the single components of the building, providing descriptive information related to their behaviour as well as their geometric digital reproduction.

Family models tested	Results
Generic Metric Model	• Great modelling flexibility • Possible inclusion in the project without constraints • No data reading (thermal and structural performance) • Difficult association about the panels connections • Excellent results by exporting the drawings
Metric Curtain Wall panel	• Good modelling flexibility • No insertion possible in the project without constraints • Presence of a reference grid linked to the "curtain wall" • Problems in the union between multiple facades • Very difficult modelling about the panels connections • Panels identified as a single collaborating Curtain Wall: presence of energy performance, lacking of structural performance • Fair results about exporting the drawings
Generic Metric Model wall-based	• More complicated modelling directly as subtraction from a reference Wall • More difficult insertion of the project about the connection to the wall, but a good level of facade flexibility • Good solutions about the intersection of facades • Extreme ease in modelling the connections between panels • Panels identified as a single collaborating Wall: possibility to insert information both on energy and structural performances • Excellent drawings exporting

Fig. 4. *Summary table of the results obtained from the tests conducted on Revit family models.*

The Decreto Ministero delle Infrastrutture e dei Trasporti n. 560/01.12.2017 [16] makes the specific times and methods of the gradual digitisation of the buildings mandatory; hence, from 2025 onwards, public works contracts must resort to software structures. The survey undertaken proves quite topical: since most prefabricated housing blocks are owned by public authorities, as a consequence of the decree mentioned above, should they opt to upgrade their buildings, they would have to resort to BIM.

The researches undertaken have suggested it is necessary to define the guidelines for the future information management of prefabricated housing stock contained in BIM software since this typology of construction highlights some incompatibilities with present-day modelling standards [17]. Unlike other construction systems, prefabricated-panels buildings are managed and built relying on quite large (generally 280x360 cm) joined-together panels, rather than on brick and concrete.

Furthermore, the in situ panels are supposed to be the exact size as laid down in the datasheet according to which they have been projected and produced – which is a realistic surmise – taking the high level of industrialisation of prefabricated-buildings techniques into account. Each panel was developed with the precision borrowed from mechanical engineering (tolerance, modular coordination) and projected so as to be industrially reproduced (serial production). Besides, the panels were joined and installed following techniques that reduced assembly times. The available detailed records allow to trace the panels, thanks to careful information models thoroughly.

Front panels have been chosen as starting points, since not only do they (together with vertical and horizontal joints) represent the distinctive feature of the patent but also owing to the fact they are the most complex elements from a material, geometric and construction-related point of view.

The data gathered from surveying the original documents (patents and archival documents) prove to be an excellent launching pad from which to tackle digital restitution, leading to BIM prefabricated-elements mod-

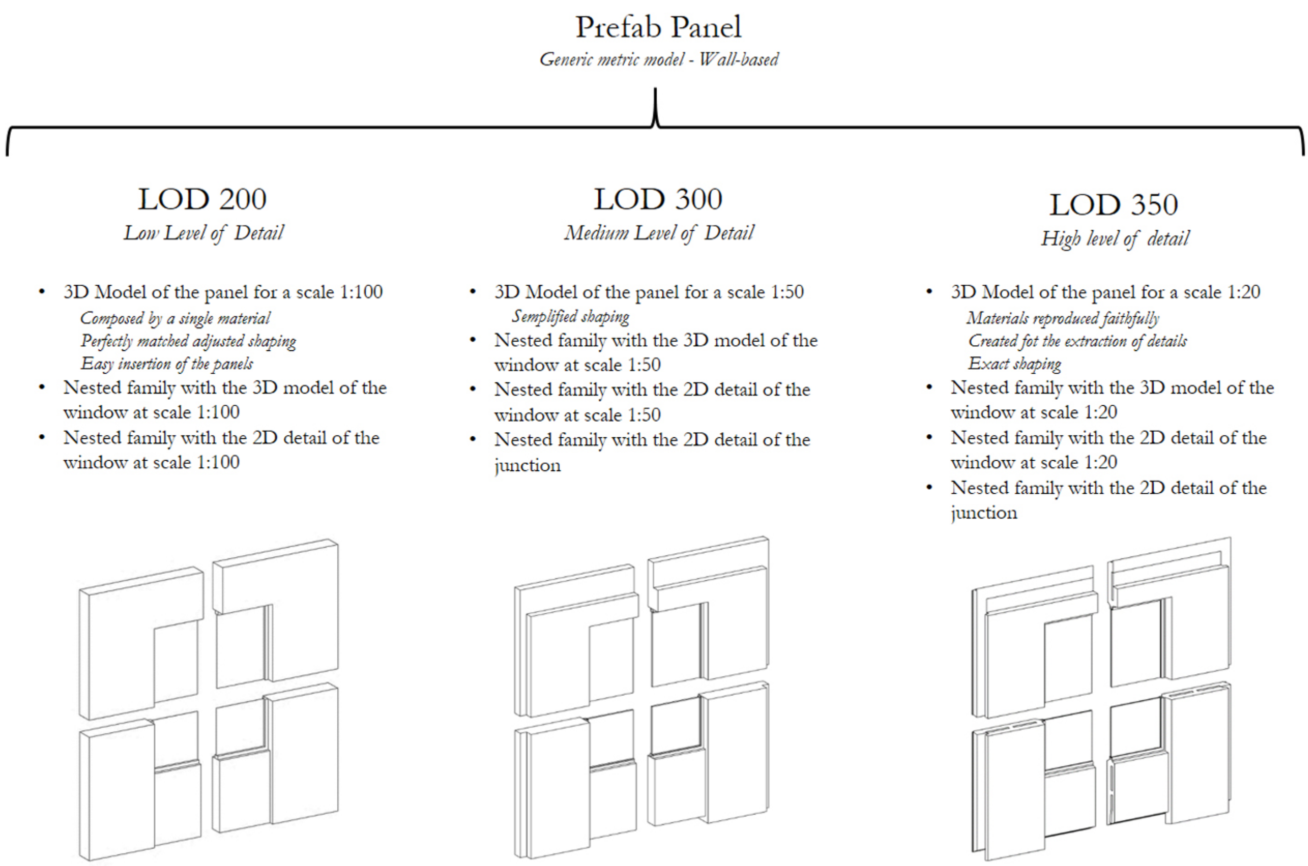


Fig. 5. *Components belonging to the generic metric family of the single prefabricated panel (Camus-Lorraine patent).*

elling in the best possible way. The main hindrance encountered is that each element is given a real function in the building; there is a specific key for the creation of single elements, though there is no equivalent option for the creation of a "prefabricated panel" and its joints. What is more, owing to the hierarchical logic of the programme, each class of elements must be subjected to system parameters that make it sharply different from all others: for example, a "window" or a "door" must necessarily be housed in a "wall"; a "beam" will be visualised in its structural, rather than architectural rendering.

The final objective has therefore been correctly modelling two-dimensional panels, which are the core elements of buildings, in order to obtain the architectural renderings necessary to assess the "as-built" conditions in an automated way [18]. Besides, thanks to resorting to BIM, the information, related to the different panels, has been connected together – for instance as regards the parameters of the materials, their state of decay, the residual performances of the various components – by means of instruments enacting simulations of the behaviour of the buildings in different upgrading scenarios.

To test the methodology proposed, Autodesk® Revit Architecture has been chosen as software. Each Revit-created element corresponds to a "family": some of these families can be customised, whereas others are defined as "system" families, that is to say, they can be modified only resorting to pre-set parameters.

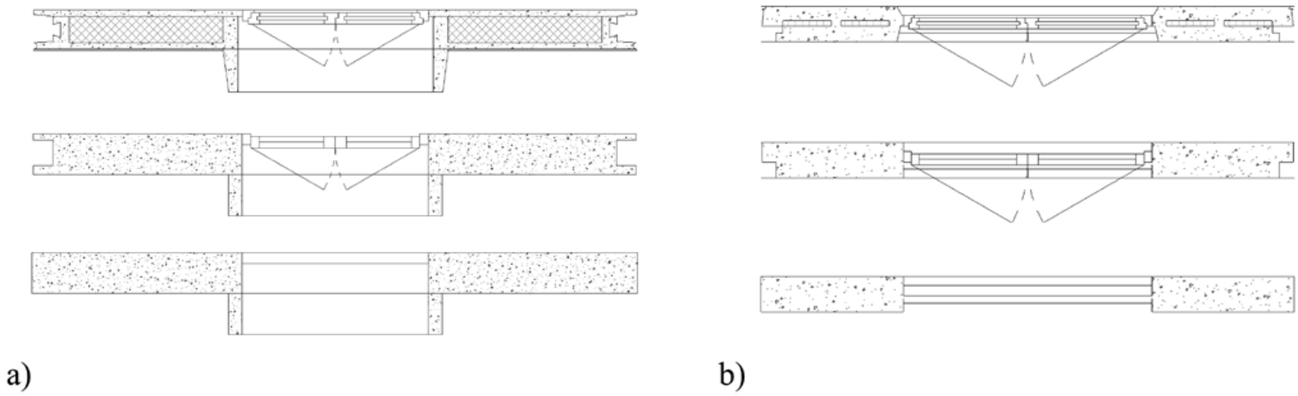


Fig. 6. *Example of the different plan LODs of the Balency & Schul (a) and Camus (b) systems.*

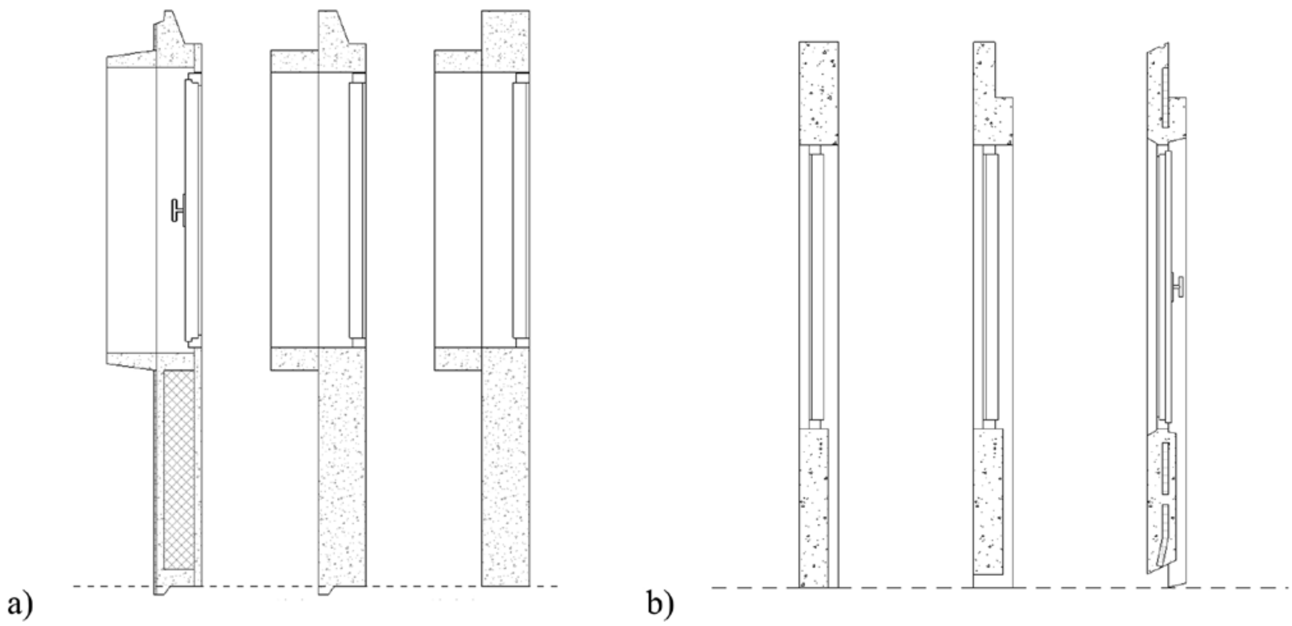


Fig. 7. *Example of the different section LODs of the Balency & Schul (a) and Camus (b) systems.*

Once a family has been created, it can be entered in the programme several times as an individual "instance" representing each different component of the model univocally: however, if the original family is modified, all the instances belonging to such family are updated automatically. Thanks to this operation logic, each single typology of panel can be modelled in the programme within a different family.

Later on, the kind of family with which to start modelling has been chosen. Several are the models of family within the software, none of which has the creation of a prefabricated panel as a defined function: various alternatives have therefore been tested in order to find the most suitable one for representing a panel with all its variables, which were identified in the phase of survey [Fig. 4].

Once the most suitable family was singled out (it was to correspond to the "Generic Metric Model wall-based"), we proceeded entering the information concerning its graphic visualisation; the correct combination of information allows to reproduce existing buildings correctly. This has been possible thanks to combining LOD (Level of Development) with the "Levels of Detail" present in the Editor of the Revit Families [19]. LOD provides references thanks to which the professionals of the AEC sector can assess at what level of clarity they are modelling: traditionally, the level of clarity varies in relation with the representative scale, though in 3D modelling such connection is not immediate [Fig. 5]. From the model it is in fact possible to select the scale automatically, so that the lines are made thicker or thinner, but can anyway be read; however, if the amount of the information needed by that particular scale is not entered, the model will prove insufficiently detailed. The LODs are defined by the AIA legislation published on BIM Forum with figures ranging from 100 to 500 [20]; the UNI 11337 Italian legislation, instead, modifies such scale with an A to G range. Such standard procedure allows to determine beforehand how specific the model has been chosen to be, so as not to make it redundant if the LOD is low (for instance when dealing with a general layout) or hardly readable if the LOD is high (for example when dealing with a construction detail). Thanks to the "Detail Levels" offered by Revit, three different modes of visualising the same object can be selected, so as to make such object more or less detailed according to the LOD agreed upon when entering the project [Fig. 6 and Fig. 7].

Three different levels of modelling panels have been created, corresponding to the three different Models of Detail, so as to obtain a more or less detailed panel, as required [Fig. 5].

The result obtained by means of modelling the various families provides a digital information tool that can be used to achieve an efficient replication methodology with reference to modelling. It will be required as far as possible "to mimic" the real assembly of a prefabricated building: after entering the series, under the heading "family", relying on the original "as-built" layouts, on a new Revit project file you proceed tracing the Walls and placing inside them – from bottom to top – each wall-or-floor panel. From the resulting model, thanks to the filter logic of the "Levels of Detail" and of the "Project Scale", the information implemented within the families can be accessed and managed; moreover, all graphic renderings of the "as-built" conditions in the various scales can be automatically extracted, avoiding redundant data.

5. CONCLUSIONS AND FUTURE DEVELOPMENTS

The research work has aimed to detect the perfect relation between the detailed study of the project and of its main components (that is to say front panels, in particular) and Revit modelling, resorting to the "families", testing the available ones, so as obtain a suitable 3D rendering of the panels, as well as the reading of all the materials and components by the programme [Fig. 8a and Fig. 8b].

As far as LOD (Level of Development) [19] is concerned, thanks to the many increasingly-detailed renderings of the same panel and thanks to setting (within the family) a visual variation of the scale, it has been possible to enter a suitable amount of information in the renderings. In this way, it is possible to resort to the families created in order to reproduce existing buildings, relying on the historical documents referring to "as-built" conditions, as well as on resorting to "Levels of Detail" in the main project with the aim of extracting the results. Following the above procedures, this research has evidenced the viability of BIM in the study of prefabricated housing, confirming the need to resort to a different methodological approach to upgrading, if compared to traditional framework-and-curtain-walls construction.

The next steps of the research will move forward towards gaining further insights into the material, geometric and construction-related features of prefabricated housing, as well as developing informatics rendering. As for the recent development, thanks to a comprehensive analysis, the research will focus on a building in its wholeness: i.e. its "as-built" local and global structural behaviour, the energy performances of external panels

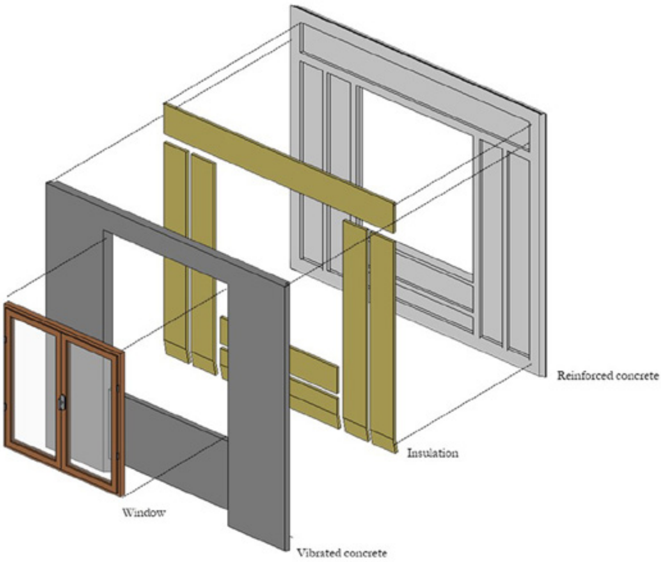


Fig. 8. *Axonometric exploded view of the Camus system panels made by Revit.*

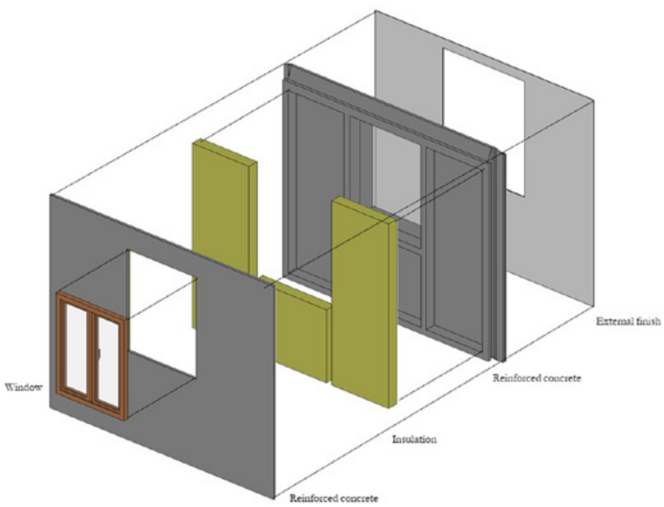


Fig. 9. *Axonometric exploded view of the Balency & Schul system panels made by Revit.*

(theoretical thermal analysis), the modelling of the whole building; this will allow to assess its "as-built" global performances, and to create a reliable model, based on the available data.

As for the latter development, control logics (code and quality checking) will be created in order to check mistakes when setting the panels, as well as to monitor the compliance with technology-and-environment-related legislation; this will apply both to realising automatically-generated 3D positioning grids and to devising methods for the automated set up of the panels. Furthermore, it will be necessary to develop the interoperability and the coordination of the extracted information in order to develop models of structural and energy-performance-related analysis.

By taking the different production stance underlying prefabricated building into account, this research has prompted a different methodological approach to upgrade prefabricated buildings, based on analysing the industrialised construction systems and the buildings resulting from their application. The analysis of the construction systems from a geometric, construction-related and material point of view, together with the technical features (that is to say structural behaviour, energy performance, and construction-related peculiarities) of an "as-built" building, allows not only to identify its main shortcomings that may be emphasised by disrepair, but even to lay down a preliminary set of upgrading criteria that can be applied to industrialised buildings; in this way, working procedures will be better focused and, as a result, the economic sustainability of the project improved.

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[P.I. PhD. A. Bertolazzi, S.D. prof. Umberto Turrini], and the PhD tesi "Approcci progettuali relativi agli interventi di recupero e di ampliamento del patrimonio edilizio del Novecento secondo criteri di sostenibilità: Requisiti connotanti, linee guida progettuali e strumenti operativi di valutazione e gestione" [PhD candidate A. Maniero, Tutor, prof. U. Turrini], carried on within the ICEA Department (University of Padova)

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