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Technological Imagination in the Green and Digital Transition

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Eugenio Arbizzani · Eliana Cangelli ·
Carola Clemente · Fabrizio Cumo ·
Francesca Giofrè · Anna Maria Giovenale ·
Massimo Palme · Spartaco Paris
Editors

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Editors
Eugenio Arbizzani
Dipartimento di Architettura e Progetto
Sapienza University of Rome
Rome, Italy

Eliana Cangelli
Dipartimento di Architettura e Progetto
Sapienza University of Rome
Rome, Italy

Carola Clemente
Dipartimento di Architettura e Progetto
Sapienza University of Rome
Rome, Italy

Fabrizio Cumo
Dipartimento Pianificazione, Design,
Tecnologia dell'Architettura
Sapienza University of Rome
Rome, Italy

Francesca Giofrè
Dipartimento di Architettura e Progetto
Sapienza University of Rome
Rome, Italy

Anna Maria Giovenale
Dipartimento di Architettura e Progetto
Sapienza University of Rome
Rome, Italy

Massimo Palme
Departamento de Arquitectura
Universidad Técnica Federico Santa Maria
Antofagasta, Chile

Spartaco Paris
Dipartimento di Ingegneria Strutturale e
Geotecnica
Sapienza University of Rome
Rome, Italy

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Foreword by Antonella Polimeni

Good afternoon to all participants, ladies and gentlemen, and welcome to Rome.

On behalf of the Community of Sapienza University of Rome, it is a real pleasure to welcome all of you to the first edition of the International Conference "Technological imagination in the green and digital transition". I am also pleased to give my best welcome to Dr Antonio Parenti, Head of the European Commission Representation in Italy, and to Prof. Mario Losasso, President of the Italian Society of Architectural Technology, as well as to all guests, students and colleagues.

The conference that we are about to open, organised by the Department of Architecture and Design and directed by Prof. Alessandra Capuano in cooperation with Sapienza Foundation, is to be a moment of methodological debate about built environments and the rise of contemporary urban challenges, so engaging for public and private institutions at national and international level.

The proposed key points of this conference—namely Innovation, Technology, Environment, Climate Changes and Health—are all interconnected priorities that cannot be further postponed, representing in the meantime strategic research and education activities for our University, perfectly aligned with the Italian National Recovery and Resilience plan, to be implemented in Italy as well as European member States, in order to overcome the present financial and social challenges.

I truly believe that Universities are, by definition, places of imagination, where planning the future is intended as an unavoidable "existential condition" as well as an essential moment of collective participation for an accomplished society.

Thank you for your attention, and I wish you a fruitful continuation of the conference.

Antonella Polimeni
Magnificent Rector
Sapienza University of Rome
Rome, Italy
antonella.polimeni@uniroma1.it

Foreword by Eugenio Gaudio

My warmest greetings to Dr. Antonio Parenti, Head of the European Commission Representation in Italy, to the President of the Italian Society of Architectural Technology Mario Losasso, to the Director Alessandra Capuano, and to Pietro Montani who will open with a Philosophical Lecture the Conference "Technological imagination in the green and digital transition".

A special greeting to Prof. Anna Maria Giovenale, my dear colleague and friend, who invited me to be here today. Thank you Anna Maria.

Let me also greet all other speakers as well other participant that will follow this Conference organized by the Department of Architecture and Design, together with the Fondazione Roma Sapienza.

From the very beginning, as President of the Fondazione Roma Sapienza, I supported the initiative of an international Conference on the theme of "Technological Imagination" having clear in mind that human imagination is inseparable from the "technical practice" with which it is entangled from the earliest origins of mankind, as Pietro Montani states in his book, *Technological destinies of the imagination.*

When the contents of the Conference were increasingly defined and focused around the areas of the green and digital transition, I realized that the very core of the Conference was becoming an attempt to respond to the contemporary challenges of the National Recovery and Resilience Plan, in their key role of revitalization for Research and University.

In this sense, the potential of technological culture is reaffirming its role of strategic tool for the conceiving, design and validation of future scenarios.

The sessions into which the Conference is structured, namely: Innovation, Technology, Environment, Climate Changes and Health, identified in order to outline the evolutionary scenarios of architectures and cities, allowing us to reflect at different levels on innovative models of building and management process, as well as design and products.

The goals of promoting digital transformation, supporting innovation in the production system, improving sustainability and ensuring an equitable environmental transition, find their clarification in the elaborations and experimentation presented through the contributions in the different sessions.

Modern technological innovation allowing multiple possibilities in all areas: nowadays digital technologies are enabling us to interact with people and things, all over the world.

There are astonishing, yet untapped potentials, suggesting that digitization, rather than a strict sense adaptive development, should be seen as an important evolutionary phenomenon and in the meantime a great opportunity.

Innovations connected with new technologies can provide to civil society a better quality of life, both at indoor and urban scale settings, addressing scientific development toward an effective culture of sustainability, reuse and security.

The employment of new technologies, a careful approach to the containment of land consumption as well as a careful consideration towards soil coverage modality and urban density, the recycling strategies and technological and typological redevelopment of degraded areas and buildings applying an energetic and eco-systemic approach, are the key elements for the conception of healthy and resilient urban habitats, able to adapt to the present global changes, as well as promoting prosperity, inclusiveness and social equity.

Last but not least, "health" issues, that need to be conceived at the very core of the potential determined by 'technological innovation and processes of ecological and digital transition.

The structure of the Conference is rooted on all these interrelated themes, and on that same basis also research needs to be reoriented.

I am confident that this first edition of the Technological imagination conference will contribute to pave the way of an innovative and interdisciplinary scientific approach to technology and policies for built environments, considered the real human challenge of the twenty-first century.

Thank you so much for your attention and enjoy the Conference.

Eugenio Gaudio
President
Fondazione Roma Sapienza
Rome, Italy
eugenio.gaudio@uniroma1.it

Foreword by Antonio Parenti

New European Bauhaus

Good morning,

Magnificent Rector of Sapienza University of Rome Professor Antonella Polimeni
President Fondazione Roma Sapienza Professor Eugenio Gaudio,
Director Department of Architecture and Design Professor Alessandra Capuano
and others.
Ladies and Gentlemen,

It is my pleasure to address you today and to open this International Conference "Technological Imagination in the digital and green transition" organized by Sapienza University of Rome.

Let me say that the title, the contents, and the proposals envisaged by the Conference match perfectly with the main pillars of the flagship initiative shaped by the President Ursula von der Leyen and launched in September 2021: the New European Bauhaus.

The New European Bauhaus is by nature transdisciplinary: it invites architects, designers, artists, scientists, engineers, artisans and citizens to share their expertise in preparing for the future.

With the New European Bauhaus, we want to make the European Green Deal tangible and "palpable".

We want to add a cultural dimension to the economic and technological transformation. This is essential to achieve our overarching goal: making Europe the first climate neutral continent by 2050. And thus reconciling our way of life with nature.

To get there, we need both: a real transformation of our economy and society, and a debate about how we can live in respect of nature and our planet.

The historical Bauhaus was founded in Weimar and Dessau. It turned into a worldwide movement. This did not happen by chance. Some ingredients of what made the historical Bauhaus a success can also be an inspiration for the New European Bauhaus.

Let me mention three.

The first ingredient: The historical Bauhaus was created in a time of **profound transformation**. People were facing the challenges of industrialisation. Gropius and the founders wanted to respond to the emerging needs of a new era. They aimed for solutions that were functional, affordable, but also beautiful. With this principle in mind, they shaped buildings, fabrics and furniture. They always aimed higher than just innovative design. The New European Bauhaus is also striving for this mix of aesthetics and affordability. But we want to add another element: sustainability. Because the New European Bauhaus wants to match sustainability with style.

Now, the second ingredient: **The historical Bauhaus boldly promoted new materials like steel and cement**. Today, we also need to look into new building materials. But this time, it is about sustainability. It is about materials that need less CO_2 in their production process. The New European Bauhaus wants to accelerate the transition of the built environment. It wants to scale up nature-based materials, to support circular design and architecture. Buildings are responsible for 40% of our energy consumption. And if we manage to change this, we have a chance to keep global warming below 1.5 degrees.

The third important element from the historical Bauhaus is **interdisciplinarity**. We want to convene people from different backgrounds and with different competences to share and grow their ideas and visions. We can create a better tomorrow, if culture and technology, innovation and design go hand in hand.

For our New European Bauhaus, the European Commission needs scientists, activists, artists, designers, architects and entrepreneurs. We want to include the ideas and perspectives of all ages and all backgrounds.

Today, at this conference we can contribute to this evolving New European Bauhaus network.

This project is a project of hope. It is a project of change and of economic transformation.

So I hope that this conference can contribute further to making the transformation happen and to connecting more and more people who want to make it happen.

Thank you very much and have a great conference.

Antonio Parenti
Head of the European Commission
Representation
Rome, Italy
antonio.parenti@ec.europa.eu

Foreword by Mario Losasso

Presentation of CONF.ITECH 2022

The green and digital transition represent in the contemporary research field the two new challenges for the evolution of technology within the themes of sociotechnical innovation. Consequently, technology and innovation in contemporary world must adapt to this general objective. Innovation in its hard and digital components once again becomes a central factor in the experimental propulsion that the project is assuming within a processuality and technologies that enable its conception and implementation.

Today, research is increasingly characterised by the need to focus on specialisms that lead to and contribute to the advancement of knowledge and the predictive value of what is studied in the disciplinary fields. However, with respect to the evolving complexity of phenomena, research requires continuous disciplinary interactions to be developed because we understand that one disciplinary field cannot alone address the most important challenges of contemporary society.

New forms of coexistence must be organized in a vision of interdependence and connection, while the green transition requires the definition of the limits of design action and the characteristics of the transformation processes. The new perspective of co-evolution will have to express a design attitude that allows to repair and, where necessary, rebuild the lost links between man, technology and nature.

The green and digital transition represent the two new challenges for the evolution of technology within the themes of social innovation. The Italian society of architectural technology SITdA has been working for a long time on the topics of the relationship between technology and urban and building development within a process-oriented and eco-systemic approach. In the field of technological design of architecture, the scientific society of the technology of architecture has activated research and training sensitivities on the themes of design experimentation framed within process and ecosystem dynamics, aimed at optimising the efficiency of products and processes by reducing inefficiencies and waste.

The SITdA supports research and spin-off outcome on territories through the activities of its scientific clusters. The Scientific Society SITdA has granted its patronage to the CONF.ITECH 2022 Conference, sharing its importance and topicality in view of the new challenges identified in the urban construction and environmental fields by the Next Generation EU Programme and the implementation programmes in the various nations of the European Union.

The topics that will be addressed during the three-day conference are fascinating and challenging, linking innovation, technology, environment, climate change and health.

These topics are strongly interrelated themes in which we are realising that it is impossible to deal with them separately, arriving in the most recent reflections at considering a single health for human beings and for the entire environment which is their living environment.

I would like to remind that the topic of digital culture, nature and technology was the central topic of the SITdA Naples 2020 Conference held last July with a delay due to pandemic difficulties, while the 2022 Conference of the Scientific Society is focused on the topic of the centrality of processes. As we can see, the work carried out in the Departments of Architecture and by the Scientific Societies in the area of architecture is an activity that has picked up significantly, foreshadowing new approaches, new fields of enquiry and new paradigms necessary for the new complexities that constitute the reference scenario of the future.

The experience of this Conference can provide a significant contribution to the sustainable and environmental evolution of the design area in its trans-scalar, multidisciplinary and challenging dimension, overcoming technocratic responses to a demand that requires the integration of the humanistic and technical-scientific dimensions.

Mario Losasso
President
Italian Society of Architectural
Technology—SITdA
Rome, Italy
mariorosario.losasso@unina.it

Foreword by Orazio Carpenzano

Welcoming Address from the Dean

On behalf of the Faculty, I wish to thank the organisers for asking me to give this opening address, while congratulating them on their efforts to bring together, in an international encounter, various perspectives on topics of such decisive importance for the future of our respective territories, as well as their people, living organisms and architecture.

My thanks go to Anna Maria Giovenale, Fabrizio Cumo, Eugenio Arbizzani, Carola Clemente, Eliana Cangelli and Francesca Giofrè, who will be giving talks on technological innovation, the environment, climate change and public health.

Thinking of energy in terms of how it relates to architecture during the green and digital transition means cultivating a *technological imagination*, a topic which leads to the broader question of the man–nature relationship and the possibility that architecture, by applying innovative ideas and concepts while promoting a growing social and emotional intelligence of its own, can contribute to inventing of new types of habitat for mankind on the planet earth, under a new pact for survival that allows all elements, both artificial and natural, to coexist in a sustainable balance which can serve as a preventive measure against the intrinsic destructive force of the Cosmos, an especially pressing problem where mankind has neglected certain methods for dissipating the energy of calamitous events made available by both ancient wisdom and scientific advances.

The 2021 Architecture Biennial, entitled "How Will We Live Together?", implicitly drew the attention of visitors to the need for a new approach to the man–nature relationship, following a thorough review of its historical and ethical premises. Hashim Sarkis, the curator of the exposition's seventeenth edition, passed on the following message: "In a scenario of exasperated political divisions and growing economic inequality, we call upon architects to imagine spaces in which we can all live in fruitful fellowship".

The man–nature relationship has always been a distinctive feature of humanistic and artistic thought on things technical, expressed in the construction of the *civitas*, the physical and political synthesis of civilisation. Medieval mysticism viewed nature as a foreboding wilderness, while the Renaissance redeemed the sense of *technè*, and the Romantic Period, with its high-strung, emotive outlook, led to the elaboration of the concept of the sublime.

Controlling and putting to use the energy generated by nature through sources of heat and movement (wind, sun, water), first through manual effort and then using the tools and machines produced by human ingenuity, was also a topic and challenge that led architecture to express, during the Modern Movement, boundless enthusiasm for the theories of Taylorism, which Corbusier summed up by interpreting human dwellings as machines of habitation.

But it is from the time of Vitruvius that architecture, engaged more or less explicitly with the triad of *utilitas-firmitas-venustas*, has addressed the problem of dissipating heat (or thermal inertia), as well as kinetic and elastic energy (in the case of earthquakes), at various latitudes of the globe, drawing on the available resources and raw materials. Historic Italian buildings, for example, built with walls roughly a metre thick and a structural layout measuring 4×4 or 5×5 m, have offered excellent thermo-hygrometric performance (in terms of energy consumption), as well as structural dependability (against seismic risk). In both cases the objective is to "mitigate", a term used by many modern-day scholars, the dissipation of different types of energy.

The history of architecture is filled with archetypes that need to be updated and reinvented. Think of the ingenuity it took to build Venice atop a giant underwater forest, or the aesthetic quality of the Tu'rat walls constructed by Southern Italian peasants, the windmills of Northern Europe and countless other magnificent examples of *swarm intelligence* collected by Bernard Rudofsky in his well-known book *Architecture without Architects: a short introduction to non-pedigreed architecture*, published by Doubleday & Company Inc., Garden City, (in 1964), following an exhibition at New York's Museum of Modern Art. Though, in truth, Roberto Pane and Gino Capponi had already touched on the topic in articles on the architecture of Ischia published in "Architettura e Arti decorative" in 1927, as did Giuseppe Pagano at the Milan Triennial "Rural Italian Architecture", published in the Notebooks of the Milan Triennial by Hoepli in 1936.

Looking beyond the confines of architecture, a recent reconsideration of the topic of Cinema and Energy can provide potentially useful points of affinity with architecture, especially in the collection of essays found in issues 7 and 8 of the periodical Imago, under the title *Cinema & Energy. Interdisciplinary Outlooks Combining Science, Aesthetics and Technology*, edited by Marco Maria Gazzano and Enrico Carocci (and published by Bulzoni in 2013). In an essay entitled *Dissipation and Aesthetic Experience*, the physicist Giuseppe Vitiello, in commenting on the film Transeurope Hotel by Luigi Cinque, writes: "The brain [which leads me to think of *swarm intelligence*] is described as an open system engaged in continuous exchanges with its surrounding environment. In both models and films, antinomies such as information/knowledge, feeling/knowing, blend with each other in the aesthetic experience, the favourable connection between 'me and the object' that characterises our existential dimension."

Dissipation, therefore, should be seen as part of the evolution of our ecosystem, of our contemporary habitat. It gauges the possibilities for losing and exchanging, through a rekindling of collective emotional intelligence and technical and intellectual micro-revolutions. It is a risk that we must continue to face, as otherwise architecture will die, depriving man of an indispensable tool for managing the complexity of the physical habitat through creativity, in order to transfigure energy in a way that, at times, can prove so unreal, and yet so effective and indispensable, that it leads to the construction of new values and sublime beauty.

Orazio Carpenzano
Dean
Faculty of Architecture
Sapienza University of Rome
Rome, Italy
orazio.carpenzano@uniroma1.it

Acknowledgments

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The Magnificent Rector of the Sapienza University of Rome, Prof. Antonella Polimeni, and to the President of Foundation of the Sapienza University, Professor Eugenio Gaudio;

Dr. Antonio Parenti, Head of the European Commission's Representation in Italy, to Prof. Mario Losasso, President of the Italian Society of Architectural Technology, and to Prof. Orazio Carpenzano, Dean of Faculty of Architecture of the Sapienza University of Roma;

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The Scientific Committee, all the reviewers and the Organizing Committee.

Contents

Contributors

Sofia Agostinelli Sapienza University of Rome, Rome, Italy

Hosam Al-Siah Sapienza University of Rome, Rome, Italy

Davide Allegri Polytechnic University of Milan, Milan, Italy

Maria Beatrice Andreucci Sapienza University of Rome, Rome, Italy

Eugenio Arbizzani Sapienza University of Rome, Rome, Italy

Marianna Arcieri Polytechnic University of Milan, Milan, Italy

Maria Vittoria Arnetoli University of Florence, Florence, Italy

Stefano Arruzzoli Polytechnic University of Milan, Milan, Italy

Davide Astiaso Garcia Sapienza University of Rome, Rome, Italy

Nazly Atta Polytechnic University of Milan, Milan, Italy

Gigliola Ausiello University of Naples Federico II, Naples, Italy

Maria Azzalin Mediterranean University of Reggio Calabria, Reggio Calabria, Italy

Meri Batakoja Ss. Cyril and Methodius University, Skopje, North Macedonia

Silvia Battaglia Polytechnic University of Milan, Milan, Italy

Oscar Eugenio Bellini Polytechnic University of Milan, Milan, Italy

Carla Álvarez Benito European University Foundation (EUF), Brussels, Belgium

Roberto Bianchi Mercatorum University, Rome, Italy

Leonardo Binni Polytechnic University of Marche, Ancona, Italy

Martina Bocci Polytechnic University of Turin, Turin, Italy

Andrea Bocco Polytechnic University of Turin, Turin, Italy

Arthur Bohn Polytechnic University of Turin, Turin, Italy

Roberto Bologna University of Florence, Florence, Italy

Steven Boon Housing Anywhere, Rotterdam, Netherlands

Martina Bosone Research Institute on Innovation and Services for Development of the Italian National Research Council (CNR-IRISS), Naples, Italy

Andrea Brambilla Polytechnic University of Milan, Milan, Italy

Timothy Daniel Brownlee University of Camerino, Camerino, Italy

Erica Brusamolin Polytechnic University of Milan, Milan, Italy

Maddalena Buffoli Polytechnic University of Milan, Milan, Italy

Francesca Caffari ENEA, Rome, Italy

Nicolandrea Calabrese ENEA, Rome, Italy

Gisella Calcagno University of Florence, Florence, Italy

Guido Callegari Polytechnic University of Turin, Turin, Italy

Maria Canepa University of Genoa, Genoa, Italy

Eliana Cangelli Sapienza University of Rome, Rome, Italy

Monica Cannaviello University of Campania "L. Vanvitelli", Aversa, Italy

Stefano Capolongo Polytechnic University of Milan, Milan, Italy

Cheren Cappello University of Sassari, Sassari, Italy

Barbara Cardone University of Roma Tre, Rome, Italy

Tecla Caroli Polytechnic University of Milan, Milan, Italy

Giovanni Castaldo Polytechnic University of Milan, Milan, Italy

Giulia Centi ENEA, Rome, Italy

Francesca Ciampa University of Naples Federico II, Naples, Italy

Andrea Ciaramella Polytechnic University of Milan, Milan, Italy

Adriana Ciardiello Sapienza University of Rome, Rome, Italy

Federico Cinquepalmi Sapienza University of Rome, Rome, Italy

Carola Clemente Sapienza University of Rome, Rome, Italy

Marta Cognigni Polytechnic University of Milan, Milan, Italy

Raffaella Colombo Istituto Comprensivo Rinnovata Pizzigoni, Milan, Italy

Alessandra Corneli Polytechnic University of Marche, Ancona, Italy

Nataša Ćuković-Ignjatović University of Belgrade, Belgrade, Serbia

Fabrizio Cumo Sapienza University of Rome, Rome, Italy

Laura Daglio Polytechnic University of Milan, Milan, Italy

Anna Dalla Valle Polytechnic University of Milan, Milan, Italy

Francesca Daprà Polytechnic University of Milan, Milan, Italy

Roberto D'Autilia University of Roma Tre, Rome, Italy

Alberto De Capua Mediterranea University of Reggio Calabria, Reggio Calabria, Italy

Jacopo Dell'Olmo Sapienza University of Rome, Rome, Italy

Valentina Dessì Polytechnic University of Milan, Milan, Italy

Raffaela De Martino University of Campania L. Vanvitelli, Aversa, Italy

Stefania De Medici University of Catania, Catania, Italy

Maria Giovanna Di Bitonto Polytechnic University of Milan, Milan, Italy

Marco Di Ludovico University of Naples Federico II, Naples, Italy

Mohamed Eledeisy Sapienza University of Rome, Rome, Italy

Lidia Errante Mediterranea University of Reggio Calabria, Reggio Calabria, Italy

Daniele Fanzini Polytechnic University of Milan, Milan, Italy

Emilio Faroldi Polytechnic University of Milan, Milan, Italy

Marco Ferrero Sapienza University of Rome, Rome, Italy

Maria Fianchini Polytechnic University of Milan, Milan, Italy

Irene Fiesoli University of Florence, Florence, Italy

Maria F. Figueira International Union of Property Owners (UIPI), Brussels, Belgium

Antonio Fioravanti Sapienza University of Rome, Rome, Italy

Rossella Franchino University of Campania L. Vanvitelli, Aversa, Italy

Caterina Frettoloso University of Campania L. Vanvitelli, Aversa, Italy

Valentina Frighi University of Ferrara, Ferrara, Italy

Matteo Gambaro Polytechnic University of Milan, Milan, Italy

Pablo Garrido Torres Universitat Politécnica de Catalunya, Barcelona, Spain

Vincenzo Gattulli Sapienza University of Rome, Rome, Italy

Marko Gavrilović University of Belgrade, Belgrade, Serbia

Emanuela Giancola UiE3-CIEMAT, Madrid, Spain

Francesca Giglio Mediterranea University of Reggio Calabria, Reggio Calabria, Italy

Elisabetta Ginelli Polytechnic University of Milan, Milan, Italy

Francesca Giofrè Sapienza University of Rome, Rome, Italy

Serena Giorgi Polytechnic University of Milan, Milan, Italy

Matteo Giovanardi Polytechnic University of Turin, Turin, Italy

Anna Maria Giovenale Sapienza University of Rome, Rome, Italy

Salvatore Giuffrida University of Catania, Catania, Italy

Evelyn Grillo Mediterranea University of Reggio Calabria, Reggio Calabria, Italy

Daniele Groppi Sapienza University of Rome, Rome, Italy

Maria Teresa Gullace Polytechnic University of Milan, Milan, Italy

Guillaume Habert ETH Zürich, Zürich, Switzerland

Sam Haghdady Islamic Azad University, Mashhad, Iran

Zakia Hammouni CRIR (Centre for Interdisciplinary Rehabilitation Research of Greater Montréal), Université de Montréal, Montréal, Canada;
Université McGill, Montréal, Canada;
Université du Québec à Trois-Rivière, Trois-Rivière, Canada

Giulio Hasanaj University of Florence, Florence, Italy

Mohammad Hassani Islamic Azad University, Kerman Branch, Iran

Tihana Hrastar University of Zagreb, Zagreb, Croatia

Azim Heydari Sapienza University of Rome, Rome, Italy;
Graduate University of Advanced Technology, Kerman, Iran

Dušan Ignjatović University of Belgrade – Faculty of Architecture, Belgrade, Serbia

Nataša Ćuković Ignjatović University of Belgrade – Faculty of Architecture, Belgrade, Serbia

Alexander Achille Johnson Vagelos College of Physicians and Surgeons, Columbia University, New York, USA

Fuat Emre Kaya University of Sassari, Sassari, Italy

Farshid Keynia Graduate University of Advanced Technology, Kerman, Iran

Alara Kutlu Polytechnic University of Milan, Milan, Italy

Adel Lakzadeh Islamic Azad University, Kerman Branch, Iran

Mario Lamagna Sapienza University of Rome, Rome, Italy

Massimo Lauria Mediterranean University of Reggio Calabria, Reggio Calabria, Italy

Francesco Leali UNIMORE, Modena, Italy

Adriano Magliocco University of Genoa, Genoa, Italy

Camilla Maitan Polytechnic University of Milan, Milan, Italy

Mariateresa Mandaglio Mediterranea University of Reggio Calabria, Reggio Calabria, Italy

Silvia Mangili Polytechnic University of Milan, Milan, Italy

Paola Marrone University of Roma Tre, Rome, Italy

Riccardo Marzo NCLAB, Rome, Italy

Luciana Mastrolonardo University G. d'Annunzio, Pescara, Italy

Redina Mazelli Polytechnic University of Turin, Turin, Italy

Eleonora Merolla Polytechnic University of Turin, Turin, Italy

Marco Migliore Polytechnic University of Milan, Milan, Italy

Martino Milardi Mediterranea University of Reggio Calabria, Reggio Calabria, Italy

Nikola Miletić University of Belgrade – Faculty of Architecture, Belgrade, Serbia

Jelena Milošević University of Belgrade, Belgrade, Serbia

Pietro Montani Honorary Professor of Aesthetics, Sapienza University of Rome, Rome, Italy

Ilaria Montella University of Roma Tre, Rome, Italy

Carol Monticelli Polytechnic University of Milan, Milan, Italy

Lucia Montoni University of Florence, Florence, Italy

Michele Morganti Sapienza University of Rome, Rome, Italy

Marco Morini ENEA, Rome, Italy

Noemi Morrone Istituto Comprensivo Rinnovata Pizzigoni, Milan, Italy

Erica Isa Mosca Polytechnic University of Milan, Milan, Italy

Elena Mussinelli Polytechnic University of Milan, Milan, Italy

Francesco Muzi Sapienza University of Rome, Rome, Italy

Francesco Nardi NCLAB, Rome, Italy

Giuliana Nardi University of Roma Tre, Rome, Italy

Ludovica Nasca University of Catania, Catania, Italy

Benedetto Nastasi Sapienza University of Rome, Rome, Italy

Berardo Naticchia Polytechnic University of Marche, Ancona, Italy

Maicol Negrello Polytechnic University of Turin, Turin, Italy

Aleksandra Nenadović University of Belgrade, Belgrade, Serbia

Antonio Novellino ETT SpA, Genoa, Italy

Filippo Orsini Polytechnic University of Milan, Milan, Italy

Giuseppe Orsini Sapienza University of Rome, Rome, Italy

Maria Giovanna Pacifico University of Naples Federico II, Naples, Italy

Giancarlo Paganin Polytechnic University of Milan, Milan, Italy

Massimo Palme Universidad Técnica Federico Santa María, Valparaíso, Chile

Elisabetta Palumbo University of Bergamo, Bergamo, Italy

Giulio Paparella Sapienza University of Rome, Rome, Italy

Spartaco Paris Sapienza University of Rome, Rome, Italy

Francesco Pasquale UNIMORE, Modena, Italy

Lorenzo Mario Pastore Sapienza University of Rome, Rome, Italy

Jelena Pavlović University of Belgrade, Belgrade, Serbia

Maura Percoco Sapienza University of Rome, Rome, Italy

Giacomo Pierucci University of Florence, Florence, Italy

Claudio Piferi University of Florence, Florence, Italy

Maria Rita Pinto University of Naples Federico II, Naples, Italy

Anna Pirani Centre for Theoretical Physics, Trieste, Italy

Giuseppe Piras Sapienza University of Rome, Rome, Italy

Nicola Pisani Colouree S.r.l., Genoa, Italy

Matteo Poli Polytechnic University of Milan, Milan, Italy

Riccardo Pollo Polytechnic University of Turin, Turin, Italy

Alice Paola Pomè Polytechnic University of Milan, Milan, Italy

Gianluca Pozzi Polytechnic University of Milan, Milan, Italy

Giulia Procaccini Polytechnic University of Milan, Milan, Italy

Donatella Radogna University “G. D’Annunzio” of Chieti-Pescara, Pescara, Italy

Alberto Raimondi University of Roma Tre, Rome, Italy

Andrea Rebecchi Polytechnic University of Milan, Milan, Italy

Rosaria Revellini IUAV University of Venice, Venice, Italy

Diletta Ricci Sapienza University of Rome, Rome, Italy;
Delft University of Technology, Delft, Netherlands

Guglielmo Ricciardi Polytechnic University of Turin, Turin, Italy

Alessandro Rogora Polytechnic University of Milan, Milan, Italy

Manuela Romano Polytechnic University of Milan, Milan, Italy

Rosa Romano University of Florence, Florence, Italy

Sabri Ben Rommane Erasmus Student Network AISBL (ESN), Brussels, Belgium

Laura Rosini University of Roma Tre, Rome, Italy

Massimo Rossetti IUAV University of Venice, Venice, Italy

Federica Rosso Sapienza University of Rome, Rome, Italy

Irina Rotaru Saint Germain-en-Laye, France

Helena Coch Roura Universitat Politécnica de Catalunya, Barcelona, Spain

Ana Šabanović University of Belgrade, Belgrade, Serbia

Samaneh Safaei Graduate University of Advanced Technology, Kerman, Iran

Ferdinando Salata Sapienza University of Rome, Rome, Italy

Sara Sansotta Mediterranea University of Reggio Calabria, Reggio Calabria, Italy

Antonello Monsù Scolaro University of Sassari, Sassari, Italy

Paolo Simeone Polytechnic University of Turin, Turin, Italy

Francesco Sommese University of Naples Federico II, Naples, Italy

Tianzhi Sun Polytechnic University of Milan, Milan, Italy

Chiara Tagliaro Polytechnic University of Milan, Milan, Italy

Maurizio Talamo Tor Vergata University of Rome, Rome, Italy

Andrea Tartaglia Polytechnic University of Milan, Milan, Italy

Chiara Tonelli University of Roma Tre, Rome, Italy

Agata Tonetti IUAV University of Venice, Venice, Italy

Matteo Trane Polytechnic University of Turin, Turin, Italy

Antonella Trombadore University of Florence, Florence, Italy

Maria Rosa Trovato University of Catania, Catania, Italy

Massimo Vaccarini Polytechnic University of Marche, Ancona, Italy

Carlo Vannini Sapienza University of Rome, Rome, Italy

Konstantinos Venis Polytechnic University of Milan, Milan, Italy

Maria Pilar Vettori Polytechnic University of Milan, Milan, Italy

Giulia Vignati Polytechnic University of Milan, Milan, Italy

Serena Viola University of Naples Federico II, Naples, Italy

Antonella Violano University of Campania "L. Vanvitelli", Aversa, Italy

Walter Wittich CRIR (Centre for Interdisciplinary Rehabilitation Research of Greater Montréal), Université de Montréal, Montréal, Canada

Alessandra Zanelli Polytechnic University of Milan, Milan, Italy

Edwin Zea Escamilla ETH Zürich, Zürich, Switzerland

Bojana Zeković University of Belgrade – Faculty of Architecture, Belgrade, Serbia

Alberto Zinno Stress Scarl, Naples, Italy

Nour Zreika Polytechnic University of Milan, Milan, Italy

Franca Zuccoli University of Milano-Bicocca, Milan, Italy

Milijana Živković University of Belgrade, Belgrade, Serbia

Maša Žujović University of Belgrade, Belgrade, Serbia

Chapter 30
Reworking Studio Design Education Driven by 3D Printing Technologies

Jelena Milošević, Aleksandra Nenadović, Maša Žujović, Marko Gavrilović, and Milijana Živković

Abstract The advances and proliferation of digital technologies impact architectural practice asking for a revision of not only design production but also the education of future professionals. Using a case study from the University of Belgrade—Faculty of Architecture, this paper examines the efficient application of 3D printing as a design tool and opportunities for the implementation of this technology in architectural education. The research goal was to establish an educational framework for the studio course that was appropriate to local settings, starting with a review of educational approaches and usage of 3D printing in architectural design. Starting with the premise that there is a bidirectional relationship between design and its tool, educational framework for architectural design studio was proposed, tested in real educational settings, and evaluated. The results indicate that the use of 3D printing in studio course proved to be an effective tool for design exploration and presentation that supports (1) linking the logical way of thinking that requires parametric modeling with concept-based thinking; (2) change in mindset that occurs in the design process when students have a physical model in front of them to assess; and (3) improvement of deep understanding of spatial cognition among students as well as their competencies related to the use of the specific technology in the design process. The paper demonstrates how 3D printing technology improved educational methods, impacted students' experiences in the design process, and elevated design exploration to previously unattainable levels of materiality, detail, complexity, accuracy, and aesthetics.

J. Milošević (✉) · A. Nenadović · M. Žujović · M. Gavrilović · M. Živković
University of Belgrade, Belgrade, Serbia
e-mail: jelena@arh.bg.ac.rs

A. Nenadović
e-mail: aleksandra@arh.bg.ac.rs

M. Gavrilović
e-mail: gavrilovic@arh.bg.ac.rs

M. Živković
e-mail: milijana.zivkovic@arh.bg.ac.rs

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30.1 Introduction

As a core methodology in architectural education (Salama 2017), studio design must constantly evolve to facilitate students to build competencies relevant to future practice. Studio allows students to learn to design and be designers (Dutton 1987) by studying curriculum topics and theoretical concepts in a practical context (Schon 1987) and simulating professional scenarios in an academic setting (Laurillard 2012). Although the basic structure of architectural design studio appears to be quite resilient to diverse cultural, social, and production changes over time (Schon 1987; Nicol and Pilling 2000), the impact of digital technologies asks for a rethinking of both design process and education in terms of new operation tools. Various publications discuss impact of digital technologies on architecture (Kolarevic 2005; Leach et al. 2005; Gramazio and Kohler 2008; Menges and Ahlquist 2011; Carpo 2012, 2017; Willmann et al. 2019), as well as technology-assisted learning (Anderson 2016) and its implementation in architectural studio pedagogy (Guler 2015; Masdeu and Fuses 2017; Ioannou 2018; Milošević 2021; Jones et al. 2021).

This paper explores the application of 3D printing (3DP) technology in architectural design studio education. The following research question arises from the premise that design and its tools have a bidirectional relationship: How can we employ 3DP tools in studio design to create a learning environment that allows future architects to better prepare for technological and professional challenges? In response to the research question, the objectives of the study are to (1) analyze diverse approaches of the implementation of 3DP technologies presented in the literature; (2) describe a studio design framework that includes the use of 3DP technologies and its implementation; and (3) summarize the challenges and opportunities of the proposed approach.

To address the research questions, an integrated literature review method was used to analyze, critically assess, and synthesize representative literature on the topic and generate new perspectives and framework. Furthermore, the new framework developed based on the literature review was empirically tested in the real educational setting and evaluated qualitatively (Groat and Wang 2013).

30.2 Literature Review

The literature on applying 3DP technology in architectural design education was searched using the following keywords: design studio, 3D printing, rapid prototyping, architectural education, in two main databases, Web of Science and Google Scholar. A total of fifteen relevant references were included in the content analysis. The themes identified in papers were concise into three main categories of research explained in the following sub-paragraphs.

30.2.1 Effects of Implementing of 3DP Technology in Design

The effects of the introduction of 3DP technologies into the architectural design curriculum have been reviewed by several authors (Loy 2014; Kim et al. 2021; Chiu et al. 2015; Lugo Nevarez et al. 2016; Kwon et al. 2017; Greenhalgh 2016; Boumaraf and İnceoğlu 2020; Budig et al. 2014; Paio et al. 2012; Gu et al. 2010; Bøhn 1997; Kristiánová et al. 2018). For example, some studies indicated that rapid prototyping (RP) technology piqued the interest of students who were previously accustomed to the manual creation of physical models and 3D modeling for design through physical models (Loy 2014; Kim et al. 2021). Furthermore, students confirmed in several studies that the use of 3DP helped them develop innovative thinking, enhanced learning motivation (Chiu et al. 2015; Lugo Nevarez et al. 2016; Kwon et al. 2017; Greenhalgh 2016), and considerably improved their design capabilities (Boumaraf and İnceoğlu 2020; Budig et al. 2014).

Many students' designs were more complicated as they adopted 3DP technology for prototyping. RP enabled them to materialize physical models with far more conceptual and geometric complexity than traditional methods (Greenhalgh 2016; Budig et al. 2014). Findings show that the use of RP, in some cases, significantly improved students' spatial cognition since they were able to perceive their design proposals in the physical environment (Paio et al. 2012). Also, making complex models on smaller scales made it easier for students to focus on the overall design concept than the details (Budig et al. 2014).

However, several authors noted that students had not used the full potential of a given technology (Gu et al. 2010). Previous was, in many cases, due to the time constraint and tight schedules that studio design projects often imply. Some studies indicate that students still tend to use 3DP technology for the final presentation of projects instead of for research (Bøhn 1997; Kristiánová et al. 2018).

30.2.2 Implementing 3DP Technology in the Studio Course

Additive manufacturing is thought to be one of the rising technologies in education that will help students learn and foster creative thinking (Chiu et al. 2015). The students' perceptions of 3DP technology in the architectural studio could be linked to their previous experience with model-making in project creation. Integrating 3DP made students accustomed to digital modeling more interested in constructing physical models using 3DP rather than traditional building methods in a workshop (Loy 2014).

Students with less CAM experience had more difficulty learning about the 3DP process and RP technology (Sampaio et al. 2013), and they should be given lectures to improve their skills (Kwon et al. 2017). Depending on their academic level, students are likely to be exposed to different teaching methods. Students with less expertise should be guided through the concepts and objectives initially, but if no methods are offered, they will be challenged to solve problems and be more proactive. More open teaching methodologies and experiments can be employed with more advanced students. They could be primarily introduced to concepts and a brief description of the problem and have greater flexibility through the project development phase (Celani 2012).

Also, Fernandes (Fernandes and Simoes 2016) explained how students in higher education with various learning styles react to using 3DP as a collaborative learning resource in their classroom. The study found that most students prefer to test their theoretical knowledge using 3DP models. It gives them more freedom and technical experience than simply having a theoretical approach to the subject (Fernandes and Simoes 2016).

30.2.3 Methods of Implementing 3DP Technology in the Curriculum

Currently, the design process is highly dependent on using information and digital technologies (Paio et al. 2012). It is generally agreed that the implementation of RP in curricula enforced innovative thinking and improved the sense of materiality and space. Additionally, using 3DP continuously fosters practical aspects of design studio methodology while model-making represents a learning-by-doing mode (Kristiánová et al. 2018).

A seven-step pedagogical model was introduced at the City University of Hong Kong to all freshmen from various fields of study enrolled in the same class. It is based on classic instructional design theory and the Conditions of Learning by Sampaio et al. (2013). The aim was to bring in 3DP technology in the educational process and analyze its practical problems. It is considered that 3DP is one of the emerging technologies in education that would support student learning and encourage innovative thinking (Chiu et al. 2015).

Another example is from the Singapore ETH Centre for Global Environmental Sustainability, where the research project "Design of Robotic Fabricated High Rises" explores the possibilities of robotic high-rise construction. This design studio aims to shift the physical model as a crucial explorative tool combined with computational design, with robotic technology used to fabricate it. Rather than simply developing forms, the design research studio focuses on designing techniques that merge design computation with robotic manufacture (Budig et al. 2014).

30.3 Case Study

The case reported is from the University of Belgrade—Faculty of Architecture (UB–FA). It focuses course Studio Design Project: Spatial Structures, which is taught annually during the fall semester at the Master Studies of Architecture–Module Architectural Engineering (MASA–AE). The course is designed to introduce architectural students to the challenge of designing spatial structures. In this course, students acquire theoretical and methodological knowledge and skills required for project development following ARB Criteria at Part 2 (ARB 2010) through practically oriented design research.

30.3.1 Course Preparation

Findings of the literature review related to techniques, concepts, and learning perspectives of 3DP technology served as a starting point for establishing an educational framework for reworking the studio design curse. As a result, two aspects of the studio design curriculum were adopted: (1) project task and (2) teaching method. It was essential to specify engaging, a problem-based assignment that fosters the exploration of complex designs using digital technology (Greenhalgh 2016; Budig et al. 2014), facilitating the acquisition of competencies relevant to future professionals (Foque 2011). Furthermore, teaching methods standardly applied in design studio education were complemented with workshops and skill-up classes in which students developed and improved skills in using digital tools for design production (Fernandes and Simoes 2016). These were organized in collaboration with the external experts to introduce, to a certain degree, a collaborative manner of work in a studio environment essential for future practice (Gnaur et al. 2015).

30.3.2 Course Implementation

The classes, which took place twice a week, included instruction, open discussions, the presentation of students' works, and workshops to enhance students' skills. Students develop their expertise through an active process of information gathering analysis, exploration, synthesis, testing, discussions, reflections, refinement, presentation, and evaluation in the collaborative learning space of the design studio. The process was broken down into five phases to ensure the achievement of learning outcomes: (1) analysis, (2) model explorations, (3) conceptual urban and architectural design development, (4) conceptual structural design development, and (5) post-production. Each phase had its goals and outcomes and diverse tools for performing activities.

Digital tools (including fused deposition modeling (FDM) 3DP devices, selective laser sintering (SLS) 3DP device, 3DP pan, and 3D scanner) were chosen regarding the (1) design problem, (2) size (Leach 2017), and (3) stage of the design process, and the function of the physical model (Fig. 30.1). Accordingly, for form exploration (phase 2), tools that enable fast production of physical models and evaluation of ideas were favored. In this case, the less precision and quality of the models were acceptable. To produce small-scale prototypes and functional models (phase 3), more sophisticated tools that construct precise models of material suitable for testing are required. Finally, models for design presentation (phase 5) were made using precise devices and materials with desired aesthetic qualities. Also, reverse engineering proved to be a good way to support the iterative nature of the design process.

Fig. 30.1 Models produced with different 3DP devices used for exploration, assessment, and presentation of designs

30.3.3 Course Results and Assessment

The outcomes of the educational process are two types of experiences: (1) operational experience and (2) subject experience. Operational experience is related to practicing a design approach that can be reused in the continuation of the studies or professional practice. Accordingly, the framework enabled students to acquire knowledge and skills architects should possess to act competently in future working environments. On the other hand, subject experience concerns developing knowledge and skills by working on a particular topic. In this respect, the framework supported students in creating designs that display simultaneous consideration of diverse aspects—context, form, function, structure, materialization, and fabrication—using the holistic design approach.

The course was evaluated qualitatively using a questionnaire on the pedagogical work regularly filled out at the UB–AF at the end of each term. Students were very satisfied with the instructions and course materials; the consistency between classes and the scope of the course; their active participation; critical thinking and creativity; the volume and quality of recommended literature and learning resources; and their results, according to the results of the survey. Students were particularly motivated by the studio's research orientation and the opportunity to explore innovative concepts and technologies. However, students indicated that the course duration and hours of classroom activities were a bedside of the course. Furthermore, some students said that finishing tasks on time was difficult and time-consuming. Accordingly, better time management should be suggested, as learning new techniques and changing students' learning and design methods requires time. The course results were displayed at the UB–FA final exhibition and as a web exhibition, which students found exciting and as a way to show their work to a larger audience.

30.4 Discussion

The paper provides a structure for an architectural design studio that integrates 3DP technologies and tests a new framework in a real-life educational context. Our teaching process was outlined for other educators and researchers to observe our experience, compare it to theirs, and consider alternative paths. It is crucial to analyze the findings in light of the study's and course's research limitations in this regard:

- The research is restricted to a single teaching experience. For generalization, more work is needed, including a comparison of distinct findings across diverse educational contexts and study programs.
- The course has technical constraints due to a lack of more sophisticated equipment that allows students to enhance their learning through hands-on activities such as building and testing large-scale prototypes or more sophisticated models made of

diverse materials. Therefore, more resources are required to further improve the course in this respect.

The following advantages of implementing a 3DP studio design course could be identified:

- Technologically advanced creative learning environment motivated students to link the logical way of thinking that requires parametric modeling with concept-based thinking.
- When students have a physical model in front of them to analyze, they have a change in a mindset that occurs during the design process, in which they work on relevant challenges.
- Students improved their understanding of spatial cognition and their competencies related to using this technology in the design process for effective exploration, assessment, and communication of ideas.

30.5 Conclusions

The findings show that using 3DP tools in a studio design course can aid design exploration, assessment, and presentation. Shared educational experience demonstrates how 3DP technology can improve learning methods, impact students' design process, and elevate design exploration to previously unattainable levels of materiality, detail, complexity, accuracy, and aesthetics. The paper offers an example of how using technological resources could improve studio structure and facilitate achieving the desired learning outcomes, such as students developing competencies that will help them operate professionally in changing work contexts with the support of digital technologies. Finally, future studies that will include interdisciplinary research on 3D printing technology in studio design education to develop product design at various scales, typological frameworks, and timeframes could be advantageous.

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