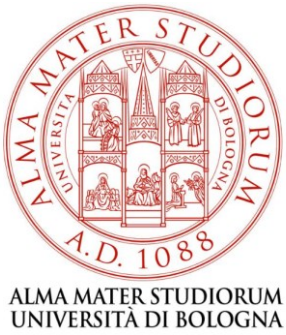
ALMA MATER STUDIORUM
UNIVERSITÀ DI BOLOGNA

CHANCES

Alma Mater Studiorum – Università di Bologna

CHANCES.
PRACTICES, SPACES AND BUILDINGS IN CITIES' TRANSFORMATION.

Curator: Prof. Arch. Annalisa Trentin



International Conference, 24th October 2019

CHANCES was an international conference that aimed to explore, from a multidisciplinary perspective, the fragile but continuous urban transformation through the effective contribution of culture, nature and technology.

The conference wanted to provide a deeper understanding of urban transformations' research and practices, focusing on the use, re-use, design, renovation and innovative governance and management of public spaces, urban commons and buildings.

The organizing committee believes that these thoughts will largely contribute to shape and increase sustainable design, construction and planning in constant cities' transformation.

The selected contributions were built on reflections and studies concerning current or historical approaches that are changing or drastically changed the cities we lived in.

The Conference has been organised by the PhD in Architecture and Design Cultures -

Department of Architecture - University of Bologna

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The scientific committee is composed by the editor in chief of SCIRES-IT and the members of the academic board of the Phd in Architecture and Design Cultures of the department of Architecture of the Alma Mater Studiorum - University of Bologna.

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XXXIII PhD cycle, Architecture and design cultures.

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CHANCES

Practices, spaces
and buildings
in cities' transformation

TRACK 3 / BUILDING DESIGN

The transformation of the cities has a direct connection with the practices of intervention in the building market sector. The dialogue between architecture and engineering allows intervention in urban contexts to respond to the needs for densification, expansion or requalification. The heterogeneity of the buildings determines a multitude of practices, starting from preventive conservation interventions and ending up, sometimes, in complete buildings' reconstruction. This process brings continuous changes in terms of strategies, instruments, design methods and techniques.

The implementation of new building design along with energetic retrofit, structural renovation, restoration, conservation, reuse, demolition and reconstruction interventions are the necessary steps to tailor and customize the built environment to cities challenges and transformations. Furthermore, the widespread use of innovative technologies has accompanied these processes to renovate design methods and digital detection.

This section introduces papers on new building design, innovative techniques, instruments, and interventions for buildings' representation, renovation and restoration.

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DIRECT 3D PRINTING FOR POST-EMERGENCY SETTLEMENTS

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Abstract

We live in an era when the already precarious post-emergency housing conditions faced by millions of people have been dramatically transformed from something extraordinary into something ordinary. While waiting for reconstruction, everyday life is further complicated by the insufficient architectural and urban quality of temporary housing solutions (which last well beyond the emergency phase), while standardisation and indifference to context, be it cultural or environmental, generates alienating scenarios. This situation is an invitation to architects to restore housing to the centre of architecture, to reformulate the very idea of the residential unit and to imagine a new and diverse condition of dwelling. The time has come to reproposed multiple relations between private and public space offered by the design of a city, even temporary. Recent advancements in large-scale 3D printing technology and digital fabrication are bringing important innovations to this field of research. The particular nature of this technology lies in its capacity to establish a relationship between the 'virtual world' of parametric modelling (the level to which design can be personalised) and the 'real world' of construction (the potential to simplify realisation). By introducing new methods of construction that continue to bring construction closer to 'production', and design closer to product, 3D printing gives new meaning to the concepts of technical reproduction and seriality. It invites us to rethink the very approach to the design of architectural and urban space. Beginning with these considerations, this text reflects on and identifies limits and possibilities for the application of large scale 3D printing technologies for minimum, evolving and transitory housing. A design experiment is presented as an opportunity for a multidisciplinary, cross-scale and iterative investigation, verification and exploration of different thematic issues: prerequisites of spatial quality (flexibility of use, personalisation, expandability over time, versality of use and aggregation, etc.), logic and the reversibility of construction and strategies of intervention referred to the entire building process.

Keywords

Large Scale 3D Printing, Post-emergency Housing, Parametric Design, Experimental Architecture

1. Unknown[2]

The unknown is by definition a "magnetic frontier of knowledge", that limit toward which man is both drawn and repelled, passing through a territory of utopias, visions and blunders that often confuse us to the point we are unable to find the way back home.

The unknown is also uncertainty, anguish and expectation and, at the same time, free will, imagination, creativity and concreteness, and thus Chance.

Likewise, in the field of architectural design, the challenge of the unknown, curiosity about overcoming the limits of what we know, what we are familiar with, is the privileged key for starting the process of knowledge; it is an opportunity to rethink old problems from a new angle; it is cognizance of the separation that pushes us toward a new goal.

In addition to being supported by the latest tools of design and construction, any experiment with space must include, together with the leading questions of our preliminary era, other issues that have yet to be raised, but which may arise. In the case of projects for post-emergency settlement systems, the condition of the unknown and the indeterminate is, structurally, an uncertainty. It is a prerogative that induces us, as architects, to push beyond the confines of design and attempt to include unpredictability by prefiguring housing scenarios capable of offering differing levels of versatility in aggregation, adaptability and flexibility of use.

In this particularly complex field of design, an experiment involving a system of settlement to be deployed under emergency conditions[1] represents an occasion for accepting the challenge (Chance)

[1] This article presents part of a study of housing for emergencies conducted by professors of Architectural Composition from the Faculty of Engineering at the "Sapienza" Università di Roma, with members of the LAPIS_Laboratorio sull'Abitare - Progetto Indagine Sperimentazione research group. The theoretical reflections in the text are supported by

presented by the unknown. It is also an opportunity for entering into a multidisciplinary investigation, verification and exploration of thematic issues linked to considerations of the dualism of space-time: flexibility of use, personalisation, expandability over time, versality of use and aggregation, etc.; temporariness/reversibility of building systems; strategies of intervention referred to the entire building process.

1.2 Ordinary Emergencies

'Emerging' means breaking through the surface of a body of water, unexpectedly, after a lengthy period of immersion. Believing that this 'below' world (submerged) does not exist, means refusing to look at the reality of facts, or fear of being unable to confront them.

This alarming vision, at a time when knowledge has provided us with the tools and methods of forecasting and analysis, is unjustified, above all if we consider the consequent results, in some cases catastrophic.

This definition of an emergency has legitimised the use of chaotic 'resolutive' actions that are not immediate and have a strong impact on the environment and the economy.

The 2018 annual report by the United Nations Office for Disaster Risk Reduction refers to approximately 60 million people who have been affected by extreme meteorological events around the world, millions of people who have been left homeless.

According to studies by the UNHCR (United Nations High Commission for Refugees), every two seconds someone in the world is forced to abandon their home due to conflicts or persecutions; 70.8 million people around the world have been forced to flee their homeland; 25.9 million are refugees, more than half of whom are under 18 years of age (UNHCR Global Trend 2017).

These numbers clearly describe how the precariousness of post-emergency housing has dramatically passed from something extraordinary to something ordinary. We live with the paradox that a state of chronic emergency is now something normal, and stripped of its original meaning.

The everyday life faced by survivors is often made even more difficult by the insufficient architectural or urban quality of temporary housing solutions (which last well beyond the emergency phase). This generates scenarios of alienation caused by standardisation and indifference toward context, be it cultural or environmental. Furthermore, these aspects imply significant delays in, when not the complete elimination of a phase of reconstruction, and thus a return to 'normality'.

The theme of a post-emergency housing system is one of the experimental workshops par excellence for architecture. It involves the study of how to integrate the principal variable of time with that of space, to create solutions proposed by and shared with users based on bottom-up practices.

This situation invites us, as architects, to restore housing to the heart of architecture, to reformulate the very idea of the residential unit, to imagine a new and diverse condition of dwelling. We must prefigure the multiple relations between private and public space through the design of a city, even temporary.

1.3 Time-Space. Virtual-Real

During the past century, studies of the relations between the parameters of space-time, fundamental to the design of architecture, produced a number of fundamental reflections on the concepts of minimum dwelling in evolving and transitory situations.

Largely standardising approaches, focused on the optimisation of functional spaces according to a uniforming logic of needs and necessities, which gave us the definition of the 'typical user', were accompanied by interesting reflections on the evolutionary potential of architectural design. These latter produced different strategies intent on providing space with a dynamic quality using standardised modular components.

Keeping pace with the new forms assumed by an increasingly more global society, in which the sense of belonging to a nation has been replaced by that of belonging to the entire world. This is reflected, what is more, in a model of nomadism, not only digital, which has defined the premises for a renewed form of temporary and transitory dwelling.

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the presentation of a design experiment developed by Giulio Paparella for his graduate thesis in Civil Engineering-Architecture 2016/17 (advisor prof. Maria Argenti; co-advisors: prof. Maura Percoco, prof. Salvatore Perno).

The period in history in which we live, dense with impressive technological innovations, leads us, other than to formulate unprecedented relations between space and time, to the necessity to introduce new design parameters linked to the relations between the real and the virtual. While new technologies of surveying, management and data manipulation have provided us with exceptional instruments for controlling the sphere of the 'virtual', it is only with the spread of new digital fabrication technologies that these products of the imagination have become useable in the 'real' world.

In the field of digital fabrication, large scale 3D printing technology offers a series of advantages and potentialities for the building sector as well: capacity to optimise the use of materials, speed and precision of fabrication, autonomous management of production costs with respect to the number and type of elements produced, instantaneous adaptation to particular environmental characteristics or specific user needs, additional reductions in the use of specialised equipment and labour on site. Recent applications in the field of architecture consider 3D printing technology particularly appropriate to a sharing economy inspired by principles of collective responsibility and respect for the environment in the name of future generations.

Among the different approaches to the realisation of building components, we can identify two principal strategies for the use of this technology: direct and indirect 3D printing. While direct 3DP (3D Printing) is an additive process of manufacturing whose final product is used directly for its intended purpose, indirect 3DP produces an object that, without additional work or added materials, would not reach its final performance criteria. The different strategies adopted at the architectural scale use these technologies for structural systems, infill and integrated components. Structural solutions are largely hybrids, primarily when used for horizontal structures, given the process of additive production.

Materials employed for structural purposes include fluid-dense materials (concrete, clay), metals (steel) and thermoplastics (PLA-Polylactic Acid, PETG-Polyethylene Terephthalate Glycol). While fluid-dense materials and thermoplastics are used both for direct 3DP and formwork 3DP, the use of metals, given their elevated mechanical performance, are used only for direct 3DP. Another question is linked

Fig. 1: Experimental projects illustrating the two principal strategies for using 3D printing technologies. Urban Cabin by AECTUAL (2015) realised in formwork 3D printing (© Sophia van den Hoek, AECTUAL). Below: Gaia by Wasp (2018) produced by direct 3D printing. (© WASP)

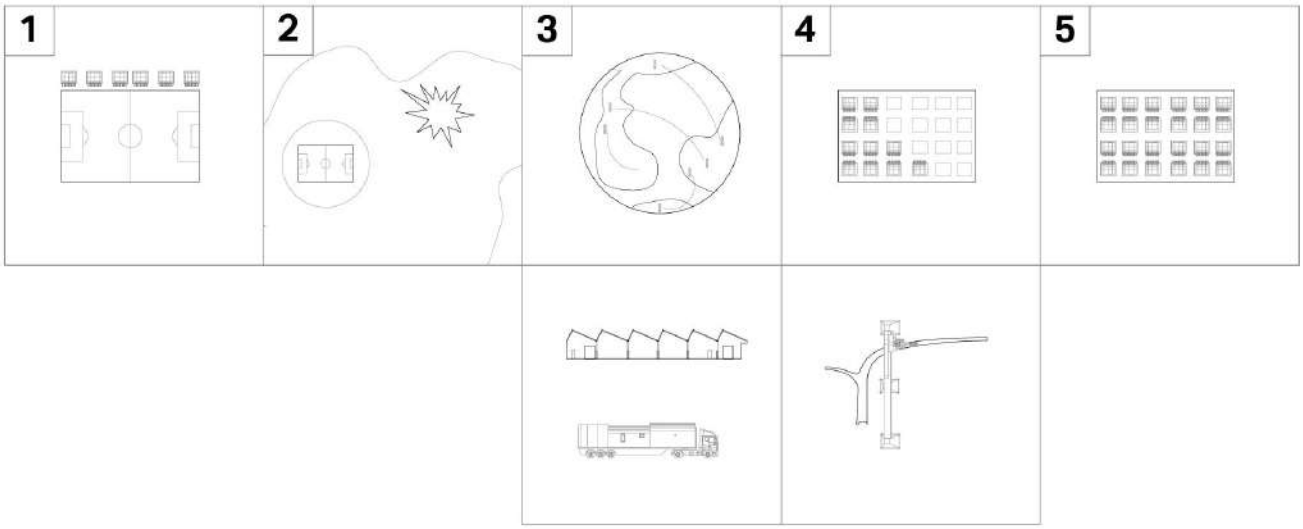

Fig. 2: Description of the sequence of phases of intervention. The programme is based on an alternation between 'peace time' and 'emergency time' and an iterative process of design updates that precedes the realisation of the temporary settlement.

to reinforcing bars, which may be continuous, like the bars used in traditional reinforced concrete, or smaller bars and meshes, or the particularly innovative use of fibres.

These possibilities, fortified by their strong ties with the world of virtual modelling, bring the theme or evolving housing to a new level of research that takes use toward the extreme limit of the condition of flexible space.

2. Intervention Strategy-Project Methodology

Dealing with such a complex theme as post-emergency housing means not only offering valid design solutions for dwelling units and settlements that must also include collective services and urban spaces; it also means rethinking the entire process focused on moving past the condition of emergency by taking advantage of the latest tools offered by technology.

While during the past century the highly functional model of the military camp provided an effective reference for supporting populations affected by calamitous events, in reality it shows little regard for the human qualities of individuality and difference.

At the end of the century, in Italy, the close relationship binding the model of emergency management with the different tools employed to face up to an emergency suggested the creation of the Protezione Civile Nazionale, the National Civil Protection Department, and the identification of four different phases[2] :

1. Forecasting
2. Prevention
3. Rescue
4. Overcoming the Emergency

This approach, while pioneering with respect to activities of risk forecasting-prevention and the rescue of populations affected by calamitous events, has demonstrated, during the course of events, a strong dichotomy between the scenario hypothesised during the forecasting phase and the real conditions of intervention.

What is more, while the requisites prescribed for SAE – Soluzioni Abitative in Emergenza (Emergency Dwelling Solutions)[3] refer to basic criteria (safety, environmental comfort, usability, disassembly, movement, erection and positioning, integration, management), in reality they do not offer a suitable level of functional and morphological flexibility. This generates conditions of settlement that are alienating and with no regard for their context or users.

Given the new surveying and data management tools offered today by the world of Big Data, the

[2] Italian Law n. 225 dated 24 February 1992: Institution of the National Civil Protection Department

[3] Tender, on behalf of the Civil Protection Department, subdivided into three geographic Lots, for the conclusion of a Framework Agreement pursuant to ex art. 59 of Italian Legislative Decree n. 163/2006 for the supply, transportation and erection of *Soluzioni Abitative in Emergenza* and relation services – Edition 2 (ID 1490).

mono-directionality of the current model of intervention, also with respect to the results obtained, is outdated and unable to offer the solutions required by an emergency situation. Instead, rethinking how we overcome the emergency phase as an iterative process of updating data and developing almost instantaneous solutions to housing is undoubtedly of great interest.

Another aspect of innovation involves design methodology. New parametric modelling instruments applied to design offer specific solutions to the type-number of users and to environmental and cultural contexts. In addition, they are also open to new forms of participatory design.

Thanks to the new tools offered by virtual-augmented reality, users can actively participate in the different phases of the building process, even remotely; they can express their needs and verify how they can be 'materialised' in space.

In parallel with the reconstruction of the urban fabric, the return to 'normality' can occur only after the reconstruction of a social fabric, which must be preserved during the various phases of an emergency. In this case, the intangibility of the Network takes on a concrete role as a powerful tool of aggregation that works to restore a sense of community, all too often considered secondary to people's primary material needs.

Once again, design loses its connotation as an occasional episode and becomes a shared and participatory process. While it varies in its form and function, it remains univocal and determinant through the coherence between intentions and instruments.

Creating a continuous flow that links parametric design, methods and digital building technologies makes it possible to activate a coherent building, flexible and changing process, specific to the area affected by an emergency, and with a cost that is independent of the type and number of building components produced.

Among the different digital fabrication technologies, the process of additive manufacturing differs from a subtractive or formative approach, for the simplicity of transportation of materials and a reduced need for complex tools and equipment during construction.

These considerations served as the basis for a design experiment studying the application of an iterative model of emergency management. The hypothesis was based on direct 3DP using a robotic arm fitted with an extrusion device for fluid-dense materials.

This design solution is founded atop a fundamental hypothesis that is part of national planning strategies in Italy: providing an area for hospitality activities, an infrastructural backbone and surface foundation systems. During 'peace time' these elements should serve public activities such as, for example, markets, supporting services and sports facilities, parks, spaces for events, performances, etc. This system represents the '0 phase' of an emergency and defines a particularly advantageous condition by making it possible to drastically reduce construction times for primary urbanisation works, in turn speeding up the ability to offer housing solutions in a short period of time.

2.1 Building-Material Systems

To satisfy the prerequisites of functional and morphological flexibility linked to the indeterminacy of contexts and the variability of the needs of users over time and, in order to guarantee the cyclicity between the 'peace time' and 'emergency time' of the planned intervention strategy, this solution proposes a 'building organism' constructed using an open building system comprised of different modular elements, each opportunely studied to permit a possible hybridisation of technologies and a versatility of languages.

The components of the building system are of two types: industrially produced servant modules necessarily transported to the site and containing a range of technological components (kitchen, w.c. or laundry module) or structural elements (stair module); non-servant modules produced in situ: structural elements, wall and roof systems and furnishings.

The architectural concept originates with the primary concept of 'shelter' and the archetypal idea of configuring a covered space by applying the principle of continuity between roof-wall. This is achieved here using modular elements. In addition to responding to the concept of 'structural form', the section of the unit was also determined by the desire to allow for different floor layouts.

The type of standardised production and the ordinary means of transport planned for the servant components influenced choices relative to their dimensions, content and reduced variability.

In situ production using large-scale 3D printing technologies, applied to the remaining parts of the system, makes it possible to modify the dimensions and quality of different elements in relation to the needs of users and the context in which they the units are to be inserted.
The ground and other floor plates, for example, are composed of modules, whose combination allows

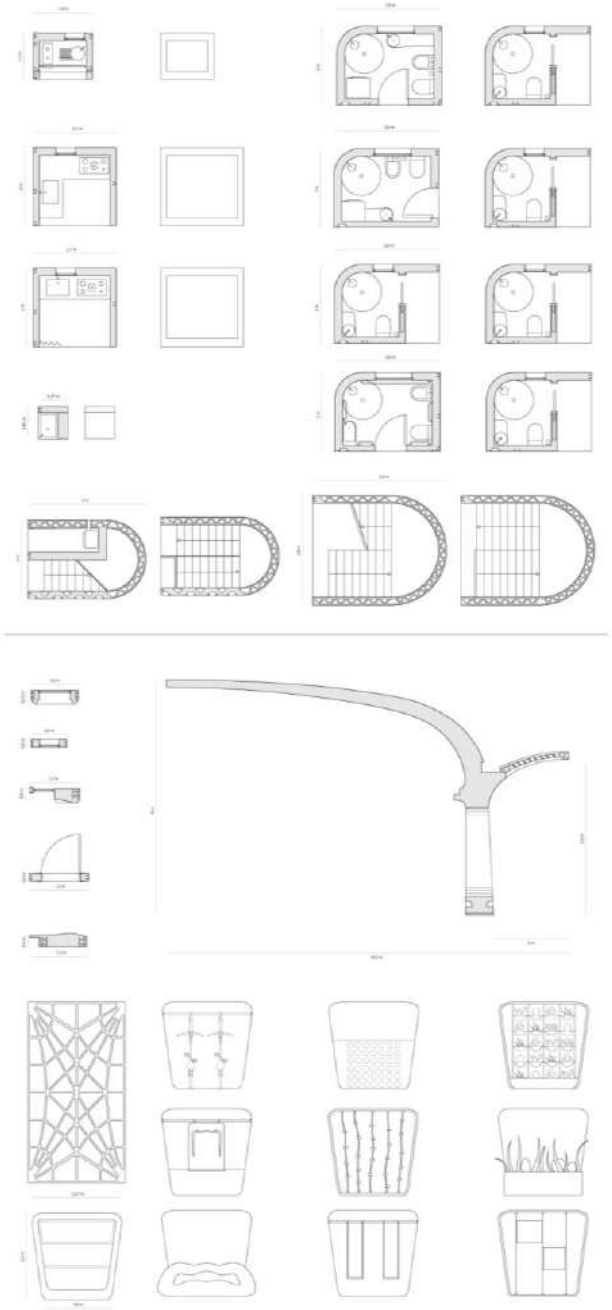

Fig. 3: The basic elements of the building system are graphically illustrated in relation to production systems: industrially produced building components and components produced in situ using large-scale 3D printing. Prefabricated modules are dimensioned to meet transportation requirements.

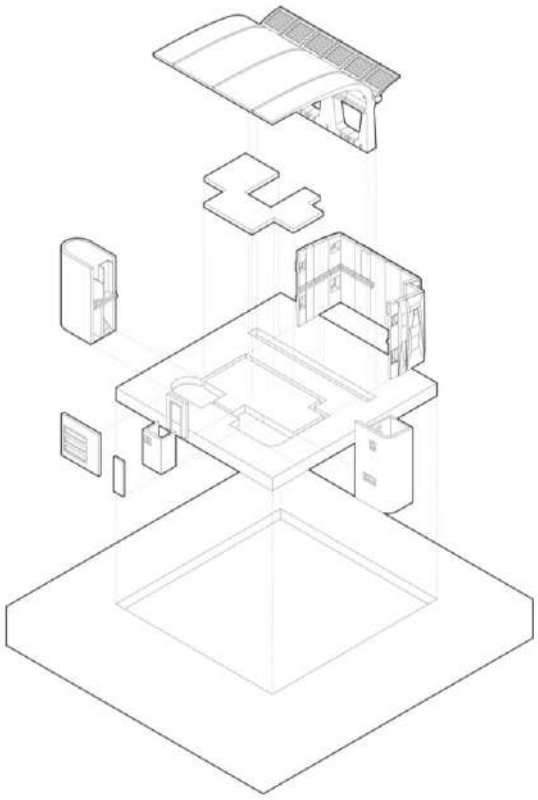

Fig. 4: The different elements of the building system arranged in one possible configuration to create a 60 sq. m base housing unit. The total volume of the unit measures 10.20 m x 9.60 m x 6.00 m.

for the insertion of radiant panels or chases for mechanical, electrical and plumbing systems. Similarly, the selection of materials allows for the integration between primary materials, used for structural elements, and secondary materials, used for infill panels and/or finishes. The objective is to guarantee an effective definition of the building system in relation to the context in which it is used. In particular, structural elements are proposed in a carbon fibre-reinforced geopolymer (a material with a mechanical resistance similar to concrete, though with minor emissions of CO2); the remaining elements are proposed in PEEK (Polyether Ether Ketone).

2.2 From (Non)-Residential Unit To City

The basic residential unit is the 'key' to the composition of a fragment of an urban fabric developed according to the principle of bidirectional correlation, effective at a vast range of scales.

The underlying premise of this system is the desire to provide, also in 'emergency' situations, a quality of space together with housing and

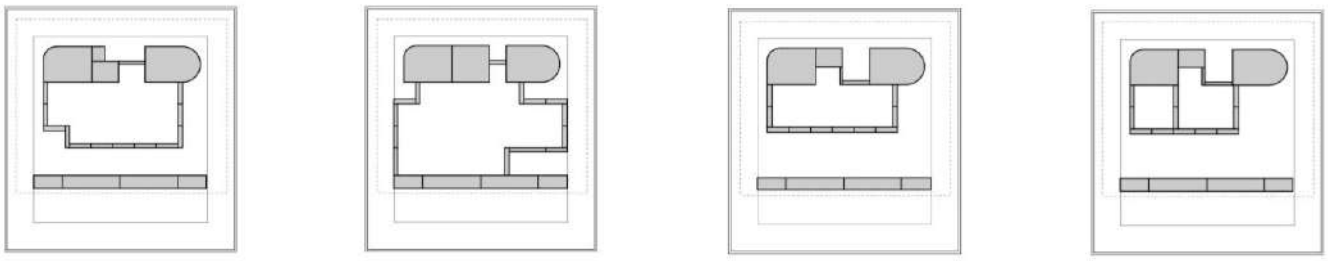

Fig. 5: Versatile layout. Diagrammatic plans of residential units in different configurations: 18 sq. m (2-5 people), 50 sq. m (2-4 people), 60 sq. m (2-6 people), 96 sq. m (4-8 people, accessible by the disabled).

programmed growth with a vast range of possible variations. It is presented as a possible 'cure' for the body and soul and a stimulus for residents to move beyond the phase of emergency.

Solutions were developed for residential units measuring 18 sq. m, 50 sq. m, 60 sq. m and 96 sq. m, suitable for a range of different families and to ensure accessibility by those with temporary or permanent disabilities.

The unit is structured in three parallel linear bands, each of which identifies a functional and compositional element: the served space and servant space inspired by Louis Kahn, and the structural axis. This division, other than ordering the interior layout, is also fundamental to the simplification of preliminary works related to the foundations and systems to be realised during 'peace time'.

The choice to concentrate the structural system along a single axis, despite the elevated loads this generates, is motivated by the desire to ensure the maximum flexibility of interior space. In detail, the portion of inhabitable space defined as served or dominant has been placed between the structural axis and the servant band resulting from the aggregation of different technological units.

The preferred typology is the duplex, with daytime spaces on the ground floor and nighttime spaces on the first floor (alternatives are proposed for this with disabilities), connected by a stair module that terminates the servant band.

The presence of a double height area creates a unified space with richer interiors, in addition to creating a potential condition for the expansion of the upper level. The development of different layouts confirms the effective flexibility of the system at the scale of the unit.

Far from ignoring external space, the threshold between interior-exterior is imagined as a free covered space, a terrain of progressive saturation that allows for the expansion of the basic unit or its appropriation for outdoor activities.

The voids marking the lower portion of the structural elements and roof can become 'containers' for equipment used for different activities (chairs, garden, exhibition panels, etc.). This strategy is also focused on stimulating the use of the external spaces and creating situations that favour encounters and integration between inhabitants.

With regards to the spatial prerequisite of functional flexibility, the project also considered an

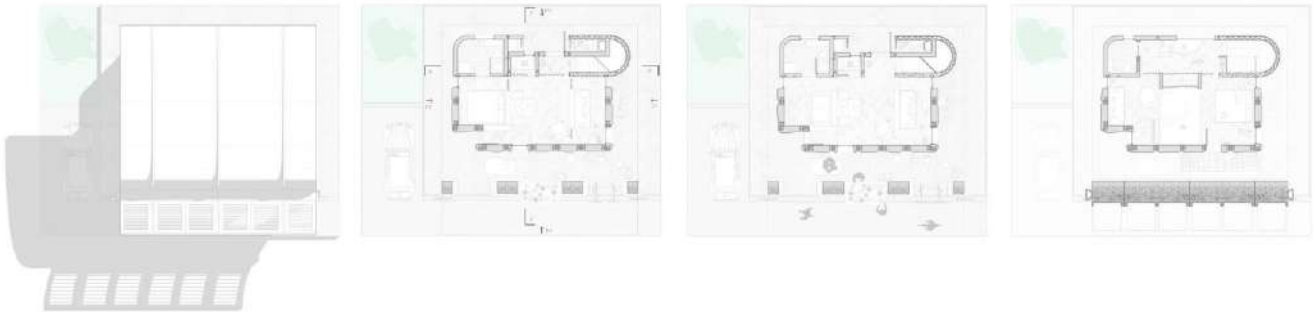

Fig. 6: The 60 sq. m unit can host between 2 and 6 people. The total roof area measures 10.00 x 9.60 m in plan. The study of the flexibility of the interior spaces is represented in different scenarios referred to the alternation between daytime and nighttime functions.

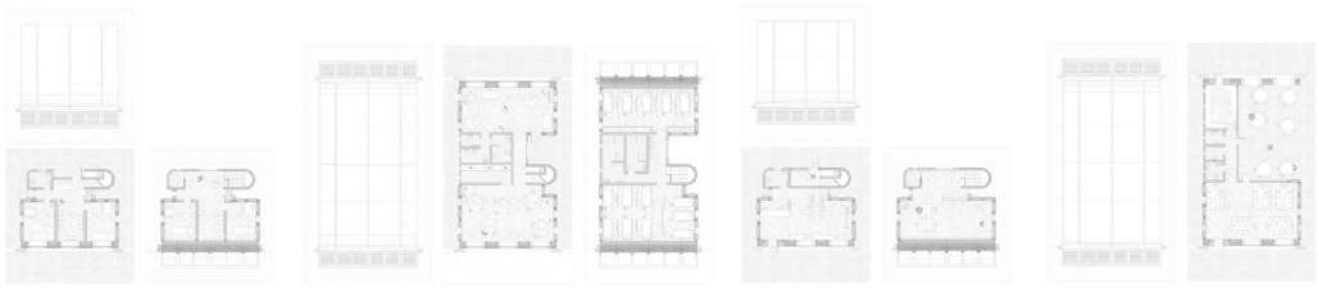

Fig. 7: Design proposal to verify the applicability of the system to non-residential uses, including, for example: healthcare facilities, dormitory, canteen, offices-commercial activities.

application of the same design logic to a non-residential function.

To avoid the creation of a dormitory neighbourhood, a post-emergency settlement system must also offer a series of complementary services and other functions: a business park, healthcare facilities, storage, school, canteen, religious buildings and administrative facilities.

As the majority of the solutions adopted to date demonstrate, the repetitive arrangement of these buildings in a checkerboard to create 'welcoming camps', rather than true fragments of a city (temporary as it may be), while functional to an approach to management inspired by military history, tends to have a negative effect on the fragile post-trauma situation experienced by those who live in them. The serial and alienating character of the units, the anonymity of the open spaces between them, the absence of a hierarchy of routes, the poor design of street widenings and public squares, all fail to recognise the values of identity and society capable of transforming banal interstitial voids into public spaces, and an ordered 'encampment' into a fragment of the city. Based on these considerations, the design experiment demonstrates the aggregative versatility of the proposed settlement system thanks to its different possible layouts, inspired by the row house, patio house, townhouse and urban block.

2.3 Construction Sequence-Details

In addition to spatial issues, the experiment also proposed technical-building solutions deemed fundamental for reaching the objectives described.

To achieve the desire level of spatial flexibility, and the reversibility of construction, the decision was made to adopt dry assembly technologies. The proposed solution uses two types of bolted joints: external (primary) connecting the elements of the system to the foundation and internal (secondary) connecting the different modules to one another.

The raft foundation, constructed during peace time, features built-in anchor bolts along the structural axis for connecting the elements of the roof.

The assembly sequence proposed begins with the different modules of the roof, followed by the servant blocks and, successively, the elements of horizontal and vertical enclosure.

The modules the floor slab benefit from principles of structural optimisation that, thanks to the use of 3D printing technologies, consent an effective reduction in the weight of different elements, which benefits the dimensioning of the resistant elements.

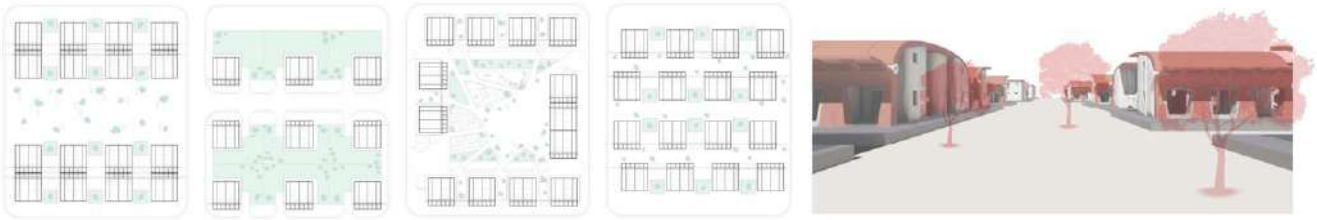

Fig. 8: Verification of the versatility of aggregation of the system based on experiments with alternative configurations inspired by residential typologies: row house, patio house, townhouse and urban block.

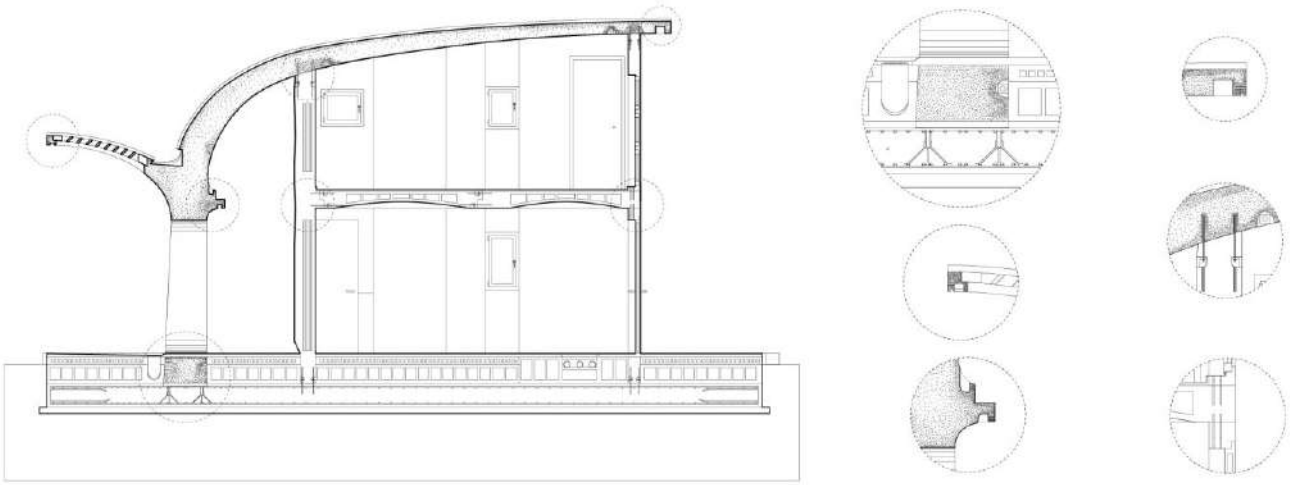

Fig. 9: Building details that satisfy the criteria of flexibility and reversibility of use of the system's components. The foundations built during 'peace time' feature anchor bolts for erection of the roof structures. The floor slab features roughed-in connections for wiring, cabling and plumbing in correspondence with the servant spaces.

Vertical infill panels, also 3D printed in situ, are characterised by an elevated number of apertures that can be left closed or opened as required by inhabitants. Furthermore, once again to the benefit of the personalisation of the building system, these panels can be substituted using alternative solutions that employ local building methods and materials.

Fig. 10: Realisation of the scale model of the dwelling unit at +LAB (3D Printing Lab of Politecnico di Milano, arch. Michele Tonizzo). The 3D printing using a polar 3D printer (max. cylindrical printing volume 40 cm x 70 cm) and the extrusion of white PLA filament. Below: post-production of the component modules of roof.

2.4 Making the Model: 3D Printing Experience-Design Iterations

The spatial model of the dwelling unit was a fundamental tool for verifying the proposal itself and for comprehending the logics behind the process of additive manufacturing and the potentials of this innovative technology for the field of design.

In concrete terms, after the file of the model was exported in STL format (Standard Triangulation Language) the components were printed using PLA filament. The model was created using a Cartesian 3D printer (PowerWasp Evo) and a polar 3D printer (Wasp 4070), both of which employ FFF technology (Fused Filament Fabrication).

In more general terms, the operative context of 3D printing technology is the "Fabrication Laboratory", commonly referred to as a FabLab: laboratories experimenting with digital fabrication where a younger generation of architects, working online as part of a network, collaborate as part of a multidisciplinary approach to identify and produce new sustainable solutions. The vision that animates and links these research communities is founded on the educational theory of "learning by doing" proposed by the American philosopher John Dewey, and the cultural logics of "Do It Yourself" and Open Source Software.

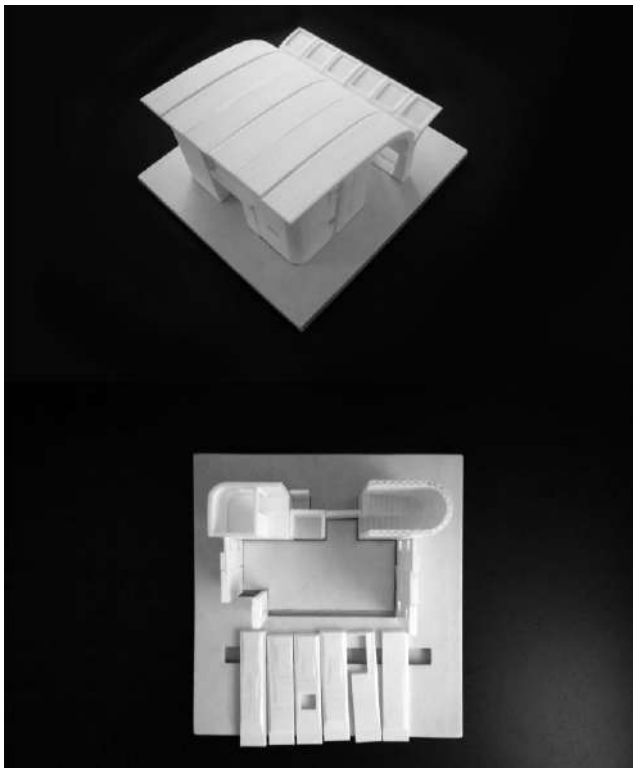

Fig. 11: 1:50 scale model of the base 60 sq. m unit.

The transposition of these theories and approaches into the field of architectural design transforms how we intend design, and the very figure of the designer.

3. *Results Discussion. Open-Ended Questions*

The investigation presented focused on defining the potentialities and limits of large scale 3D printing in the building industry, in this specific case applied to the theme of emergency housing.

In methodological terms, the theoretical-design study began with an identification and analysis of the state-of-the-art. This step was propaedeutic to the definition of an approach to the development of a model of emergency management and the operative phase of 3D printing. The association between these two themes, which converged during the successive phase of the design experiment, is the true characteristic of the proposed research and key to its understanding: attempting to satisfy the needs and necessities of temporary housing in emergency situations by offering an instantaneous solution to housing that is both sustainable and flexible thanks to the use of additive manufacturing technologies.

In synthesis, the proposed technical solution demonstrates a notable flexibility resulting both from the selection of the robotic printing arm (6 axes of rotation offering a very high level of freedom in the positioning of material) and the method of its use (positioned on a sliding rail) during the printing process, which makes it possible to overcome the maximum volumetric dimensions allowed by fixed support printers. This characteristic orients the experiment toward the definition of building components whose volumes have been optimised to reflect a growing awareness of the need to limit the consumption of materials. Together with this dimensional and geometric freedom, the proposed solution also guarantees elevated flexibility during printing. This is important above all for in situ work. In other words, this solutions makes it possible, for the same cost, to realise a vast range of products, almost instantaneously, of the project-type required by the adoption of an iterative model for emergency management.

The pioneering nature of this investigation highlights a number of important criticalities. Other than the strong limitations imposed by the reduced mechanical and compressive strength of deposited material, there was also a need to test new materials that can be integrated in the process and which are able to respond to tensile forces. The proposed solution to use direct 3D printing with a carbon fibre reinforced geopolymer raises questions about the effective mechanical resistance of the structural members hypothesised, as well as the complexity of their in situ realisation and movement.

The advantages and limits revealed make it fundamental to the development of the study to proceed with a second phase that metabolises the previous experience.

An interesting part of the search for light and more reversible structural solutions is represented by a comparison between direct printing and formwork printing. In parallel, there is also a need to reflect on the validity of the integral use of 3D printing for the realisation of all of the building components, as opposed to hybrid solutions that may resolve a number of criticalities (realisation of elements subject to bending, for example, as part of the roof) and to consent an effective definition of the system in relation to local building technologies as part of a collaborative objective that wishes to involve future residents in the building phase.

In this specific case, the future objectives of the study involve experiments with new parametric modelling tools to explore spatial flexibility, to reflect on the effective validity of the modular logics of

digital fabrication and to analyse possible form-finding strategies to be applied to structural elements. Other objectives include the identification of solutions for reversible foundation systems and an in-depth study of the assembly sequence of the system's various components. Finally, an a posteriori comparative analysis of the design proposal using different traditional settlements adopted during an emergency, based on shared parameters, may provide important results for comprehending aspects of the research worth pursuing in successive studies.

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