Design in the Digital Age

Technology
Nature
Culture

MAGGIOLI EDITORE

SITdA Società Italiana della Tecnologia dell'Architettura

neapolis

DiARC dipartimento di architettura università degli studi di napoli federico II

La SIT*d*A, Società Italiana della Tecnologia dell'Architettura fondata nel 2007, è un ampio network di docenti e ricercatori universitari con l'obiettivo di sostenere la cultura della ricerca nell'area disciplinare della Tecnologia dell'Architettura e di offrire risorse per la formazione e la qualificazione dei giovani ricercatori, promuovendo studi di carattere teorico e applicativo, incoraggiando l'internazionalizzazione della ricerca e l'esplorazione di aree emergenti dell'innovazione tecnologica in architettura.
La pubblicazione raccoglie i contributi di studiosi, *PhD* e ricercatori che hanno risposto alla *call for paper* promossa dalla SIT*d*A in vista della conferenza internazionale "Design in the Digital Age. Technology, Nature, Culture", che si terrà a Napoli l'1 e il 2 Luglio 2021.
I saggi raccolti in questo volume costituiscono un insieme di idee, riflessioni, posizioni e proposte che, nel quadro della crisi epistemologica che investe le ragioni, il senso e le strutture stesse del progetto, possono aiutare a comprendere in che modo la svolta digitale sta trasformando profondamente il ruolo della cultura progettuale nel rapporto tra tecnica e natura in una transizione storica caratterizzata da cambiamenti climatici e sociali con enormi ricadute di tipo politico, economico e produttivo.

SITdA, the Italian Society of Architectural Technology founded in 2007, is a wide network of university professors and researchers aiming to support the culture of research in the disciplinary area of Architectural Technology. It also provides resources for the training and qualification of young researchers, promotes theoretical and applicative studies, encourages the internationalization of research and the exploring of emerging areas of technological innovation in architecture.
The publication collects the contributions of scholars, PhD and researchers who participated in the call for papers promoted by SITdA for the international conference "Design in the Digital Age. Technology, Nature, Culture" to be held in Naples on 1 and 2 July 2021.
The essays in this publication provide a set of ideas, reflections, positions and proposals that, in the context of the epistemological crisis that affects the reasons, the meaning and the very structures of the project, can contribute to understand how the digital shift is deeply transforming the role of design culture in the relationship between technology and nature in a historical transition affected by climate and social changes with enormous political, economic and productive consequences.

a cura di
Massimo Perriccioli
Marina Rigillo
Sergio Russo Ermolli
Fabrizio Tucci

MASSIMO PERRICCIOLI
Professore ordinario di Tecnologia dell'Architettura
DiARC - Dipartimento di Architettura
Università degli Studi di Napoli Federico II

MARINA RIGILLO
Professore associato di Tecnologia dell'Architettura
DiARC - Dipartimento di Architettura
Università degli Studi di Napoli Federico II

SERGIO RUSSO ERMOLLI
Professore associato di Tecnologia dell'Architettura
DiARC - Dipartimento di Architettura
Università degli Studi di Napoli Federico II

FABRIZIO TUCCI
Professore ordinario di Tecnologia dell'Architettura
PDTA - Dipartimento di Pianificazione, Design, Tecnologia dell'Architettura
Sapienza Università di Roma

ISBN 978-88-916-4327-8

Published in November 2020

Maggioli Editore is part of Maggioli S.p.A
ISO 9001 : 2015 Certified Company
47822 Santarcangelo di Romagna (RN) • Via del Carpino, 8
Tel. 0541/628111 • Fax 0541/622595

www.maggiolieditore.it

e-mail: clienti.editore@maggioli.it

Call for paper promossa in occasione del Convegno Internazionale

"Design in the Digital Age. Technology, Nature, Culture"

Napoli, 1-2 Luglio 2021

SITdA - Società Italiana della Tecnologia dell'Architettura
DiARC - Dipartimento di Architettura - Università di Napoli Federico II

MAGGIOLI EDITORE

Comitato Scientifico/Scientific Committee

Vicente Guallart, Guallart Architects
Thomas Herzog, Thomas Herzog Architekten, Socio Onorario SIT*d*A
Matteo Lorito, Rettore dell’Università degli Studi di Napoli Federico II
Mario Losasso, Università degli Studi di Napoli Federico II, Past President SIT*d*A
Maria Teresa Lucarelli, Università Mediterranea di Reggio Calabria, Presidente SIT*d*A
Gaetano Manfredi, Ministro dell’Università e della Ricerca
Fabrizio Schiaffonati, Politecnico di Milano, Socio Onorario SIT*d*A
Bernard Stiegler, Institut de Recherche et d’Innovation, Paris
Martin Tamke, The Royal Danish Academy of Fine Arts, Copenhagen

Coordinamento Scientifico/Scientific Coordination

Ernesto Antonini
Eliana Cangelli
Valeria D’Ambrosio
Laura Daglio
Pietromaria Davoli
Massimo Lauria
Elena Germana Mussinelli
Massimo Perriccioli
Sergio Russo Ermolli
Fabrizio Tucci

Segreteria SITdA/SITdA Secretariat

Antonella Violano

Comitato organizzativo di Sede/Coordination Committee of Naples

Paola Ascione
Erminia Attaianese
Eduardo Bassolino
Mariangela Bellomo
Alessandro Claudi de St. Mihiel
Valeria D’Ambrosio
Paola De Joanna
Katia Fabbricatti
Antonella Falotico
Mattia Leone
Pietro Nunziante
Massimo Perriccioli (responsabile)
Marina Rigillo
Sergio Russo Ermolli
Serena Viola

Coordinamento organizzativo/Organizing Committee

Maria Azzalin
Enza Tersigni

Segreteria organizzativa/Organizing Secretariat

Anita Bianco
Marina Block
Francesca Ciampa
Maria Fabrizia Clemente
Ivana Coletta
Federica Dell’Acqua
Giuliano Galluccio
Giovanni Nocerino
Giuseppe Vaccaro
Giovangiuseppe Vannelli
Sara Verde

Grafica e comunicazione multimediale/Graphic and multimedia communication

Raffaele Catuogno
Vincenzo Pinto

Indice

Digito Ergo Aedifico
Digital Chains for Advanced Building Processes

Roberto Ruggiero[1], Roberto Cognoli[2]

Abstract

The paper focuses on the digitalization of the building processes (design, production, construction) in the awareness that "construction" is, today, the weakest link of a possible digital chain in the building sector. In particular, the paper shows the first findings of research focused on the application, in post-natural disaster areas, of an automated process to build temporary shelters and little facilities services. The illustration of this ongoing activity is an opportunity for some critical reflections about the potentiality of the digital revolution applied to the building sector.

Keywords: Digital, Architecture, Construction, Automation, Process, Emergency

1 SAAD - School of Architecture and Design Eduardo Vittoria, University of Camerino, roberto.ruggiero@unicam.it
2 ISAS - International School of Advanced Study, University of Camerino, roberto.cognoli@unicam.it

"Where" is the digital in architecture?[1]

In the last decades, the results of the so-called "digital revolution" have profoundly changed some of the rules and processes of twentieth-century industrial production. Despite its low inclination to experiment with the results of technological innovation, also the building sector is today deeply affected by the new opportunities provided by the digital culture, even if to a different extent depending on the geographical contexts.

Since the diffusion of Computer-Aided Design (CAD) in the '80s[2], many things have changed in design, production, and construction processes. In particular, in the design processes, a new generation of digital software and devices have become permanently part of the "architect's toolbox". Particularly in the last ten years, the development of ICT technologies has made available new families of interconnected tools. The latter has turned out to be so powerful to stimulate, in a short time, the emerging of new design cultures and, with them, the rise of new rules and roles in design processes[3].

Nevertheless, digital innovation has not spread homogeneously in the other phase of the building process. Only in recent years, in some advanced contexts, and under the push of Industry 4.0 template[4], CNC technologies, robotics applied to the manufacturing field, and 3D printing has allowed experimenting the production of innovative *non-standard*[5] systems, and components and prepared the ground to a new form of prefabrication: the *off-site* construction, i.e. one of the so-called MMC (Modern Method of Construction) that can be considered as a mature form of prefabrication based on digital methods of design and production. Otherwise, digital innovation seems to "touch" very little the "construction" procedures, including the building site, that generally is still linked to "analogic" approaches that strongly reduce the benefits deriving from the digital innovation[6]. In the transition between design, production and construction, this discontinuity represents an obstacle to the development of entirely digital approaches to building processes – i.e. a digital construction chain[7] – and the benefits that could derive from it.

If the research in the field of the digital building site and on-site use of digital equipment shows remarkable results, they often seem to be too futuristic and sophisticated for immediate applicability in ordinary construction processes, whose know-how in many contexts is still very low. From ETH of Zurich to MIT of Cambridge, from Mecanoo Architecten to UN Studio or Zaha Hadid Associates, digital fabrication counts today an enormous amount of futuristic applications through ambitious research projects or applied in not ordinary architectures.

Aware of this scenario, we are legitimate, today, to ask ourselves some questions, decisive for understanding the future. For example: whether, when and how the completion of the digital revolution will interfere with the processes of ordinary constructions. Is this a plausible scenario? Such a powerful conceptual and instrumental apparatus (such as that of the digital technological context) can be put at the service of the most urgent and current issues such as, for example, new and widespread hous-

1 This title paraphrases the title of a book - Goodhouse, A. (2017), *When Is the Digital in Architecture?,* Sternberg Press, Berlin - that focuses on the beginnings of the digital in architecture.

2 In 1982 AutoCAD (by Autodesk) was the first 2D design CAD software made for PC. It spreads – in a few years and many fields (including architecture) – as a revolutionary design tool.

3 Parametric and Computational Design are just two of the most evident and not fully explored outcomes of the "revolution" underway.

4 It is recalled that the Industry 4.0 develop model is specifically founded on advanced digital technologies like automation, artificial intelligence, robotics, 3D printing, internet of things to name a few.

5 See P. Beaucé, B. Cache (2003), *Towards a non-standard mode of production*, in "Non-Standard Architecture" exhibition catalogue, Georges Pompidou, December 2003/March 2004, available at: http://architettura.it/extended/20040214/index.htm

6 That is why this disparity contradicts one of the main postulates of the digital culture based on the concept of "digital workflow" between all the process phases, already applied in other manufacturing fields. This implies a sharing of data between the different "actors" of the process but, above all, that all the stages of the operational chain make use of digital tools, approaches, and technologies. This model, still far from being applied in the ordinary building experiences, entails a shift of paradigm in the way the architects' design, the way that builders build, and the way that industry produces.

7 In the most recent scientific literature, the concept of "digital construction chain" emerges as a necessary pre-condition for the completion of the digital revolution in the construction field. Although nowadays "digital" has penetrated many phases of the building process, its presence is still discontinuous. For example, if the building design has long been heavily digitized, «despite rapid digitization in almost all other industries, construction remains one of the least effected» (Claypool, 2019). This «discrepancy between design and fabrication» constitutes «a gap between the two processes» but also a gap for the entire building process. (Retsin, 2016). To develope in a complete way a "digital constructive reality", a fully digital building process is necessary, i.e. «an architecture that is both digital in its design, production, syntax, and economy» (Retsin, 2016). As stigmatized in one of the reference texts for digital culture applied to construction, «far beyond purely digital rhetoric, we recognize digital constructive reality as a unique breeding ground to induce new meaning in architecture» (Gramazio, Willmann, Kohler, 2014 p. 192).

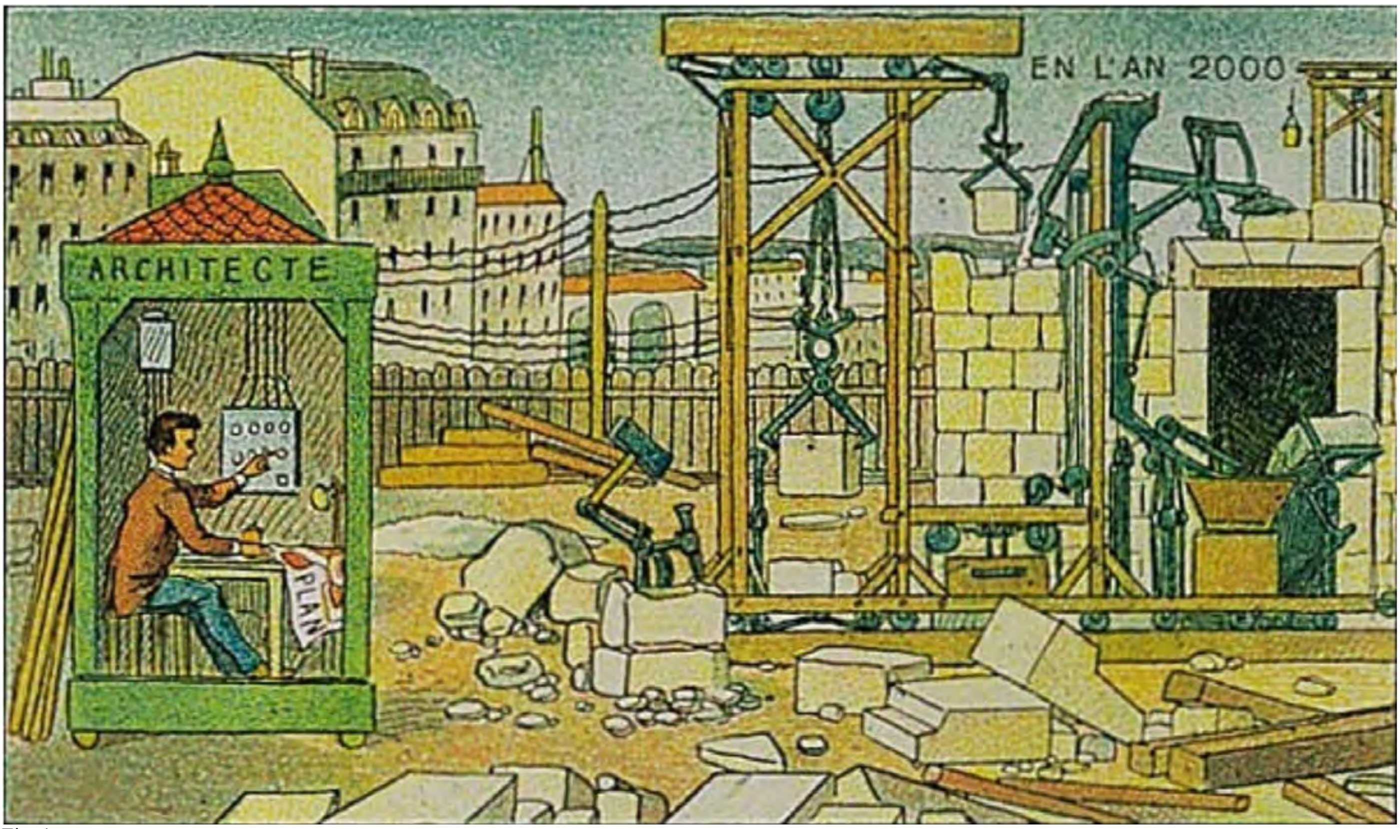

Fig. 1

ing emergencies, the sustainability of construction processes and the quality of the built environment? Concerning the declared inhomogeneity of the impact of digital technology on the different steps of the building processes, is it possible that 3D printers, robots and other devices for the "digital construction" find room steadily in a more or less near future?

These and other questions should encourage a reflection about, updating Martin Heidegger thought, "the question concerning *digital* technology" in architecture[8].

The development of avant-garde components, new and compelling spatiality, of fluid processes capable of realigning design, production, and construction in a single workflow, probably represents the first result of an advancement whose potential is yet to be discovered. Understanding how and if such powerful technologies, if systemized, can help us make environmental transformation processes more efficient, timely, sustainable, and even ambitious remains a challenge. Reducing this challenge to a mere instrumental question, without considering its cultural implications, would be a step backward for architectural culture. Otherwise, experimenting with new digital approaches to the conception and construction of Architecture according to the objectives, which today are stringent, of social and environmental sustainability, appears instead to be a compelling way of accepting this challenge.

The "good machine". A research about robots in post-earthquake reconstruction.

The effects that a natural disaster (an earthquake, for example) usually determines in an anthropized context are both material and immaterial. The collapsed building represents just the physical damage: the "cut" of the social, economic, cultural, environmental relationships between people constitutes instead priceless harm that can even compromise the community's survival, particularly in contexts of low-density urbanization. If the time for the physical reconstruction is, as usually is, too long, the reconstruction of human relationship – i.e. the reconstruction of the "community" – risks to be irreparably compromised.

The 2016 earthquake[9] that destroyed a substantial part of a small town and ancient villages in Central Italy is a perfect example of this. After more than three years from the disaster, that community doesn't know yet when and how the reconstruction will be carried out. Uncertain on its future, people are obliged to live in what are called "emergency living solutions", that is to say, "temporary" (a euphemism) settlements built in a very economical way, devoid of any architectural quality and in the total absence of facilities. Based on previous Italian disaster experiences, we know that those settlements will house most of the people for more than twenty years. The lack of any sort of amenities in this "small dormitory suburbs" prevents the rebirth of any kind of social life. Moreover, we know that Italy has a fragile territory where earthquakes are cycling and recurring phenomena, so as any natural disasters.

With a reach tradition of studies in the field of housing emergency and directly affected by this event (for reasons of territorial contiguity), the School of Architecture and Design "Eduardo Vittoria" (SAAD) of Ascoli Piceno, University of Camerino, since 2017 has developed different research lines in the field of emergency management. The most experimental of these concerns the possibility of creating, in the emergency sites (SAE, emergency housing solutions), small and medium-sized temporary structures devoted to facilities for the community. The research develops in two directions: the definition of participatory construction processes; the use of advanced digital technologies and, with them, the introduction of automation systems. In both cases, the research aims at extending its focus, progressively,

8 The reference is to the famous work "The question concerning technology" published in 1954, where Heidegger discusses the essence of technology in full "machine age".

9 The earthquake that hit Central Italy in 2016 involved 138 municipalities, 4 regions, 299 victims, around 50,000 displaced persons, 4,000 are the SAE (emergency housing solutions), 80,000 are the damaged buildings. (Source: ISTAT, Italian National Statistical Institute).

from the small temporary structures to the emergency houses and, in a longer and more ambitious perspective, to the reconstruction process[10].

About the second topic (automation systems), SAAD obtained funding from the regional government for an experimental application of “automated construction site” in contexts of post-earthquake reconstruction[11]. The research, which is carried out in partnership with a company specialized in the field of programming of collaborative robotic arms and automation systems[12], aims at defining an innovative scenario deriving from the use of “*advanced automation systems”* in the construction of temporary artifacts in post-earthquake emergency contexts. In particular, its main goal is to define an innovative and intelligent process for design, production, and on-site construction of “light” wood structures, with low environmental impact (thanks to an efficient construction process), customizable, of rapid execution, flexible and adaptive.

The achievement of a building process based on the “*advanced manufacturing systems*” mentioned by Industry 4.0[13] can refer both to evolved prefabrication chains (“offsite”) and to scenarios of digital on-site construction, where skilled labor could resort to the use of “cobot”[14] for routine or precision operations (positioning of curtains, coverings, drilling, etc.) or for the production of customized building components, with a consequent reduction in processing times and costs.

The possible integration between the two scenarios (transportable advanced prefabrication chains and lighter, smarter, and collaborative systems) would allow intervening efficiently and quickly in emergency contexts.

In particular, the research aims at:

- simulating a scenario of a project/production/construction chain focused on the use of different hardware and software instruments, automation systems, and the use of cobot and AGV (Automated Guided Vehicle). In particular, the generic cobot will be modelled along with the flow of the production process as a sort of “lean” cell 4.0, a solution that fully meets the OEE (Overall Equipment Effectiveness, the standard for measuring productivity) and MES criteria (Manufacturing Execution System) criteria, characterized by low operating cost because it is managed by a single operator, in which the handling is minimal while ensuring maximum quality, in which the flow is “lean” (i.e. without interruptions, bottlenecks, and extraordinary maintenance);
- making a demonstration prototype of a building artifact or part of it deriving from one or more scenarios among those previously defined that are already applicable concerning the technologies and devices available today. In this phase, through the “building-oriented” reprogramming of cobot, some phases of the building process will be simulated such as the precision assembly of wooden construction systems.

With the industrial partner support and SAAD lab#Protoype, we started to develop a constructive simulation of the entire digital construction process. In this early phase, we are simulating different operating scenarios to evaluate their actual feasibility. The simulation is carried out mainly using the Rhinoceros 6 software and the Grasshopper[15] visual programming plug-in with some specific components. These tools allow you to program industrial robots or CNC milling machine directly from the parametric modeling environment, whose generated files can be run directly on the machines, without requiring additional software. These operations are coordinated thanks to the application of sensors that send continuous physical feedbacks to the digital simulation model, allowing the coordination of machine movements, operations, and processes through machine learning algorithms.

The first step of the research involves the construction of a temporary pavilion to be built with an innovative one wooden construction system based on an innovative reinterpretation of “wood-wood” connection systems (without the contribution of metal joints or other material). This system is typical of Japanese construction tradition. Its reference material is “plywood” (un this case 18/20 mm thick) that can be “cut” trough subtractive techniques of digital fabrication. The system was previously developed as part of an experimental activity carried out between SAAD and Keyo University of Tokyo[16]. We choose wood for his versatility of use that not only covers the structural aspects of a building, but also the thermal aspects of the building envelope and the aesthetic of the external and internal finishes. The prevalent use of one material allows controlling almost the entire design-production-assembly cycle of a wooden building.

In this first phase of the research, we are planning the simulation of two scenarios based on the building site organization typology. The first one involves the installation of a transportable production unit (*flying factory*); the second one is a lighter and collaborative system that uses provisional works as a support. Despite both the systems can be imagined as systems of the same process, in this first evaluation phase they have been analyzed separately.

Scenario 1

a) development of a 4D BIM model of the artifact[17]; b) a robotic arm, equipped with a vacuum gripper end-effector, provides to the load/unload cycle of CNC milling machine storing the parts in a designated area; c) the components are assembled through the double-action the robotic arm and the rotating work table; d) an AGV machine transfers the components to the construction site; e) workers, even unskilled, can quickly assemble the various parts produced. This system allows to handle heavier parts (even 1220x2440 plywood panel) and in larger quantities[18].

10 In this case, we are dealing with a very ambitious and futuristic goal.

11 The project won two regional calls POR MARCHE ESF 2014-2020 Axis 1 for total funding of about 300,000 €

12 The company is Joytek s.r.l.s., headquartered in Ancona

13 Industry 4.0 model integrates automation and data exchange into production technologies and processes based on cyber-physical systems (CPS), Internet of Things (IoT), Industrial Internet of Things (IIOT), cloud computing, cognitive computing, and artificial intelligence.

14 Cobots, or collaborative robots, are robots intended to interact safely with humans in a shared space. Cobots stand in contrast to traditional industrial robots which are designed to work autonomously with safety assured by isolation from human contact.

15 Grasshopper is a graphical algorithm editor tightly integrated with McNeel Rhinoceros,3-D modeling tools. Grasshopper requires no knowledge of programming or scripting, there are several different applications for geometric, logic, and simulation operation, available at: https://www.grasshopper3d.com/

16 The research involved prof. Hiroto Kobayashi and his department at Keyo University of Tokyo. Cfr. Ruggiero, R. (2019), "Progetto esecutivo e processi di costruzione digitale. Una sperimantazione costruttiva tra Italia e Giappone", *Techne. Journal of Technology for Architecture and Environment,* vol. 18, pp. 300-308.

17 4D Building Information Modelling (BIM) refers to the fourth dimension of time. 4D is a 3D model that includes the construction schedule. It adds a time dimension to a 3D model, enabling teams to analyze the sequence of events on a time-line and visualize the time it takes to complete tasks within the construction process.

18 The basic equipment for this scenario is: one six axes industrial robot on a 3000 mm track; one standard 3-axis CNC milling machine with a minimum 2000 x 3000 mm working plane; a rotating working plane 1500x1500 mm; one tracked AGV (Automated Guided Vehicle) with an onboard sensing system; Lidar (Light Detection and Ranging) and proximity sensors; a design station.

Scenario 2

a) development of a 4D BIM model of the artifact; b) two cobots are installed on a special scaffold that allows them to move along the entire perimeter of the construction site, the third is installed on the AGV and can move more freely thanks to lidar and GPS sensors. This type of equipment could be used from skilled labor for routine or precision operations (positioning of curtains, coverings, drilling, etc.) reducing time and therefore the construction costs. This system is certainly lighter and more adaptable, but the most evident limit is the maximum load that the robot can handle[19].

Once both the scenarios have been developed, a small-scale prototyping phase will be launched. The lab#Protoype, equipment is about to be implemented with small-scale collaborative arms capable to faithfully simulate the prefigured process for both scenarios. At the end of this phase and following the experimental method adopted, we will proceed with an evaluation of the costs and benefits, of the feasibility and criticality of each option. Only after this evaluation, we will proceed with the 1:1 scale prototyping.

"Where are we now?"[20]

The work described so far represents experimentation of digital project/production/construction chains applied in contexts of "service" architecture, according to the well-known definition of Renzo Piano[21]. In terms of expected results, the research will have to demonstrate which are the most suitable operative supply-chains but also their real feasibility and applicability, the levels of complexity to which the artifacts and the underlying processes can be driven, the added value of similar processes compared to traditional procedures. The horizon is vast and the outcome is not obvious.

Safety, efficiency, rapidity, flexibility, sustainability, the exponential increase in technical control capacity are just some of the characteristics that can be associated with an entirely digital construction process that, also hybridized with traditional analog processes, could have "revolutionary" implications for the built environment, for the building sector and, as for the context adopted in the research presented here, for the communities.

The work carried out so far, being in a largely initial phase, does not allow conclusions to be drawn but allows us to focus on some questions concerning the implications between the project and digital construction processes. The digital and partially automated construction site represents the attempt to bring levels of efficiency and control over a phase, that of construction, traditionally characterized by uncertainty. This model allows not only to capitalize on the levels of efficiency and complexity of the digital design processes but also an attempt to "industrialize" the construction site, also making it "cybernetically" controllable (Ciribini 2019, p. 14). This does not necessarily require an upgrade of the current building systems and materials, but a modification of some processes and above all the acquisition of new know-how in the field of the project.

In a fully digitalized construction process, the design phase is confirmed to be the "black box" of the building, the place where everything must be foreseen also concerning the construction process of the final artifact. The prototyping phase is not limited to the architectural artifact but must be extended to the entire construction process. This latter must be prefigured in every detail through the construction of informative and predictive models regarding the whole building process, included the physical organization of the construction site. This is required to guarantee the efficiency of complex processes and the interoperability and interaction between machines, operators, and physical spaces. This new "responsibility" implies an expansion of the skills involved in the construction process but also the design process. That's why the architectural culture should ask itself if and how the Architect, as trained and conceived today, can respond (in terms of understanding and acceptance) to the possible spread of hyper-technological building processes, to the need to implement his know-how, to the necessity to interface with hyper-specialized professional figures coming from fields of knowledge sometimes very distant. Without adequate training, not only the Architect will not be able to fully grasp the opportunities that today discipline such as computer science, mathematics or cybernetics offer to the world of construction, but it risks becoming – according to a famous Manzonian definition – «a clay pot, forced to travel with many iron pots» [22].

In more general terms, this scenario requires an acknowledgment especially in the most advanced sectors of technological research in architecture so that such a powerful innovation process, such as the digital one, can be governed and not suffered; so that it is not the "specialism" linked to the digital universe that "dictate the line" in the development of a new, necessary balance between the man and his environment. In particular, the scientific disciplinary sector of Architectural Technology, born in Italy in the context of the first building industrialization, today seems to have a second chance – linked to the progressive acquisition of digital approaches and technologies – to codify, elaborate and spread a new technological culture of the project necessary to deal responsibly with the various emergencies facing the planet today.

References

Carpo, M. (2017), *The Second Digital Turn: Design Beyond Intelligence*, Mit Press, Cambridge Massachusetts, US.

Ciribini, A., (2019), *Il cantiere digitale,* Esculapio, Bologna, IT.

Corsini, L. and Moultrie, J. (2019), "Design for Social Sustainability: Using Digital Fabrication in the Humanitarian and Development Sector", *Sustainability*, vol. 11, p. 3562.

Claypool, M. (2019), "Discrete Automation", *Becoming Digital, e-flux Architecture magazine*, available at: https://www.e-flux.com/architecture/becoming-digital/248060/discrete-automation/ (accessed 2 February 2020).

Goodhouse, A. (2017), *When Is the Digital in Architecture?*, Sternberg Press, Berlin, DE.

Gramazio, F., Willmann, J. and Kohler, M. (2014), *The Robotic Touch: How Robots Change Architecture*, Park Books, Zurich, CH.

Retsin, G. (2019), *Robotic Building: Architecture in the Age of Automation*, Detail Editions, Munich, MC.

Retsin, G. (2016), "Discrete and Digital", *Proceedings of the 77th Annual Convention and Expo: 2016 TxA Emerging Design + Tech Conference*, Texas Society of Architects, San Antonio, TX.

Russo Ermolli, S. (2020), *The digital culture of Architecture*, Maggioli, Sant'Arcangelo di Romagna, IT.

Testa, P., Lunn, G. and Owen Moss, E. (2017), *Robot House: Instrumentation, Representation, Fabrication*, Thames & Hudson, London, UK.

19 The basic equipment for this scenario is: three collaborative robots (Universal Robots UR10, with a max payload of 10kg and 1300 mm of max reach); one tracked AGV (Automated Guided Vehicle) with an onboard sensing system; lidar and proximity sensors; one design station.

20 The paragraph title is a quote of the homonymous David Bowie song from the album "The next day" (2013).

21 This definition, repeated several times by the Genoese architect, is given for the first time by Piano in his speech in 1998 after winning the Pritzker Prize.

22 The reference is to Alessandro Manzoni's novel "I promessi sposi" and the famous and unflattering author's description of the character Don Abbondio.

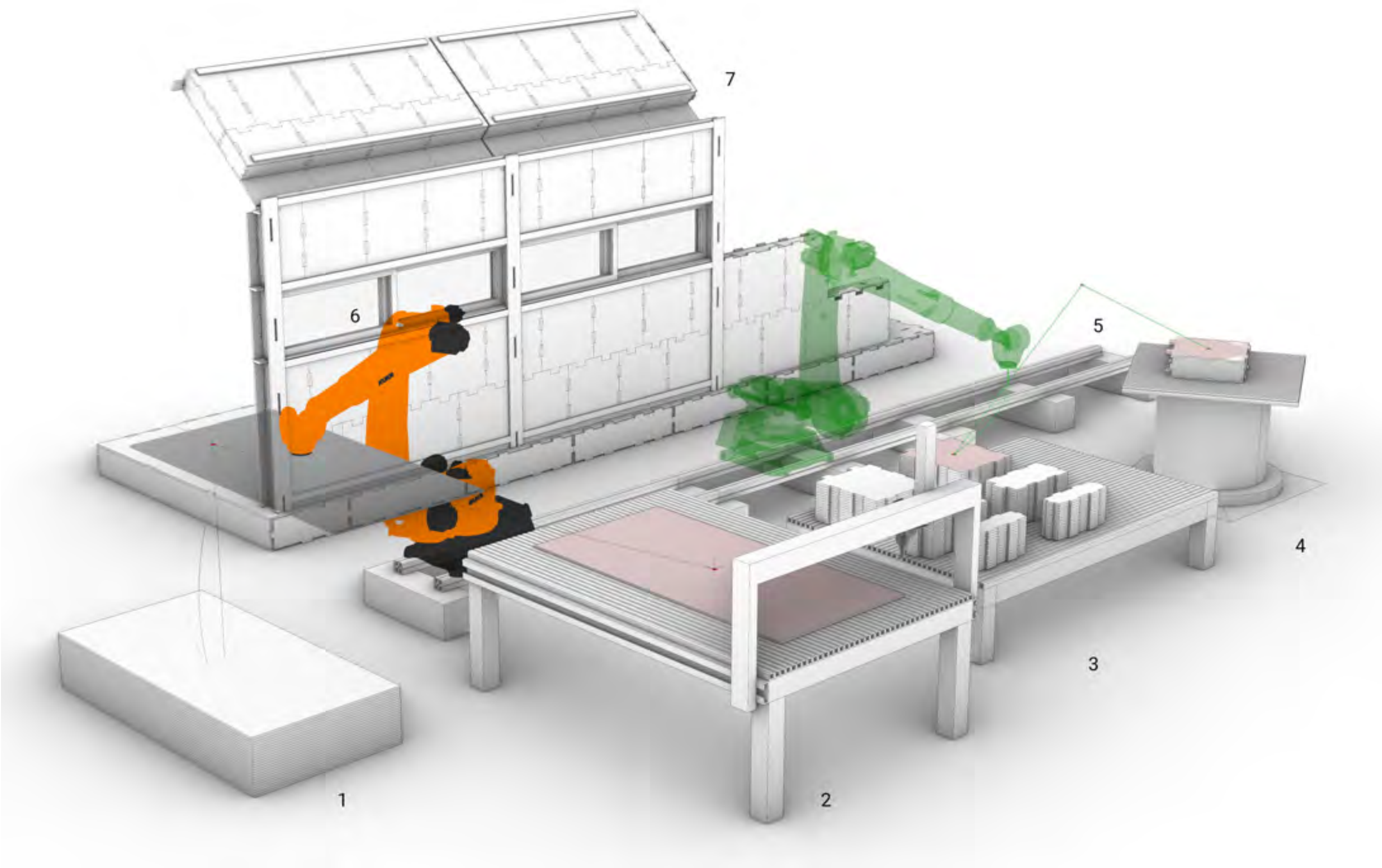

Fig. 2

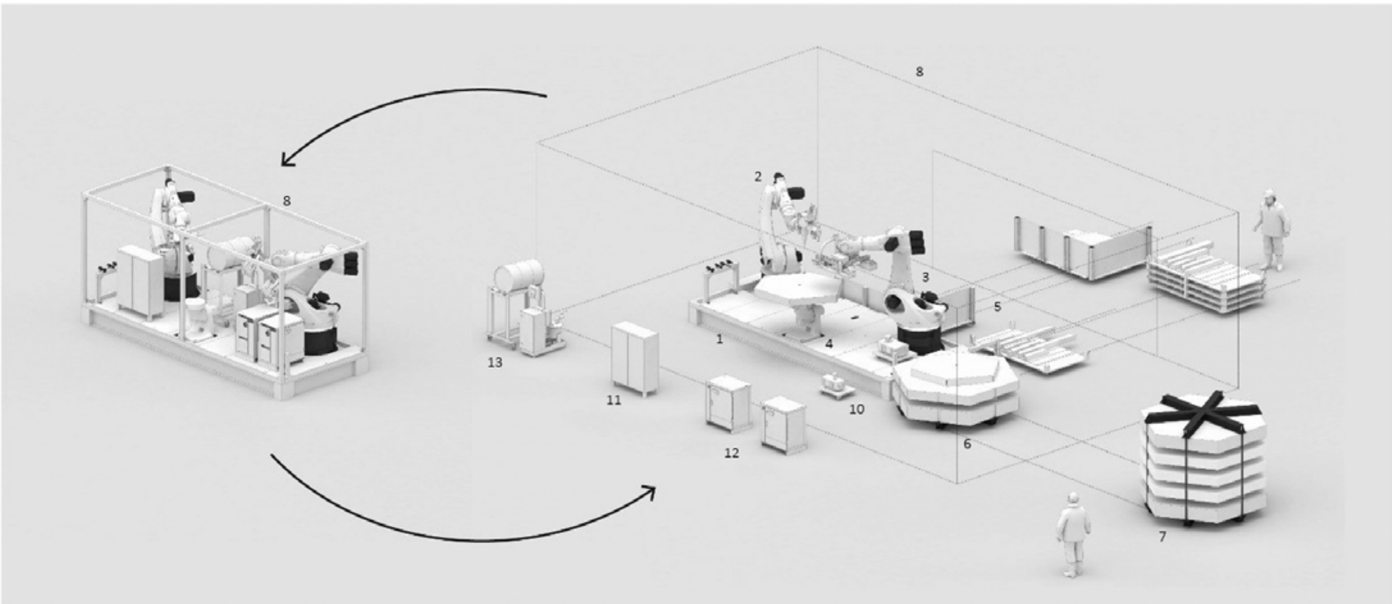

Fig. 3

Fig. 1 - En l'an 2000" or "Visions de l'an 2000", 1910, picture by French illustrator Villemard. Source: https://www.slideshare.net/timbuckteeth/learning-30-and-the-smart-extended-web/6-Work_2000httpwwwsabotagetimescomlifeavisionofthefuturefrom1910_Villemard

Fig. 2 - Simulation of a digital, automated construction process through robotic arms. [1]Material feeding station;[2]3 axis milling machine;[3] Worked parts;[4]Building component assembly station; [5]Robotic arm track;[6]6 axis robotic arm;[7]Building construction. Credits: Roberto Cognoli

Fig. 3 - Flexible and transportable robotic timber construction platform. Source: Hans Jakob Wagner et Al. Flexible and transportable robotic timber construction platform, in Automation in Construction, SET 2020