Doctoral Dissertation

Doctoral Program in Management, Production, and Design (35th Cycle)

IoT for Innovation in the Building Process.

IT for Design and Life Cycle Management of the Building Envelope

By

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Declaration

I hereby declare that the contents and organization of this dissertation constitute my own original work and does not compromise in any way the rights of third parties, including those relating to the security of personal data. Part of the work described in this thesis was previously published in the publications listed in the “List of publication” section.

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Abstract

The Internet of Things (IoT) has been recognized as a key enabling technology. In the last twenty years, the mainstreaming of IoT technologies into business and organizational processes had an overwhelming impact. In many sectors, production and consumption models have been rethought thanks to large amount of data provided by "smart" asset and ubiquitous computing's opportunities. The ability to monitor and quantify different phenomena has enabled data-driven approaches able to optimize our actions and guide our decisions. Currently, information technologies are emerging in the architectural debate as potential driver for addressing the complexity of the current environmental, social, and economic crisis condition. With a view to promoting the transition to the Circular Economy (CE) and ensuring more sustainable consumption and production patterns as promoted by Sustainable Development Goal agenda (SDG 12), the IoT technologies promise new scenarios in achieving objectives in scarce resources condition enabling a continuous and cross-cutting knowledge crucial to action.

In the construction industry, the building façade sector represent a perfect incubator to explore IoT opportunities. In this context, the need to foster product and process innovation arises from several reasons. On the one hand, the linear approach of the market is stressed by the continuous economic fluctuations and heteronomous factors (e.g., rising material and energy prices), on the other, the high environmental impact in terms of resource consumption, energy, and waste production still represent outstanding issues. Therefore, the development of innovative strategies for façade sector is to be intended as a crucial to decouple economic growth and environmental impact for the entire construction industry. On the bases of these premises, the threefold interplay between IoT, building façade technology, and CE is the research starting point. This research, within the disciplinary field of Architectural Technology, investigates the potential disruptive impact of IoT technologies in supporting product and process innovation to drive the circular shift. More specifically, this thesis aims to answer the following research question:

Can (and how) the IoT enable the Circular Economy in the façade sector?

To answer the question, a theoretical framework identifies nine potential actions generated by the interlinkages between the information produced by the IoT and the CE. In this way, the benefits (and barriers) of a digital and circular transition are systematized to help façade industry stakeholders understand the enabling role of the IoT and engage in innovative product development.

The manuscript is organized as follows. *Chapter 1* introduces the background of the research, the objective, the boundaries, and the methodological approach used. The following chapters (2,3, and 4) present from a theoretical point of view the three key concepts of the research: CE, IoT, and building façade technology. More precisely, *Chapter 2* illustrates the CE topic by identifying five Circular Business Models (CBM). *Chapter 3* examines the IoT paradigm through the analysis of literature review, case studies, and lesson learnt by other sectors. *Chapter 4* presents the technological paradigm of building façades by looking at its evolution, setting new requirements imposed by the circular transition, and identifying the trajectories on the field. After the theoretical background section, *Chapter 5* reports practical experiences on the use of IoT. Assuming an integration of IoT into the façade component, three activities were carried out to test the potential (and limits) of the IoT: (i) Near Field Communication (NFC) tags for tracking and storing asset information in the building component; (ii) Radio Frequency Identification (RFId) sensors to monitor environmental parameters affecting the asset's behavior; (iii) air quality sensors to envision new functionalities to integrate into the building component. Subsequently, *Chapter 6* matches the results from the theoretical and practical experiences in a single framework (namely "Internet of Façade") to clarify the enabling role of IoT technology in promoting circular approaches in the façade sector. The framework was validated through a series of interviews and a questionnaire. This made it possible to intercept market needs and identify fields of investigation to be implemented in the future. Finally, *Chapter 7* provides conclusions and perspectives on the topic. Based on the opportunities that emerged from the IoT-CE relationship for façade systems, the idea of an integrated IoT device is proposed to increase the asset circularity. Summarizing, the main findings of this thesis are:

- clarifying the state of the art of IoT for the construction sector;
- identifying information needed to activate CBMs for façade sector;
- defining the enabling role of IoT for the CE.

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