Chapter 32
Technological Innovation for Circularity and Sustainability Throughout Building Life Cycle: Policy, Initiatives, and Stakeholders' Perspective

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Abstract The introduction of innovative technologies across the design decision-making leads to a change of entire management of operational and organizational models, lengthening the design time, as many more predictive and cognitive phases are introduced. Nevertheless, the traditional character of construction sector obstacles the introduction of new technologies which need an acceptance process that must be triggered. The paper identifies how the non-tangible technological innovation, towards sustainability and circularity, is promoting by policies and how it is perceived by stakeholders of supply chain, providing inspiration for further actions to increase diffusion in practice. The results, shown in this paper, come up by a dialogue at national and international level to stakeholders in the occasion of research works and participation to national and international working groups and co-creation groups, fulfilled by the author. To this end, at first, some emblematic policy measures, from national and international level, addressing the introduction of technology to enable circularity and sustainability in the building sector are shown. Secondly, the point of view of stakeholders regarding the difficulties linked by technological innovation is highlighted. Finally, necessary initiatives to introduce and diffuse acceptance of technologies within construction sector are discussed.

Keywords Circular economy · Enabling technology · Green transition · Stakeholder networks · Co-creation process

32.1 Introduction

Research and innovation in the field of architectural technology currently have, on the one hand, the commitment to respond to green policies which require greater attention to circularity and environmental sustainability and, on the other hand, the

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E. Arbizzani et al. (eds.), *Technological Imagination in the Green and Digital Transition*, The Urban Book Series, https://doi.org/10.1007/978-3-031-29515-7_32

responsibility to support practices at building project and process, understanding the change attitudes and the necessary drivers.

In fact, it is necessary to guide the various actors involved in construction processes towards a change of mentality, supported by technologies that allow a circular and sustainable approach to design, construction, maintenance, and demolition of buildings.

The European Commission is promoting technological innovation in all economic sectors, setting organizations responsible for identifying, co-financing, and coordinating specific activities (an example is the commitment of the European Institute of Innovation and Technology—EIT), and supporting priority areas research and innovation (as a case of Key Enabling Technologies—KETs).

A generative and responsive technology within construction sector can establish new and more correct relationships between humanity and nature (Perriccioli 2020). Technological innovation in the construction sector is necessary to predicting the transformation and impact that the design action causes on the environment, in order to respect the aims of circularity and sustainability.

Technological innovation has been already achieved by some industries, in order to increase energy and resources efficiency, circularity of resources, productivity, highly products' customization, the commercial and social value of products, and for the acquisition and data management to monitor input and output flows.

Nevertheless, the construction sector is resistant to change toward and high technological innovation, and the reason is intrinsic to the construction sector itself, which has a strong traditional character.

Technological innovation, in construction sector, can concern tangible technologies, such as constructive solutions aimed at reversibility, but mainly, by non-tangible ones, constituted by digital technologies. In fact, modeling, monitoring, and simulating processes, the Internet of things (IoT) and digital platforms are priority areas of research, which help and increase the ability to prefigure design scenarios, measure their impacts, increase the adaptability of spaces, and activate circular material flows to extend the useful life of the products and buildings.

The objective of this contribution is to investigate technological innovation for a green transition (in term of circularity and sustainability) in the construction sector, showing some political measures and initiatives that some European countries are promoting, and highlight how stakeholders of value chain are experiencing this growing demand for innovation.

32.2 Technological Innovation for Circular and Sustainable Transition

Technological innovation, towards resource efficiency and circular economy, is not limited to the production processes or new materials, but also regarding the reconfiguration of the entire building life cycle (from design phase, construction phase, use phase and end-of-life management).

In literature, it is possible to identifies research areas of non-tangible technological innovation to support design and construction phases, aimed at design optimization, reduction of environmental impacts, material flow management, circular/reverse logistics of resources.

In the context of circularity and sustainability, building information modeling (BIM) is identified as enabling technology for monitoring the use of resources during the whole building life cycle, sharing information between operators and simulating the potential reuse of building materials early in the project (Akanbi et al. 2018, 2019; Charef and Emmitt 2021). Together with BIM, material passports are identified as BIM-interoperable tools to keep knowledge of all building materials in the long term and preserving their (economic) value (Luscuere 2017; Munaro et al. 2019).

In order to predict the environment impacts of activities on the built environment, the use of life cycle assessment (LCA) during the design phase is considered fundamental, especially to activate material flows circular dynamics (Campioli et al. 2018; Lavagna et al. 2020, Eberhardt et al. 2019).

To improve material flow management and to allow knowledge of potential components to be reused in a new project, traceability systems based on digital technologies are considered able to trace geometric and mechanical characteristics of the components, the location of building, the residual value of the materials, and the expected building and material life cycle (Minunno et al. 2018; Rašković et al. 2020). Furthermore, when the product reaches the end-of-life stage, traceability technologies enable the collection of products, the potential of reusing, remanufacturing, or recycling and the economic feasibility (Alcayaga et al. 2019). Moreover, digital platforms for exchanging materials are considered useful digital technologies to support material revers logistics (Baiani and Altamura 2018) and to pursue collaborative process and networks among different actors (Konietzko et al. 2019; Talamo et al. 2020).

32.3 Investigation Method for Policy, Initiatives and Stakeholder's Perspective

Given the main technological innovation dealt with in the literature to support the green transition of construction sector, this article focuses on some emblematic policies, the stakeholders' perspectives, and the necessary initiatives to support the technological innovation in the building sector.

The results, shown in this paper, come up by a direct dialogue with building stakeholders at national and international scale, occurred in different occasion from 2019 to 2022, fulfilled by the author. In particular, the occasions of dialogue occurred in the field of:

- in part for PhD thesis research and in part for a short-term scientific mission funded by the COST-Action "CA15115—Mining the European Anthroposphere (MINEA)" which were opportunities for direct interviews with numerous building stakeholders, like policymakers, designers, investors, researchers, and operators of building process;
- the participation at national Working Groups of the Italian Circular Economy Stakeholder Platform (ICESP), which allows to focus the opinion of Public Administration (PA), manufacturer, research organisms, and environmental consultants;
- the participation of co-creation groups, organized by SocKETs project, funded under the H2020 framework program, with the aim of discussing barriers and opportunities related to the introduction of key enabling technologies for circular economy in construction sector, involving industry representatives, market operators, researchers, policymakers, civil society, and citizens;
- the participation and organization of roundtable with stakeholders, organized by Re-NetTA Project, funded by Fondazione Cariplo and coordinate by Dept. ABC of Politecnico di Milano, with the aim of defining new organizational business models related to circular economy strategies in the construction sector, involving mainly manufacturer, seller, general contractors of tertiary building sector and social cooperatives.

At first, some policy measures, from national and international level, which address the introduction of technology to enable circularity and sustainability in the building sector are shown. Secondly, the point of view of stakeholders regarding the technological innovation is underlined. Finally, some important initiatives to introduce and diffuse acceptance of technologies are discussed. To conclude, the foreseeable risks and misunderstandings to be avoided in a field of innovation technologies are highlighted.

32.3.1 Policy Measures Addressing Technological Innovation for Circularity and Sustainability in the Building Sector

To support the design and construction phases toward circularity and sustainability transition, emerging policy measures regards non-tangible technology, rather than tangible ones, which remain less applied at legislation level (Giorgi et al. 2022).

There are some policy measures which imposed the use of BIM during the design phase, particularly regarding public building. The introduction of BIM is aimed at enabling efficient information sharing throughout the operators, reducing the risk of building design errors and waste during the construction phase.

For example, Denmark, through the “ICT Regulation” n. 118 of 06-02-2013 and n. 119 of 07-02-2013, establishes the obligation to submit digital building models for public tenders that exceed a cost limit. The government also requires that digital information related to the project must be processed during the construction phase and organized as construction project documentations useful for future building management.

Also, Italy, following the Ministerial Decree 560/2017, in public construction, considers the use of digital BIM tools mandatory, in order to put interoperability and usability of building project information, by every operator during the design, construction and management process. The mandatory use of BIM tools concerns projects that exceed a cost limit. This cost limit decreases every year and by 2025 will affect the majority of public project. Another example regards the UK which, since 2016, through the “Government Construction Strategy 2016–2020,” has established the obligation to incorporate and increase the use of digital technology in public construction contracts, asking for a 3D BIM Level 2, to facilitate the reduction of construction waste.

Even if BIM is a technology useful for mapping the information of buildings, legislative measurement does not yet introduce the mandatory digital systematization of information, using material passports to keep all information in a common digital platform, accessible by enabled and qualified users, as experimented in the Netherlands by Madaster Platform (Baiani and Altamura 2020; Giorgi 2020).

To achieve sustainable building processes, in the field of circular economy transition, the legislation of some countries promotes the introduction of technologies capable to quantify the environmental impact of building life cycle. In particular, the introduction of LCA tools during the design phase represents an important support for forecasting and optimizing materials and energy in-flows and out-flows. For example, the Netherlands with the legislative decree “Milieuprestatieberekening van gebouwen” (art. 5.8 and 5.9), called MPG, set the mandatory reporting of buildings’ environmental performance through a LCA study, for new homes and office buildings (with a surface greater than 100 m^2). Moreover, the LCA must respect a maximum environmental impact limit value defined by legislation.

A similar initiative has been established by Belgian policy plan, which has promoted the development of a shared methodology for calculating buildings environmental impacts (MMG). Policy measure providers also a digital tool called Tool to Optimize the Total Environmental impact of Materials (TOTEM) based on the LCA methodology, to support designers, investors, and policymakers (OVAM, 2018).

In Italy, LCA has been introduced to building process by the Green Public Procurement, (Legislative Decree 50/2016) and the related Minimum Environmental Criteria—CAM. In the first version, CAM referred to LCA through the request for Environmental Product Declarations (EPDs) which are based on LCA assessment, to demonstrate compliance with some mandatory CAM criteria. The updating of CAM (DM 23 June 2022 n. 256), incentivize the use of LCA and LCC assessment with a rewarding logic, giving reward credits, for public tenders, to design firms and construction companies that use LCA as a decision support tool.

To improve a circularity management of materials/waste (e.g., reuse, recycling), policy measures have developed traceability system to follow along the building process.

In particular, Belgium legislation sets a system for materials traceability, called Tracimat (VLAREMA, article 433) which controls the material flow in output of demolition process, requiring the drawing up of pre-demolition audit and the waste monitoring. Tracimat system is currently mandatory only for non-residential buildings > 1000 m^3 and residential buildings > 5000 m^3, but in order to spread it on the whole building stock, the legislative framework establishes economic incentives (as well discount on gate-fees at recycling plants). Tracimat is based on a digital platform where all operators of the building process can have an access. This digital platform creates a link between operators and the entire traceability process, put available all necessary information and documentations.

32.3.2 Point of View of Stakeholders Regarding the Technological Innovation

The introduction of innovative technologies across the design decision-making leads to a change of entire management of operational and organizational models, lengthening the design time, as many more predictive and cognitive phases are introduced. Multiple interdisciplinary interactions are needed from the initial stage, through the involvement, in the decision-making process, of owners, designers, builders, and manufacturers, to co-create building solutions in a "horizontal" way.

If the technological innovation represents the fundamental support for achieving certain environmental, economic, and social objectives, inevitably the addition of evaluations and informative monitoring constitutes an extension of the design and decision-making phase, requesting sometimes new professional figures, new roles, and new operators along the construction process. For example, traceability systems lead to the need to complete and follow the entire procedure, such as completing the pre-demolition audit, performing data analysis, monitoring the demolition work, and checking the correct separation of materials. Other example, LCA leads to the need to make an inventory of materials used in the project, monitoring the input and output, collect environmental data, calculate, and interpretate the LCA results.

Following the legislative boost, the knowledge of technology is quite widespread, but sometimes stakeholders show that companies often do not fully exploit the innovative technologies equipment to full potential. Mainly in the case of BIM (when it is not mandatory), the real potential of the tool for keeping information along the building life cycle and for increasing the interoperability between operators along the building process is not applied.

For example, the use of the LCA is still complex, and the application is often performed as a post-design analysis. Consequently, the potentiality of impacts assessment for orienting choices toward sustainability is not achieved, and the design solution is not optimized.

When the introduction of technology (for green transition) is set by legislation, the success of technological diffusion depends also on the capacity to verify the right application by governmental authorities. Nevertheless, sometimes the Public Administrations (PA) are not trained to have the skills to control the right accomplishment of process innovation.

In order to face the green transition, PA highlight the limited information capacities, the need for simplification of the legislation, the scarcity of financial resources (ICESP 2022), highlighting the need for a choice of priority actions to be implemented.

The opened dialogue with stakeholders of the building value chain allowed to highlight that, beside a first spirit of interest for innovation of the construction sector, especially by young entrepreneurs, there is a general concern about the commitments that technological change entails in practice. In particular, there is a general lack of aware on the advantages offered by the new technologies, and a general difficulty in identifying the benefit.

The main concern of design firms, construction companies' association, and order of architects regards the different ability for introducing new technologies, based on company size. In fact, the introduction of BIM technology and LCA requirement implies the need to increase the digital technology capacity of all operators involved, sometimes through specific fee-paying trainings. It is clear that medium and small firms (SMEs), very widespread on the national territory (and which form part of the national economy) feel threatened and, without any national subsidy, unable to sustain the request for economic resources and time necessary to acquire the technologies and specialized personnel.

Consequently, SMEs fear that they will not be able to remain competitive on the construction market and be destinated to disappear.

Moreover, stakeholders highlight that the ability to learn the use of new technologies is generational, so the introduction of technologies often creates a gap between generations, creating a great loss of generational cognitive transmission.

Moreover, stakeholders underline the need of understand in advance the benefit of circular business and sustainability choices, with a clear network of operators, and a defined market. Consequently, it is necessary to introduce accessible and inclusive training models to allow all dimensions of firms to keep up with technological innovation and to prepare PA to play a role of assessment and support for circular and sustainable practices' activation.

32.4 Initiatives for Encouraging Knowledge Sharing and Acceptance of New Technologies

In order to spread a greater awareness of technological innovation in support of the project, in an inclusive way, involving big firms, SMEs and PA, important initiatives are represented by the green deal approach, which promotes the activation of Living Labs to create an exchange of knowledge and expertise, as an accelerator in the transition to a circular construction practice.

The research institutions and universities play a key role in encouraging the experimentation of innovative technologies and promoting "knowledge sharing" through the involvement of a large panel of stakeholders who activate new forms of interaction and collaborative innovation, with significant social repercussions.

Belgium and the Netherlands have been activated, with the support of their government the "National Green Deal," aimed at removing obstacles to circularity in legislation and practices through cooperation and experimentation between stakeholders in the areas of "Circular Building Living Lab". The goal of these Living Labs is to creates places for the exchange of research experiences and results, to develop policies and practical recommendations, based on an "experimental field" of practical experiences and research results that are shared, disseminated, and questioned, to accelerate the transition to a circular economy in construction.

The National Green Deal developed in Belgium in 2019 under the boost of government and 300 companies and institution involved in the building value chain, promotes the activities of experiences exchange and "learning by doing". Also in the Netherlands, the Green Deal Circular Buildings (GDCB) started from early 2015 and last around four years. The Dutch GDCB are working with the aim of providing suitable tools to assess the circularity of a building. To this end, the GDCB has developed a circular passport, which describes the circularity of buildings and a circular manual that supports and explains how buildings become circular.

The green transition therefore requires a great effort that not only implies technological innovation, but also cultural innovation, based on educational and training programs, which are expressed in a new way of operating and looking at needs.

32.5 Conclusion

Technological innovation in the construction sector allows to carry out complex assessments to achieve process optimizations, to increase knowledge of materials/resources, to facilitate the exchange of information and materials throughout the building life cycle.

By the technological support, humans can achieve the activation of new sustainable supply chain dynamics based on circularity. Nevertheless, the utilization of technologies for cognitive and predictive assessments must be conduct with humans' awareness, knowledge, and culture; otherwise, the use of technologies become a mean to govern complex system with a "black box approach", without knowing how technologies generate responses to imputed actions.

Moreover, the enabling of collection of big data for monitoring and keep information on built environment must be content in the limit of data management.

Consequently, in the field of scientific research, it is necessary to understand how to activate innovation training practices both for operators, who should change their practices, and for PAs, who should verify their correct performance. Furthermore, it is important to target accessible and inclusive technological innovation to all construction operators. It is therefore necessary to understand whether the diffusion of simplified means (e.g., simplified tools to trace materials, to keep buildings information, to calculate environmental impacts, etc.) accessible and usable by all is the key for the diffusion of innovation, or whether it can become a means of trivializing virtuous practices, for example, for the sole purpose of satisfying innovative legislative requests.

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