Chapter 23
Energy and Digital Scenarios. Is the European Buildings Future Smart?

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Abstract Two apparently distinct scenarios have an effect on the architecture, engineering and construction industry: the energy and the digital transitions. Technology evolves at a never before seen pace, transforming the ways we visualise and understand the world, and providing new tools for designing and building architecture. This paper explores the impact renewable energy and digital technologies are having on the construction industry and the new possibilities they offer.

Keywords Energy transition · Digital changes · NZEB · Sustainability · Smart city

23.1 Introduction

Contemporary society is facing with two apparently distinct scenarios, that have an effect on the architecture, engineering and construction industry (AEC): the energy and the digital transitions.

The former deals with the shift to a wide electrical use in transportation, home functioning, and energy production by renewable sources, involving strategies for low energy consumes. The latter engages people’s lifestyles and way to work, buildings production and construction methods.

Today, technology evolves at a never-before seen pace, transforming the ways we visualise and understand the world, and providing new tools for designing and building architecture.

In this evolution, the majority of our buildings, which ought to mirror an evolving society, are seemingly not responding to the transformations affecting our daily lives, remaining almost unchanged since the Second World War.

Which effect should digital have on the energy efficiency of our homes and cities?
How the latest innovations in smart technology can be applied in the construction industry?
Is citizenship prepared to exploit these digital opportunities?

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### 23.2 The Energy Transition

The energy transition is part of the wider transition to sustainable economies through the use of renewable energies, the adoption of energy saving and sustainable development techniques.

Thanks to the greenhouse effect human life could exist on the earth planet. Unfortunately, human activities’ pollution is modifying this effect, bringing the global temperature rising.

Buildings use a huge amount of energy during their operation. According to the European Commission Statistic Institute (Eurostat 2020), buildings account for 39.6% of energy consumption in the European Union, more than any other sector, including transportation (30.5%) and industry (25.8%). The residential buildings account for 26.1% of the total. The vast majority of the energy used in buildings is due to heating and cooling systems (85%). Moreover, the construction sector in Europe accounts for more than 40% of the total carbon emissions (Ecofys Document 2010). Among the 265 million Europe’s buildings, 240 million (90%) are housing. Thus, our cities, and above all our dwellings, are the main responsible of the climate change.

In this precise moment, a global emergency caused by the Covid-19 virus, in a matter of a few months, transformed the entire world. The pandemic spread of the virus has convinced many governments to introduce exceptional measures to contain the disease, leading to the temporary closure of many businesses and extensive restrictions on travel.

An important consequence of this emergency is the impact on Air Quality, that improved dramatically in 2020 April. Data collected by the European Space Agency (ESA) reveal the decline of air pollution, specifically nitrogen dioxide concentrations (NO₂), over Italy (ESA 2020).

A Harvard study has found that long-term exposure to air pollution may significantly increase the risk factor for many predicted to die from Covid-19 (Harvard University 2020). Efforts to reduce pollution post-Covid-19 emergency is thus essential to decrease vulnerability in the population, also to the virus.

While satellites found decreases in one air pollutant, that does not mean the air is free of all pollution (Committee for the Coordination of Statistical Activities - CCSA 2020), being housing over occupied during this period.

If the actual tendency remains unchanged, the prevision for the near future is critical: in the retail sector, for example, the electricity requested has doubled in the period between 1980 and 2000, and it is expected to increase up to 50% by 2050 (Pilkington et al. 2011). European Union tried to enhance buildings performance and limiting their energy use through the Energy Performance of Buildings Directive (EPBD) and the related recast Directive, aiming at the drastic reduction of buildings
greenhouse gas emissions of 80% by 2050, through a step-by-step definition of minimum requirements that will lead to the Nearly Zero Energy Buildings (NZEB) wide spread (Building Performance Institute Europe 2015).

Nevertheless, improving energy performance and reducing their environmental impacts in new buildings can be achieved by a simple two steps approach: reducing the energy demand and exporting energy optimally (Andaloro et al. 2010; Voss et al. 2011). Reduce the energy consumption of building is achievable using simple measures such as thermal insulation material for the building envelope (Voss et al. 2012) and designing properly the building in terms of orientation and ratio between opaque and transparent surfaces (Butera 2013), according to the local climate and microclimate (Tonelli and Grimaudo 2014).

It is clear that energy efficiency alone is not enough (Erhorn and Klutting 2012). On the other hand, it is also necessary to consider that buildings must provide a comfortable and healthy indoor environment to users (Sesana and Salvalai 2013; ISIAQ-CIB 2004).

Also because of this Covid-19 global alert, more than ever the awareness of how important is to live in comfortable and healthy environments has broaden. It has been estimated that European people spend about 90% of their time in both public and private indoor environments, such as homes, workplaces, schools, transportation vehicles, gyms (World Health Organization 2013).

So, the Indoor Air Quality has a great impact on health and quality of life. For many people, the health risks from exposure to indoor air pollution may be greater than those related to the outdoor one.

Anyhow, energy efficiency, environmental impacts and thermal comfort usually influence each other in an opposite way but should all have encompassed in sustainability visions (Bluyssen 2010; Yang and Wang 2013). Thanks to technological advancements it is nowadays possible to measure and control all these parameters: our dwellings are being transformed by home automation technologies and these approaches are predicted to become more prevalent in the future.

### 23.3 From Research to Practise

The challenge to reach a widespread NZEB standard involved many paths, from certifications, to legislations, to competitions or tests and prototypes. Among all this trials, the most spectacular and effective practice should be considered the Solar Decathlon Competition (Tonelli and Bellingeri 2016).

It is an international competition, established by the United States Department of Energy in 2002 in Washington DC. Since then, the competition moved to Madrid, Los Angeles, Beijing, Versailles, Colombia, Morocco, Dubai, Budapest, with many hundred thousand people involved, thanks also to the important communication and social awareness activity that teams, and organizations are required to develop.

Each edition involves 20 multidisciplinary teams selected internationally and led by universities. Teams are required to design, engineer, build and run zero energy
residential prototypes, powered by the sun, assembled in 10 days in a solar village, a small smart city, based on the Internet of Things (IoT). A full set of sensors is installed in every competing housing prototype and sensors are all connected to a centralized data-logger, transmitting real-time performance data (comfort and energy balance) over the web. Every team is required to simulate the tasks of daily home use, according to a competition calendar that establishes what is to be accomplished daily, leaving it up to the teams to decide how and when to combine these activities, such as laundry, showers and cooking.

Hence, user behaviour becomes one of the parameters influencing the result of the performance, and therefore of the competition ranking.

Actually, the final result of the competition is a combination of measured performance contests (energy balance, comfort conditions, house functioning) and juried contests (architecture, energy efficiency, sustainability, engineering, affordability, communication and social awareness, innovation).

The competition originally targeted single-family homes. In the 2014 edition, in Versailles, France, the competition moved towards a more urban and local approach, asking teams to develop and build modules to densify urban settlements in their country of origin.

The Roma TRE University team was selected three times for participating in Solar Decathlon:

- in the 2012 edition, with its prototype called “MED in Italy”, fast-assembly lightweight energy efficient housing tailored to the Mediterranean climate, overall awarded 3rd;
- again in 2014, with its prototype called “RhOME”, namely “a home for Rome”, overall awarded 1st;
- and for the 2020 edition, in Dubai UAE, that has been suspended for the Coronavirus pandemic, with a proposal for a housing prototype called “MOON”.

Since two of the main points of the competition rules ask to emphasize ease and speed of assembly and disassembly, this competition provides for the mandatory use of advanced prefabrication. This involves Building Information Modeling (BIM) design instruments, and Computer Added Manufacturing machines.

Since sensors, IoT, smart village, digital design and production are some of the keywords of this competition rules, thus we can affirm that this competition is based on digital exploitation in order to attain energy efficiency and therefore we can move describing the second scenario taking place today.

### 23.4 Digital Transition

The digital changes are affecting not only our daily lives, but also all the economies, including the construction one. In this sector, in the last few years, we have assisted at big changes in the way to conceive the design project, to build it, and to measure, control and run buildings (Tonelli and Bellingeri 2016).
The ordinary way to envision an architectural project had been strongly modified by the BIM workflow. The BIM model, with the components defined in 3D, offers the possibility to foresee problems, so as to improve the design and reduce the time for their solution during production.

Building performances, such as phase shift and damping of the thermal wave, lighting, luminance, day light factor and glare are easy to be simulated in a reliable output, as guide to assess what has been conceived. It is not too wide diffuse the employ of such instruments, but it is anyway possible to experiment innovative approaches matching different softwares, to test strategies and evaluate results in order to enhance the design solutions.

The construction phase, although the traditional way to build still remains the most employed in the AEC industry, should address and be always more related to advanced prefabrication and assembly on the construction area.

The most cutting-edge way to fabricate building components or, moreover, entire buildings, is the Construction 3D Printing (C3DP), in development since the mid-1990s. The 3D printing has steadily gained pace since 2012 and the sub-sector of C3DP is beginning to mature. Now C3DP refers to various technologies, with the main ones being extrusion (concrete, wax, foam, polymers, carbon fiber), powder bonding (polymer bond, reactive bond, sintering), and additive welding. Advantages of these tools can be identified as faster construction, lower labour costs, increased complexity, accuracy, and less waste produced.

A number of different approaches have been demonstrated up to now, which include on-site and off-site fabrication of buildings and construction components, using industrial robots, gantry systems and tethered autonomous vehicles. Demonstrations of construction 3D printing technologies to date have included fabrication of housing, construction components (cladding and structural panels), bridges and civil infrastructure, follies, and sculptures.

On 2016 Chattanooga startup Branch Technology launched an architectural competition challenging participants to use the company’s patented cellular fabrication technology to design a 3D printed single-family home that “rethinks traditional aesthetics, ergonomics, construction, building systems, and structure from the bottom up” (Scott 2016). First place went to WATG Chicago, with “Curve Appeal,” a swooping structure that resembles some sort of natural rock formation. With this project they have indicated the direction in which architectural theory is turning, taken a break from creating the next tallest tower and quietly revolutionized the way we think about homes.

In Dubai a new 3D printed office was recently built, printed out layer by layer over 17 days at a cost of $140.000. Dubai hopes the project will kick-start its plans to transform the sheikhdom into an incubator for emerging technologies.

I am among the sceptics that these tools can give as complex and performing results as our houses require. However, I came across Bill Gates’ statement of 1981, when he supposedly uttered, in defence of the just-introduced floppy disk: «640 KB of RAM limit ought to be enough for anybody».

The digital age is set to cause more upheavals than previous technology revolutions because change is happening faster than ever before and is fundamentally altering
the way we live. 4 days were required to download 10 million apps from the newly opened app store in 2008. We predict technology will continue to follow this trend. It will not be long until a new app is downloaded at such incredible rates that 50 million consumers will be reached in days. The telephone technology, in the last century, took 75 years to reach a similar number of customers (Interactive Schools 2018).

23.5 Digital Role for the Existing Building Stock Retrofit

The technological evolution of digital will allow to permit greatly easily to link design output to production machines. But ones again this concerns the construction of new buildings, as above the way to design a NZEB. Nevertheless, is digital able to supply the existing real estate retrofit and refurbishment?

It is clear, today more than in the previous ages, that the main urgency does not consist on how to build future homes (as we wrote above it is well known how to solve dramatically this issue), but on how to retrofit the old and energivorous existing real estate. In Europe, 180 million of the existing residential buildings have been built after 1945 (77%). In Italy 12 million buildings exist. 7,4 million has been built in between 1950 and 1991 (the year of the 1st law that deals with energy efficiency) (ISTAT 2011). So that, more than 60% of the constructions were built before limitations of energy uses and carbon emissions, with corresponding high-energy consumption.

In the post Second World War period the Italian economic boom and the technological advances allowed to split the building envelope from the role to create indoor comfort conditions. Comfort was devoted to HVAC, forgetting all the elements that characterized the Italian Architecture, since ever: genius loci, or in English the relation between shape, orientation and building techniques with local climate and materials. The upsetting result consists of: imitation of archetypes beyond the Alps, prevalence of glazed facades, housing models far from our culture, and big amount of energy use that with the rising costs of fossil fuels has become increasingly unsustainable and unaffordable.

It is important to underline that to produce 1 °C of cold air requires 3 times more energy than to produce 1 °C of warm air. This means that to avoid discomfort from summer conditions is demanding 3 times more energy than in winter ones. This concerns seriously Italian and south European latitudes. Many techniques have been developed since the first Reverse Engineering/Retrofit method thought by a TUM research, based on large scale, timber panels for substantial improvement of the energy efficiency of a renovated building (Heikkinen et al. 2010). It was a systemized modernization process from survey, planning, production off-site to assembly on-site as a consistent structure along a digital based workflow.

Although this or other similar technologies have already been tested in several European countries, they are not feasible to be used in the Italian context, characterized by specific geometric features of the building stock, by cold and hot climate requirements and by seismic constraints, which are not relevant for most of European countries. The Ri.Fa.Re. Project (Malacarne et al. 2016) presents an innovative
timber-based prefabricated panel for the energy refurbishment of the existing Italian buildings façades that does not aim only at developing a product but also at adopting a new process, based on parametric design and lean construction principles. The main outcome is a concrete kit for energy refurbishment suitable for the Italian context, including a technological prefabricated but customizable product and a more efficient process to decrease time and cost wastes during the whole process.

23.6 Less Automation, More Information

A perfectly designed and engineered house will likely not work properly if its inhabitants do not know how to use and live in it. It has been studied that in some cases, there are NZEB in which users behave and consume in the exact same way as they would in non-efficient homes (Keesee 2005), as if they do not recognize the direct relationship between their behaviour and the performance of the house (Tonelli and Converso 2014).

The active role of users has proven its effectiveness in several successful experiences. One of the first documented is the Empire State Building energy retrofit, in which a number of measures to increase the passive and active behaviour of the building itself (i.e., new windows, more efficient systems) saved a yearly amount of $4.393,796 and user awareness reduced 8% of consumption costs, $386,709 (Rocky Mountain Institute 2012).

In residential use, this number would evidently increase (Janda 2011), but its exact determination is difficult, because the ratio that is attributable to user behaviour can vary according to context strategies.

The impact of human awareness on reducing energy consumption is particularly evident with cars. Currently, cars are equipped with increasingly information systems that tell the driver in real time the impact of his driving behaviour. The simple evidence of immediate consumption and the projection of the remaining distance have proven to stimulate drivers to change their behaviour and adopt a less energy-consuming driving style. Some authors (Kurani 2007; Inbar et al. 2011) also identified in particular cases a “game-effect” (Deterding et al. 2011) whereby social rewarding is used in strategies to promote eco-driving. This relationship between different players in a competitive environment, based on shared monitoring, is already present in the Solar Decathlon competition. Thus, each competitor can see in real time the performance of others and observe the differences on how his house is performing.

Despite architecture is still about designing static environments, devices and sensors increasingly embedded into buildings provide dynamic information on its behaviour: comfort conditions, energy balance, and also user’s interaction. Sensors are not new in buildings. Lights and gates embed sensors since decades. Even our smartphones have many sensors. However, smart homes are not very intelligent simply because they are pre-wired accordingly to algorithms and decisions made by the systems designers, rather than the dwellers. In contrast to such homes, which are not able to adapt structurally over time, what we designed to participate in Solar
Decathlon, was a 3D model, accessible on web, that allow to navigate in real time and back in the time, named “DWELL!” (play on words that, extended, could sound like “do well to dwell well!”).

Following the philosophy of “more information less automation”, we created a building/technological systems synergy that allows to obtain a better balance between comfort and consumption, having an active participation of the users through a data visualization guiding the inhabitant to a correct practise in the house. It is also an interactive point-and-click model of the house where the user can visualize what’s going on in real-time through simple animations (changing colours, point clouds, opening/closing windows and doors, etc.) and popup windows (Converso et al. 2013).

Likewise, we believe that true improvement begins with improving people, not just the places they live. It is possible to design homes with high levels of efficiency, but to get an effective energy saving is necessary that dwellers can be aware of how the house works and the extent of consumption related to their behaviour in order to learn how to use the house in the best way to get the comfort most suitable for themselves with the minimum energy consumption.

The same happens at an urban level, where advances in technologies ranging from sensors to broadband, artificial intelligence and big data are making smart cities a reality. Nevertheless, the smart city of the future will have little hope for sustained prosperity if its people are not themselves smart (Tonelli 2015). It also takes thoughtful citizens to correctly interpret data produced by smart devices. Indeed, the success of cities depends greatly on the ability of individual citizens to intelligently engage with each other and their environment (Tonar and Talton 2019). ICT and IoT are already transforming cities around the world into hyperconnected networks and it is thanks to these emerging technologies that during the Covid-19 pandemic our lives remain efficient and productive: we assisted to the conversion of our homes in offices, schools, restaurants, and leisure environments in the time of few days. Covid-19 virus restriction measures created a more innovative, educated, talented, resilient and empowered citizenry: smart working entered in our homes and fast accelerated the process of digitalization.

In 2019 Roma Tre University has been selected again to participate in Solar Decathlon, in the Middle East 2020 edition (SDME). The Covid-19 emergency stopped the competition and it is still unknown if or when it will be possible to start working again. For SDME we proposed MOON, a housing prototype designed for a harsh, adverse, hot and very humid climate, like the one in Dubai, which we looked at as a new world we need to explore and understand. We liked to think of ourselves as astronauts, leaving for a new planet, arriving where we need to conceive new neighbourhoods, built with the most advanced technologies at a sustainable and human scale. The MOON project will convey space technologies into a human habitat, considering it a challenge that of building in such a harsh climate (a same approach was foreseen by NASA in the 3D Printed Habitat Challenge for Mars (NASA 2020). The concept will combine innovation with tradition, with a strong outlook onto the future. The house will be shaped as a closed volume, protected from the sunshine and the dust by a double skin, yet open towards an inner courtyard, shaded and climatized by vegetation able to live through humidity.
The urban concept enhances local resources, optimizing passive and active energy strategies, densifying and encouraging electrical and shared mobility, as tools for reducing harmful emissions and activating sustainability. MOON for SDME is the dream project, a dream lunar world that can finally connect with the Earth. A new world: technologically smart, able to offer a sustainable opportunity to the future city of Dubai. Pursuing again the claim “Less automation, more information” (Tonelli 2013) who guided the home control of RhOME prototype, we were supposed to design a system able to give awareness to its users on the ecological footprint of their behaviour. The device will be a dashboard based on Machine Learning technology, grounds on five “cycles”: Energy; Environmental features (air quality); Water consumption; Waste production; Food consumption. It would been designed for measuring and monitoring in real time the ecological footprint of the house on the basis of the environmental data and the behaviour of people living in the house, predicting future scenarios and effects.

### 23.7 Conclusions

We are at a turning point dictated by many new needs. We must look for new possible paths and meet change without fear of it. These are in synthesis the different ways that the architect profession must try to follow in order to meet the real needs of today: to review operational and organizational methods, to redefine project requirements, also recovering a tradition from the past, and lastly to keep in mind the demographic and social reality, in constant and violent modification. In parallel, knowledge increases. Life is facilitated by the digital revolution, a very fast and upsetting revolution, which, if on the one hand helps, on the other ousted the less qualified from the world of work.

A Google algorithm has narrowly beaten the world’s best player in the ancient Chinese board game of Go, reaffirming the arrival of what its developers say is a ground-breaking new form of artificial intelligence. This application have learned by millions of played games, thanks to the Machine Learning technology, but to win have created a new strategy, not belonging to what studied (Barricco 2018).

We ought to consider creativity as the only true quality that can make a difference between man and machine. But, perhaps, creativity, the soul of humanity, of some in humanity, is about to be reached by machines. This drastically reduces the supremacy of the human being, because it was the real difference between an evolved society and one still linked to manual work. In the Chinese board game Go, inventing a strategy not present among those learned, represents in a nutshell a creative act. This, if it become a machine potential, will affect principally the Architects’ job.

The Solar Decathlon competition give us a lesson on how to face this digital revolution in the AEC industry, putting people, students in particular, at the centre of the challenge. It is an opportunity to fully tackle a new kind of design process, using an integrated and multidisciplinary design team, made by researchers, students and technicians. The digital tools could be considered as shared culture enhancing
exchange and interaction between different disciplines and people. The intention is
to challenge the existing distinction between design conception and design develop-
ment, working towards a process based on form resolution. The process will therefore
be based on a cyclical structure, rather than a linear sequence. The ultimate research
goal of the interaction and sharing system overcomes the current distinction between
communication and design development environments, by integrating as much live
design data as possible into the management system. These are the premises that
allow for the proposal of a model for customized interventions based on advanced
prefabrication, implying the combination of digitally controlled models with CNC
manufactured components, starting from a shared digital model.

In the process the fabrication manufacturing model is constantly interfaced with
energy analysis platforms, which take into account all the involved parameters, with
models made to teach the team on the numerical impact of the measures adopted for
passive strategies, with both stationary and dynamical simulation.

But in our view, all this does not come to an end with construction. A bigger part
of energy savings is possible during life cycle management which is an emergent
and increasingly important domain in digital systems for the building sector.

The approach to home automation has gone beyond domotics, in order to put
people at the core of the system. Awareness is the main objective of a control structure
that generates a continuous stream of data. In the Solar Village of each edition of
the competition, a local server is bundled to a network of wireless sensors linked
to all kinds of appliances (HVAC, lighting, kitchen appliances, monitoring comfort
conditions, movement and position of doors and windows, security webcams). This
will not just assure remote control, but also transfer data to a remote server, online,
where a home portal provides an integrated view of the house network, where the
link between systems normally considered as separate is crucial.

The web space is based on social networking technologies. If it integrates into
the smart city, it will allow a comparison between different users and data sharing
across multi-family buildings and neighbourhoods or different areas of the city or
the country itself.

This approach belongs to gamification, an emerging field of research, to encourage
energy conservation behaviour in house occupants.

An innovative serious game should be developed to promote reduced energy
consumption and carbon emissions by changing social tenants’ energy efficiency
behaviour.

Nevertheless, although smart infrastructure helped to facilitate value creation, we
consider people still the protagonists in the urban drama.

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