DESIGN CULTURE(S)

Cumulus Conference Proceedings Roma 2021

Volume #2

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Cumulus Association

Cumulus Conference Proceedings Series
07/2021 Rome

Design Culture(s)
Cumulus Conference
Proceedings Roma 2021
Volume #2

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Layout and Graphic Design
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Concept for Cumulus Conference Proceedings Series was developed in 2018 by Jani Pulkka

Cumulus conference
Design Culture(s)
hosted by
Sapienza University of Rome, Italy
on June 8-11, 2021.
Conference website:
www.cumulusroma2020.org

Published by Cumulus
Cumulus the Global Association of Art and Design Education and Research. Aalto University, School of Arts, Design and Architecture
PO BOX 31000, FI-00076 Aalto
www.cumulusassociation.org

ISBN 978-952-64-9004-5 (PDF)
ISSN 2490-046X
Cumulus Conference Proceedings Series, N°7

Cumulus Conference
Proceedings Series

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of Art and Design Education and Research

Rome 2021

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ROMA 2021

JUNE 08.09.10.11

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JUNE 08.09.10.11, SAPIENZA UNIVERSITY OF ROME

Smart, Safe and Green System. A Resilient-Based Strategy for Sustainable Buildings and DIY Design

Cecilia Cecchini*[a], Miriam Mariani[b], Paolo Mondini[c]

[a]Sapienza University of Rome
[b]Sapienza University of Rome
[c]Ergonixart s.r.l.
*cecilia.cecchini@uniroma1.it

Abstract | This paper - after an overview of the sector's issues - aims to present Smart Safe and Green System, a working prototype for small and medium-sized buildings and industrial warehouses. It is an integrated and scalable green technological system, aimed at the energy adaptation of pre-existing façades, at the improvement of ambient air quality, at the aesthetic redesign of urban spaces, at the structural and thermal monitoring of buildings. What we intend to propose in this paper is an economically accessible and easy to implement project, which represents the synergy between methods, processes and tools of Design discipline and the most advanced research in the field of Smart Products, IoT and plant-based technologies, for the promotion of a Do-It-Yourself approach as well as a Transition Design as a guide for a resilience-based social change aimed at a more sustainable future.

KEYWORDS | DO-IT-YOURSELF DESIGN, PLANT-BASED TECHNOLOGIES, INTEGRATED SYSTEM, ARTIFICIAL INTELLIGENCE, CLIMATE-CONSCIOUS CONSUMER

1. Introduction

As recalled by ISPRA (Istituto Superiore per la Ricerca e la Protezione Ambientale) and Rapporto del Sistema Nazionale per la Protezione dell’Ambiente (SNPA), for several decades our continent has been facing the unavoidable issue of sustainability, which any project proposal and resource management depends on necessarily (SNPA, 2019). In the building and energy field, the common goal is to reduce building organisms to "zero energy" - or even transform them into POA, "Positive Energy Architectures" (Tucci & Monticelli, 2018) - by 2020 and also to reduce to zero the consumption of new land by 2050. In practical terms, therefore, the feasible strategies will be directed towards a more responsible use of materials and sustainable building technologies, together with an adaptation of the existing buildings through a redevelopment and conversion of disused structures and unused land (Finocchiaro & Di Leginio, 2019). The theme of redevelopment of buildings is therefore the core of this project, in fact the research focuses on the recovery of the existing and energy improvement, through the study of hypotheses of application on various types of construction in order to cover a larger percentage of cases. There are two main areas of interest to which the project is addressed: on the one hand the housing area, and on the other disused industrial areas. In the case of housing, the main problems of adaptation are in the energy field, as most old buildings do not have (or are strongly lacking) any criteria in terms of sustainability and energy saving, as they are characterized by traditional technological systems, now obsolete, or because they are the result of design errors. In the case of industrial areas, these are abandoned buildings: according to the WWF's Report "Re-use Italy 2013", from a functional point of view, out of 575 reports no less than 131 relate to buildings that have had industrial use in the past (Ombuen, 2013), which could find new life through an adaptation of technological systems and a use reconversion. More in detail in this paper, an overview of the themes that frame the design proposal will be followed by a description of the prototype structured in three sections, one for each part of the project.

2. Plant-Based Technologies for energy adaptation

The preliminary analysis phase of the research was based on the investigation of construction techniques more widely used or experimental, effective for the buildings’ adaptation, focusing interest on those "hybrid" systems consisting of the integration of the building with vegetation, or the so-called "green façades" - or VGS, Vertical Greenery Systems (Radić et al., 2019), winning in terms of effectiveness on both the building and urban scale. The design of the green façade is not only an excellent remedy to the problems of overheating of poorly insulated and energy-wasting buildings, but also a proposal for the aesthetic redevelopment of anonymous, poorly maintained and crumbling façades in urban or industrial areas where the presence of designed greenery is particularly scarce (Tatano, 2008). The presence of vegetation in urban areas is nowadays a fundamental reflection theme regarding the adaptation of cities to the important climate changes in progress, which must be faced with effective and intelligent systems. The design of green surfaces (both horizontal and vertical) is in fact relevant in the abatement of the so-called "heat islands" inside urban centres, in the thermal absorption, in the production of oxygen and in the purification from pollutants, which plants are responsible for, through physiological mechanisms such as chlorophyll photosynthesis, phototropism, evapotranspiration (Bellomo, 2009).

The state of the art analysis has made it possible to identify, first of all, the distinction of two main categories of green façades, which are on the one hand green covering - or green façades - and on the other hand vegetated walls - or living walls (Bit, 2012). These two systems differ in their technological characteristics and used components: green covering is a relatively simple technological system, which provides for the application of vegetation on any envelope, as it is not integrated with the structure, but rather supported or detached; while the vegetated wall is a type of façade integrated with the envelope and equipped with an organization, and therefore a more complex realization with functions of support and nourishment for the vegetation (Patrick Blanc's patent of "mur vegetal", in Blanc, 2008).

As far as the realization of the supports is concerned, it varies according to the envelope on which they are assembled. They can be divided into rigid or stretched support structures: in the first case the elements are parts of the structure, or lattice panels, as well as elements modules-moulded and assembled in different configurations, while in the second case they are tensioned cables, meshes and nets, mostly made of steel or fibre-reinforced synthetic materials (Bellini & Daglio, 2009).

In parallel, the variety of plant species most commonly used was examined, each with its own characteristics of growth, appearance and exposure. The green cladding, compared to the vegetated façade, allows a greater versatility of configuration at a much lower cost and maintenance, while maintaining a very high level of energy efficiency, including a good result with respect to the solar radiation shielding, a good success in the control of heat and energy flows, in the management of noise pollution, as well as in the protection of the envelope from atmospheric agents, in some cases up to excellent results that see significant energy savings (Flores Larsen et al., 2014).

3. DIY approach and Transition Design for smart resilience

"The art of resilience" (Bohigas & Montlleó, 2018, p. 28) is a complex operation that requires interventions of radical change, of redesign not only on a large scale, but also of precise green oriented interventions, focused on the small scale. Since the objective of the research is the application of a sustainable system for the redevelopment of existing buildings, case studies and technological systems that respond to the category of green coatings have been analysed more specifically for their flexibility of use, adaptation to the pre-existing and

energy efficiency. As argued by Calzolari: "In recent decades the concept of resilience to be developed at different scales has emerged: from the product, to the building organism, to the city". (Calzolari et al., 2018, p.191) and consequently the need to act with modular and scalable systems, applicable according to different configurations, depending on the structure to be upgraded.
From an economic point of view, most of the green cladding systems currently on the market, despite being less expensive and easier to manage than vertical gardens, are still subject of specialized companies that offer different products at different price ranges.
Smart Safe and Green project is based on the desire to fill the gap between the ordinary user and the highest forms of technological sophistication, particularly in the field of energy adaptation of building structures. It represents an intervention hypothesis designed ad hoc by a multidisciplinary team, characterized by a high degree of flexibility, adaptability and simplicity of implementation that directly involves the end user in the installation and operation of the technology.
The inclusive and participatory approach reflects emerging trends in the field of Transition Design, a "design-led approach for addressing complex, wicked problems and catalysing societal transitions toward more sustainable futures" (Irwin, 2018, p. 19). Transition Design argues that the unsuccessful problems solution results from a wrong involvement of stakeholders in the processes, because social and environmental problems that people face today are too complex. The Do-It-Yourself approach of this kind of design is core in the process of individual user empowerment and action, in the will to face very complex problems and systems such as climate change and energy adaptation of buildings. The involvement of users within the process is considered as a "more democratic design process" and "closer to the user" (Atkinson, 2006, p.1), not identifying it as the opposite of professional designers’ activity (the most amateur form of bricolage), but as an opportunity to "express a greater aesthetic individuality not bound by the constraints of mass production" and to avoid "passive consumption" (Atkinson, 2006, p.1).
Professional-user interaction, in a process of Transition Design, is identified as a potential, not a deterrent, within the design process of renewal and transformation. As claimed by Sangiorgi, in fact, "the key ingredient for transformative practices is the understanding of citizens as agents and their active role in the creation of well-being" (Sangiorgi, 2010, p. 4). Objective of the transformative approach of these processes is the definition of the most effective tools and methods for the realization of what is called Lifestyle or Lebensstil, explained by Smith as a "kaleidoscope of transformations realized and imagined, a complex collage of activities, values, visions, roles and skills" (Smith, 2014, p. 5).

4. Smart, Safe and Green project

The proposed experimentation is a prototype of a technological system applicable in a rather wide range, in particular in the energy adaptation of pre-existing façades, in the improvement of the air quality of indoor and outdoor environments and in the aesthetic redesign of urban spaces, as well as in the structural and thermal monitoring of buildings. First of all, the research has been carried out according to a desk mode, oriented to the collection and analysis of case studies, both from a technological and botanical point of view: some examples of realization (both green coverings and vegetated walls) have been examined and analysed according to different parameters to verify their effectiveness in terms of microclimatic control functions (both in summer and winter), depending on the used configurations, materials and species. Each case study was analysed in the form of a sheet, taking into consideration the geographical location and exposure, structure, construction details, used species, in order to identify compatible and efficient solutions. After the preliminary desk research phase in the field of green systems, we moved on to the development of the prototype project, analysing what emerged from the comparison between different technologies and the collection of case studies: Smart, Safe and Green consists of a light support system to be fixed dry on the skin of existing buildings, aimed both at housing purifying plants and at positioning a data collection system using sensors, with the aim of improving the energy performance of buildings, structural monitoring and air quality improvement. In order to fulfil these functions, the project involved the construction of a prototype set out in three parts: a façade system, a roof system and a series of specially developed markers accompanied by special monitoring software. The third function of the system differs from the first two because it is not part of the green theme of energy adaptation, to focus on the equally important one of the structural health of the buildings, thanks to a monitoring system (Fig.1).

Figure 1. Left: assembled prototype of the steel mesh screen, with Tillandsia plants leaning against it. On the right, detail of the position of the plant on the prototype.

In the project, both for the façade system and the structural one, the same screen/structure is used both to support the vegetation, to be affixed to façades to be redeveloped, and to monitor their stability and deformations related to external actions through intelligent technological systems. The creation of grid systems with a modular configuration would make it possible to adapt the cladding to the pre-existing envelope, also referring to the presence of openings for lighting and natural transpiration, using suitably designed uprights and knots.

4.1 Façade system: one green screen, many benefits

The green system for the façade consists of a kit of stainless-steel stretched cables - with cheap accessories and fastening elements - configured as a frame and put together at a distance from the wall to ensure adequate ventilation behind it, on which plant species are housed. For the greening of the support, the research experimentation proposal foresees the use of the Tillandsia Usneoides species also known as "Spanish moss" or "Moses' beard". Belonging to the Bromeliads species, it is native to Central America which prefers therefore very humid and warm climates. The main characteristic of Tillandsia is the absence of underground roots: in fact, it looks like a tangle of long leaves with aery roots, which feed on the air's humidity that they absorb through special structures placed on the epidermis (trichomes) that open when the plant needs to hydrate and close under a certain threshold of humidity to prevent the evaporation of what has accumulated (Kuaanan et al., 2014). Another very important peculiarity of this species is its function as a detector and purifier of pollutants and fine dust (polycyclic aromatic hydrocarbons). A team of researchers at the University of Hidalgo (Mexico) claims that Tillandsia Usneoides is "one of the most widely used organisms for the biomonitoring of atmospheric metals due to its ability to accumulate and retain pollutants" (Martínez-Reséndiz et al., 2015, p. 262). In addition to the phyto-purifying action, the advantages of Tillandsia are different: the skin's trichomes of this plant have the dual function of shielding the sun's rays and facilitating the water reception by ensuring a reduction of solar radiation on the façades; this species can live in direct sunlight, therefore preferring a south-east orientation and can withstand the winter cold up to several degrees below zero; it does not require maintenance because of its rather slow and regular growth.
Although from the technical point of view, therefore, the façade-prototype falls into the category of stretched systems, it lends itself to further customization: the steel rope mesh can also be combined with prototype segments made with the proprietary patent of the Med Marine s.r.l. company, made of composite fibres, which allow the insertion of plant pots (and therefore the possibility to choose crop species other than Tillandsia Usneoides), drip irrigation or hydroponic systems and humidity sensors.
It should be remembered that, for the prototype, it was decided to prefer an executive project that, not anchored directly to the building walls, but fastened to protruding elements

of the roof (in this specific case wooden beams) would allow a greater detachment of the frame from the external perimeter surface. In fact, being able to detach the frame 30-50 cm from the subfloor, allows to maximize the advantages of the shading effect of the frame itself, as it guarantees a back ventilation. In this way, the heat generated by any uncovered parts can be taken away, as well as the moisture generated by any irrigation, residual moisture from rainfall, condensation from low temperatures at night, or simply moisture and escape from the interior of the building through the perimeter wall. In the case of adherent plants, this humidity may not dry out, resulting in the formation of mould and biological patina.
In addition, in the components' executive design, an attempt was made to standardise the lengths of the eyelets in order to simplify assembly as much as possible: therefore, the presence of the difference in height was managed through the cable tension system itself, consisting of a lamellar wooden beam, anchored to the floor of the courtyard with threaded rods (Fig.2). The use of threaded rods drowned in the floor allows, in combination with anti-slip nuts, to adjust the height of the wooden beam from the ground and therefore the tension of the steel ropes. Being able to easily manage the length variations of several eyelets with a single adjustment (the beam system), is an important simplification of maintenance activities.

Figure 2. Left: detail of the anchoring system of stretched cables to the ground through a wooden beam; right, detail of the steel mesh knots.

4.2 Roof system: green indoor comfort

Referring to the roof, the project foresees a micro-ventilated horizontal greening system, consisting of a main element, a container tray in composite material (derived from fibres processing), also made with proprietary technology developed during the project, which through assembly and fixing components is easily anchored to the main types of roofing envisaged (tiles, corrugated sheets, shaped panels), together with accessories with windproof function to prevent it from tipping over. The production technology developed has made it possible to customize the tray's shape, making its use possible on any type of cover, without the need for adaptation. In order to meet the specific requirements of energy regulations and economic evaluations two issues have emerged: on the one hand, the need to switch from longitudinal profiles to a continuous coating package and, on the other, the replacement of the Tillandsia plant species (used in the façade system), which is excessively expensive for the entire roofing surface, with different species which, not being epiphytic, adapt perfectly to a pre-cultivated soil substrate (Fig.3).

Figure 3. Left: installation of the trays on the roof for the experimentation phase; right, detail of the installation of the cultivation layer

The crop selection aimed at the use of species capable of withstanding both summer heat, with periods of reduced water supply or drought, and resistance to winter temperatures. In particular, has been organized three zones, with three different species: a zoysia matrella

meadow (macroterma species), a zoysia tenuifolia meadow (macroterma species) and a sedum miscellany meadow (belonging to the crassulacee).
Using rockwool layers put between the trays and the meadow, and applying techniques typical hydroponics techniques, it is possible to obtain both the insulating effect and the substrate effect to house the plant component to be developed within the system. The wool mat, although flexible, maintains its shape and does not fill the central gutter: in this way the excess water flows and flows into the gutter (Fig. 4).

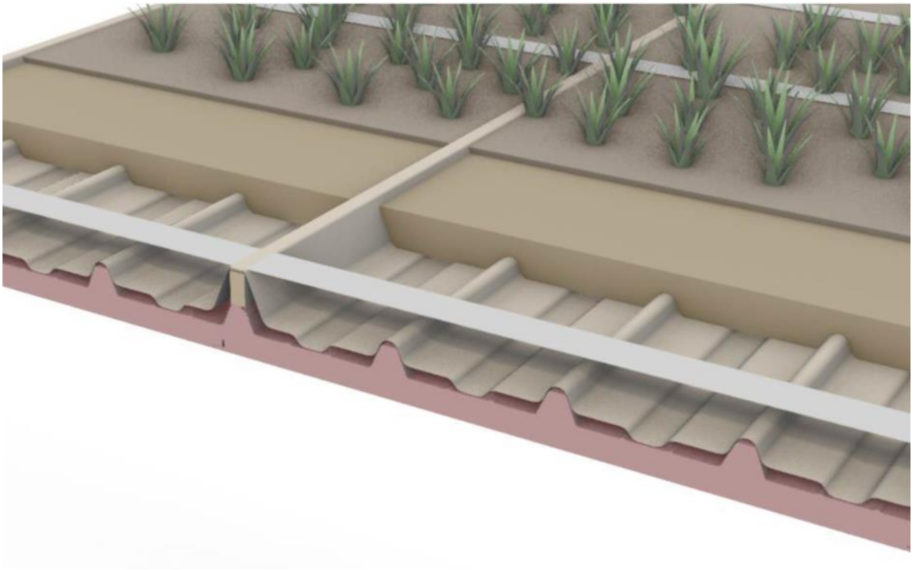

Figure 4. Three-dimensional representation of the roof system: detail of the stratification

The windproof function is achieved by fixing the rock wool under a fibreglass mesh. In a short time, the plants, rooting beyond the soil block and stretching inside the rock wool, will also anchor the crop finish to the whole system, which will remain firmly on the roof.
The strength point of the roofing project is the capacity of the fibreglass tray to maintain its shape, creating a ventilation cavity and, at the same time, a sufficiently flat surface to be trampled on. Compared to previous applications of the existing patent, in fact, the shape of the trays is particularly innovative due to the continuous ribs that increase the moment of inertia of the section and the resistance to vertical weights, allowing the trays to be walked on during assembly and in case of maintenance. It is important to note that the creation of the trays was based on a completely new application of the existing patent and therefore required a strong commitment to research, development and experimentation. In addition, together with the innovative shape, the dimensions of these elements are also particularly

important, as they are modular, with a width that can be raised as desired, limited in the prototype to one metre for ease of transport and assembly. The experimentation has also revealed a considerable reduction in temperature during the summer climate and good thermal insulation during the winter, making the energy-wasting environment of an industrial shed, as comfortable and habitable area.

4.3 DIY monitoring: Smart product for structural safety

As the third and last part of the Smart system, we describe the technological prototype of the software for structural monitoring of buildings. The objective of installing a structural monitoring system is to verify the availability of non-invasive diagnostic tools, able to provide detailed information on the state of conservation of the monitored structures and to detect risk factors at an early stage.
The prototype for the structural monitoring function of the test building uses various techniques and technologies: a minicomputer connected to a camera takes photographs at regular intervals at the structure to be monitored and then sends the captured images to a remote server, while expert software processes the images stored on the server. Using computer vision techniques, the points to be monitored are recognized, the data sets are produced and then analysed, using machine learning algorithms, for the actual detection of any anomalies (Fig. 5).

Figure 5. Monitoring system: detail of markers applied on the structure for the point detection

The identified system exploits the branch of technology linked to DIC (Digital Image Correlation), which is essentially a non-contact optical method to measure displacement, deformations and vibrations in objects or materials subject to applied forces. The method, in fact, compares two images, before and after the deformation and displacement, acquired in white light or IR with a camera.
In order to take into account irrelevant displacements (such as possible camera rotation due to wind or other small instabilities), a complex artificial intelligence system has been developed that compares the relative positions of the various monitoring points, making the system reliable even when unskilled labour is used during assembly. The entire complexity of the measurement has been moved to the server side, so that the user does not have to worry about anything. For this reason, systems for self-calibration and self-configuration of devices via Qr Code have also been developed so that the user only must position the devices to start the entire monitoring process (Fig. 6).

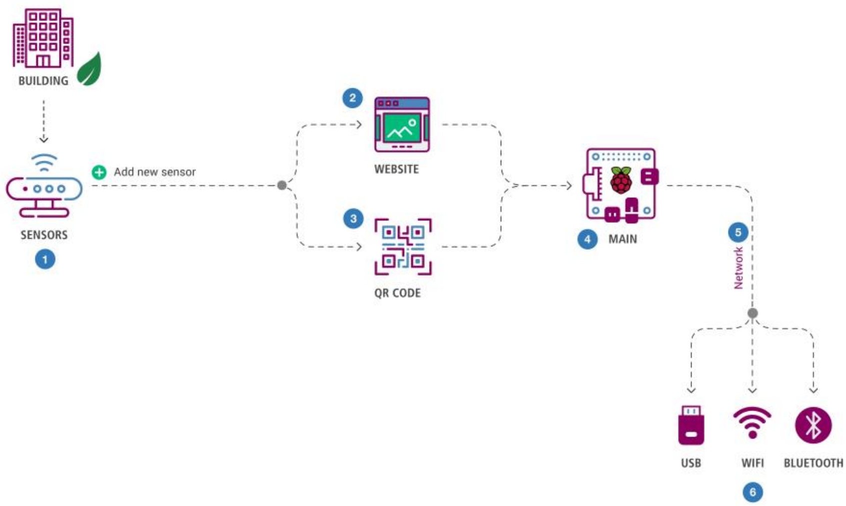

Figure 6. Representation of the installation and operation process of the monitoring system

Since the system stores and detects images and metadata in a database, it was decided to extend the database also to the data monitoring from third-party sources such as weather or environmental data on air quality, as well as data from other sensors, such as electricity, water consumption or other. Each of these parameters can generate specific alarms when pre-set thresholds are exceeded, warning of the need for specialist intervention. In order to simplify the specialist intervention, the database also contains the entire design history of the building, so that all relevant information is stored in a single repository: from

construction projects to consumption, from authorization documents to the various interventions to the description of maintenance operations carried out. With a view to simplifying the user side, a data access grid has been created so that the data can be seen or managed according to use: owners, tenants, administrators, professionals have all been profiled and each of them has a visibility of the data linked to the specific need for intervention or monitoring.
Therefore, we can say that the monitoring system’s core is an expert system related to a series of sensors and an informatics network, an intelligent device in full IoT area, connected to network. Moreover, it falls within the well-established category of Smart Product-Service Systems (SPSS), which "integrate intelligent and e-service products in a single solution" (Lu et al., 2019, p.1). These systems, in fact, go beyond traditional services, as they are based on sharing and access, no longer based on ownership, and are "preferred (by consumers) because they provide more benefits at a lower cost" (Lu et al., 2019, p.4).

Conclusions

Referring to the issues raised upstream of this proposal, concerning possible building adaptation interventions, energy-wasting buildings and disused industrial sheds, an attempt was made to respond through the study of current proposals’ panorama, overcoming it through an innovative project. Smart Safe and Green intends to propose itself as a modular, adaptable, scalable and customizable model for interventions on problematic building structures. It represents a possible answer, alternative to the commercial proposals, often too expensive and impossible to realize without a skilled workforce. Referring to the green façade and roof system, "the use of plants in the façades of buildings is a useful bioclimatic strategy that offers many advantages for the thermal, acoustic and psychological comfort of the inhabitants. There are also environmental benefits through the reduction of energy for heating/cooling indoor spaces and CO2 emissions" (Flores Larsen et al., 2014, p. 1772). Referring to the software, simulating the operation of this system in a wider range, we could think of using this detection technique for monitoring the structural integrity of even large buildings and large transport infrastructures, such as bridges, viaducts and dams, since monitoring has become a crucial aspect for the prevention of natural disasters, in order to ensure the safety of people and things. In design terms, the bottom-up approach is certainly representative of this proposal, as it would allow individual citizens (inhabitants and consumers) to provide for their own change, to be actors in an evolving change project over time. As argued by Burns (2006), it is no longer a question of "designing a response to a current problem, but [...] designing a means to continuously respond, adapt and innovate" (Sangiorgi, 2010, p.3). The Design objective, in this climate of enormous and immanent changes, is therefore denoting itself as a promoter of practices and projects as flexible, economic and efficient as possible, which review the role of the end user in a non-marginal position: not simply a "user" of a product-service, but a participant in the implementation process.

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About the Authors:

Cecilia Cecchini Architect, PhD in Architecture Technology, Associate Professor in Industrial Design. Founder (2007) and Director of the Master in Exhibit & Public Design. She carries out research about advanced materials, technology innovation, public design and cultural heritage.

Miriam Mariani PhD Student in Design. She collaborates in different researches in the field of Architecture and Design, in particular about Sustainable Architecture and Communication Design. She specialized in the study of Accessible Design, Design theories and Information Design.

Paolo Mondini Senior Material Scientist. After a few years in the academic research environment, he started working in the private sector, as member of the R&D department for industry groups in Italy and other EU countries. Actually, he works as project manager.

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