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Technological Imagination in the Green and Digital Transition

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Chapter 28
3D Printing for Housing. Recurring Architectural Themes

Giulio Paparella and Maura Percoco

Abstract Our present era asks architecture to confront new questions; visions and scenarios that project social, economic, and environmental issues toward that particular intersection between the green transition and the prefiguration of housing solutions for the city of tomorrow. In this drive toward a sociocultural renewal, digital architectural tools play a crucial role in the optimization of resources, customization of building components, and promotion of participative designing-building processes. As an innovative technique of digital fabrication, Additive Manufacturing makes this mass production economically accessible, also on-site, and using local materials. While the topic of a 'home for everyone' has started to be addressed, experiments and applications often focus primarily on technical aspects. To be understood, controlled, and aimed at truly improving quality of life, these innovations require a reflection on the paradigms that inspire digital design. Can the adoption of 3D Printing change design theory and the ways of conceiving the spaces of the habitat of tomorrow? More in detail, is it already possible to identify some particular architectural features? Using a selection of case studies, this paper critically interprets and analyzes these questions. The return of recurring architectural themes—the concept of instant architecture, the relation between natural–digital ecosystems, or the issue of self-determination—offers different ways of looking at 'printed' architecture.

Keywords Large-scale 3D printing · Architectural design for dwelling · High-tech processes and low-tech materials

28.1 Introduction

The complexities and criticalities of our current era force us to think in a new way.

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There is a need for requires visions and scenarios that project social, economic, and environmental problems toward the intersection between the green transition and the prefiguration of near-future forms of housing and the city. Perhaps more than other disciplines, architecture is asked to do its part by reversing the indiscriminate exploitation of resources and production of waste.

The numbers tell the story. The built environment has 'consumed' some 50% of all raw materials extracted. In Europe, the construction sector is responsible for more than 35% of waste production, and greenhouse gas emissions from raw materials extraction, production, construction, and building renovation account for 5–12% of total emissions (DGIMIE 2021). Roughly 75% of all buildings in Europe are energy-inefficient (European Commission 2020). However, in the coming thirty years we will have to reach emissions neutrality to respect the objective of the European Green Deal!

Moreover, if we consider that the world population is forecast to grow by 2 billion people in the next thirty years and potentially reach almost 11 billion in 2100 (United Nations 2020), what scenario can we expect?

In addition to the environmental impact of the construction sector, we cannot ignore the socioeconomic effects induced by population growth. The spread of alternative living models—in response to economic restrictions, flexible working and, increasingly, the dramatic consequences of conflicts and natural disasters—is a clear signal.

Facing these challenges, as designers, we are asked to radically rethink the paradigms, processes, and logics that have contributed to defining this dramatic reality.

We must 'reverse the course' by rethinking architecture, setting aside models and habits, and adopting a transversal and systemic approach based on a holistic mediation between environment, society, and economic issues.

Faced with this challenge to manage multiple aspects, to reduce complexity to simple problems without losing sight of the whole, the visionary nature of architecture plays a central role, today more than ever thanks to the support of IT tools. In this effort to achieve an ecological, inclusive, and collaborative sociocultural renewal, the use of digital tools during different phases of the building offers significant opportunities in terms of resource optimization, mass customization of building components, and the activation and growth of participatory processes, during both design and construction.

Specifically, Digital Manufacturing tools, initially developed for other sectors, allow designers to faithfully materialize a series of computational design experiments, beginning with digital project modeling. Among large-scale Subtractive or Formative Digital Manufacturing tools, Additive Manufacturing[1] brings a particular advantage: It allows for the production of highly customized building components, also on-site and using local materials, employing an automated and economically accessible process.

[1] Additive manufacturing (sometimes referred to as rapid prototyping or 3D printing) is a method of manufacture where layers of material are built up to create a solid object (Redwood et al. 2017).

This intersection between architecture and industry is certainly nothing new. During the last century, the prefabrication of modular building components has contributed to reducing construction costs, although within the limits of standardization. In parallel, reinforced concrete construction enabled the development of modern housing models.

Given the impact of these technological-building innovations, it is essential that we attempt to predict the effects of the recent introduction of Digital Manufacturing technologies.

What advantages and objectives justify the application of 3D Printing tools in architecture? Is it possible to identify some of the architectural themes this innovative building method allows us to develop? Will the adoption of large-scale 3D Printing change the design theory and conception of the city and the shape of space? Theoretical-design research finds ample room in these considerations.

28.2 3D Printing for Architecture. What Questions Is It Answering?

Recent years have seen a significant rise in the number of studies of Additive Manufacturing in architecture; in 2016 only 3% of 3D Printing investigations involved this specific sector (Kianian 2017). Among the precursors, in 2006 Professor Behrokh Khoshnevis (University of Southern California) began to develop the Contour Crafting construction method for integrating the layering of fluid dense materials with standard robotic building processes (Bosscher et al. 2007). In Italy, the engineer Enrico Dini experimented with Binder Jet printing technology to produce load-bearing construction elements from cement powders (Gardiner and Burry 2009). Thanks to further national and international research, these initial insights would be consolidated in the following years. The aim is to investigate the characteristics of 3D Printing for the construction sector: flexible production brings significant advantages in terms of mass customization for on-site fabrication, accuracy of production, automation, and cost-effectiveness, all of which can be challenging to obtain from other Digital Manufacturing techniques (Lim et al. 2012).

Today numerous ongoing investigations are exploring large-scale 3D Printing. They focus primarily on technical aspects, such as material 'printability' and the structural and energy performance of pavilions and small infrastructures. In recent times, these preliminary studies have fostered a diffuse and growing interest in applying 3D Printing as a possible solution to the 'home for all.'

In 2018, Locatelli Partners applied Additive Concrete to construct the 3DHousing05 prototype in Milan (Locatelli Partners 2018); the minimum housing unit *UnaCasaTuttaDiUnPezzo* (AHouseMadeFromOnePiece) by D-Shape and the architect Marco Ferreri, built using Binder Jet printing technology for cement powders (D-Shape 2010); the first printed village consisting of customizable housing

for low-income people by New Story + Icon (New Story 2019); the TECLA—Technology and Clay project by MCA—Mario Cucinella Architects and WASP for sustainable raw earth housing units constructed on-site from local materials (Andreoli 2019); the recent project in Africa by 14Trees demonstrates that affordable housing can be achieved quickly using Additive Concrete (Holcim 2020) (Fig. 28.1).

In this frenetic race of experiments, focused largely on quantitative aspects such as speed of construction and cost-effectiveness, there seems to be little space for a parallel meditation on architectural aspects. 3D Printing technology is certainly one possible answer. But to what question? What idea of the future is being proposed?

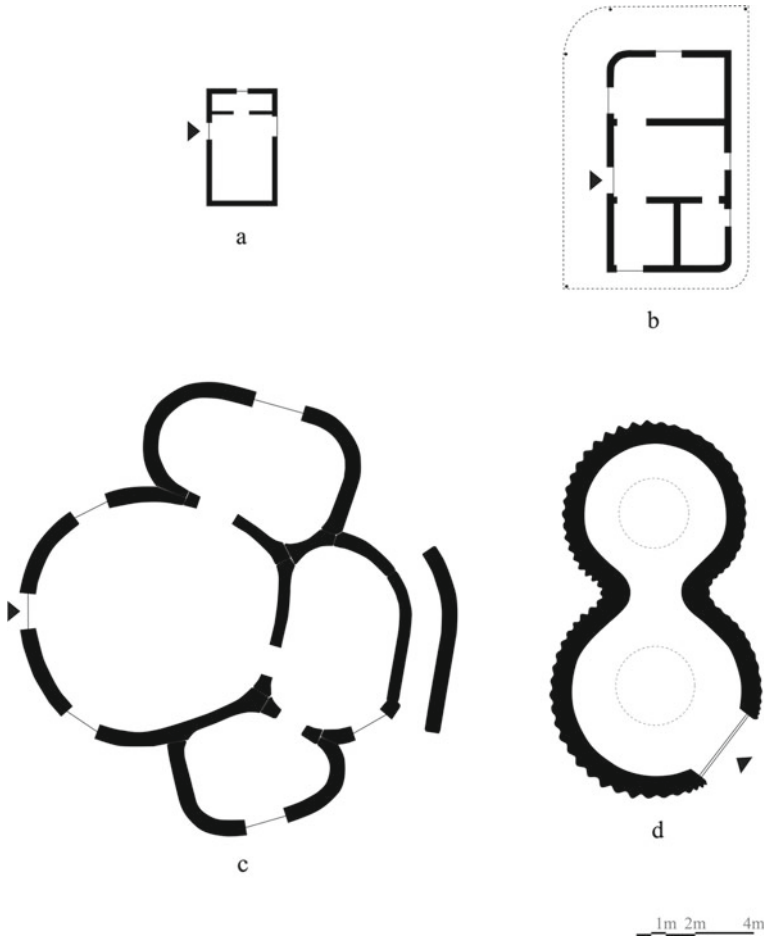

Fig. 28.1 Plans for 3D printed architecture. *UnaCasaTuttaDiUnPezzo* by D-Shape and Marco Ferreri (**a**), 3D printed house in Austin by New Story + Icon (**b**), 3DHousing05 by Locatelli Partners (**c**), TECLA—Technology and Clay is a project by MCA—Mario Cucinella Architects and WASP (**d**). Drawings by the authors

What image will the 'printed' house have? Will it belong to the habitat of a greener and digital tomorrow?

28.3 Recurring Architectural Themes of 'Printed' Living

Today's technical and constructive innovations require a reflection on the paradigms that inspire design practice, now 'digitalized.'

These innovative tools must be understood and controlled by designers to generate real social progress with the ability to improve everyone's quality of life. As it was at the end of the last century for other technical-constructive innovations, contemporary dwelling is probably also the true test bed. Since most current studies analyze performative aspects of 3D printed elements in the absence of a real functional context, this research defines projects explicitly developed for contemporary living as case studies. A critical analysis of these pioneering examples aims to deduce some recurring architectural themes.

28.3.1 'Here and Now.' Instant Architecture

'Here and now' is more than just a mantra that invites us to live in the present with more awareness. In a world often constrained by the past or projected into the future, 'here and now' represents an alternative way of thinking about architecture. It allows us to imagine a different idea of the city, other forms, and ways of living and building through which to seek alternative solutions for our fragile habitat. There are many signals that this renewal process is already underway, from themes of self-construction and participation to the preservation of nature, and the return from the metropolis to the countryside. In this evolutionary process, what role can 'printed' architecture play?

Instead of considering digital architecture as a mechanical result of an operation of 'copy and paste,' 'printed' architecture is rooted directly to the site of intervention. The sensitivity of designers is crucial as it brings subjective data into a digital project.

Hence, at a time when technique still prevails over content, and when the tool often ends up overshadowing reasons and forms, 'printed' architecture helps us rediscover the key role of the designer, and echoes how 'the whole is greater than the sum of its parts.'

Data usage may be a collaborative action strategy for identifying a shape that is 'suitable,' informed but non-formal, to optimize the structural, thermal, or functional improvements of a component. Hence, it is clear that we cannot define in advance whether printed architecture is 'good' or 'bad' architecture; there are only valid designers or other 'code executors.'

Nowadays, designing also means taking a step back, not looking for appearance and spectacularity, and putting ourselves at the service of the community. In a society exhausted by its devotion to the viral image, where architecture is successful only when it is 'Instagrammable,' we must move the act of building away from the expressive whims of the individual. This period of multiple changes invites us to approach design with caution and, at the same time, with immediacy and decisive action: 'here and now' (Fig. 28.2).

Architecture presently responds to social and environmental questions with a more resilient approach, and it increasingly captures a possible answer in the theme of temporariness. Moreover, this low-density design strategy is 'printed' architecture's contemporary answer to the question of urbanization, far from the usual high-density approach. Any 'disposable' logic is rejected, while privilege is given to buildings designed to be 'circular,' recyclable, or relocatable elsewhere, or even degradable within the host ecosystem.

Fig. 28.2 'Here and Now,' instant architecture. TECLA—Technology and Clay is a project by MCA—Mario Cucinella Architects and WASP (a ©WASP, b, c ©Iago Corazza). 3DHousing05 is a project by Locatelli Partners (d–f ©Luca Rotondo, courtesy Locatelli Partners)

28.3.2 *Ecosystems in Dialogue. Between the Natural and the Digital*

The vision of future technological development often leads us to think of an apocalyptic scenario of machine domination, in increasingly urbanized and alienating contexts, distant from the 'natural world.' In some experiments, however, there is a strong influence among traditional building techniques and Additive Manufacturing. Together with other digital tools, such as 3D Scanning technology, 3D Printing allows for technological-constructive hybridization thanks to design solutions 'modeled' directly on the existing. This intersection of worlds (past and present), materials (natural and artificial), and tools (analogue and digital) is evident in the Digital Twin design methodology, also based on the potential to digitalize low-tech materials and components (Boje et al. 2020). Architecture behaves like an 'organism.' This is evident in the use of organic building materials and the emulation of the natural lifecycle (conception, birth, growth, and development, to the transformation of the already built).

The advancement of knowledge, which has led science to discover new materials during the past century, has introduced an elevated specialization of building components. The result is that structural parts are disconnected from non-structural ones; walls are divided into a multiplicity of layers made of different materials. This 'specialization' of building elements may have answered the needs of a past era by supporting the search for spatial flexibility (indeterminacy). However, this strategy requires complex production and recycling processes. On the contrary, many 3D Printing approaches exploit the geometric properties of building elements to ensure adequate structural or thermal performance in association with natural materials (Fig. 28.3). In this sense, the potential of virtual modeling tools is fully exploited by identifying and optimizing building shape: geometry once again plays a pivotal role in architectural design, far from any decorative purpose.

28.3.3 *Digital Self-determination*

An online community, only apparently distant, can conceive of ideas, generate projects, and constructive actions, even at a neighborhood level. This apparent incongruity led to an investigation of current advancements to design and production strategies. In our global world, characterized by strong political and economic interdependencies, where the well-being of entire populations is in the throes of an international crisis, it is strategic to think of integrated design-construction processes both in dialogue and as potentially independent.

The potential to use local materials and resources is crucial also from this perspective, and this logic is also explored in other sectors and at other scales of application. Indeed, the Makers community has been sharing digital knowledge for years and placing it at the service of the community using Digital Manufacturing

Fig. 28.3 Ecosystems in dialogue. Between the natural and the digital. Sombra Verde Pavilion by AIRLAB and SUTD (a–c ©Carlos Bañón AIRLAB @SUTD). Digital Adobe by IAAC Open Thesis Fabrication 2017–2018 (d, e ©Giulio Paparella)

machines (Fig. 28.4). Scaling this logic from the neighborhood to the city, the Fab City model is based on sending and receiving data instead of exchanging goods: processes whose sustainability comes from reducing transported volumes (Fab City 2021).

In architecture, the preference for local materials opens new frontiers of expression for contemporary forms of digital regionalism: the global design solution is locally diversified according to specific needs and available resources. This logic is applicable also at the scale of furniture; for example, plastic materials can be recycled and reused to produce street furniture, favoring the appropriation and livability of public spaces (The New Raw 2021).

Finally, from the point of view of participatory processes, printed architecture is more inclusive and capable of supporting contemporary forms of shared living during the design and construction phases: several cost-effective variations of the proposed architectural solution allow for the implementation of the 'city for all.' During the construction phase, Mixed Reality technology can also be used to remotely guide non-highly qualified workers. These settlements can accommodate low-income families without neglecting spatial quality and the personalization of individual housing units.

Fig. 28.4 Digital self-determination. Maker Economy Starter Kit by WASP (©WASP)

28.4 Conclusions and an Open-Ended Question

Among digital tools for the green transition in architecture, 3D Printing occupies a crucial position because it permits the production of energy-efficient components, and the optimization of material quantities related to structural performance. Furthermore, since Additive Manufacturing can communicate with other 'IT ecosystem' tools, it is also decisive to the digital transition. In terms of social repercussions, this opens up potential scenarios in which Additive Manufacturing responds sustainably to housing issues arising out of the now widespread phenomenon of urbanization that increasingly characterizes the areas around large cities; these new sustainable building processes allow us to think of alternative horizontal models of urban expansion that can replace outdated high densification solutions.

In conclusion, it is essential to reiterate the fundamental role of the designer in coordinating and caring for the coherence of the final outcome as part of the green and digital transition of architecture, which includes 3D Printing. Design must be integrated with its quantitative–qualitative aspects.

For architecture, the innovative aspect is the high level of inclusiveness that increasingly characterizes the building process. Many ongoing experiments promote activities that involve people in the phases of design and construction, thus helping to 'build' a community and the spaces in which its members will live together; in short, the utopia of CoDesign-CoBuild-CoLiving is finally being realized.

As our past teaches us, the image of architecture is constantly changing, and the advent of 3D Printing technology is the latest demonstration. Albeit in an embryonic phase, this initial architectural shift already shows some recurring aspects: continuous and optimized structure, often hybridized with other construction techniques

and materials; fluid and wrapping plans; elevations whose surfaces are 'marked' by 'informed' lines of layered printing; openings conceived as excavations made by inserting frames during the printing process; roofs that are either seamlessly joined to the walls or formally autonomous.

Only by monitoring the evolution of these experiments will we manage to understand if these still unripe traits will be consolidated into a true language of 'printed' architecture.

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