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BUILDING AND DESIGN TECHNOLOGIES

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Editorial

THE INGENUITY OF HUMANKIND IN COMPLEX TIMES

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This magazine issue is published amid an epochal systemic crisis. Perhaps we can imagine this crisis as a biological response that our living planet is giving to the ecological and social emergency humanity brought upon itself. However, we seem to be all in agreement that this crisis foreshadows a transitional phase, in which the scientific community this magazine is addressed to has to portray a prominent and proactive role.

This statement is supported and confirmed by the themes and contributions presented during the annual Ar.Tec. Congresses, and is validated by the essays published in the previous five volumes of TEMA, which refer to these Congresses. As mentioned in the association's first convention, in Rome in 2004, the necessity to support the life of the planet is a concept more and more prominent in the relationship between Architecture and Technique. The protection of nature and its resources, for future generations and social and individual life, entails the development of a profound knowledge of controversial environmental issues on one side and, on the other side, the ability to carry out the consequent actions throughout individual and collective decisions.

The technical, entrepreneurial, and design dimensions intertwine with cultural transformation, education, and learning, outlining a path of local and sustainable development. In these dimensions, a person must be considered as part of a collectivity (organism) that lives and operates in a specific territory (biosphere).

The innovative methodological aspects of this path consist of perfecting a design method, based on systemic vision and interdisciplinarity, and realized through the management of its complexities. All the different phases of the process must be corroborated, and the relevant results, which are verified through the participation of all involved parts, shall be integrated. Construction experts cannot deal solely with material structures anymore; they must explore and find connections with those sciences that study social structures. The challenge for social scientists, natural scientists, and all others is to build ecologically sustainable communities, designed to ensure that their technologies and social institutions do not undermine the world's innate capacity to sustain life.

Humankind's activities have always been intertwined with those of the surrounding natural realm, creating a complex and dense network of relations, in a constant dynamic equilibrium of actions and feedbacks; this equilibrium allowed life on our planet to be preserved and to evolve. Life is not only intended in a biological meaning, but also in a social and economic sense, and it refers to the entire ecosystem. Humankind's construction activity is strongly integrated with the ecosystem and is therefore responsible for the self-regulation process that sustains life.

In the current situation, the focus of the most recent Ar.Tec. Congress "Forma Urbana e Individualità Architettonica. Ingegno e Costruzione nell'Epoca della Complessità" appears even more relevant. In a historical time frame where town-planning design turns to tools such as equalization to reduce ground usage, it seems extremely interesting to reconsider the responsibility of building engineers and architects in the relationship between ethic, landscape, and aesthetic. Responsibility cannot be measured solely in terms of safety, durability, and efficiency of constructions, but also in terms of mutations in the perceptive quality of the *Ambitus*, which is permanently affected and modified by the single buildings, by the ultimate "form" we perceive of them, and, first and foremost, by the "individuality" of the relationships they generate.

Hence, for example, the need to thoroughly evaluate an intervention cost-benefit, to put construction as a creative act at the center of an interpretation, which includes the analysis of its connection with the external context's resilience, or even the possibility to make drastic decisions such as demolition for rebuilding.

In the contemporary world dominated by velocity, digitalization, and the fast transformation of knowledge, the ambitious call to ingenuity can appear outdated and contradictory. However, if our time is dominated by complexity and uncertainty, referring to the primary human ability, i.e., ingenuity, means taking back technical and architectural matters to their essence. Highlighting ingenuity means recalling the fundamentals of Building Technology and reaffirming the central role of design in the time of complexity, in order to strengthen the ability to face contemporary challenges and opportunities. For example, we need to focus on the emerging needs of a society in perpetual transformation and combine environment, safety, inclusivity, and, now more than ever, social justice. In fact, one of the milestones in the general appraisal on environment and development is affirming the principles of freedom, equality, and the right of appropriate living conditions for all. Another general appraisal in this day and age concerns the interpretation of the concept of "home" as a refuge, safe zone, office, classroom, meeting room, multi-generational space, garden, conversation space, gym, and so on. Will this recent experience be the pivot of a turning point in the redefinition of the concept of "home"?

In our country, it is also essential to recognize, care for, and give value to the enormous and widespread artistic, architectural, and cultural heritage. While referring to minor architecture, landscape organization, and the connection between tradition and innovation, we could repossess the principle of "Tradition to Innovation", which implies observing the future from a vantage point of view "the Shoulders of Giants of the past". In this sense, the building engineer or the architect should advocate for the most innovative techniques, such as Big data analytics, in order to process the existing with tools that are appropriate for the present and the future, and that can make the design more innovative, conscious, congenial and effective.

We are faced with the challenge and the opportunity to contribute in a transition from an undifferentiated economic growth to a regenerative and qualitative growth, from excessive mass tourism to the revitalization of sustainable local communities; from energy-intensive industrial agriculture to regenerative agriculture that respects biodiversity. The challenge and opportunity are to contribute to the restoring of the world's ecosystems so that viruses dangerous to humans are confined again to other animal species, where they do not harm. We have the knowledge and the technologies to seize the opportunities and favor these transitions. Will we also have the ability to transform them into the political will?

This editorial is inspired by the topic of Congresso Colloqui.AT.e2019, by the preface of Book of Papers from Emilia Garda, Caterina Mele, Paolo Piantanida http://2019.artecweb.org/it/atti/ and by the principles divulged by Fritjof Capra https://www.fritjofcapra.net/

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TOWARDS A USER-CENTERED FRAMEWORK TO SUPPORT PROACTIVE BUILDING OPERATION AND MAINTENANCE: PRELIMINARY RESULTS OF A COMMUNICATION PLATFORM BETWEEN USERS AND STAKEHOLDERS

Gabriele Bernardini, Elisa Di Giuseppe, Marco D'Orazio

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Highlights

A user-centered approach includes users' impact on building Operation & Maintenance.
A framework is proposed to include users' monitoring and engagement in O&M.
A users-stakeholders communication platform is developed to report building failures.
A web-based application is implemented and applied to a complex building case study.
It supports corrective maintenance and provides data for proactive O&M.

Abstract

Users' needs and behaviors can alter the building efficiency, thus leading to significant efforts to support Building Operation & Maintenance (O&M) tasks. This work develops the preliminary concepts of a framework for O&M including users' monitoring and engagement strategies. In the context of a complex university building, we developed and tested a users-stakeholders communication platform including a web-based application to report and check failures and damages to building's components and devices.

Keywords

Building maintenance, Occupants' behavior, Users' engagement, User-centered approach, Proactive maintenance.

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1. INTRODUCTION

Designing sustainable buildings, from the environmental, social and economic perspective, and considering the whole life cycle, is a priority objective, which should increasingly consider the effective occupants' behavior, in both normal and emergency conditions [1–3].

As a response to environmental stimuli, building users can decide to perform specific actions and interactions with building components and systems to achieve or restore optimal conditions in terms of well-being and safety. As a consequence, behavioral tasks modify environmental and/or building components conditions, thus generating a gap between the expected (planned) and effective (in-use) performances [4].

Building Operation and Maintenance (O&M) tasks are widely affected by such behavioral issues related to occupants' tasks and flows [5, 6]. A relevant example in this sense is the action of windows opening, which can be due to different occupants' needs and preferences (e.g. air change, temperature regulation, pleasure) and strongly influences the energy consumptions because of the indoor air temperature variation [7]. In working places and public buildings, the room occupancy can be organized according to specific schedules, thus also affecting occupants' flows. For instance, the elevator use is affected by the occupants' motion, with different solicitation levels depending on the distribution of people over time and space inside the building [8].

Methods, tools and integrated systems to support building O&M should take into account such effective occupants' responses [1, 3, 9, 10], including monitoring, modeling and users' engagement as key design and planning factors. Such a "user-centered" approach has been considered by many types of research on building energy efficiency [11–13], as well as on building safety in emergencies and evacuation process [3, 14, 15]. In the context of building O&M, in general, the "user-centered" approach aims to the optimization of related tasks, according to the following main aspects [1, 3, 16]. "Monitoring" of buildings and components allows defining the effective building conditions and users' actions to define representation models. Such "models" can be used to assess the impact of the occupants' behaviors on O&M tasks and evaluate the effectiveness of O&M strategies. Then, "Building Automation Systems" (BAS) could be connected to such models to support building stakeholders in adopting proper O&M strategies [10, 11, 17]. Finally, a direct "interaction with the users" can be useful to increase their awareness, to lead them to perform "proper" behaviors and to rise their satisfaction level in the building use [18–21].

This approach should be extended to the whole number of ordinary and extraordinary O&M tasks involving building components and systems (e.g. elevators, doors, flooring, electrical devices, etc.), as well as building management activities (e.g. cleaning, occupants' flows in the building, occupancy, etc.), since these tasks highly impact on the overall building life cycle impacts and costs [16]. Public buildings are the most significant application contexts because of the continuous presence of occupants (both visitors and frequent users), combined with the possibility to reach overcrowd conditions over space and time (e.g. large offices, universities, transport stations, etc.) [1, 22].

Hence defining fruition and maintenance priorities is a key issue for public buildings. According to EN 13306 standard [23], during the life cycle of an activity, "maintenance" tasks include the combination of all the technical, administrative and management actions aimed at maintaining the activity functional level (i.e. the building) or bring it back to a correct functional state. In this context, maintenance tasks should be conceived as an organized set of actions (and not as the sum of single corrective interventions) that involves technical and management aspects, within a life cycle perspective. In this view, *preventive maintenance* (before the system failure, to avoid its degradation) and *corrective maintenance* (after the failure has occurred, to restore the conditions) should be strictly linked [5, 10, 22, 24] by optimizing the organization of preventive actions (to limit unexpected failures due to the elements degradation) and providing immediate interventions to restore the functional conditions of the building element.

In this sense, maintenance strategies can take advantages of control-based (or rather, "cognitive") approaches, such as those related to: 1) *BAS* and *internet of things* (*IoT*)-based technologies [10, 25]; 2) direct communication from and to the users and the professionals within the maintenance team [19, 26]. BAS can manage data on the condition of the components, especially for those that can be directly and remotely monitored (e.g. lighting and cooling), eventually merging the information within Building Information Modeling (BIM)-based systems [25, 27]. Nevertheless, some building components cannot be directly monitored by BAS (i.e. "passive" components like doors, floorings, façade elements) or, in case of existing buildings, introducing BAS is challenging due to e.g. technical or economic issues.

Hence, previous studies underlined the importance of maintenance teams' actions, which can provide specific data from direct inspections (when and where they are necessary), as well as from direct involvement of the occupants, since they use the space daily and are the first subjects who directly suffer from the elements failures [20, 25–27]. Indeed, the participatory engagement of users in maintenance management processes (i.e. failures signaling and checking) makes them "aware" in the use of the building, thus supporting the stakeholders in identifying the scheduled or extraordinary actions to be taken. According to a "user-centered" approach for O&M, such communication framework could be additionally backed up by the monitoring of the occupancy conditions, so as to generally trace all the man-built environment interactions which can stress the overall system [10, 20, 28].

Finally, the possibility to combine and analyze all these data can ensure to move from a simple "planned" and "corrective" maintenance approach to proactive and predictive ones [1, 16, 20, 22]. In this sense, data on the current state and the ongoing failures of the building components/systems can be merged to the building use monitoring information, providing integrated simulation tools to forecast future maintenance needs and optimize time-based maintenance actions. Meanwhile, the proactive perspective could be improved because of the interaction between the stakeholders and the "maintenance-aware" occupants, in the building use. The advantages of such O&M method have been widely demonstrated in manufacturing [29, 30], but they could also be extended to buildings O&M to decrease impacts and costs of O&M tasks and to increase the users' satisfaction.

This work focuses on the development of proactive and predictive O&M strategies for complex buildings. The overall research aims at adopting the "user-centered" methodological approach based on the combination of data from cognitive building-integrated systems (for monitoring: users' presences, flows and behaviors; building components/systems state and degradation) and management communication platforms (involving building stakeholders, professionals of the maintenance teams and, mainly, the users). A merged control-based (to improve "conditions-based maintenance" and quick response to needed corrective actions) and a simulation-based framework is then developed to move towards proactive strategies in O&M. According to the methodological bases (Section 2), as a result the general operative framework is provided (Section 3.1), especially focusing on the development and testing of a web-based communication platform (Section 3.2). Such platform is applied to a significant case study, the Faculty of Engineering at Università Politecnica delle Marche (Ancona, Italy) (Section 3.3).

2. PHASES AND METHODS

The current work is divided into three main phases (in brackets, M refers to the methodological section, while R to the result section):

1. definition of the general user-centered framework for building O&M, combining condition-based and proactive criteria with cognitive building automation systems and users-stakeholders communication tools (M: section 2.1; R: section 3.1);
2. development of the platform for communications between the users and the stakeholders about failure signaling and conditions checking, within the context of a relevant case study (a university building) (M: section 2.2; R: section 3.2);
3. application to the case study to demonstrate the capabilities of the proposed communication platform, by performing a long-lasting testing campaign (M: section 2.3; R: section 3.3).

2.1. CRITERIA FOR THE OVERALL FRAMEWORK DEFINITION

The user-centered operational framework should dynamically collect data about [3, 4, 13, 20, 25, 28, 29, 31, 32]:

1. the users' occupancy and behaviors, over time and in space (including the interactions with building components and technological systems), in relation to the environmental conditions;
2. the "active" building systems (electrically supplied, connected to BAS via wireless or LAN connections) operation and state, through automatic and remote-control solutions (e.g. "on board" sensors), plus direct inspection processes (e.g. by the professionals of the maintenance team);
3. the "passive" building components status (those not provided with direct electrical connection) and the building management elements (e.g. cleaning), by means of the control on the users' actions, data on scheduled activities, direct inspection processes;
4. the users-stakeholders communication to report systems abnormalities and failures, through communication platforms, which can also be used for further feedback on occupants' satisfaction level.

According to a "cognitive" building perspective [3, 25], the collected data must be immediately shared with the stakeholders and analyzed to predict future scenarios in the building use, thus enabling the detection of critical conditions towards the alarms signaling and the application of conditions-improvement measures (i.e. interventions by the building O&M teams; automatic actions by the "cognitive" building elements).

2.2. CRITERIA FOR THE DEVELOPMENT OF THE COMMUNICATION PLATFORM WITHIN THE CASE STUDY APPLICATION

The campus of the Faculty of Engineering at the Università Politecnica delle Marche (Ancona, Italy) has been chosen as a relevant case study for the development of the framework, and especially of the communication platform. It includes several multi-story buildings, with an overall area of about 150000 m^2, hosting both teaching, laboratory, and office spaces, with an overall presence of over 5000 people per day. The presence of university staff members and students, as well as the size and the mixed-use of the structures, make the case study particularly relevant for the application of the O&M framework and, in particular, for the users-stakeholder communication platform.

The Faculty's Technical Department (FTD) is the stakeholder in charge of collecting failures and abnormalities reports from the users and addressing them to the maintenance service teams. In a period of about 15 months between 2018 and 2019, over 2100 O&M failures reports (intervention "request tickets") were made in the Faculty of Engineering, by covering the 40% of the total reports of the University. In this period, the management of the request tickets was quite complex and obsolete in terms of users-stakeholder communication (e-mails, phone calls), while an automatic process to manage the requests was limited to the FTD-maintenance service team interactions. Hence, to identify the requirements of the overall communication platform, the aforementioned general criteria [13, 25] have been combined with the outcomes of an interview with the FTD.

According to the interview, the new communication platform should: 1) trace unambiguous request data (in terms of type of intervention request, time of signaling, position of the damaged/not working element within the campus layout) and identity the user to activate a direct contact for further information requests from the FTD; 2) immediately inform the FTD of the failure signaling, and keep a copy of it in a shared central database; 3) immediately send a confirmation to the user and track the progress in the O&M activity state according to the FTD-maintenance service team interaction; 4) allow failures' signaling from different devices (including smartphones) only to a limited number of users who have a recognized rule within the Faculty (e.g. representatives of the student body, teachers and researchers, technical and administrative staff members).

2.3. TESTING CAMPAIGN

The new communication platform has been preliminarily tested by a limited number of users, which is representative of the building occupants' typologies (51 volunteers within professors, researchers, and representatives of the student body), from January to August 2019. Such a choice allowed improving the system by direct feedback from them, and different releases of the platform have been then published thanks to their support. However, during the test phase, the traditional communication channel between users and the FTD was still maintained.

Results collected from the communication platform in the considered period of 10 months are analyzed in absolute and percentage terms according to: the type of intervention, to evaluate the incidence of each considered building element; the building area where it occurs, to evidence which part of the buildings are most affected by the failures; the rule of the user, to evaluate the related engagement per typologies; the number of requests which needed additional information from the users to the FTD.

3. RESULTS

3.1. USER-CENTERED FRAMEWORK FOR BUILDING O&M

Figure 1 represents the schematics of the user-centered operational framework for building O&M proposed by this work. The framework is based on 4 main pillars (P), which are described in relation to their main elements and functions (evidenced in italics in the following).

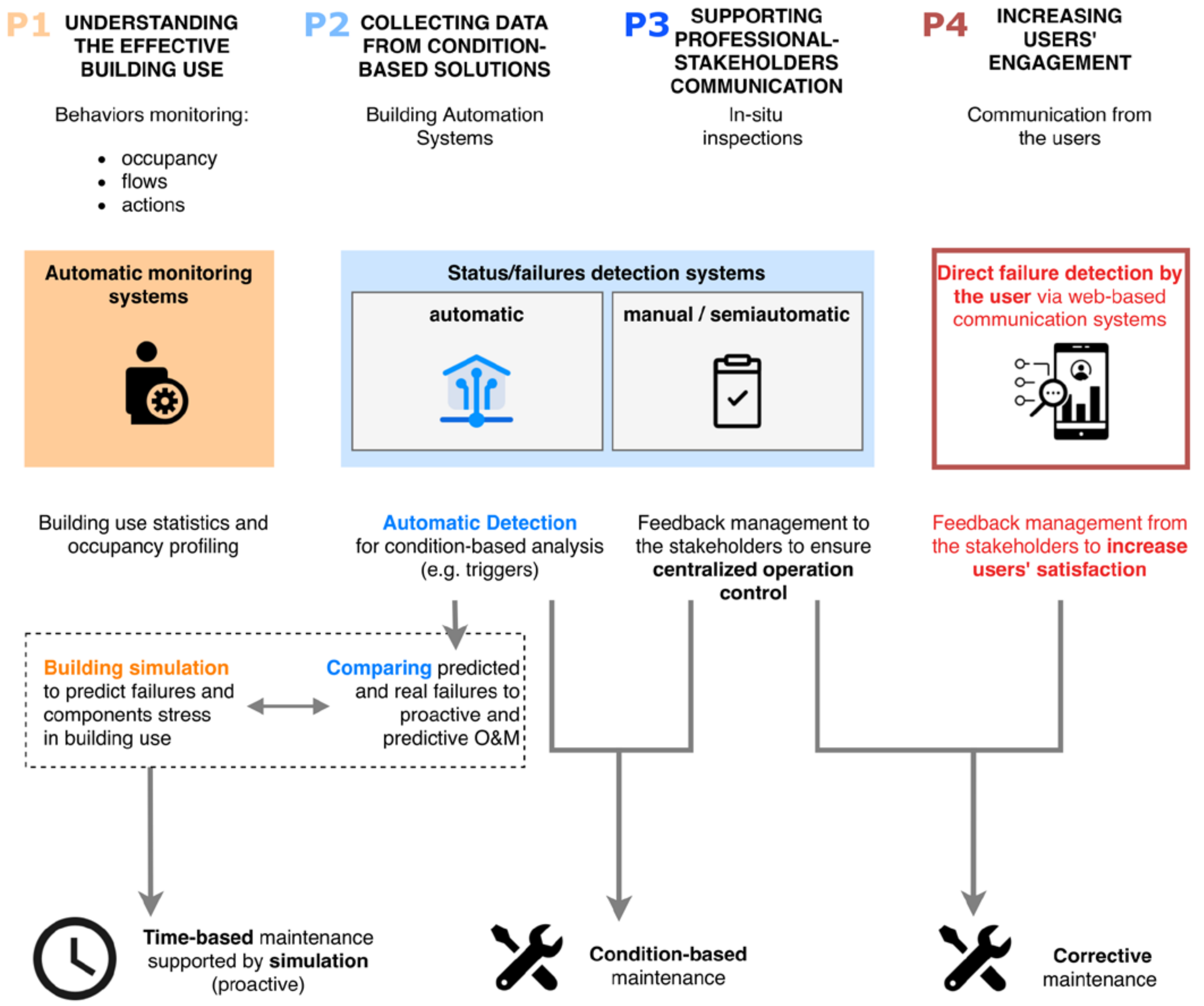

Fig. 1. *Overview of the proposed user-centered operational framework according to the main discussed pillar (P1 to P4 on the top) and towards the maintenance strategies (on the bottom).*

From a general point of view, *Understanding the effective building use* (P1) and *Collecting data from conditions-based solutions* (P2) can be achieved by means of BAS-based solutions, and should be integrated by *Supporting professionals-stakeholders communication* (P3). Furthermore, *Increasing users' engagement* (P4) will ensure system redundancy and quick-detection of failures, by promoting users' awareness towards O&M issues and checking their level of satisfaction while using the communication systems.

Monitoring systems aimed at P1 and P2 should be modular, easy-to-implement and maintain, as well as directly connected to a central elaboration unit within the BAS (e.g. by using wireless or low-energy communication systems; LAN and power-by-ethernet solutions), especially by considering "active" building systems and devices, such as the electrically-supplied ones (i.e. cooling, heating, lighting, elevators) [1, 3, 10]. The collected data allow defining if (and how) the monitored element is used by the occupants, so as to define occupancy and flows-related actions of the users, but also to check the state of the components in an automatic manner and additionally supply information on failures. For instance, the integration of sensors in lighting systems within a BAS-network would both allow to roughly estimate the lighting time due to the presence of individuals inside the room. Data for *automatic monitoring systems* of human behaviors and presence in the building space connected to P1 will support such kind of analysis (in the previous example, by giving additional data on the effective occupancy time). These sensors could also be used to trace the use of "passive" elements (e.g. doors, windows, flooring) by the occupants, which can stress the building components during the time (e.g. for door: number of openings; for floorings: users' flows density) [1, 13]. P1-related systems can use [10, 13, 33, 34]: "collective" monitoring solutions (per room/space/component, e.g. elevator), such as ultrasonic or infrared sensors; "object-based" monitoring solutions (per building component/device, e.g. windows, shadings), such as on/off (open/close) or power-based control systems; "individual" monitoring solutions (per occupant), such as those based on badges or personal devices tracking (e.g. via wireless connections) of occupants' position during the time. "Individual" solutions have a prominent rule in all the spaces where access control strategies are activated (also due to individuals' safety issues) and allow to include tools for users-stakeholder communication, also according to P4.

Data from such monitoring systems in P1 and P2 can be linked to derive occupancy profiles over space and time, depending on the activities carried out in the building spaces, in order to create a database concerning the effective use of the structure by the occupants [1]. This possibility is essential in complex buildings (such as universities) where different modes of use over time can exist, both in the short term (e.g. daily use for students, researchers and visitors; correlation with the lessons during the year) and in the long term, that is during the life cycle of the building (e.g. in relation to the number of students over time). *Building simulation* models can assess how future scenarios could be managed in terms of O&M tasks (but also in an individuals' safety perspective), so estimate the possible components failures or unacceptable stress levels due to the building use. This would lead towards the quantification of maintenance, renovation and building interventions/modifications tasks over time and space (e.g.: planning the replacement of building components; coordinate the cleaning tasks according to the presence of occupants over time; interventions on elevators due to different users' flow density) [10, 35–37]. *Comparing predicted and real failures* (and other maintenance actions) allows validating the simulation process, according to an experimental-based approach in a long-term perspective. Then, simulation data will support *time-based maintenance* (thus moving towards a proactive approach) [16, 20].

Merging P2 and P3 tools allow a complete control on condition-based maintenance tasks. In particular, the *automatic detection tools for condition-based analysis* (e.g. triggers connected to stress conditions and failures of the components) can be supported by *in situ-inspection* (through manual/semiautomatic methods, including both scheduled and one-off inspections) by [10, 38, 39]: creating *centralized operation control* platforms to connect the professionals of the maintenance teams and the stakeholders; managing the staff assignment for building maintenance when and where they are effectively needed. In this sense, the use of tools based on a multi-dimensional BIM approach can be useful for managing inputs in structured databases (by component, system, use) [25, 37].

Finally, P3 could be supported by P4 tasks because of the direct involvement of the users as active subjects into the failures signaling process for *Corrective maintenance* actions [1, 13, 25, 40]. Such an approach is relevant especially in case of limitation of implementation of BAS (P2), as well as with respect to the aforementioned "passive" elements to be monitored. The specific elements of such pillar P4 for the case study application of this work are discussed in Section 3.2.

3.2. COMMUNICATION PLATFORM

P4-related tasks shown by Figure 1 are aimed at encouraging the participation of users with regards to the maintenance issues and at increasing the interactions with the building stakeholder. Simple communication platforms can be implemented at this aim to: gather information on the failures and degradation/abnormality state of the elements; gather feedbacks on users' satisfaction; interact with occupants to support "good practices" in the building use, making occupants aware of the surrounding conditions and benefits of a proper maintenance in respect to

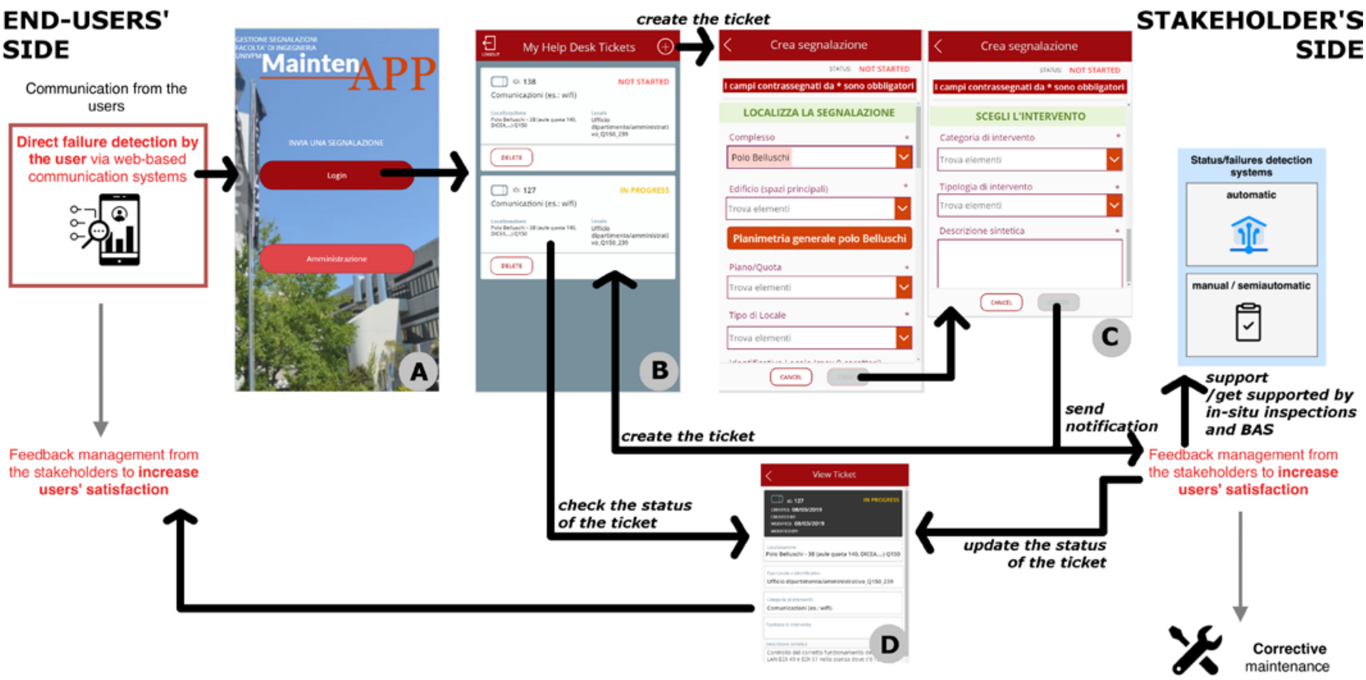

Fig. 2. *Communication platform for the failures signaling and checking according to the general framework perspective and by defining the relations (black arrows) between the end-users and the stakeholder. The main interfaces of the web-based application are described: after the login page (A), the main page lists the current users' request tickets (B), allows creating new ones (C) and checking the status of the existing ones according to the manager updates (D).*

their activities inside the building (e.g.: increased comfort, safety and productivity).

According to the general framework of Figure 1 and the methodological criteria of Section 2.2, the communication platform developed in this work is based on a web-based application, which is actually focused on the users-stakeholder interconnection for failures signaling. Figure 2 traces the general functioning of the platform from the end-users' and the stakeholders' sides.

According to the FTD requests, the access to the platform is only possible for university staff members and students, through individual access credentials, in order to ensure consistency between reported maintenance requests (called "tickets") and effective building users, in a traceability perspective in the flow of information.

As shown in Figure 2, the users can log into the platform by using an application called "MaintenApp" (Figure 2-A). The app is available both by smartphone, tablet and personal computers and was developed within the *PowerApps* platform of Microsoft Office 365. In the main app page, each user is informed of the state of his/her "ticket" (Figure 2-B).

While creating a new "ticket", the user is guided to fill in different form fields, which ensure the introduction of all the required details for the univocal identification of the intervention request (Figure 2-C). Firstly, to provide the location of the failure, a map of the campus is provided, in combination with information on the building level and room typology (via drop-down menu). More precise indications can be provided through an identification of the element or the room, thanks to the existing identification codes placed on the specific element or on the access door of the room. In view of BIM-based solutions for data storage, this choice could allow a direct integration between the location of the element, its characteristics and the related history of the "tickets", thus allowing failures reports and analysis, which can also be used to support simulation models (see Section 3.1).

Depending on the type of room and element, different lists of intervention categories are activated (e.g. fire-fighting system, mobile components, building components, electrical system, etc.). The exhaustive list is reported in Figure 4, according to the testing campaign results. A cascade correlation is established between type and subtype of interventions, e.g. for electrical faults, the types include interventions on lighting bodies, audio system, electrical outlets. In this way, the users are guided towards a proper compilation of the form by ensuring the consistency between the input data. Nevertheless, a further field of "free description" is introduced to obtain further detail on the failures. Then, the user provides contact information (e-mail address; for employees, internal phone number), to guarantee the possibility of contact by the FTD in case of need for further information.

Once the "ticket" has been completed, the user receives an immediate notification to the inserted e-mail address, while another communication is sent to the stakeholder. Then the online database where the "tickets" are organized is automatically updated (i.e. using the *Sharepoint* platform of Microsoft Office 365). The stakeholder can access the complete list of "tickets" from the webpage or through the dedicated section of the app.

Finally, the stakeholder can update the "tickets" state via the central online database, to notify the users about the resolution of the failure conditions (Figure 2-D). According to a BIM-based approach, the online database can be directly connected to BAS-related ones to ensure an automatic update of the elements state.

3.3. RESULTS FROM THE APPLICATION TO THE CASE STUDY

During the testing campaign, although the small participants' sample dimension, 151 "tickets" have been managed via the developed communication platforms, thus involving the 15% of the maintenance requests for the whole campus of the Faculty of Engineering. 37% of the "tickets" did not report any information on the "free description" field. Nevertheless, only 14% of the whole 151 needed further intervention by the FTD to check or request further data to correctly identify the failure (all of them were related to Plumbing, Cooling and Heating systems, characterized by a certain complexity within the building structure). 62% of "tickets" were sent by the representatives of the student body, thus highlighting a greater engagement of students with respect to the university employees. The majority of the "tickets" refers to failures located in the building floors with a mixed-use (classrooms and offices: 86%), while office spaces (9%) and labs (5%) were limitedly reported, also depending on the user-type related engagement results previously mentioned.

Figure 3 traces the "tickets" percentage in relation to the type of space where the failures occur. Most of the "tickets" are related to common spaces, i.e. corridors, staircases, elevators, main halls, and other open spaces where students can wait before and after the lessons. This result can be essentially due to the high flows of users inside the structure during the building opening time, as well as to the limited control of such intermediate spaces with respect to activities rooms. The same trend involves the toilets, where similar issues exist. Classrooms and offices show the same "tickets" percentages, while labs refer to minimum "ticket" percentage thanks to the high level of control inside such spaces (i.e. maintenance support by the lab technicians).

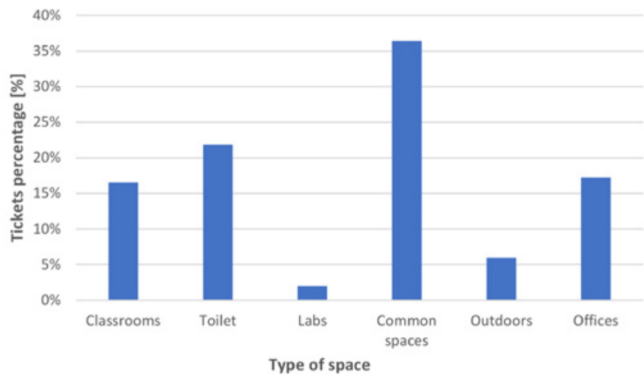

Fig. 3. *Statistics of the maintenance/failures "tickets" percentages in reference to the type of space in the university campus buildings. Common spaces include corridors, staircases, elevators, main halls within the building and other open spaces where students can wait before and after the lessons.*

Figure 4 shows the "tickets" percentage in relation to the type of intervention. Plumbing, Cooling and Heating (PHC) systems are considered within the same type of intervention according to the FTD interviews. This choice implies the higher number of failures signaling, essentially due to subtype of intervention concerning Cooling/Heating systems. In fact, Heating and Cooling related "tickets" correspond to the 17% of requests (see the light blue area for HC in Figure 4), thus being comparable to the intervention requests on the electrical systems. From a time-based point of view, requests on Cooling/Heating systems were essentially linked to the winter season (Heating systems; about 55% of the PHC system-related "tickets") rather than to the summer season (Cooling systems). The "free description" fields (combined with the subtype of intervention list) allowed a complete definition of the requests.

According to Figure 4, a significant part of the "tickets" is referred to "passive" components (Building components plus Windows and doors refer to about the 25% of the "tickets", and to about 35%, if also including furniture), thus evidencing the utility of the communication platform for the control of such elements. Finally, "tickets" organized in the "Others" type are essentially due to requests about the inaccessibility of some parts of the buildings during the opening time (e.g. some rooms are closed or unusable): such kind of requests e affects the operational tasks inside the spaces (performing activities by the users) and not to direct maintenance issues. In this case, the "free description" field allowed a complete definition of the intervention requests.

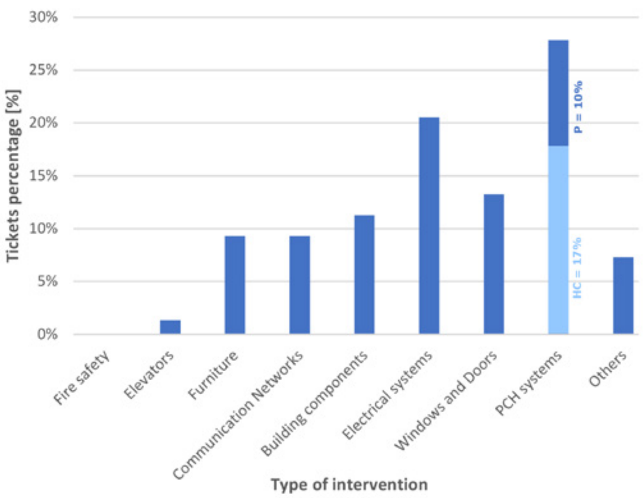

Fig. 4. *Statistics of the maintenance/failures "tickets" percentages in reference to the type of intervention. PHC systems include Plumbing (P, dark blue area), Cooling and Heating (HC, light blue area) systems, according to the FTD requests. "Others" includes additional kind of interventions.*

4. CONCLUSIONS AND REMARKS

Sustainable building management combines the optimization of available resources, the minimization of related costs, and the guarantee of a high level of satisfaction for users. In this context, Building Operation and Maintenance (O&M) tasks are one of the most relevant, during the whole building life cycle, and should jointly consider building components/systems oriented-strategies (e.g. based on a "condition-based" approach, by using building automation systems) and the actions of occupants inside the spaces (e.g. based on a "user-centered" approach). Linking these two key factors will also allow improving O&M tasks by including estimations of the impact of users' occupancy and actions, by means of simulation tools, to move from a corrective (and simple time-based) approach to a proactive one. Meanwhile, engaging the users in the O&M process can ensure a higher level of satisfaction due to the improved engagement.

This work provides a contribution in this sense, by proposing a methodological and operational framework according to the existing literature. In particular, the first results involve the development and implementation of a users-stakeholder communication platform based on a web application, for reporting building components/systems failures and abnormalities and checking the O&M action performance. The platform has been tested within a significant case study (a university campus), by involving a reduced number of users, so as to evidence its capabilities and create a reliable system.

Results evidence how the system can support the O&M process, especially for "passive" components (e.g. doors, windows, ceilings and floorings, walls, furniture), which cannot generally be monitored by building automation systems. Future activities will involve an extensive application of the platform within the university spaces used as a case study, to evaluate its effectiveness as the main O&M communication tool, over a broader time horizon, as well as the implementation on other significant public buildings. Occupancy schedule and spaces use modes (e.g. activities-based calendar, such as teaching for universities) can be implemented to correlate occupancy statistics and failures to O&M tasks. In this way, the system will provide data for simulation-based approaches in O&M. Furthermore, automatized communication between a central O&M control station and the users could be included in the communication platform, especially for the issues related to occupancy of rooms (also in the view of the optimization in the number of occupants inside each space, e.g. due to airborne disease mitigation or individuals' emergency safety) and users' flows inside the buildings (e.g. elevators' failures in combination to the planning of travel paths). Statistics on the "building needs" (efforts and costs for e.g. energy, maintenance) will be shared with the users to increase their awareness towards O&M tasks. Finally, the implementation of technologies for behavioral monitoring in strategic areas of the building will be implemented to pursue a proactive approach as a whole.

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PASSIVE SINGLE-STATION TECHNIQUES APPLIED FOR DYNAMIC CHARACTERIZATION OF REINFORCED CONCRETE BUILDINGS

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Silvia Castellaro, Annarita Ferrante

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Highlights

Seismic structures have always been a topical and critical issue in recent decades because the consequences of inadequate designs are often catastrophic and periodically recurring. The most widely used method for evaluating buildings behavior is the modal analysis with the response spectrum, where stiffnesses and masses determine the linear dynamic response of the model. The hypotheses that guide the designer are dictated by regulations and often allow approximations that lead mathematical models to deviate from reality. The dynamic characterization on an experimental basis, therefore, seeks to bridge this gap between model and reality.

Abstract

This work aims to better understand and improve the dynamic characterization of concrete frame buildings through the combined use of finite element modeling and applied seismology. The behavior of the FEM model is compared with values obtained directly in situ through non-invasive tests based on a sensor capable of detecting the seismic microtremor and provide direct information in terms of oscillation periods and displacements. The case study structure was measured using a seismometer, and, at the same time, modeled using SAP2000. By starting from extremely different initial data, multiple variations were made to the model to produce an increase in frequency, aligning it with the one detected instrumentally.

Keywords

Dynamic Characterization, Ambient Seismic Tremor, Single Pocket Seismometer, Structural Analysis, Targeted Structural Modeling.

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1. INTRODUCTION

The dynamic characterization of existing structures can be addressed with two different approaches.

The first approach is based on finite element (FE) digital modeling, which can simulate the behavior of the structure and derive characteristic frequencies and participating masses. In-depth analyses are necessary to obtain a good model and to know the dimensions of the load-bearing elements and mechanical characteristics of the materials that make those structural elements up. Accurate surveys and destructive material tests are generally the basis for modeling as faithful to reality as possible; in fact, the accuracy of the response given by computer calculations is very high but would undoubtedly be useless if the input data are not correct. Often many simplifications are made to create the model. The modal analysis is never used by itself, but it is the base for the assessment of the maximum acceleration that the system would receive in case of seismic events. To make this assessment, the regulations require the application of specific conditions and assumptions that are not always in line with the actual reality.

The second approach, less known, is based on the use of seismometers, to directly obtain experimental results. These instruments can identify the main modal frequencies with few measurements, also carried out non-simultaneously. Although simultaneous measurements allow getting the phase information, the main features of the dynamic behavior of a structure can be assessed even with a single instrument. For framed structures, it is relatively easy to determine the first three vibrating modes, while it is more complex and less accurate to gain information on modes above the third. In particular, the first three modes often involve different percentages of masses in flexures alongside the two main directions and a torsional rotation. The flexures associated to the first vibrating modes of the structure are characterized by a phase deformation, in which each node moves in the same direction. This type of measurement provides real data without having first known the characteristics of the materials used or the cross-sections of the load-bearing elements. It is, in fact, a non-destructive test that is performed on the whole building, without the need for artificial external loads, and which provides accurate data on the actual behavior of the building. The test is based on the measurement of microtremors. They are low amplitude environmental vibrations of the ground caused by human or atmospheric disturbances. Recorded microtremors can provide useful information about the dynamic properties of soils, such as specific periods and predominant amplitude.

Experimental data [1] have often highlighted the presence of a large gap between the frequency of the first mode of vibration of the computer-modeled structure and that detected by the seismometer, even if the two methods should lead to similar results. This discrepancy means that the FE model does not correctly describe the actual behavior of the building under microtremor conditions.

A real case study has been selected for an in-depth investigation to overcome this problem. In this actual case, the modal analysis data obtained through the use of SAP2000 software [2] have been compared with the in-situ measurement results, and a further effort has been made to bring the values to convergence. The intention is to understand which are the primary and secondary structural elements (parameters) that contribute most to the variation of stiffness.

2. STATE OF THE ART

The research aims to deepen the characterization of buildings from a dynamic point of view to optimize structural interventions on existing constructions, using tools that can provide satisfying results in a relatively short time. Although it is feasible to carry out structural core drilling and extrapolate samples to retrieve information on the resistance and the morphology of vertical and horizontal elements, it is now growing the need to find direct and prompt answers able to limit destructive-tests. Technological developments in the geological field seem to be promising in this direction. In particular, the instruments used for the detection of seismic environmental noise are worth mentioning. These instruments measure vibrations coming from natural and non-artificial sources and therefore defined as “*passive*”. The HVSR (Horizontal to Vertical Spectral Ratios) method represents one of the main techniques in this field; it was first applied by Nogoshi and Igarashi in 1970 and developed by Nakamura in 1989 [3]. By evaluating the relationship between the horizontal and vertical components of surface waves, the method can identify the amplification frequencies of the subsoil, thus allowing to compare them with those of buildings, verifying the presence or absence of resonance phenomena [4].

Although the invention of rudimentary seismographs dates back to the 2nd century AD, the authorship of the first seismograph, in a modern sense, can be attributed to the mathematician and philosopher Luigi Palmieri from Campania who laid the foundations for its subsequent development [5]. A seismometer is defined as an instrument that measures the temporal dependence of displacement, speed, or acceleration, using a mass that provides enough inertia. The seismometer produces a seismogram, i.e., a graph representing the dependence of the collected data on time. In structural assessments, a seismometer is generally used to detect acceleration, speed, or displacements depending on time, whose operation is based on sensors, amplifiers, and analog or digital recording instruments [6]. Typically, structural surveys are based on the use of accelerometers [7–9]. Under operation (or passive) modal analysis, it is assumed that the background noise is a white function. In the present research, we used a seismometer, also known as tromometer (from the Greek word for 'tremor'), tuned to record ambient noise. These instruments were originally developed to study the ground amplification properties (e.g., using the HVSR method) and were later found to apply also for the modal characterization of structures. The instrument has also been used for the dynamic characterization of a notable structure (the Eiffel tower [10]) and the soil-structure interaction during recent earthquakes [11–14]

3. CASE STUDY: ATHENS STUDENT HOUSE

Within the framework of the EU Project Pro-GET-onE [15], the design of an integrated seismic, architectural, and energy improvement system is currently in progress which is aimed at the realization of a prototype applied to a building belonging to the Zografou campus of the National and Kapodistrian University of Athens.

The in-line building is built in reinforced concrete (RC) frame with a total length of 58m. In the integrated

Fig. 1. *Ground floor plan of the Athens case study. In the blue box, separated by the expansion joint, the northern part of the building, and the different measuring stations.*

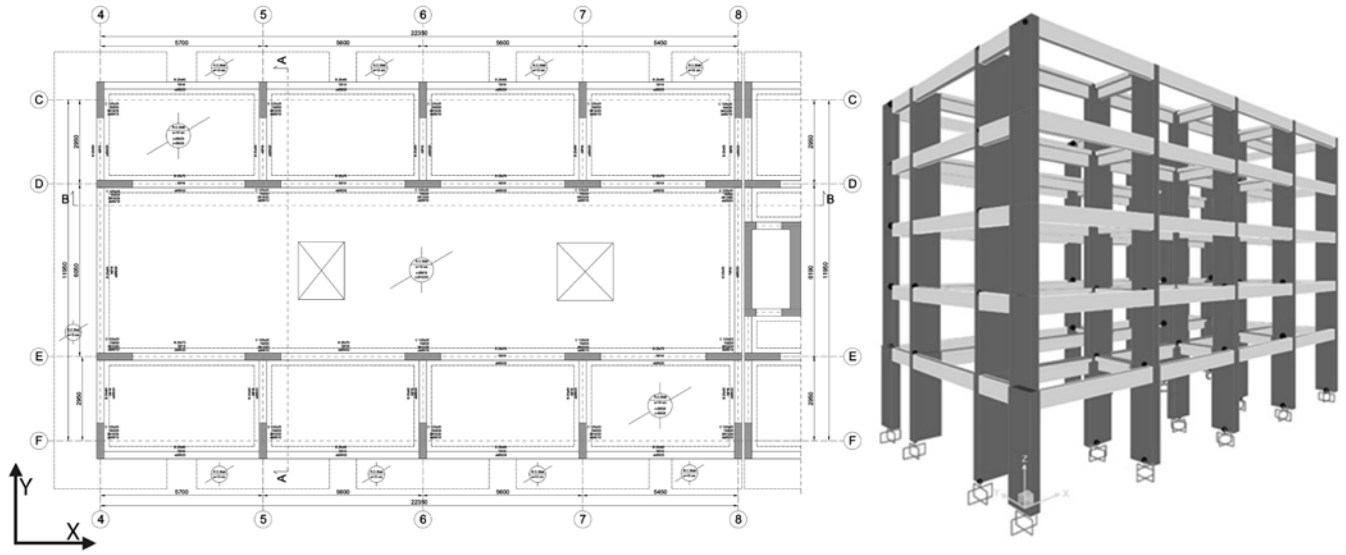

Fig. 2. *Structural plan of the type floor and a picture of the finite element model.*

system development as well as in this article, the northern portion of the building, separated by an expansion joint, will be taken into consideration (Fig. 1).

The structure consists of five floors, the basement 3,9 m high, and the four upper floors 3,0 m each; the plan dimensions of the Norther building are 22,35x12 m. The horizontal slabs are made of 18 cm thick RC and can be considered as diaphragm constraints. The vertical elements are RC walls of 125x25 cm arranged alternately in the two main directions, while the beams have different heights (from 55 cm to 70 cm) depending on the spans with a recurring web of 25 cm in width.

In the structural layout of the model floor (Fig. 2), all around the perimeter of the structure, there are balconies, made with a 15 cm thick slab, protruding 1 m on the larger sides and 1,5 m on the smaller ones. All the information concerning the building structure has been taken from a technical report made to obtain an intermediate level of knowledge. The reference categories for establishing imposed loads refer to Eurocode 1 [16]. Category A for parts of the floor dedicated to the rooms of the students (2 kN/m^2) and C3 for the central corridors (5 kN/m^2). Balconies were considered as loads applied on the perimeter beams of the frame. Hence a distributed torsional and shear loads were determined based on a cantilever scheme, also considering the imposed loads of 4 kN/m^2. Finally, for this discussion, it is essential to indicate the real stiffness values adopted, considering the cracking phenomenon. These values (Table 1) refer to the approach presented in the table 10-5 of the ASCE 41-13 [17]. Because of a lack of data about existing foundations, the FE model has been simplified by inserting rigid joints at the base.

Element	Flexural Rigidity	Shear Rigidity
Beam	0,3 EI	0,4 GA
Column	0,7 EI	0,4 GA

Tab. 1. *Effective stiffness values due to cracking.*

3.1. FIRST RESULTS FROM MODAL ANALYSIS

The evaluation of the dynamic characteristics of the building is carried out through a modal analysis that follows the indications provided by Eurocode 8 [18] (Tab. 2). By analyzing the results, it is possible to state that the first vibrating mode of the building has a frequency of 1,24 s$^{-1,}$ and it is a flexure in the transverse direction (y) that activates a mass percentage equal to almost 58% of the total mass of the building. The second vibrating mode is mainly torsional around the z-axis, with about 60% of the total mass activated with a frequency of 1,26 s^{-1}. The third vibrating mode is flexural in the direction of the longitudinal development of the building (x), with a frequency of 1,40 s^{-1}, and an activated mass equal to 85,7% of the total (Fig. 3).

Mode	Frequency (s^{-1})	Participating Mass		
		Ux	Uy	Rz
1	1,238	0	57,9%	26,0%
2	1,264	0	25,6%	57,9%
3	1,396	85,7%	0	0
4	4,151	≈ 0	6,6%	5,0%
5	4,261	≈ 0	5,3%	6,5%

Tab. 2. *Athens student house. Main results in terms of frequencies from the modal analysis.*

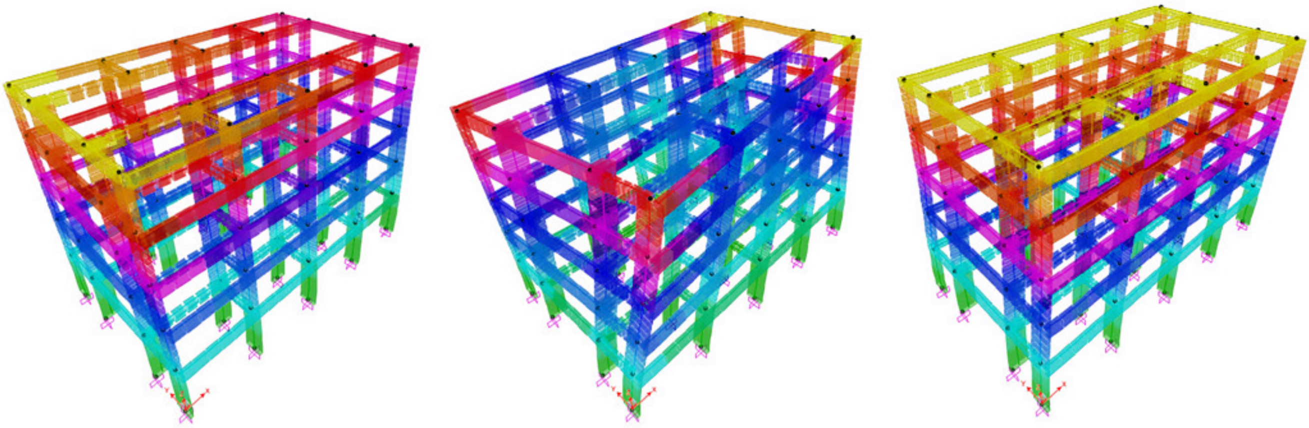

Fig. 3. *Deformable shapes of the first three vibrating modes. Respectively in ascending order from left to right.*

3.2. EXPERIMENTAL SURVEY

The survey of the building provided four measurements per each floor so that the structure could be analyzed as if it consisted of two independent parts separated by the expansion joint. Two measurements per section were taken, one in a central position for the single structure and one along the perimeter. Two stations for floor allow better studying the behavior of the building, also highlighting possible torsional modes. The measurements were made with Tromino® in positions A, B, C, and D (Fig. 1) on each floor on the same vertical axes. The acquisitions made in point A on different stories were superposed, and normalized to the basement level measurement, to highlight the relative displacements. In measurements on buildings, the smoothing of the curves is set to 2% so that the peaks are visible (Fig. 4).

Grilla software [19] was used to process the data. Each measurement is highlighted with a different color: the displacement is more significant as the floors increases for both the N-S and the E-W components. There is a peak around the frequency of 4,5 Hz for the E-W component, which indicates flexural behavior as the first vibrating mode. A second peak is detectable at 5 Hz frequency for the N-S component; this maximum means a flexure as the second vibrating mode. Other peaks with smaller amplitudes can be detected at 11 Hz, 14 Hz, 15 Hz, 21 Hz, and 25 Hz frequencies, indicating subsequent vibrating modes. Frequencies peaks above 50 Hz are of no longer interest in the analysis because they are too close to typical human activity frequencies. It is advisable to compare central and perimeter measurements to verify the presence of torsional peaks choosing the curves of the roof that have the highest amplitudes (Fig. 5).

By comparing these two measurements, it is possible to notice that the previously identified peaks are also present for the measurement of point B (blue curve).

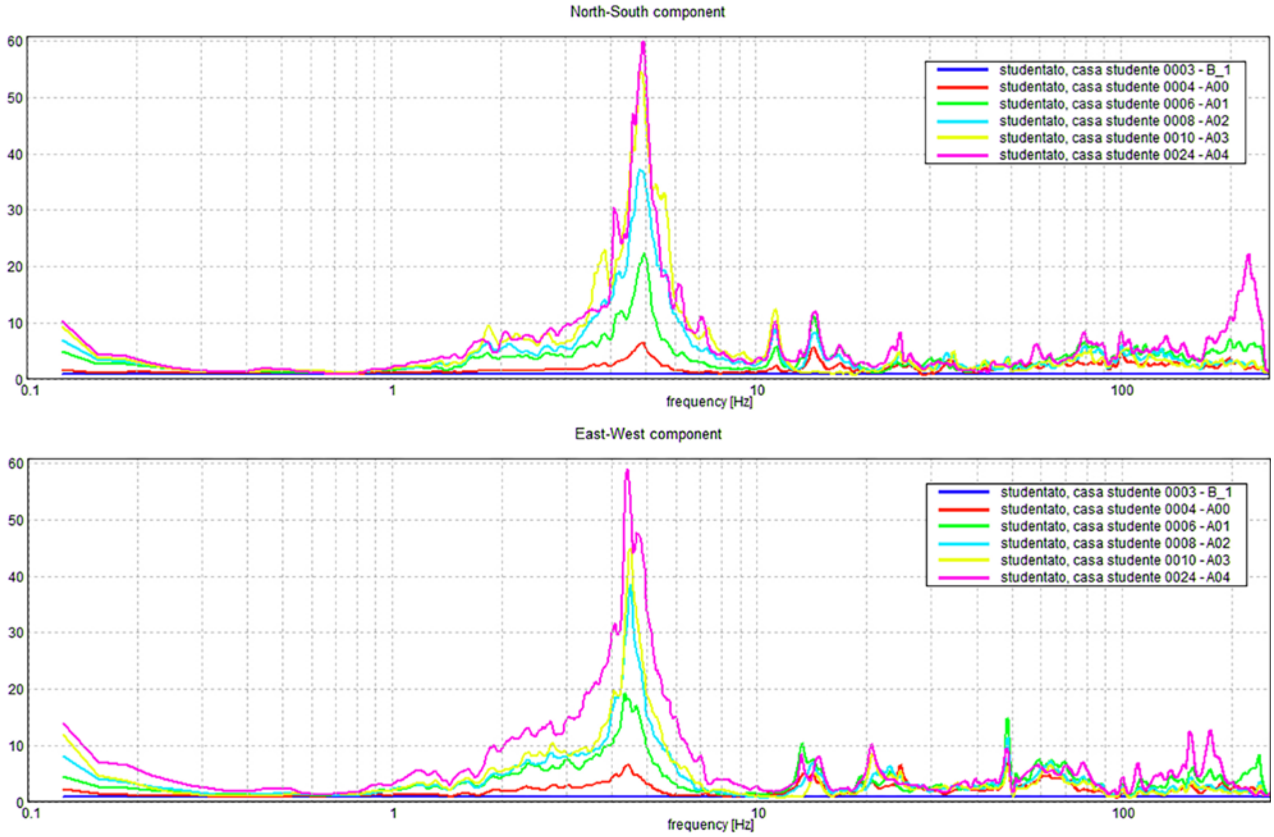

Fig. 4. *The spectral ratio between the N-S component recorded at different levels at site A on the structure and the spectral component recorded at the ground level (top). Same for the E-W component (bottom).*

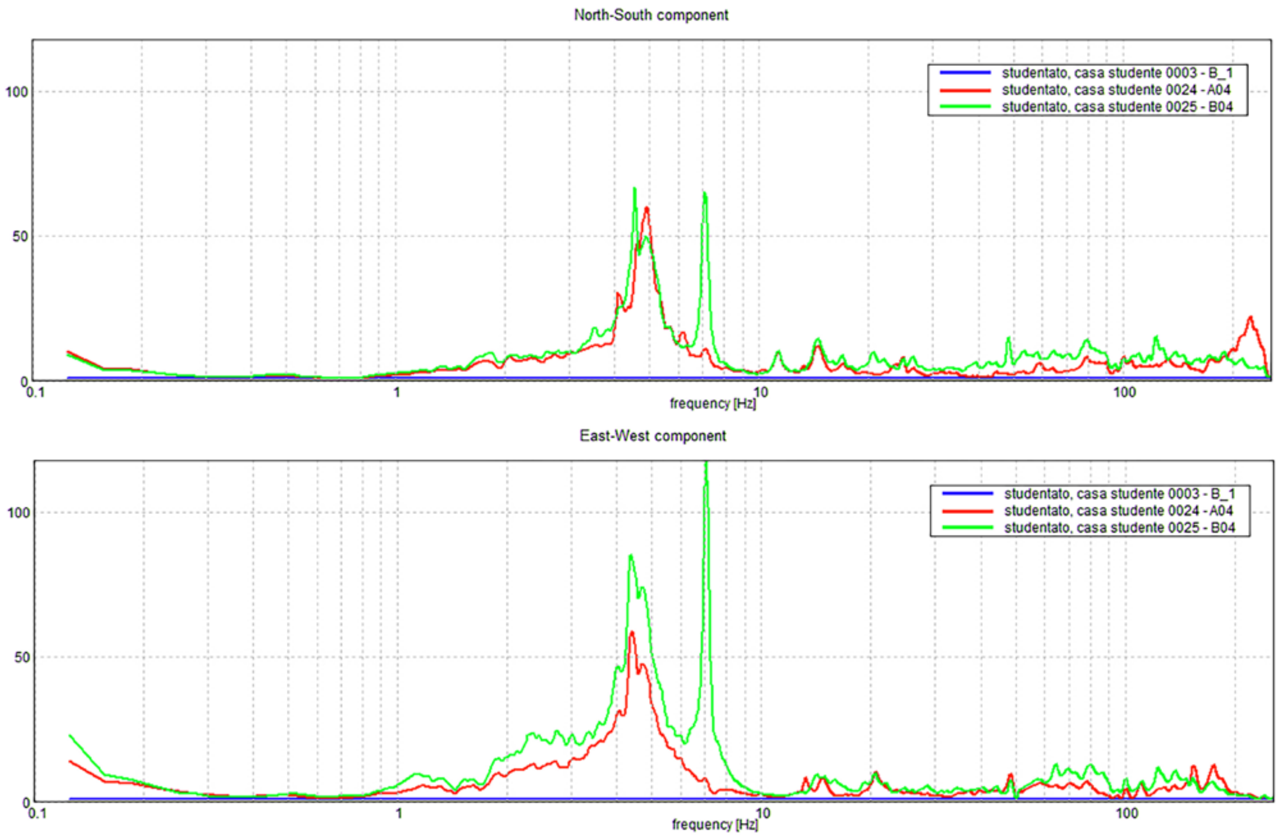

Fig. 5. *The spectral ratio between the N-S component recorded at the roof level at site A on the structure and the spectral component recorded at the roof level at site B. Same for the E-W component (bottom). A highlight of the torsional peak.*

From the graph of the East-West component, it is possible to register that the maximum at 4,5 Hz probably has a torsional component, highlighted by the fact that the amplitude of the B curve is much larger than the amplitude of the A curve. It is confirmed that the first vibrating mode at 4,5 Hz is predominantly flexural but with a relevant torsional component. The peak at 5 Hz, on the other hand, has a similar trend for both curves, so the second vibrating mode is a flexure. In comparison, at the frequency of 7 Hz, there is a maximum of curve B that is not present on curve A, indicating exclusively torsional behavior. Therefore, the third vibrating mode is the first torsional mode. As the frequency increases, the precision in reading the data is lower, so it is superfluous to go beyond the 5th mode (Tab. 3). Due also to thermal fluctuations of the structural parameters, the uncertainty in the assessment of the modal frequencies is around 2-3%.

Mode	Frequency (s^{-1})	Behavior
1	4,5	1° mode – flexure/torsion (E-W)
2	5,0	1° mode – flexure (N-S)
3	7,0	1° mode – torsion
4	11,0	2° mode – flexure (N-S)
5	14,0	3° mode flexure/torsion (N-S)

Tab. 3. *Athens student house. Dynamic characterization carried on with Tromino®.*

The frequencies detected in situ are almost four times higher than in FE modeling. The first vibrating mode is activated at about 4,5 Hz in microtremor conditions, while at 1,2 Hz in the software modal analysis, with a difference of 3,3 Hz. The in-situ frequency is 275% times higher than the one registered in the FE model. The same is true for the modes after the first, which for the FE model appear at 1,3 and 1,4 Hz frequencies, while the measurements are at 5 and 7 Hz frequencies. This discrepancy is considerable, but it is not the only one. The data measured under microtremor conditions show an inversion between the second and third modes of the structure. While for the analysis performed with the FE model, the second vibrating mode is mainly torsional, the experimental data show that the third mode is torsional. These discrepancies are due to several factors. Since under microtremor conditions, the loads are minimal, non-structural elements can contribute to stiffening the structure. During an earthquake, when this contribution fails, the building's frequency may be lower than that measured under microtremor conditions. At the same time, it may be relevant to report also that the FE models that are created for the dynamic assessment of structures are subject to strong approximations and are often using safety parameters or coefficients that bring to different results. This simplification brings to an underestimation of the real frequency, which is higher than that calculated by the model. Especially considering frequent earthquakes, with a low return period.

4. INFLUENCE OF PARAMETERS ON MODELING

The most important parameters that affect the modal analysis of the structure will be analyzed: characteristics of the construction system and materials, the magnitude of the loads, evaluation of the curtain walls, modeling of floors, and the underground level with related restrains. For this study, reference was made to the master thesis developed in collaboration with Carretti C., Fusco G., and Marini L. on the passive dynamic characterization of reinforced concrete structures for the calibration of numerical models [20–22].

The identification and characterization of the building construction system under examination is the first step to be taken to reach a level of knowledge, such as to be able to estimate its behavior. The definition of the spatial distribution of the load-bearing elements and their geometry is essential to create the stiffness matrix that determines the vibrating modes. A laser scanner survey showed that the walls in the basement were larger than those provided by the project reports. Instead of having a constant horizontal cross-section of 25x125 cm, the walls are 40x125 cm at the underground level and 35x125 cm on the upper floors. This variation was attributed to the vertical elements. Again, regarding the RC walls, the replacement of beam elements with shell elements indeed represents another possible, if not necessary, variation based on the dimensional ratios of the elements. The presence of the balconies was initially considered only through loads applied on the perimetral beams; as a third variation linked to the characteristics of the building, their insertion as cantilever slabs was evaluated. The uncertainty about the materials used during construction can also be very high and, at the same time, decisive on the results. The impact on the dynamic modal analysis depends directly on the elastic modulus (E) of the materials that characterize the structure and, consequently, on the degree of cracking. It can be considered in the software through a general reduction of E, or, as in this case, in a more specific way, on the resistant elements flexural and shear stiffness. Specifically, the elastic modulus has been varied from the initial precautional value given by the technical report of 29962 N/mm^2 up to a maximum of 45420 N/mm^2 relative to a C80/90 concrete. Concerning the cracking phenomenon, it was decided instead to eliminate the precautional reduction since it is immediately perceptible from the current conditions of the building that the assumed cracking values are too high for the real conditions of the structure.

Once the characteristics of the load-bearing structure have been established, the next step is to determine the loads it must bear. In the analysis aimed at identifying the seismic vulnerability, it is necessary to comply with the indications provided by the regulations. However, the aim of the regulations is the life-safety of inhabitants. The expected loads can, therefore, be much higher than those that the structure bears and very different from the crowded condition assumed by the regulations. Therefore, different load reduction solutions have been assessed, ranging from a drastic reduction to complete removal. Besides, the stratigraphies of the floor were progressively detailed, obtaining the precise value of permanent loads carried by also removing the generic distributed load resulting from the internal partitions.

The curtain walls are among the others, the most influential components on the stiffness of the structures and the consequent vibrating modes. It has been demonstrated how these can be relevant to the overall behavior of a building [23, 24]. Three solutions were considered: linear loads applied to the beams, equivalent X-braces, or shell elements inserted in the frame spans affected by the presence of significant masonry walls. The thickness of the masonry is 25 cm considering an elastic modulus of 3000 N/mm^2.

Like what happens with curtain walls, there are different ways of representing floor slabs. If sufficiently rigid, they can be compared to a rigid diaphragm constraint that connects all the points belonging to the same plane. In this case, modeling using shell elements, with weight and stiffness characteristics like those of the material arranged on-site, is one of the possible alternatives to a rigid diaphragm.

Finally, the presence of the underground floor implies the need to evaluate the incidence of the variation of the ground level for the application of seismic loads. Its presence, or absence, affects the global behavior of the structure, and it must be evaluated in the modeling variables. Not having enough data on the soil characteristics, it was difficult to model its behavior in detail. Therefore, different hypotheses of restraint of the vertical elements at ground level have been evaluated. The use of a rigid link represents the most extreme and relevant (in terms of vibrating frequency results), situation. Under micro-tremor conditions, it simulates the correct behavior of the building as directly connected to the ground.

Parameters	Frequency increase (%)	Mass variation (%)	Order variation
Constructive system	12,0	7,0	No
Shell for modeling walls	1,4	20,0	No
Modeling of balconies	2,0	28,2	No
Modulus of elasticity	23,1	-	No
Cracking	44,1	19,1	No
Loads	7,9	17,9	Yes
Curtain walls and internal partitions	16,0	16,0	Yes
Modeling of floor slabs	16,0	23,6	No
Underground floor	27,9	25,6	No

Tab. 4. *Incidence of the most relevant parameters on the characteristic frequencies.*

4.1.RESULTS AND SUMMARY

It is worth remembering how the analyses carried out refer to an existing building on which surveys and measurements have been carried out to determine specific parameters as useful variables to understand their impact on the model's behavior. After having analyzed the impact on the modal analysis in terms of frequencies, participating masses, and order of vibration modes, it is possible to illustrate the summary of the most relevant data. By using the acquired data, it is possible to intervene in the initial model to make it converge on the experimental data collected. It is possible to notice that the most relevant parameters on the modal analysis of the building are the cracking, which affects the frequency up to 44%, the elastic modulus (23%), and the evaluations on the underground floor, about 30% (Tab. 4).

4.2. FINAL MODEL

Based on the analyses conducted and data collected on the key parameters, various modifications were made to the initial FE model:

- Use of C20/25 for all the elements of the structure without stiffness reduction due to cracking.
- Use of rigid diaphragm constraints and floors considered as equivalent loads distributed on the RC beams.
- "Real" configuration of permanent and imposed loads (G_2=1,4 kN/m^2 on each type floor while for the roof G_{2roof}=1,85 kN/m^2; Q_k=0,5 kN/m^2 for the corridors and 1 kN/m^2 for the rooms).
- The extension joint that divides the buildings is eliminated in the model, and a concrete slabs connection is considered. In seismic microtremor conditions, the whole building vibrates together.
- Walls modeled using shell elements with the horizontal cross-sections obtained by the laser scanner survey.
- Balconies are considered in the rigid diaphragm constraints around the perimeter of the building with the proper loads' definition.
- Insertion of the stairwell and elevator spaces using shell elements to simulate the walls considering the whole structure in the model.
- The underground floor is considered by inserting perimeter partitions and considering the influence of the ground with perimeter supports (restraining the translations) at the level of the external soil.
- The external curtain walls and the main internal partitions have been inserted considering a 30 cm masonry walls modeled with shell elements.

The modal analysis of the modified model led to the results presented in the following table (Table 5), together with the results of the initial model, carried out following the indications of the regulations, and the experimental data obtained with Tromino®.

N° Mode	Frequency (s^{-1}) – Main direction		
	1° Model	Final model	Experimental data
1	1,238 – Uy	4,542 – Uy	4,5 – Uy
2	1,264 – Rz	4,818 – Ux	5,0 – Ux
3	1,396 – Ux	4,849 – Rz	7,0 – Rz
4	4,151 – Uy	15,931 – Ux	11,0 – Ux
5	4,261 – Rz	17,674 – Rz	14,0 – Rz

Tab. 5. *Comparison of characteristic frequencies between the initial and final models with the experimental reference data.*

The results show that in the final model, the first vibrating mode occurs at a frequency of 4,54 s^{-1} and mainly involves a flexure along the y-axis that activates a participating mass equal to 68% of the total mass of the building. The second vibrating mode, at a frequency of 4,82 s^{-1}, consists of flexure in the x-direction, activating 78,5% of the mass. The third vibrating mode is a torsion around the z-axis, at 4,85 s^{-1}frequency, which activates the 67,2% of the total mass. It is possible to notice how all the modifications applied to the model allow getting values very close to the experimental data both in terms of vibrating modes frequencies and directions.

5. CONCLUSIONS

The research shows how it is possible to calibrate the numerical model realized during the design phase, bringing the characteristic frequencies to convergence with the experimental data measured by a single station survey. The discrepancy that can be found seems to be mainly due to the presence of curtain walls, partitions, and considerations related to cracking and modulus of elasticity of the material, parameters often not considered or reduced based on prudent assumptions. The most incisive parameter on the variations appears to be the external curtain walls, especially where they are present in a significant way and have significant dimensions. Considering them induces changes not only to the participating frequencies and masses but also to the order of the vibrating modes. The discrepancy between the frequency values of the structures modeled according to the regulations and the experimental data found on-site raises questions about the safety assessment. By applying different periods to the response spectra, it is possible to obtain significantly different values of reference pseudo accelerations. On the one hand, these differences, lead to an increase in the structure resistance, due to an increasing number of resisting elements and a reduction in displacements due to a considerably increased stiffness; on the other hand, a lower period increases the seismic demand and an overall structure ductility reduction. Last, beyond the difference between experimentally assessed modal frequencies and frequencies computed through numerical models, another aspect to consider is the resonance frequencies of the ground, particularly when they are close to those of the structure.

6. ACKNOWLEDGMENTS

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ADAPTING TOWARDS RESILIENCE: ANALYSIS OF THE CONSTRUCTION FEATURES AND DYNAMIC ENERGY PERFORMANCE OF AMPHIBIOUS AND FLOATING HOUSES

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Highlights

Adaptation to changing climate conditions could support resilience. Amphibious and floating houses can be employed in flood-prone regions. Their peculiar construction characteristics are analyzed. Their energy performance in different climates is assessed. The application in Mediterranean regions needs tailored passive strategies to improve energy performance.

Abstract

In the current scenario where urban areas are exposed to extreme climate phenomena, resilience of cities and buildings becomes fundamental. Thus, not only defensive, traditional actions, but also alternative solutions towards resilience need to be implemented. Amphibious and floating houses, still not investigated in literature, allow the building to adapt to water presence due to their specific construction and technical properties. Here, we consider such buildings' typologies under the construction and thermal-energy performance lenses, by means of yearly dynamic energy simulations.

Keywords

Amphibious Architecture, Construction Elements, Thermal Energy-Performance, Resilience, Flooding Risk.

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1. INTRODUCTION

In the current scenario of cities' growth, the United Nations predictions state that in 2050 66.4% of the world's population, about 9.5 billion people, will reside in urban areas [1]. This data assumes greater relevance when compared with contemporary data: today, of the total world population of 7.2 billion people, 54% resides in cities, which corresponds to 3.9 billion citizens living in urban areas nowadays; by 2050 there will be 6.3 billion living in cities.

This means urban areas will be one of the main fields where the challenge for sustainability will be held, by means of social, economic, and environmental sustainability. In addition to the increased population and land use, other challenges regarding decision making and social issues, frequently reported by the scientific community, need solutions to mitigate their negative consequences. Therefore, it is essential to take into account climate change [2–4], which effects include global warming, an increase in extreme climatic phenomena, drought and desertification. The forecasts for these changes are more or less exacerbated according to the achievement of specific objectives, such as the drastic reduction of consumption and therefore of emissions.

Specifically, urban areas are affected by climate change in terms of increased temperature, due to the phenomena known as Urban Heat Island [5, 6], and increased flood risk, caused by extreme rainfall and soil sealing, due to the constantly increasing land consumption [7–9], as well as sea-level rise (Fig. 1).

Both phenomena constitute risks to the safety of the population and a significant economic burden: just considering the last twenty years, flooding has affected 2.3 billion people and caused damage for over 165 billion dollars. The built environment, "responsible" for the sealed soil and for protecting people's safety, has an important role in reducing these critical issues, through strategies that are increasingly aimed at resilience and adaptation, rather than traditional defence.

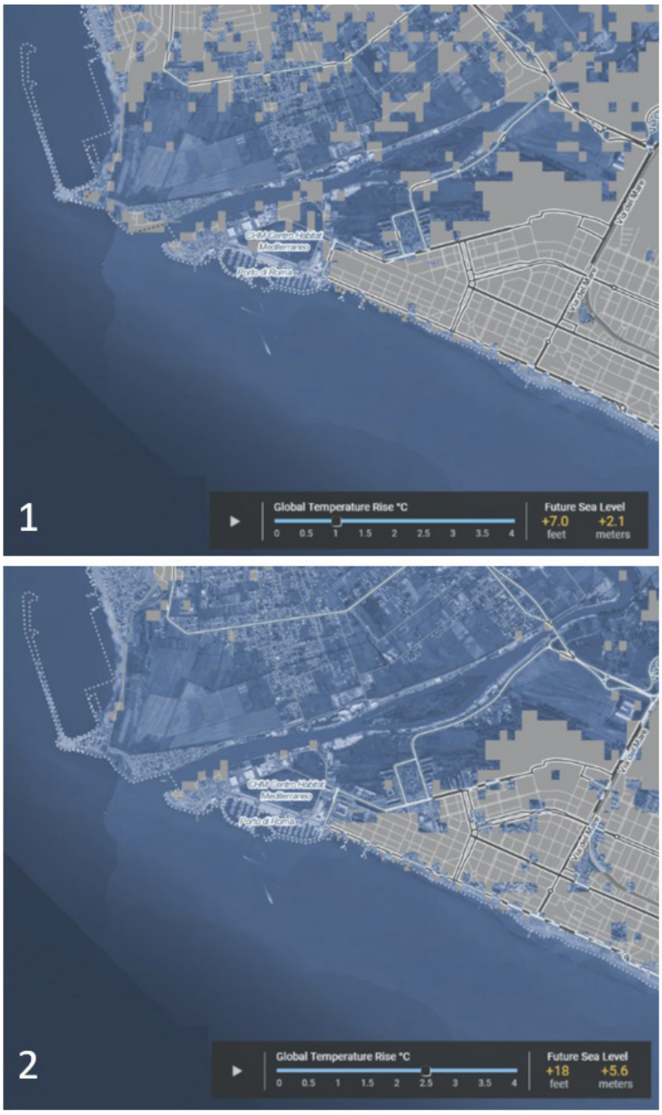

Fig. 1. *Sea level rise and flooding risk in Ostia Lido, Rome (Italy). 1, scenario in the case of 1°C temperature rise. 2, scenario in the case of 2.5°C temperature rise. Projection from [10].*

Resilience means the ability of a system (for example, the city) to adapt to changes that disturb its balance: in this case, the risk from climate change is mitigated by adapting flexibly to the changing environmental conditions. This approach is seen by the scientific community as more effective or complementary to the traditional defensive approach.

An example of this strategy, applied to the built environment and buildings, is the development of water resilient building typologies [11–14]. In this article, amphibious and floating houses are taken into account, which are designed to increase resilience in urban and non-urban areas vulnerable to floods. The construction features make these buildings suitable to be livable in the presence of water while maintaining safety and well-being requirements.

In this work, a careful analysis of the construction and technical characteristics of the amphibious and floating buildings is carried out and their energy performance is particularly considered, since knowledge of the consumptions is fundamental to reduce emissions, mitigate climate change and Urban Heat Island. While amphibious and floating houses are gaining popularity – especially in flood-prone areas – and the state of the art is advancing, there are still not numerous scientific studies aimed at analyzing their characteristics to better understand the technologies applied, and improve their overall performance [12, 15]. The objective of this contribution is to analyze amphibious and floating houses, highlighting their constructive characteristics and energy performance, hypothesizing improved application particularly suitable for the Mediterranean area.

2. METHODOLOGY

The study is conducted throughout different phases, which are described in greater detail in the following subsections.

In the first phase, the technological and construction characteristics of amphibious and floating houses are presented. The differences between these two building typologies are evidenced and the most suitable applications, depending on the surrounding context, are highlighted. A case study is then selected, and an existing amphibious house in England is modeled in the Mediterranean environment also. The case study is eventually modeled and simulated by means of yearly dynamic energy performance. Results are gathered and discussed in the last sections of the work.

2.1. ANALYSIS OF CONSTRUCTION CHARACTERISTICS

For the analysis of the construction characteristics of amphibious and floating houses, a careful investigation of the state of the art and literature was carried out. Most of the existing examples are located in the Netherlands, but there are some cases of amphibious and floating architecture also in Australia, Canada, England, Bangladesh, and Thailand [12], where the need to be protected and adapt to the presence of water has led to the diffusion of resilient solutions.

In the volume "Aquatecture" [16], the authors, co-founders of the architectural studio BACA, define amphibious houses as "houseboats designed to rise on fixed foundations […] and that rise on guide-posts, floating on the water", while floating houses "rise on a floating base, designed to rise and fall with the water level". BACA Architects, London, are the designers of the first amphibious house in the United Kingdom, located on the River Thames [17] (Fig. 2 and Fig. 3).

In the Netherlands, entire neighborhoods are built on water, as in the case of Ijburg in Amsterdam, where Mar-

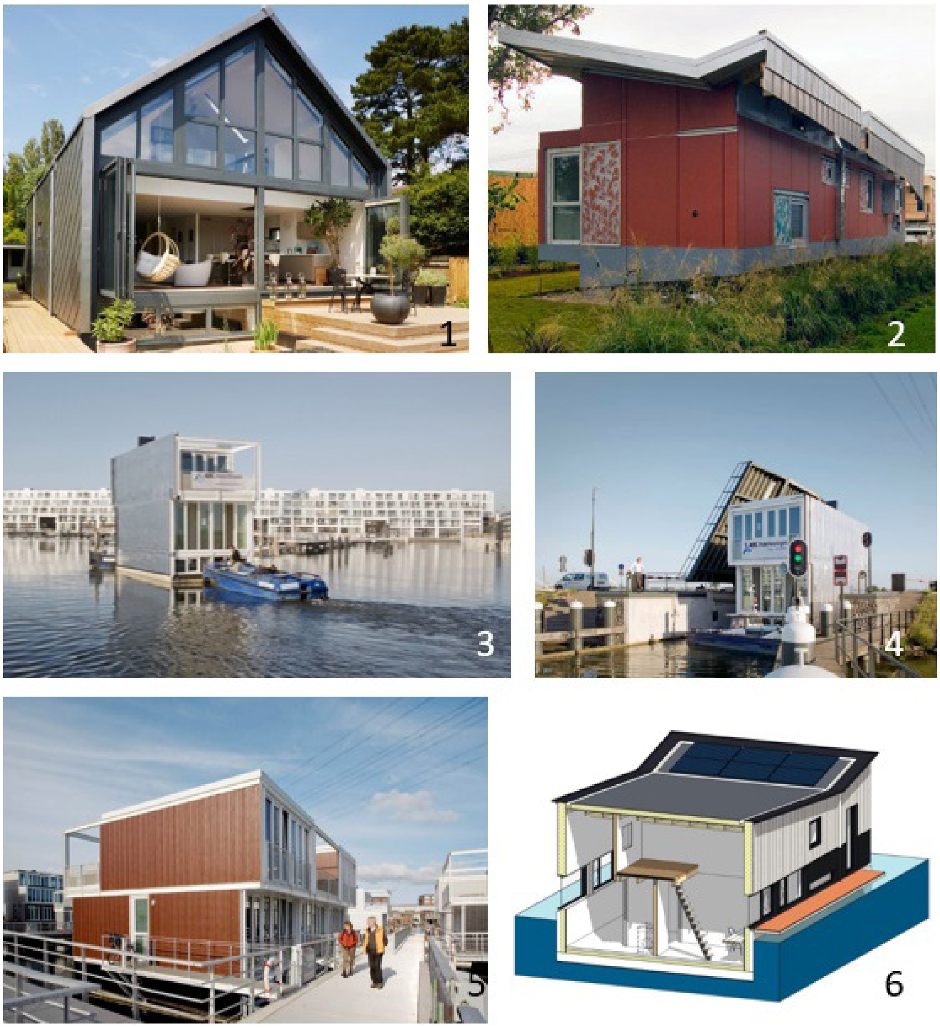

Fig. 2. *1, Amphibious home, BACA Architects, UK; 2, amphibious home, Morphosis, USA; 3, 4 and 5 Floating homes Ijburg NL, Marlies Rohmer; 6, floating home, Attika, NL.*

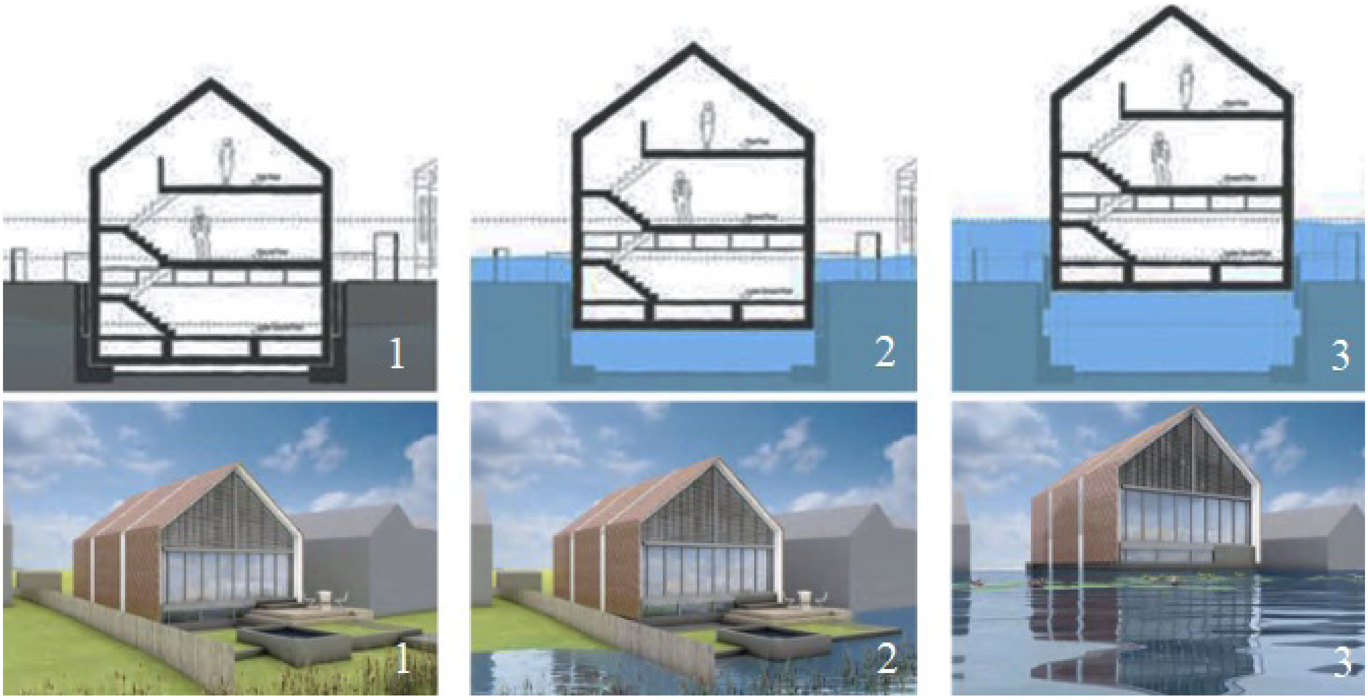

Fig. 3. *The amphibious home by BACA architects in UK: 1, static position; 2 e 3, floating in different flooding stages. Image adapted from [16]*

lies Rohmer Architects and Waterstudio studios [18, 19] designed the floating buildings (Fig. 2). The architecture studio Attika [20] built many houses of these typologies, as well as ABC Arkenbouw and Dura Vermeer, which is a construction firm specialized in floating houses [21, 22] (Fig. 2). Another North-European example of floating architecture is "Urban Rigger", by BIG Architects, which consists in 12 floating studio apartments for students in Copenhagen, and which received multiple awards in 2017 [23] (Fig. 4).

In Canada, MOS Architects built a floating house, a "houseboat" on Lake Huron, while in the United States, following Hurricane Katrina, Morphosis designed LEED-platinum-certified amphibious houses to improve resilience. Images of the above-cited floating houses are visible in Figure 4.

From the analysis of the considered examples, the construction and technical characteristics of the two building types emerge. Buoyancy, which is the main physical basis for the functioning of such typologies, is based on the Archimede's principle, according to which a body immersed in a fluid receives a vertical buoyant force equal to the weight of the fluid that the body displaces. The buoyant force is applied to the center of gravity of the displaced mass. For both amphibious and floating houses, the internal arrangement of partitions and furniture components must be designed with particular attention. Indeed, it is crucial to have a uniform and symmetrical weight distribution to achieve and maintain the equilibrium.

With respect to amphibious houses, they are characterized by two fundamental conditions: (i) the "static" position, in the absence of water, and (ii) the "floating" position, in the presence of water at different heights (flood depths), depending on the intensity of the flood (Fig. 3). The house is partially built inside a hole in the ground, the so-called wet-dock, which is about 2.5-3.0 m deep. The base of the wet-dock is a concrete slab, permeable to water, placed on piles, with Larssen sheet piling retaining walls along the perimeter. In static conditions, the house rests on the stalls and is secured to the wet-dock by two "guide" poles, on which it slides, rising and lowering, in case of flooding. The ground floor of the house (*caisson*) is made of dense and waterproof reinforced concrete, designed to be resistant to impact damage but also for ensuring the buoyancy. Above the caisson, which constitutes the basement, and which can be partially underground, the house has a wooden frame or still employs other light materials for the above-ground parts. The utilities' connections between the building and the ground are made of flexible and well-insulated pipes so that they can move when the house floats. The space between the building and the walls of the wet-dock is reduced as much as possible by a concrete curb, to avoid the access of debris that could prevent the floating mechanism, which works within certain height limits: it is limited to 2.5 -3.0 m elevation compared to the static condition.

The difference between amphibious and floating houses is that the latter is always in the water, i.e., in a floating condition, while the former is in the water only in case of flooding. Floating homes are connected to the mainland by a jetty and are subject to greater variety. They are very similar to amphibious houses; they are anchored through guide-poles, but they differ from each other in the techniques used to guarantee buoyancy. Some floating homes, such as those in Ijburg, are built with a heavy base made of waterproof concrete, just like the above-described amphibious houses, with a light wooden frame structure above to keep the center of gravity low and ensure stability. As already mentioned, unlike amphibious houses, floating houses always remain in floating conditions, and the mooring posts are placed on the two diagonally-opposite corners to avoid overturning. The floating houses are built entirely in the factory and then transported to the site, sometimes directly by water, as shown in Fig. 2.

Other floating homes are simply based on floating foundations of different types, as in the case of MOS Architects building on Lake Huron: in this example, the floating home is a light, wooden house designed with a careful analysis of weight distribution, placed on floating foundations (Fig. 4, images 3 and 4). The latter, as suggested by English and colleagues [12], can be both a

Fig. 4. *1 and 2, Floating home in Boiten-Ohe-Laak, Maasvillas complex [22]; 3 and 4, Lake house Huron, Canada, MOS Architects [24]; 6 and 7, Urban Rigger in Copenhagen, Denmark, BIG [23].*

solution for new buildings and a retrofit solution for existing buildings in critical environments, such as in Florida or Louisiana, which are often hit by extreme flooding events. Furthermore, especially in the case of developing countries, these floating foundations can be made up of recycled elements, such as empty plastic bottles [25].

Both floating and amphibious houses require careful maintenance and annual tests to verify the buoyancy. They have a construction cost that is 20-25% higher than standard houses on the mainland. In addition, amphibious and floating houses cannot withstand high water speed (>2 m/s), therefore they must be located in suitable areas according to flood characteristics.

2.2. CASE STUDY AND DYNAMIC SIMULATION

In consideration of the greater variety of amphibious houses, with their "double identity" of being employed either with or without water, we decided to analyze this typology as a case study. Moreover, the choice is supported by the additional consideration that some floating houses (e.g., Jiburg) also have the same construction characteristics. As evidenced in the previous sections, the main difference in construction characteristics of amphibious houses with respect to floating houses resides in the presence of the wet-dock.

In this work, we aim to test – under the energy perspective – the construction typology of the amphibious home, as it was designed by the British designers, but in a Mediterranean context, so as to investigate its behavior and compare it to the Dutch and British ones. Therefore, Ostia (Roma, Italy) is selected as a location for the case study, also due to the increasingly frequent flooding events [7] in the area and the future projections confirming this trend (Fig. 1). Within the Ostia environment, amphibious homes could be employed to improve resilience in the built environment and safeguard citizens living in more prone-to-flooding areas.

The case study building is residential, and is modeled after the amphibious house designed and built by BACA Architects with respect to the construction characteristics of the wet-dock, the concrete caisson and the envelope (vertical and horizontal) of the floors above the caisson. The building has three levels. One of them is partially underground when the building is in its static position and goes above the ground when the building rises when the wet-dock is inundated.

Each floor has 68.5 m^2 surface area, for a total surface area of 205.5 m^2. The thermal zones are modeled in accordance with each room's function and occupancy (e.g., bedroom, kitchen), with the same schedule described in [26]. The external envelope is composed of a finishing wooden layer (2 cm thick); a waterproofing layer; a prefabricated layer composed by a sandwich panel with 14 cm of thermal insulation and an internal finishing layer. The thermal transmittance of the entire vertical opaque envelope is equal to 0.25 W/m^{2}K. The energy system is entirely fueled by electricity, both for heating (CoP of 0.83) and for cooling (CoP 1.67) and does not vary among the different simulated cases. The only differences among the simulated cases are location (Ostia, Amsterdam, London) and the position of the building with respect to the ground (amphibious, amphibious in floating position and partially-underground).

The modeled building is then simulated (dynamic annual energy performance) by means of EnergyPlus software, which is widely employed and validated in literature. Different simulations are performed, for different configurations of the amphibious building. In greater detail, simulation is performed (i) in the static position and (ii) in the amphibious-floating condition; moreover, we compare the amphibious typology performance with that of (iii) a building with the same construction characteristics, where the first floor is underground; finally, the static position of the amphibious building is simulated for the climates of (iv) Amsterdam and (v) London for comparison purposes. The results are presented in the next subsection.

3. RESULTS

The results of the simulations are presented below in the Table and Figures below. The results evidence that the semi-underground house is linked to slightly reduced consumptions, 1-2 kWh/m^2 with respect to the amphibious house, and this finding is consistent in all the considered locations. This is an expected result since, in the amphibious house, there are air and water flowing between the ground and the vertical envelope. On the other hand, the semi-underground house is thermally protected by the adjacent ground.

Annual energy consumption [kWh/m²]			
Location	Ostia	London	Amsterdam
Amphibious house	84.75	98.41	101.85
Semi-underground house	81.63	96.56	99.59

Tab. 1. *Annual energy consumption for the case-studies in the different locations, for the amphibious and the partially-underground cases.*

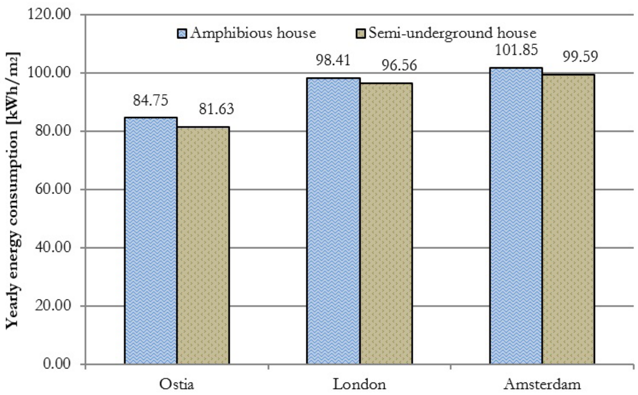

Fig. 5. *Annual energy consumption for the case-studies in the different locations, for the amphibious and the partially-underground cases.*

Such comparison is merely indicative and is conducted due to the similar configuration of the two house typologies in question, since both typologies have one floor below the ground level and the other floors are above the ground. The similarity, as evident from the description of the construction and technological features of the two houses, is merely apparent and derives from the houses' configuration with respect to the ground.

The design and technological features of the amphibious houses are driven by the requirement to withstand inundation, while in this situation the semi-underground house would be absolutely inadequate. However, as demonstrated by the results of the numerical computations, the difference in the energy performance of the two houses is not enormous.

Moreover, the difference in the energy performance of the amphibious house in static and floating position is not significant. Thus, in the tables, only the results of the static position are reported. Significant differences can be noticed when considering the yearly and monthly energy demand in the different locations of the case studies, Ostia, London, and Amsterdam. From the simulations, it is evident that the energy demand related to Ostia is mainly for cooling purposes in the hot season, while that for heating in the cool season is lower. Instead, in London and Amsterdam the opposite happens. This finding is significant for the Mediterranean cities and evidences the differences with respect to the other Mittel-European countries, where, until now, the amphibious house typology is mainly employed and diffused. This difference is due to the local climates in the cases at hand, leading to different air temperatures, direct solar radiation, wind velocity and other variables throughout the year (Fig. 6).

In Ostia, air temperature is higher and wind velocity is lower throughout the entire year, leading to lower energy consumptions, around -15 kWh/m² each year, than they are in London and Amsterdam. In greater detail, in Ostia, cooling energy demand is prevalent; this finding is visible in Fig.7 where the highest peak is in summer months. While London and Amsterdam consume around 850 kWh each for cooling throughout the year, Ostia consumptions are three times higher, equal to 3000 kWh. On the contrary, during the cold season, Ostia consumptions for heating, equal to 3000 kWh, are less than 1/3 lower than in London and Amsterdam, where heating energy consumption is 9000-9600 kWh. The same ratio, equal to 1/3, is thus observed between cooling (Ostia 3, London and Amsterdam 1) and heating (Ostia 1, London and Amsterdam 3) energy demand.

The findings of this study evidence two main observations:

– The adaptation capacity towards inundations does not significantly affect energy performance when compared to the "non-adapted" solution (from the comparison between the amphibious house and the semi-underground house).

– In the Mediterranean area, energy-efficient measures for the inundation-resilient house typology – which are mainly designed and implemented in northern European, heating-prevalent countries – should aim at reducing cooling-energy demand.

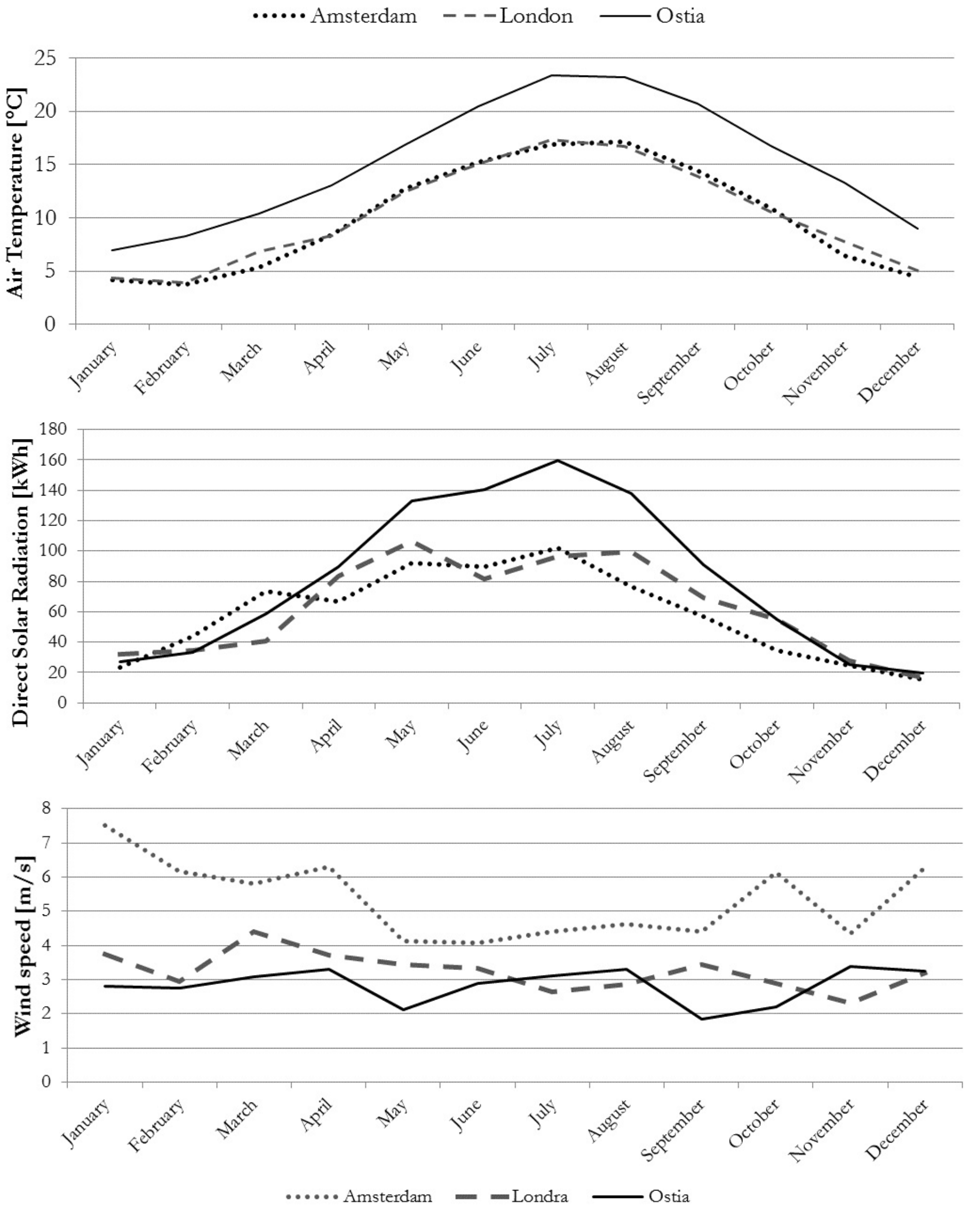

Fig. 6. *Weather variables in the locations in question.*

The possibility of reaching optimal energy performance in amphibious and floating houses could have great potential towards the diffusion of such houses in Mediterranean countries. Indeed, these house typologies could be suitable for those locations, where, due to the changing climate and more frequent extreme rain events, adaptation actions are required towards resilience.

4. CONCLUSIONS

In the work presented here, two peculiar residential building typologies are taken into account, which are designed to adapt urban areas to the growing inundation risk that follows the increase in frequency of extreme rain events. Such inundation risk, according to the United Nations, will be exacerbated in the near future as an effect of climate change.

Amphibious and floating houses are solutions aimed at contributing to resilience and adaptation of urban areas with respect to such climate-related issues, mitigating the risk and safeguarding safety and well-being of the urban population.

These building typologies are mainly used in places such as Northern European countries, whose climates differ from those bordering the Mediterranean. Here,

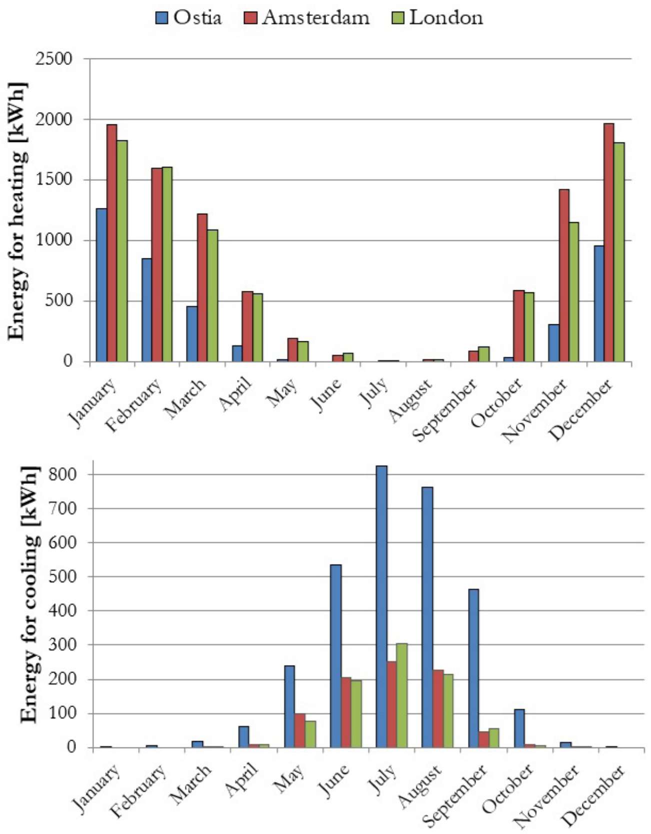

Fig. 7. *Monthly energy consumptions for heating and cooling throughout the year in the locations in question.*

we aim to (i) analyze the construction features of amphibious and floating houses, based on existing examples mainly located in the Netherlands and England, and (ii) consider such typologies in Ostia (Rome), where inundation risk of some areas is high, and where climate conditions are typically Mediterranean, especially with respect to their influence on energy performance. Dynamic simulations to evaluate energy performance are conducted for Ostia, London and Amsterdam and results compared. Findings demonstrate that the typology in question consumes less energy in Ostia than it does in London and Amsterdam, but it can be potentially improved with respect to hot-season performance, in terms of reduction of energy demand for cooling. Moreover, energy performance is not significantly worse, with respect to energy consumptions in all three locations, to that of a traditional semi-underground building with similar ground position.

As a closing remark for this first part of the study on the considered typologies, we can say that amphibious buildings are a promising solution to improve resilience towards inundation in some urban areas with a Mediterranean climate. Future studies should provide a more in-depth focus on the application of passive strategies for reducing energy demand for cooling, thus improving the energy performance of these typologies. Also, their economic, and regulatory feasibility should be addressed, given the scarce diffusion of such buildings in Mediterranean countries.

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SEISMIC VULNERABILITY AND CONSTRUCTION TYPES IN HISTORICAL BUILDINGS

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Highlights

The seismic vulnerability classes can be identified based on the observation of some constructive-behavioral aspects of buildings, i.e., *indicators of vulnerability*. In la Graziella area of Ortigia, the following seismic vulnerability classes have been identified: 5 Structural Units (from now on US), in the vulnerability class A; 33 Structural Units in class B; 73 Structural Units in class C1; 2 Structural Units in class C2; and 13 Structural Units in class D1. The qualitative assessment of seismic vulnerability identifies the weak points in a global framework of damage in case of an earthquake, which is useful for designers to operate consistently in the historical center of Ortigia.

Abstract

This study is part of a research, aimed at the definition of a new expeditious method, in the pre-seismic phase, for the analysis and assessment of the seismic vulnerability of the historical urban centers. The typological-probabilistic approach adopted for a sample of buildings leads to qualitative assessments of vulnerability through the preparation of thematic maps and the adoption of Damage Probability Matrixes (from now on DPM). The paper reports the results obtained for the historical center of Ortigia.

Keywords

Expeditious Method, Seismic Vulnerability, Urban Centers, Indicators of Vulnerability, Qualitative Evaluation.

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1. INTRODUCTION

The history of earthquakes that occurred in Italy over the centuries shows that the country is among those at highest seismic risk.

This consideration is added to the awareness that most of the Italian building heritage was built with no appropriate regulatory requirements to be met to withstand seismic events.

Certainly, this is the case in the historical centers, often of great artistic and architectural value, in large Italian cities and smaller towns.

The observation of the damage suffered by urban centers following seismic events, as happened, for example in L'Aquila or Amatrice, has dramatically highlighted the need to address the recovery, strengthening, and seismic improvement of the building heritage with reference to both isolated buildings and structurally connected groups of buildings.

By virtue of the extension of historical urban centers on the Italian territory, the methodologies of analysis and assessment of seismic vulnerability should lead to the adoption of simplified models and expeditious analyses, without neglecting the uniqueness and value of each historical center [1].

In this context, this research was launched, aimed at the definition of an expeditious method, which is applicable in pre-seismic conditions, for the analysis and assessment of seismic vulnerability that provides useful indications and criteria for designers to operate consistently within a specific historical center with the extrapolations that similar situations allow [2]. The aim of the research is, therefore, to provide the tools for proper assessment of the seismic behavior of the structural units and structural aggregates that make up the building network of historical centers through understanding their construction system [3].

The first investigation procedures on the historical building masonry were carried out after the earthquakes of Friuli in 1976 and Irpinia in 1980 in order to identify seismic vulnerabilities on a regional scale [4].

In summary, they refer to three methods, i.e., direct type-based approaches, indirect inspection and classification methods, and mechanical analytical methods [5].

These methods are related to the building characteristics (i.e., type, materials, dimensions and shape, construction details, etc.) and may have different degrees of detail, depending on the level of knowledge of the items under investigation.

The third mechanical-analytical method provides a high level of information based on detailed investigations and surveys of individual buildings and leads to a quantitative assessment of vulnerability through mechanical modeling. The high level of detail required is challenging to achieve, both economically and in terms of time, if the analysis is extended to an entire historical center.

For this reason, this research has focused on the so-called "hybrid methods", originating from the combination of the first two methods (direct type-based approaches and indirect inspection and classification methods). Both of them adopt typological-probabilistic approaches to be applied to a more or less extensive sample of buildings in order to achieve qualitative assessments of vulnerability through the formulation of thematic maps and the adoption of Damage Probability Matrixes (DPM) [6].

In the framework of the Italy-Malta 2007-2013 project, the method has been tested in the areas of Ortigia (Syracuse - Italy), Malta, and Lampedusa (Italy) [7, 8].

In this Italian research framework (FIR 2014), this method was tested in the historical center of Catania, Italy [9, 10, 21].

This article reports the latest results obtained from the implementation of this method, with a specific reference to the historical center of Ortigia.

2. METHODOLOGY

The expeditious method for the analysis and assessment of seismic vulnerability is divided into three successive phases, i.e., knowledge, analysis, and assessment [2].

The first phase studies the historical evolution of the urban layout of the historical center through the identification of the areas of expansion and the succession of earthquakes in various eras.

The data collected in this way highlight the significant elements of historical, urban, and technical-constructive nature that characterize the historical center and the behavior of the building network towards an earthquake.

In the second phase, the Structural Aggregates and Structural Units of the area are initially identified.

Mauro Dolce argues that the vulnerability of the Structural Aggregates (from now on AS) and Structural Units (from now on US) can be described through the observation of some behavioral symptoms, which are translated into indicators that contribute to a range to define a global vulnerability value [3, 4].

These indicators consist of a list of structural characteristics a priori considered as significant, based on the experience of seismic events that have already occurred, and a posteriori validated by damage statistics.

In the previous researches, starting from the already existing sheets (AeDES, GNDT, CLE), two lists of vulnerability indicators have been identified, one related to the US sheet and one to the AS sheet [11, 12].

The US sheet consists of 4 sections:

a) Identification Data;

b) General Engineering Characteristics;

c) General Geological and Geophysical Characteristics; and

d) Specific Characteristics.

In particular, the General Engineering Characteristics contain 21 indicators referring to:

- Vertical and Horizontal Structures;
- Geometric-Constructive Characteristics;
- The State of Conservation; and
- Location.

The AS sheet consists of 3 sections:

a) Identification Data;

b) General Engineering Characteristics; and

c) General Geological and Geophysical Characteristics.

In particular, the General Engineering Characteristics contain indicators referring to:

- Geometric-constructive characteristics;
- The state of conservation; and
- Location.

The General Engineering Characteristics contain 21 indicators, 10 of which are specific to the AS, while the other 11 indicators derive from the US that forms the aggregate and they are considered when their presence exceeds 30% of cases.

The data obtained from completing the sheets, and collected in a database, allow the analysis and qualitative assessment of the vulnerability of the historical center at different scales.

An initial qualitative assessment of seismic vulnerability was carried out through the preparation of thematic maps based on the presence of indicators in the US and AS.

To this end, for the Ortigia historical center, as for the other case studies, a score from zero to one was assigned to each vulnerability indicator. A higher score has a more significant influence on harmability.

For each US and AS, the sum of the vulnerability indicators gives, as a result, the vulnerability index I.

Three levels of vulnerability were defined based on the vulnerability index [12].

By assigning a color to each level, it was possible to represent the qualitative maps of seismic vulnerability of

CLASS A						
Intensity	Damage Degree					
	0	1	2	3	4	5
VI	0.188	0.373	0.296	0.117	0.023	0.002
VII	0.064	0.234	0.334	0.252	0.092	0.014
VIII	0.002	0.020	0.108	0.287	0.381	0.202
IX	0.000	0.001	0.017	0.118	0.372	0.498
X	0.000	0.000	0.002	0.030	0.234	0.734

CLASS B						
Intensity	Damage Degree					
	0	1	2	3	4	5
VI	0.360	0.408	0.185	0.042	0.005	0.000
VII	0.188	0.373	0.296	0.117	0.023	0.002
VIII	0.031	0.155	0.312	0.313	0.157	0.032
IX	0.002	0.022	0.114	0.293	0.376	0.193
X	0.000	0.001	0.017	0.111	0.372	0.498

CLASS C						
Intensity	Damage Degree					
	0	1	2	3	4	5
VI	0.715	0.248	0.035	0.002	0.000	0.000
VII	0.401	0.402	0.161	0.032	0.003	0.000
VIII	0.131	0.329	0.330	0.165	0.041	0.004
IX	0.050	0.206	0.337	0.276	0.113	0.018
X	0.005	0.049	0.181	0.336	0.312	0.116

Load-bearing masonry	Damage Degree	Description
	0	No damage
	1	Minor damage: thin cracks and falling of small pieces of plaster
	2	Medium damage: small cracks and falling of small pieces of plaster
	3	Heavy damage: formation of large cracks in the walls, chimney falls
	4	Destruction: detachments between walls, possible collapse of portions of buildings
	5	Total damage: total collapse of the building

Macroseismic intensity levels	
VI	Slightly harmful
VII	Damaging
VIII	Heavily damaging
IX	Destructive
X	Very destructive

Tab. 1. *DPM for classes A, B, and C, (Braga, Dolce, and Liberatore).*

the investigated areas for US (I ≤ 2.5 low level, in yellow; 2.5 < I ≤ 5 medium level, in orange; and I > 5 high level, in red), and for AS (I ≤ 3.5 low level, in yellow; 3.5 < I ≤ 6 medium level, in orange; and I > 6 high level, in red) (Fig.1).

The DPM adopted in this research derives from the DPM developed by Mauro Dolce et al. following the earthquakes that struck the historical centers in Friuli and Irpinia. In this table, Dolce et al. associate three classes of vulnerability A, B, and C to 13 structural types originating from the different combinations between vertical and horizontal structures [15, 16].

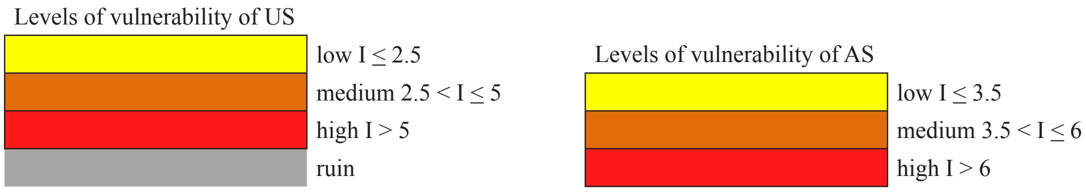

Fig. 1. *Seismic vulnerability levels.*

At this stage, the investigation does not lead to a numerical assessment of the damage to be correlated to a parameter of measurement of earthquake severity, but consists in identifying the particular points of weakness or strength to the earthquake in the aggregate, interpreted in such a way as to form a global picture of the damage to the historical center because of the earthquake, so as to plan the preventive actions for risk mitigation, set the priorities, and allocate financial resources [13].

The second step of qualitative analysis and assessment of vulnerability is based on the experiences of Mauro Dolce et. al., who claim that through the data obtained from filling the US sheets concerning structural vulnerability indicators, it is possible to identify categories of *isovulnerable* buildings [3, 4]. Isovulnerable buildings are those that belong to the same vulnerability class A, B, and C (Table 1) that can be identified through the Damage Probability Matrixes (DPM) [14]. These matrixes express the relationship between a certain degree of damage, for a given type of buildings and a related macroseismic intensity (Table1).

The DPM reported in Table 2 was reworked to be adapted to a historical building network of the 18th-19th century, consisting of US built in the absence of an anti-seismic design (classes A, B, and C1), some of which, over time, have undergone structural improvements (class D1) or, albeit rarely, full replacement with reinforced concrete buildings (class C2) (Table 2).

The DPM reported in Table 2 associates the 5 classes of vulnerability to the 25 types defined by the combination of the three structural indicators, i.e., vertical structures, horizontal structures, reinforcement items [17].

The vulnerability analysis at this level allows identifying classes of *isovulnerable* buildings that are identified as representative models of the structural characteristics of the building network examined [20].

For the case study of the historical center of Ortigia, the results related to the phases of knowledge, analysis, and qualitative assessment of vulnerability through thematic maps and the identification of the classes of vulnerability through DPM are described below.

Structural classification	Vertical structures						
	Poor quality masonry		Medium quality masonry		Good quality masonry		Reinforced concrete
Horizontal structures	With no reinforcing items	With reinforcing items	With no reinforcing items	With reinforcing items	With no reinforcing items	With reinforcing items	
Pushers	A	B	A	B	A	B	
Deformable	A	B	A	B	B	C1	
Semirigid	B	C1	B	C1	C1	D1	
Rigid	B	C1	C1	D1	C1	D1	C2

Tab. 2. *Classes of vulnerability associated with 25 structural types.*

3. THE HISTORICAL CENTER OF ORTIGIA

The first cognitive phase defined the evolution of the historical network of Ortigia, identifying the different areas of expansion and construction techniques that have followed in different eras as a prerequisite for a solid cultural and technological basis on which to make the necessary assessments for filling the sheets.

The current appearance of Ortigia is conditioned by the presence of medieval roadways, the 18th-century building reconstruction, which took place after the earthquake of 1693 that destroyed the Val di Noto, and the significant urban development that took place during the 19th century.

In the district La Graziella, one of the oldest in Ortigia, already included in previous studies coordinated by Prof. Antonino Giuffrè [18], we note that its triangular layout is defined by three most notable streets: via Dione, via Resalibera, and via Vittorio Veneto, of medieval origin (Fig. 2). Inside there are more ancient road structures that are widely distributed through the "ronchi", which are cul de sac routes that sometimes reach private or semi-public courtyards. At the beginning of the 19th century, the inhabitants of La Graziella district were poor people, such as fishermen and carters. The district consisted mainly of buildings with only one above-ground floor, such as terranean houses, stables, and warehouses. Only along the main roads, it was possible to find larger buildings.

Fig. 2. *The historical center of Ortigia, La Graziella district. (Giuffrè A. 2003).*

Fig. 3. *The historical center of Ortigia, La Graziella district, the structural aggregates.*

In the nineteenth century, there was significant growth in the number of buildings built in horizontal layers by merging adjacent building units, with the consequent changes to the interior partitions and not infrequently accompanied by elevation; on the other hand, there developed phenomena of fractionation by vertical layers of buildings hitherto of a single-family type [18].

The load-bearing walls have a thickness varying between 70 and 45 cm (45 cm only for walls of upper floors), arranged with an average spacing varying between 4.5 and 6 m.

The building stones came from quarries in the Syracuse area and were usually of two types: hard limestone and "giuggiulena" stone.

Only in buildings dating back to the beginning of the twentieth century, it is possible to find the presence of squared soft limestone blocks, which, while allowing greater workability, deteriorate faster over time, under the action of atmospheric agents.

The mortar was composed of lime and sand. Sand could come from rivers, quarries, or cutting stone dust.

The low quality of the materials corresponds to a low technical level of the workers.

By starting from the first half of the twentieth century, the use of wood for the construction of flooring was replaced by the use of metal bars; this construction technique was widespread throughout the first half of the century. The use of reinforced concrete, on the other hand, started in local architecture in the years following the Second World War.

Since those years, a rather common building practice was followed in La Graziella as well as throughout Italy, with the replacement of the original, often deteriorated flooring with brick and concrete flooring made with "breccia" rocks.

Reinforced concrete is sometimes found in the construction of elevations and flat roofs. Buildings with a framed structure are almost completely absent.

With the entry into force of the "Piano Particolareggiato Ortigia" (PPO – Ortigia Detailed Urban Plan) following the 1990 earthquake, improvement work was carried out on the vertical structures with the installation of reinforcements, while the rebuilding of the flooring was oriented towards a recovery of traditional techniques, which involved the use of wooden floors with reinforced concrete slabs.

4. RESULTS

The preliminary historical-urbanistic-constructive study based on consultation of the historical cadastral registers and visits on-site carried out initially in collaboration with Regional Civil Protection experts allowed a direct exchange of information with the local population and

ORTIGIA US INDICATORS		Total	%
13 A	Vertical structures	122	98
13 B	No reinforcement items	107	86
13 C	Horizontal structures	58	47
14	Position in the aggregate	48	39
16	Specialist US	0	0
17	Total number of floors	124	100
18	Basement floors	0	0
19	Floor height	7	6
20	Height of roof base	1	1
21	Single volume	1	1
22	Irregularities of layout	31	25
23	Presence of juxtaposed or poorly connected items	16	13
24	Presence of incongruous opening system	56	45
25	Isolated pillars	0	0
26	Pilotis layout	0	0
27	Presence of elevations	19	15
28	Presence of structural damage	36	29
29	Poor state of maintenance	25	20

Tab. 3. *US Vulnerability Indicators.*

	Ortigia AS Indicators	AS1	AS2	AS3	AS4	AS5	AS6	AS7	Total	%
15	Large spans	0	0	0	0	0	0	0	0	0.00
16	Height of roof base	0	0.5	0.5	0.5	0	0	0.5	2	28.57
17	Coverage index	1	1	1	1	1	0	1	6	85.71
18	Regularity of shape	0	1	1	1	1	0	1	5	71.43
19	Merging or clogging	1	1	1	1	1	1	1	7	100.00
20	Roof base misalignments	1	1	1	1	1	1	1	7	100.00
21	Floor misalignments	1	0	1	0	0	1	0	3	42.86
22	Façade misalignments	1	1	1	0	1	0	1	5	71.43
23	Interior partition misalignments	0	0	1	1	0	0	0	2	28.57
24	Slender head	0	0	0	0	0	0	0	0	0.00
25	Juxtaposed items	0	0	0	0	0	0	0	0	0.00
26	Incongruous wall opening system	1	1	1	1	1	0	1	6	85.71
27	Isolated pillars, porches	0	0	0	0	0	0	0	0	0.00
28	Elevations	0	0	0	0	0	0	0	0	0.00
29	Towers, bell towers	0	0	0	0	0	0	0	0	0.00
30	Degraded US	1	1	0	0	1	1	1	5	71.43
31	Absence of reinforcement item	1	1	1	1	1	1	1	7	100.00
32	Presence of ruins	1	1	1	0	1	0	0	4	57.14
33	Soil morphology	0.5	0	0	0	0	0	0	0.5	7.14
34	Location	0	0	0	0	0	0	0	0	0.00

Tab. 4. *AS Vulnerability Indicators.*

workers. It was crucial to fully understand the merging of adjacent building units, otherwise difficult to deduce from layouts.

Seven structural aggregates and a total of 160 structural units were identified, including 8 buildings in ruins. Therefore, 7 AS sheets and 152 US sheets were filled in, of which 124 buildings in load-bearing masonry, 2 in reinforced concrete, and 24 US not totally surveyed [7, 19].

The data concerning the total number of indicators present and the percentage value on the total of the 152 US that form the 7 structural aggregates are summarized in Table 3. The numbers reported in the 'Total' column show how many times that particular indicator is present in the structural units examined, while the 'Percentage' column shows the ratio between the number in the Total column and the total of the structural units.

The data concerning the total of indicators forming the aggregate are summarized in Table 4. Some indicators are considered when their presence exceeds 30% of the cases, while the others are specific to the aggregate.

The results show that 6 AS (86%) present a high level of vulnerability, while 1 AS (14%) presents a low level of vulnerability. More than 70% of the aggregates have a layout irregularity indicator. This is justified by the fact that after the 1693 earthquake, Syracuse was rebuilt in the same site according to the pre-earthquake urban layout of ancient origins, giving rise to structural aggregates with irregular layouts.

All the buildings analyzed – therefore 100% of the US – have the merging or clogging indicator, as they are mainly extremely poor residential buildings. The rather spontaneous growth mechanisms are regulated by purely existential needs that generate continuous transformations that are still present today.

The coverage index indicator that exceeds 85% shows the clogging due to the progressive occupation of public or semi-public space inside the courtyards, with buildings mainly for residential use.

The massive presence of clogging has led over the years to a growth of the aggregate or even to several aggregates union with the free space occupation that originally separated them.

This is why in La Graziella district, we find AS composed of a very high number of structural units such as AS2 with 45 US and AS4 with 40 US. Moreover, since these are extremely poor buildings, the structural units are mainly made up of tiny courtyard-row houses with no more than two floors, of modest height. Only 6% of the structural units have an average floor height indicator

>3.5 m, and none of the US units analyzed have a coverage height indicator >12 m.

The few larger buildings are located only along the main streets via Dione, via Resalibera, and via Vittorio Veneto.

About 40% of the US buildings examined occupy end or corner positions in the aggregate due to the highly irregular shapes of the aggregates and their spontaneous growth mechanism. In fact, there are no aggregates with a slender head.

In addition, since the ends of the aggregate are the most valuable areas, as they overlook the main streets, they are usually occupied by the most formally and dimensionally important buildings.

In these cases, these buildings are highly vulnerable due to their extreme position in the aggregate and their

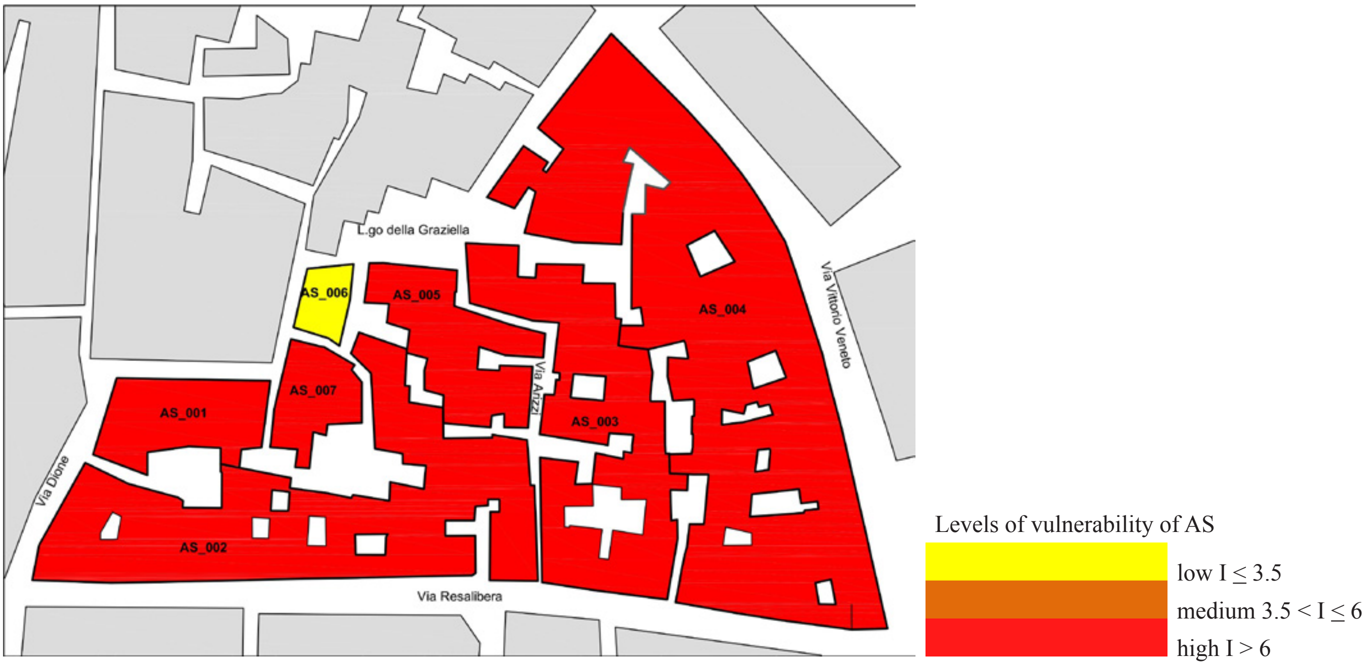

Fig. 4. *AS Vulnerability Map.*

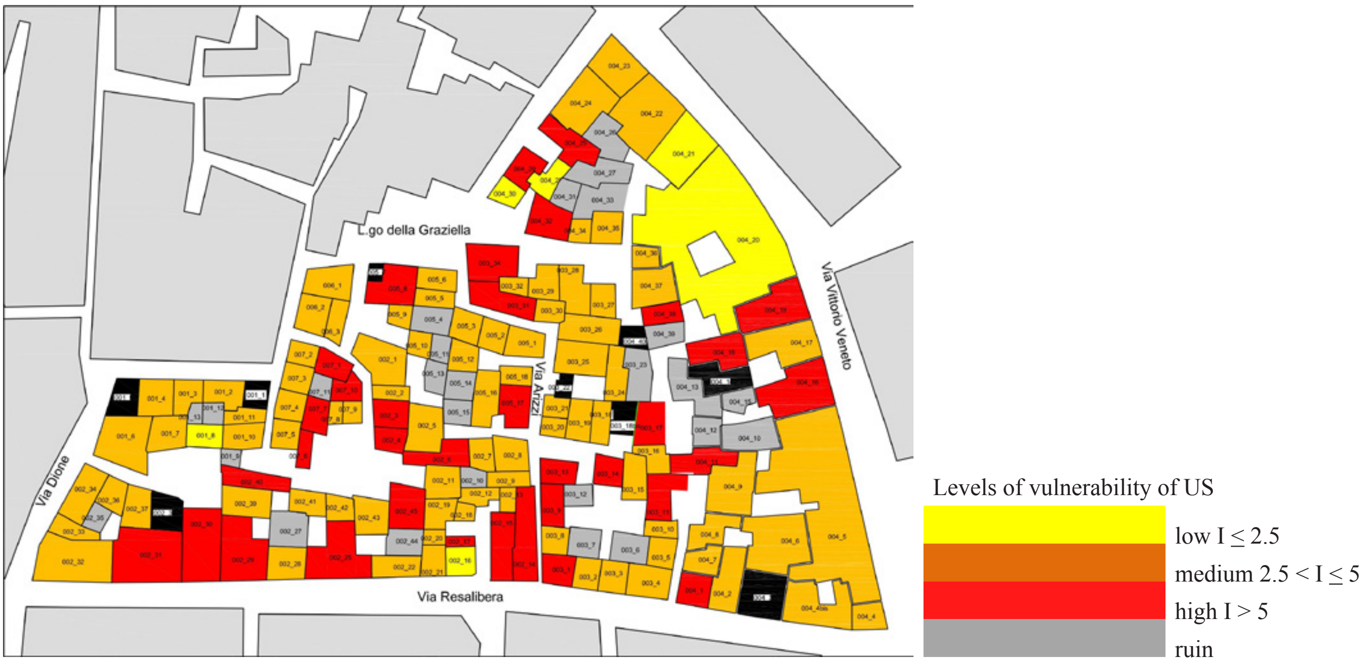

Fig. 5. *US Vulnerability Map.*

larger size. The internal US, of minor importance, frequently present a medium-low vulnerability.

About 70% of the aggregates have the misalignment indicator in the façade.

This is due to the fact that only the US facing the main streets create continuity on the outer fronts ensuring, in principle, the alignment of elevations on the street fronts, while on the inner front, they occupy spaces more or less spontaneously, creating misalignments on the inner fronts.

The presence in the same aggregate of spontaneous buildings formed by US with different formal and dimensional characteristics causes a greater vulnerability due to the misalignments of roof bases (100%) and ceilings (42.86%).

The Incongruous Wall Opening System indicator at 45% also shows that the building network of La Graziella in Ortigia has been remodeled over the centuries to adapt to the new needs that gradually appeared.

Other indicators, albeit with lower percentages, such as the presence of elevations (15%) and the presence of juxtaposed items (13%), also confirm the transformations suffered by the building network over time.

The vulnerability of the US in aggregate is also due to 98% medium-low quality load-bearing masonry (respectively 90% medium and 8% poor quality) and, at the same time, to the widespread lack of reinforcement systems (86%).

In almost half of the US there is no horizontal structure indicator because in recent times, the original ceilings have been replaced by rigid or semi-rigid ceilings.

Only 20% of the units have not undergone any recent interventions and are in a poor state of maintenance.

Finally, 29% of the US units analyzed showed structural damage.

Therefore, referring to the layouts and related vulnerability levels I (Fig. 4, 5), we can say that 23% of the structural units have a high vulnerability level, 72% medium vulnerability, and only 5% low vulnerability [19].

Eighteenth and nineteenth-century structural aggregates are mainly highly vulnerable, especially if they are large and irregular. The highest vulnerability is found near the heads.

The data collected through the AS and US sheets, besides forming a database used to define a qualitative vulnerability map, can be used to trace categories of *isovulnerable* buildings.

Isovulnerable buildings are those that belong to the same vulnerability class.

Considering the vulnerability classes defined and reported in Table 2, for the US of La Graziella district of Ortigia, we find the vulnerability classes A, B, C1, C2, and D1 distributed in each aggregate as reported in Table 5. In particular, we find respectively, 5 US in vulnerability class A, 33 US in class B, 73 US in class C1, 2 US in class C2, and 13 US in class D1.

It appears evident that the most numerous class is class C1, consisting of 73 US composed by the masonry of medium quality combined with rigid horizontal structures and medium quality masonry with reinforcements combined with semi-rigid horizontal structures.

Next is class B with 33 US, represented by structural units with medium quality masonry combined with semi-rigid horizontal structures, the masonry of poor quality combined with semi-rigid and rigid horizontal structures, and structural units with poor and medium quality masonry and reinforcement items, combined with deformable horizontal structures.

Only 5 US belong to vulnerability class A. They consist of poor and medium quality masonry combined with

	AS1	AS 2	AS 3	AS 4	AS 5	AS 6	AS 7
A	1	0	2	2	0	0	0
B	4	7	6	8	4	0	4
C1	3	25	17	16	8	0	4
C2	0	1	0	0	1	0	0
D1	0	5	3	0		3	2

Tab. 5. *DPM for La Graziella district in Ortigia (Syracuse).*

pushing or deformable horizontal structures, with no reinforcement items.

Thirteen US belong to vulnerability class D1 characterized by medium quality masonry with reinforcement items combined with rigid horizontal structures.

Two reinforced concrete buildings belong to vulnerability class C2.

With reference to Table 1, we can say that, if a heavy earthquake (8^{th} level) occurs in the 73 buildings belonging to class C1, 9 buildings will suffer damage of grade 0 (no damage), 24 buildings will suffer damage of grade 1 (light damage), 24 buildings will suffer damage of grade 2 (medium damage), 12 buildings will suffer damage of grade 3 (heavy damage), and 3 buildings will suffer damage of grade 4 (destruction, i.e., detachments between walls and possible collapse of portions of buildings).

5. CONCLUSIONS

The expeditious method of seismic vulnerability assessment applied to La Graziella district in the historical center of Ortigia has given positive results as it highlights the real historical-constructive characteristics of the buildings on an aggregate and structural unit scale.

The formulation of the maps based on the presence of structural and geometric indicators of the US and AS showed that the majority of the US (72%) have a medium vulnerability level and only 23% have a high vulnerability level; this is partly due to the structural improvements carried out on the individual US following the 1990 earthquake.

Despite the fact that the US mainly have a medium vulnerability level, the maps show the high vulnerability of the aggregates (86%), due not so much to the characteristics of the individual US but to the specific indicators of the aggregation mechanisms, that is generated by the spontaneous growth of the building network of the past centuries. This phenomenon has given rise to irregular shape aggregates with a very high number of US without alignments on the fronts, except along the main streets and without alignments on all ceilings.

It is therefore believed that this method, extended to the entire historical center of Syracuse, may be valid in identifying specific weakness or strength points to earthquakes in the aggregates, to be interpreted in such a way as to form a global picture of damage to the earthquake in the historical center, in order to plan preventive actions for risk mitigation, establish priorities, and allocate financial resources.

The second level of qualitative assessment of vulnerability, on a structural unit scale, was obtained through the use of DPM. For La Graziella of Ortigia, associating the structural types to the vulnerability classes, the results shown in Table 6 were obtained, respectively 5 US in vulnerability class A, 33 US in class B, 73 US in class C1, 2 US in class C2, and 13 US in class D1.

The most numerous class is C1. Isovulnerable buildings of class C1 are US consisting of medium quality masonry combined with rigid horizontal structures and medium quality masonry with reinforcement items combined with semi-rigid horizontal structures.

Table 1 developed by Dolce et. al. for the data collected shows that in the event of a heavy seismic event (8^{th} level) most of the class C1 US will suffer from mild to severe damage with cracks in the masonry and detachment of parts of plaster; only a small number of them will suffer heavy structural damage with collapsing portions of buildings. These data record the beneficial effects of the actions carried out following the 1990 earthquake with improvements mainly due to the replacement of the original floors and, in a few cases, to the installation of reinforcement items.

However, at the aggregate level, the map showed a high degree of widespread vulnerability due to the fact that the improvements were carried out only on a US scale, and did not affect the specific indicators of the aggregation mechanisms, as there are aggregates with irregular shapes and with a very high number of US, with no alignments on the fronts, except for the main streets, and with no alignments on ceilings.

At present, the small number of samples analyzed has made it possible to carry out a first verification of the methodology of analysis and assessment of seismic vulnerability for historical centers, rather than reaching results that can be extended to the whole historical center.

The results obtained at this stage of the research encourage us to continue in this direction.

The research will be extended to other areas of the historical center in order to have a larger and, therefore, more representative sample of US and AS of the building network.

Further methodological development of the research in the future consists in assessing the effects caused by the set of geometric indicators present in the US to *isovulnerable* buildings (Table 5).

The vulnerability analysis at this level allows identifying subclasses of *isovulnerable* buildings that are identified as representative models of all the structural and geometric characteristics of the building network examined.

On these models, being limited in number, it is possible to apply the analytic mechanical methods that, through structural verifications, provide the quantitative assessment of seismic vulnerability. The results obtained, extended to the entire building network, will provide useful indications and criteria for designers to operate consistently within that particular historical center with the possible extrapolations for similar situations.

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MANAGEMENT OF DEMOLITION PHASES AND RELATED WASTE, IN A BUILDING RENOVATION PROJECT NEAR SALERNO, ITALY

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Highlights

In accordance with current environmental regulations, in the Italian and European context, it involves, at first analysis, an increase in costs due to the adaptation of the operations of the building process to the quality and quantity parameters imposed. These higher costs can be a painful burden for small-medium enterprises. However, for building replacement interventions, it is possible to organise the management of demolition operations according to the reuse, after recycling, of fractions of the demolished materials. This approach allows for an almost complete reduction of the initial gap, also by assessing the achievement of rewarding scores.

Abstract

Compliance with recent environmental regulations, the demolition phase, within the building replacement process, plays a decisive role, in terms of execution and management methods. The contribution addresses the problems related to the management of the site, in compliance with regulatory requirements for selective demolition and disposal of waste materials. Possible organisational and procedural solutions were investigated with particular reference to the phases of selective demolition (in compliance with Minimum Environmental Criteria), excavation, handling, treatment, recycling, and disposal of waste materials.

Keywords

Sustainability, Environmental-criteria, Demolition, Recycling, Waste-reduction, Building-site.

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1. INTRODUCTION

The problem of urban degraded area renovation is particularly complex by investing multiple impacts: social, environmental, urban, architectural. In addition to physical and functional obsolescence, over the years, there is social obsolescence, a progressive phenomenon of disownment by the community of its identity. It is mainly suffered by the suburban and intensive neighbourhoods dating back to the Second World War: "… in Italy, post-war building rubbish must be scrapped, without quality, historical interest and anti-seismic efficiency. There are about forty million rooms, built between 1945 and 1972-75, which no longer meet any of the criteria for which conservation operations are worthwhile…" [1]. According to this approach, the strategy to be pursued is to plan at 'zero volume', without consumption of new land; this is possible through environmental compensation, i.e. through demolition and reconstruction in situ [1].

Italian legislation has recently regulated the Minimum Environmental Criteria for Construction [2], for renovation and construction interventions, in accordance with the strategic objectives defined by the European Commission [3], in line with the European strategies for the construction sector and waste management, as well as with the objectives of the Waste Framework Directive 2008/98/EC, which aimed at achieving a 70% share of recycled construction and demolition waste by 2020. These guidelines are also in line with the Construction Strategy 2020 [4] and the Communication on opportunities for improving resource efficiency in construction [5]. They also form part of the most recent and ambitious circular economy package presented by the European Commission in 2015 [6], which contains legislative proposals on waste to stimulate the EU's transition to a circular economy [7]. The Minimum Environmental Criteria for Construction [2] regulate, among other things, technical specifications for construction sites (art.2.5), concerning those operations that lead to potential environmental pressures, namely: demolition and dismantling of materials, materials used, environmental performance, staffing, excavation and backfilling. Prior to demolition operations, quantities and types of materials that can be reused, recovered, or recycled shall be determined through the following operations:

- identification and risk assessment of dangerous waste that may require special treatment or emissions that may arise during dismantling;
- estimation of the quantities of different construction materials;
- estimation of reuse rates and recycling potential based on proposals for sorting systems during the dismantling process;
- estimation of the potential percentage achievable with other forms of recovery from the demolition process;
- on-site provisioning, and subsequent reuse, of the plant-soil for a depth of 60cm, for the construction of embankments and public and private green areas.

These indications [8] are an integral part of the Italian Public Contracts Code (Legislative Decree 50/2016 and subsequent Corrective Decree 56/2017), art.34 as regards the basic environmental requirements (energy and environmental sustainability criteria) and art.95 as regards the award criteria in the award of the contract [9]. The study, therefore, intended to investigate the hypothetical scenario resulting, in the first instance, from the application of the mandatory regulatory parameters imposed by the basic CAM, as well as to develop the scenario relating to the achievement of the award scores, for the purposes of awarding the contract (art. 2.6 of the DM 11.11.2017).

2. STATE OF THE ART

The Italian residential heritage of the 20th century includes examples of high architectural quality, such as the one realised with the INA Casa Law, in force from 1949 to 1962, thanks to a specially planned economic-qualitative mechanism. Older than this historical period, some examples of settlements, which developed quickly in the Second World War as an immediate response to the housing emergency, are now at the end of their life cycle both structurally and technologically, also of poor architectural quality. The pilot project concerns the demolition and reconstruction of a social housing district in the province of Salerno, dating back to the late 1940s. The buildings are made up of a reinforced concrete load-bearing structure, reinforced concrete and hollow tiles mixed floor and hollow bricks. The structures, although sized before the anti-seismic regulations, show almost irreversible degradation pathologies. The same is true for technological systems and finishing works. For this and similar cases of current construction, the need of demolition and reconstruction "in situ" becomes unavoidable. Until a few years ago, this scenario was characterised by the organisation of the site according to traditional methods, whose demolition phase was characterised by "empty for full" type of metering, which generated a chaotic mixture of waste, delivered to the landfill in an undifferentiated manner (representation of model '1'). This outdated demolition dynamic was also characterised by a particular speed of execution since the resulting materials were disposed of almost at the same time as the demolition operations. Compliance with the

Building CAM [2] requires innovative organisational methods: the storage operations of the materials to be selected and of the sooty ground require further exhaustive layouts of such management. There is a need to find neighbouring areas where to move, deposit and treat the waste materials. Furthermore, the simultaneous demolition and reconstruction must be properly planned according to the possibility of reuse and/or recycling "in situ" of part of the waste material. This strategy would allow the reduction of part of the costs of transport, disposal and delivery.

3. METHODOLOGY

The experimental model, called model '2', is divided into the following phases:

- 1st phase) definition of the dynamics of the demolition and reconstruction process;
- 2nd phase) technological characterisation of the buildings to be demolished (in order to determine the types of materials and the respective quantities by weight);
- 3rd phase) definition of the objectives (basic CAM / rewarding CAM);
- 4th phase) identification of the most suitable demolition techniques and estimation of their economic impact;
- 5th phase) definition of the layouts of the significant phases of the demolition process, with regard to the organisation of the site as well as the possible annexation and use of neighbouring areas;
- 6th phase) development of the time schedule for the demolition site scenario, based on the set objectives;
- 7th phase) estimation of direct costs related to the demolition intervention, materials handling and management of the site;
- 8th phase) preparation of the reconstruction project, in accordance with the qualitative and quantitative parameters of the minimum environmental criteria, with regard to the technical specifications for groups of buildings [10], single building and building components;
- 9th phase) simulation of the recovery/recycling scenario of the resulting materials, as part of the concomitant in situ reconstruction project, through the elaboration of the demolition and construction waste management plan [11] in order to determine the recycling and reuse potential of the resulting materials [12]. This phase is in line with the principles, recommended by current legislation, aimed at minimising the quantities of demolition waste to be sent to landfill [13-15].

The variables taken into account for the development of the model are:

- the organisation of the site, according to the phases of the intervention;
- the execution and management time of the demolition and waste treatment phases;
- the logistics of the selective site, with the annexation of any areas, possibly adjacent, for the storage, selection and preparation of waste materials;
- the technological characterisation of existing buildings and those to be rebuilt, for the estimated amount of potential recovery/reuse of waste materials, depending on their intended use.

The final objective, given the peculiarities of the new organisational approach, is to determine any direct costs changes, deriving from the different organisational and management methods of the scenarios envisaged.

3.1. DEFINITION OF CRITERIA AND TECHNIQUES

From this point of view, the adoption of suitable criteria and techniques for the execution of the demolition phases, according to the methods of selective demolition, i.e. through dismantling, disassembly and/or disassembly of components, in order to differentiate waste by homogeneous fractions, orienting it towards recycling operations [13], in accordance with the shared criteria and technical guidelines for the recovery of inert waste, governed by the Italian legislation in force [11, 12]. Demolition must be carried out in a sequence that is exactly the opposite of the construction sequence, from top to bottom, first of all on the finishes, then on the partitions and curtain walls, in order to achieve the maximum result in terms of resulting materials' selection, and then proceed in succession with the structural elements demolition. One of the most effective demolition techniques is the use of hydraulic grippers and shears, which is advantageous in terms of impact with the surrounding environment and risk reduction, i.e.: reduction of percussion on the building and the ground, reduction of vibrations, noise and dust towards the surrounding environment, reduction of fragments to wheelbarrow size, minimisation of temporary shoring, simplification in the selection of material for subsequent recovery and recycling. The boom of the demolition vehicle will be suitably equipped with a water mist jet system for dust abatement and will be assisted by an excavator for the removal of debris from the work area, for the handling of rubble inside the site and for loading onto trucks for the handling of waste materials. The latter, if already selected during the demolition phase, after the allocation of the appropriate CER code [11], will eventually be prepared for the reuse phase on-site, or, if they require a further selective phase, they will be deposited in a special site area.

3.2. SETTLEMENT DYNAMICS

The dynamic hypothesised for the intervention, of reconstruction in situ, takes up the one conceived for the Complex Urban Redevelopment Programmes of the Municipality of Naples, with the aim of reducing the mobility of the occupants to almost zero. It is divided into successive phases, according to an implementation mechanism that provides for the temporary relocation of the inhabitants to a neighbouring area, called "triggering area", where temporary housing has been previously installed. The settlement dynamics are as follows [16]:

– first phase: identification of the triggering area, within the neighbourhood or in neighbouring areas;
– second phase: in the case of availability of an "internal" area, the reconstruction of the first lot is carried out directly; in the case of availability of an "external" area, temporary accommodation is installed in which residents can be moved from time to time, based on a rotating mechanism
– third phase: gradual demolition of the buildings and simultaneous construction of replacement buildings with the relocation of the inhabitants through successive phases;
– fourth phase: completion of the external accommodation in the spirit of integration of the neighbourhood equipment and integration into the surrounding area.

Given the peculiarity of this dynamic, the experimental scenario hypothesised takes into account the organisation and management of the demolition phases according to the overcoming of the basic CAM, i.e. the achievement of the rewarding requirements as per art. 2.6 of DM 11.11.2017, useful for the awarding of the contract (art.95 of Legislative Decree 50/2016) [9].

3.3. APPLICATION OF MODEL '2' TO THE CASE STUDY

In order to exceed the basic requirements, i.e. to obtain the bonus requirements, the verification of the model with respect to the case under consideration is structured in the following phases.

3.3.1. 1ST PHASE

Implementation of the dynamics of the demolition and reconstruction work [17]. The intervention has been divided into functional lots (five steps), in order to optimise the size of the temporary settlement complex, defined as the "triggering district". To this end, an adjacent area was identified, about 350m away from the site area (Figure 1), with an extension of about 2300m^2, in which to install the prefabricated monoblocs (6.05m x 4.9m), aggregated according to housing types congruent with the types of households that must pass through, according to a rotation mechanism. At the end of the demolition and reconstruction programme, the prefabricated monoblocs can be reused in another place, for another building replacement or, as a subordinate measure, they can be reconfigured to perform a different function. The costs relating to this installation, considered to be unchanged for the types of the site under investigation, have not been taken into account in the relative economic quantifications.

Fig. 1. *a) Localization of the trigger area. b) Installation of the triggering quarter.*

3.3.2. 2ND PHASE

Technological characterisation of the buildings to be demolished. To this end, the archival documentation of the public administration was retrieved and analysed, as well as through on-site surveys. On the basis of this information, the nature of the materials and the respective quantities to be subjected to selective demolition were determined.

3.3.3. 3RD PHASE

Organisation and management of the building-site aimed at meeting the minimum environmental criteria or at achieving the rewarding criteria. In order to achieve rewarding requirements, it was intended to act on the following work activities. Increase in the percentage of selective demolition, in order to exceed 70%, by weight, of materials to be sent for reuse or recycling, through operations of disassembly, removal and/or decomposition, of the following architectural elements/materials such as bituminous conglomerate and road foundation of the road network inside the district; external and internal windows and doors; sanitary fixtures and fittings; floor and wall coverings; coverings and screeds; internal partitions; cladding; structure in elevation after setting aside 60 cm of sooty ground for subsequent reuse.

3.3.4. 4TH PHASE

Demolition techniques. For the demolition works, selective techniques have been foreseen for the majority of building structures, excluding only those building systems and/or components characterised by the aggregation of several materials and elements (horizons, screeds, etc.) for which the selection, after demolition, would not have guaranteed a convenient material weight/cost ratio.

3.3.5. 5TH PHASE

Elaboration of the layouts of the demolition phases. Due to the peculiarity of the settlement dynamics, the demolition process is divided into five significant layouts (Figure 2). The demolition phase requires the temporary occupation of a neighbouring area, identified near the site area, where the materials are transported, deposited, and treated according to their final destination.

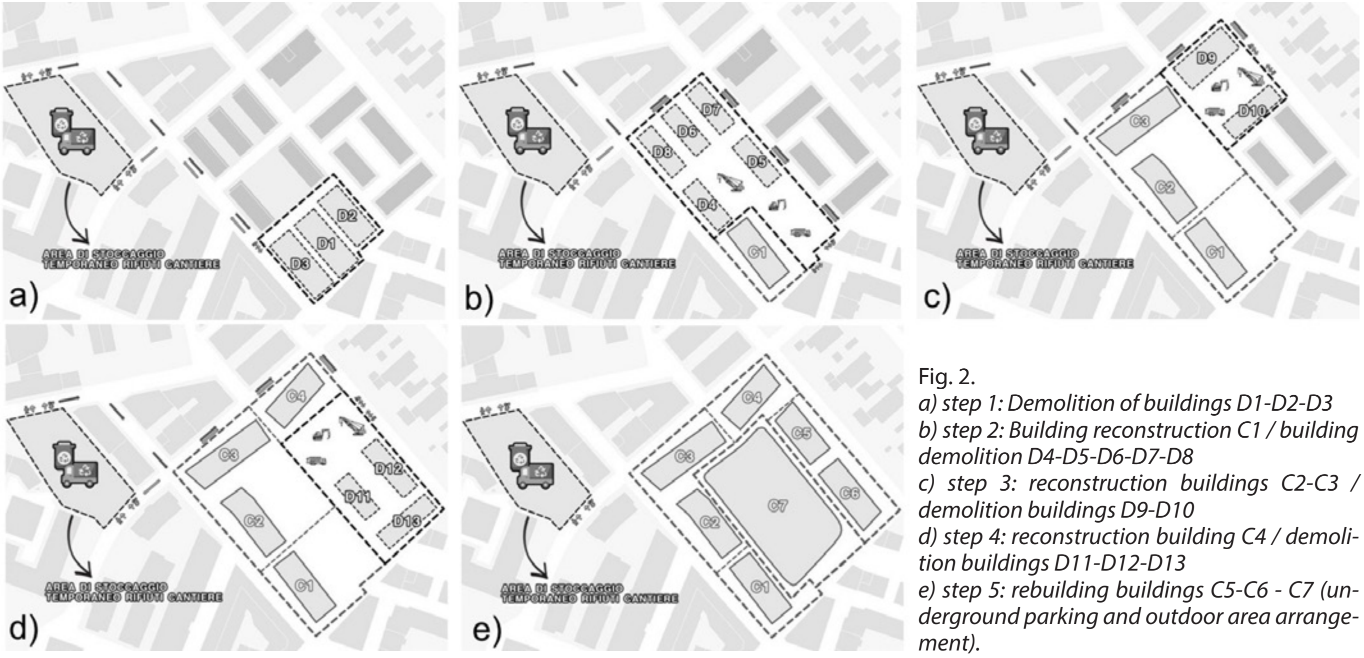


Fig. 2.
a) step 1: Demolition of buildings D1-D2-D3
b) step 2: Building reconstruction C1 / building demolition D4-D5-D6-D7-D8
c) step 3: reconstruction buildings C2-C3 / demolition buildings D9-D10
d) step 4: reconstruction building C4 / demolition buildings D11-D12-D13
e) step 5: rebuilding buildings C5-C6 - C7 (underground parking and outdoor area arrangement).

3.3.6. 6TH PHASE

Chronoprogram development. The chronoprogram of the experimental model ('2' model) shows a duration, of the overall demolition process, of about 70 days (compared to the 26 days estimated for reference model '1', i.e. related to the traditional site).

3.3.7. 7TH PHASE

The estimate of direct costs related to the demolition and management of the site (table 1). The costs of model '2' have been quantified on the basis of the price list of the Campania Region with the exception of the cost relating to selective structural demolition, defined with an appropriate price analysis. These costs amount to a total of euro 902,848, of which euro 675,459 for work, and euro 227,389 for site preparation and logistics. The layouts in figure 3 show the different configuration of the site area, between the traditional model ('1') and the experimental model ('2'), the latter requiring more space for the transformation of materials.

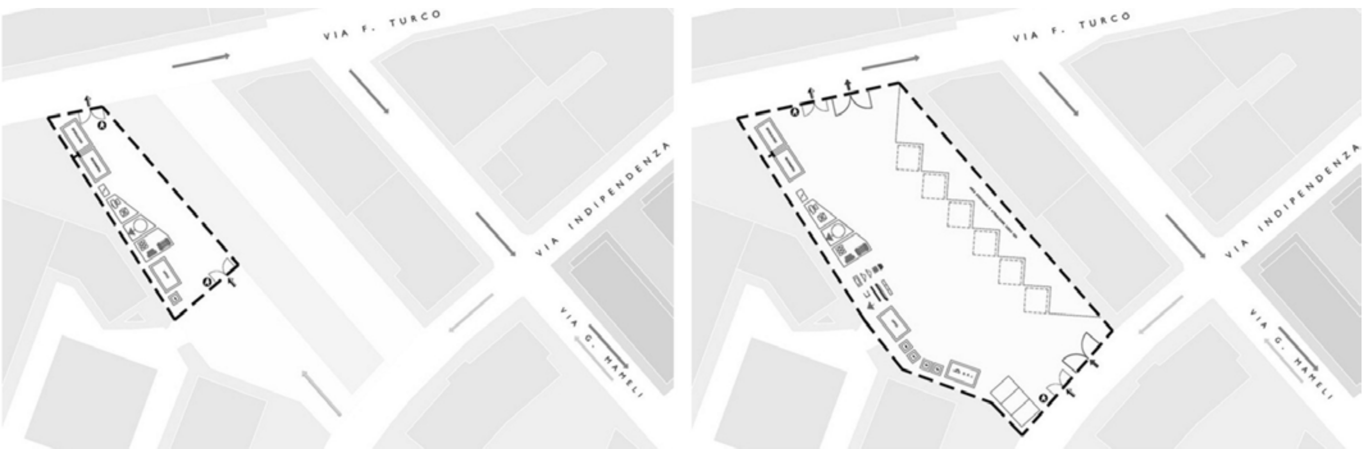


Fig. 3. *a) Perimeter of the annexed area (configuration relative to model '1' - traditional building site). b) Perimeter of the annexed area ('2' model configuration - experimental site).*

WORK ACTIVITIES	QUANTITY		COSTS	
			NON Selective Demolition [0% selection].	Selective Demolition [94% selection]
			MODEL "1"	MODEL "2"
DURATION OF DEMOLITION AND TRANSPORT ACTIVITIES			26 days	70 days
1. CONSTRUCTION SITE PREPARATION / LOGISTICS				
1.0 Rent public land			€ 18 078,00	€ 159 280,10
1.1 Provisional fence			€ 32 004,72	€ 66 676,50
1.2 Monoblocks, WC			€ 1 432,00	€ 1 432,00
Total costs related to site set-up and logistics			€ 51 514,72	€ 227 388,60
2. DEMOLITION AND LANDFILL TRANSPORT	m^3	kg		
2.1 Asphalt removal (road)	906,87	1450987,52	X	€ 14 321,53
2.2 Demolition of road foundation	1133,58	1700376,00	X	€ 7 280,28
2.3 Demolition of fixtures (frames and glass)	35,47	38983,40	X	€ 5 621,62
2.4 Sanitary Removal	-	5130,00	X	€ 1 876,50
2.5 Removal of sanitary ware (tubs)	25,20	4050,00	X	€ 813,60
2.6 Removal of floors (marble tiles)	41,04	23596,85	X	€ 35 703,06
2.7 Screed demolition	164,15	180567,20	X	€ 17 138,90
2.8 Total coverage removal	9,07	27,22	X	€ 16 740,00
2.9 Demolition screed cover	143,63	157987,50	X	€ 14 995,36
2.10 Demolition of partitions (up to 10 cm thick)	322,88	209869,92	X	€ 15 433,51
2.11 Demolition of partition walls (10-15 cm thick)	26,59	17286,05	X	€ 1 830,55
2.12 Demolition of partition walls (15-30 cm thick)	122,69	79747,20	X	€ 5 417,90
2.13 Demolition of infill masonry	1747,44	1223208,00	X	€ 63 187,43
2.14 (A) Demolition of traditional elevation structure	16828,00	20869505,71	€ 283 720,08	X
2.14 (B) Demolition of elevated structure with hydraulic grippers on excavator	12453,47	20869505,71	X	€ 211 160,71
2.15 (A) Transport to authorized landfill (empty for full)	16828,00	20869505,71	€ 279 681,36	X
2.15 (B) Transport to authorised (selective) landfill	12453,47	20869505,71	X	€ 206 968,86
Total charges related to work activities (2)			€ 563 401,44	€ 618 489,82
3. EXCAVATIONS AND TRANSPORT TO LANDFILL				
3.1 Surface humus h.60cm	2885,00	4905180,00	X	€ 6 203,61
3.2 Humus handling and storage for reuse	2885,00	4905180,00	X	€ 19 505,30
3.3 Excavation	7894,00	13419800,00	€ 50 768,78	€ 31 260,24
Total excavation costs			€ 50 768,78	€ 56 969,15
COMPLESSIVE AMOUNT WORK AND FACILITIES (excluding landfill charges)			€ 665 684,94	€ 902 847,57

Tab. 1. *Comparative overview between models 1-2, regarding the estimation of site set-up costs and demolition and transport activities.*

3.3.8. 8TH PHASE

Elaboration of the reconstruction project. The design criteria, expected to meet the minimum basic environmental criteria, can be summarised as follows: maximisation of the passive behaviour of the building envelope by minimising the plant contribution; optimisation of thermal bridges and winter/external heat loss; use of eco-compatible and low CO_2 emission insulating materials; exploitation and control of natural lighting in the interior spaces; exploitation of natural ventilation for summer cooling; use of external materials and finishes aimed at minimising the effect of urban heat island; installation of systems powered by renewable sources for winter/summer air conditioning and domestic hot water production; volumetric reconfiguration in order to optimise the free spaces, unified in an internal square (Figure 4).

Fig. 4. *a) Reconstruction project: view of the entrance from the city to the inner square. b) Reconstruction project: internal view of the complex.*

3.3.9. 9TH PHASE

Estimation of the potential economic viability of the recovery/recycling of demolition materials [12], as part of the on-site reconstruction work. The reference scheme adopted for this phase is as follows:

The first step of phase nine (i.e. scenario 2) foresees the estimation of the cost reduction related to the choice

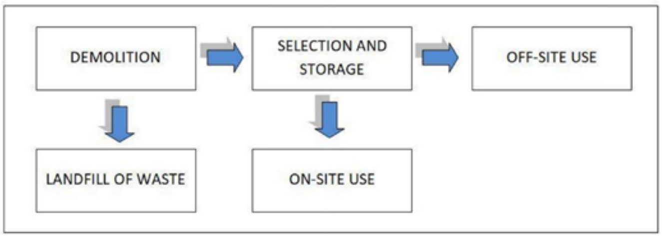


Fig. 5. *Schematic diagram of waste recovery/recycling/disposal dynamics.*

Table 2a	*Starting economic scenario (scenario 1)*				
	model 1		model		model 2
			(basic CAM)		(CAM rewarding)
waste sorting percentage	0%		70%		94%
total demolition costs, waste transport, site logistics	665684,94		723091,98		902 847,57 €
model 2			without reuse SRM (second raw materials)		with SRM reuse
Table 2b	*Comparison of scenarios with and without reuse of MPS (secondary raw materials). The unit prices assumed as landfill charges are national average prices for recyclable (sorted) and non-recyclable (undifferentiated) waste*				
type of scenario			(m³)	incidence of demolition, transport and landfill costs	
1) economic impact of transport and transfer of the entire quantity of waste materials (differentiated up to 94% by weight)			12453	206 968,90 €	-
2) economic impact of transport and 30% waste disposal, not reusable on site		24% differentiated waste	2988	-	17 928,00 €
	30% rejection	6% undifferentiated waste	747	-	7 470,00 €
Table 2c	*Summary table of costs and percentages of material to be allocated to recovery/recycling operations, in compliance with art.2.5 of the CAMs*				
total cost of demolition, transport, and related site logistics			**902 847,57 €**		**721 276,71 €**
			model 1		**model 2**
CAM satisfaction			**0%**		**94%**
total costs			**665684,94**		**721276,71**

Tab. 2. *Starting scenarios and application of strategies aimed at optimizing the '2' model.*

of reusing waste materials (inside or outside the building-site), resulting from the lower costs of waste transport and landfill of 70% of waste materials (table 2a). Table 2b shows the costs related to waste transport and landfill, in relation to scenarios '1' (traditional construction site, with an undifferentiated transfer of the entire quantity of waste materials) and '2', which is expected to reach the target of 94% (by weight) of materials to be differentiated. In the latter case, the economic savings will be obtained by reducing waste transport costs by 70% of the materials; a further reduction in costs is also recorded with regard to the costs of the landfill, having assumed the ratio of 0.6/1 (according to the average prices of landfill) between the costs of the differentiated fraction (24%) and the undifferentiated fraction (6%).

The economic convenience resulting from the reuse, through recycling of waste materials, makes the experimental model particularly competitive ('2'). Table 2c shows in fact that the scenario '2', which allows the achievement of rewarding scores, regardless of the re-

Table 3a	*Quantity of materials needed for the reconstruction of buildings and internal roads*				
construction of road works			buildings reconstruction		
section	m^3	kg	materials	m^3	kg
bituminous conglomerate	341,275	546040	concrete	7858	19645000
inert	1706	2559000	steel	100,74	785800

Table 3b	*Costs for the purchase of new and recycled material for road foundations and earthworks*		
purchase cost of materials for road foundation and earthworks			
quantity (m^3)	new (€)	recycled (€)	cost difference (€)
1706	25590	11942	13648
7894	85255,2	56915,74	28339,46

Table 3c	*Costs of recycled material in situ for foundations and earthworks*			
on-site recycle				
cost €/d	m^3 / day	m^3 to be treated	days	total cost €
1200	400	8717	22	26400

Table 3d	*Summary table of total expenditure for road foundation equipment*
total expenditure for road foundation materials (inert quantity to buy = mc 823)	
inert new cost (€)	12348
total cost for recovery/recycling (€)	26400
total cost (€)	39571

Table 3e	*Summary table comparing the costs of the scenarios envisaged*	
comparison of the costs of the various options		
new purchase (A)	recycled purchase (B)	on-site recycling (C)
110845,2	68857,74	39571

Table 3f	*Summary table of costs and incidence with and without reuse of MPS, relative to the experimental model ('2')*	
model 2	without reuse SRM (second raw materials)	with SRM reuse
cost of demolition and related logistics	902 847,57 €	721 276,71 €
incidence reuse of recycled materials	0	-71 274,20 €
	902 847,57 €	650 002,51 €

Tab. 3. *Cost trends resulting from the application of the model to the case study.*

use of waste materials inside or outside, is almost equal, economically, to the virtual scenario of the basic CAM (at least 70% selection of waste materials), in Table 2a.

The second step of phase nine (corresponding to scenario 3) foresees the option of recovering/recycling the waste materials in the site, in order to reuse them within the reconstruction project. It is therefore assumed that part of the recovered material will be used, mainly for the roadbeds and backfill works, as these operations, and in particular, all those for non-structural use can be carried out without significant changes to the recycled materials. In fact, the recycled aggregates, milled in different grain sizes, are purified from foreign fractions also through the use of mobile plants, with evident economic and environmental gains [16].

Otherwise, assuming the use of aggregates for the packaging of concrete for structural use with a percentage of recycled concrete, it would be necessary to pass such waste from C&D through a specific treatment plant system that deals with the selection of materials, separation of fine elements, sorting, crushing and packaging of the finished product, with the relative attribution of CE certification.

At this point, the economic savings range of possible solutions is determined. The following table shows the purchase of new and recycled material (table 3):

In this way it is possible to obtain, for the case study, comparing (C) with the hypothesis of repurchase of new material (A) one obtains a saving of 71,274.20 €; while, comparing (C) with the hypothesis of repurchase of recycled material (B) one obtains a saving of about 29,286.74 €.

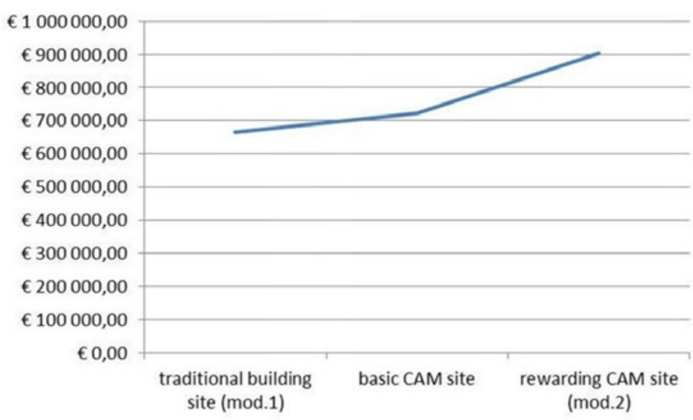
4. RESULTS

The configuration of the 'innovative' site (post CAM) involves a substantial change compared to the 'traditional' one, when the resulting materials did not need to be stored and hinged and therefore, almost at the same time, transported and delivered to the landfill. The traditional site (model 1) requires the annexation of a service area limited to logistics; the experimental site (model 2) requires the annexation of a larger area, not only for logistics but also for the storage and storage, in the medium-long term, of waste materials. The results of the study show changes in costs that lend themselves to subsequent levels of interpretation depending on the type of scenario:

1) demolition without reuse of waste materials
2) demolition with the reuse of waste materials (on-site/off-site)
3) demolition with reuse on-site (as part of the reconstruction project)

Results of scenario 1 (demolition without reuse of waste materials):

The first scenario, which takes into account only the demolition phases, shows a considerable variation in costs, in the transition from the traditional site to the CAM adapted site (Figure 6a). The graph shown in Figure 6b shows the trend of the percentage change in direct costs, in relation to the satisfaction percentage for CAM.



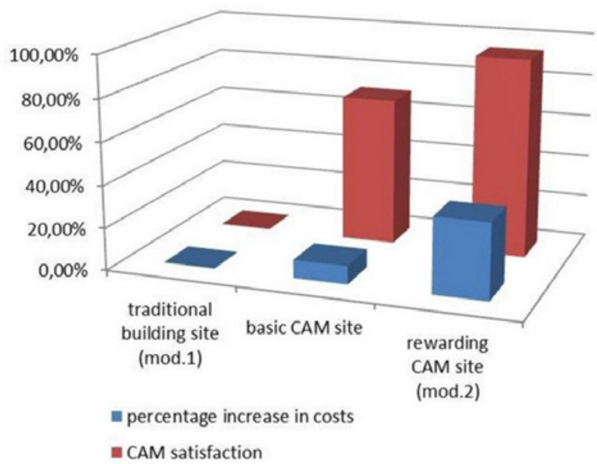


Fig. 6. *a) Graph of demolition cost trends for scenario 1 (without reuse of materials). b) Graph showing the trend of the percentage change on direct costs, in relation to the percentage of satisfaction with CAM.*

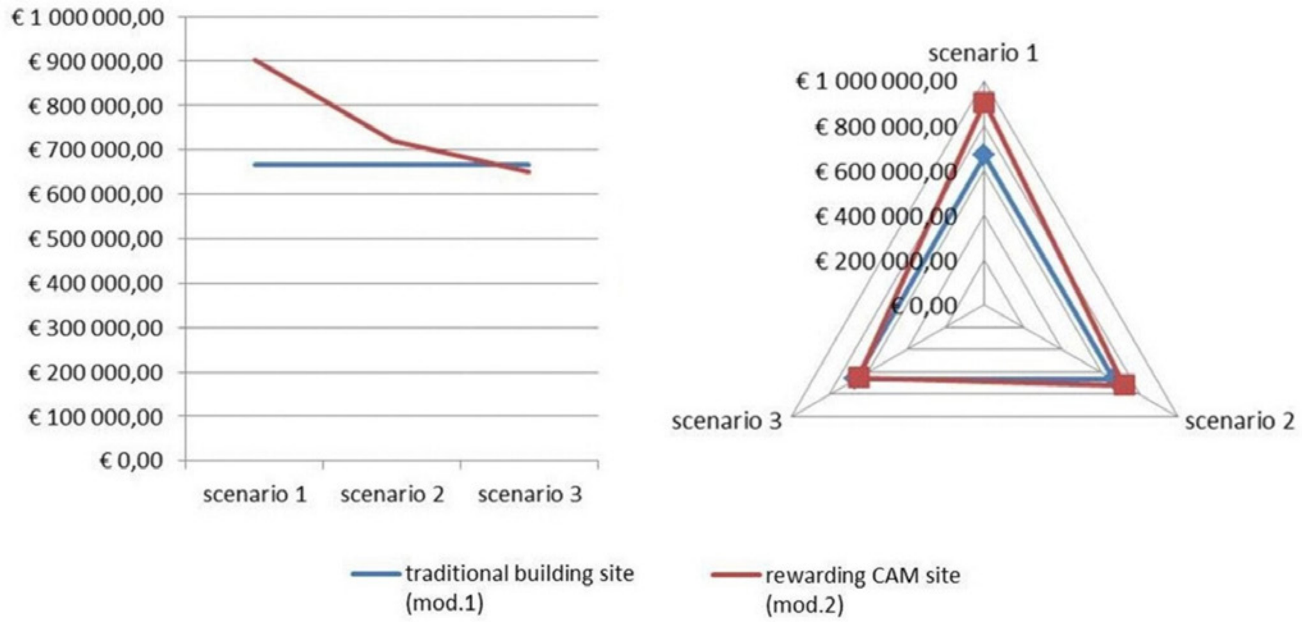


Fig. 7. *Graph show the trend of costs relating to model '2', according to the assumed strategies, as well as the relative variation with respect to the traditional reference model.*

The second scenario presupposes the possibility of using the resulting materials (for now, indifferently de on-site or off-site). The forecast of reuse of waste materials, after the elaboration of the waste management plan according to the current legislation, with reference to model 2, aimed at the pursuit of rewarding CAM, allows an economy, compared to scenario 1, equal to 28% (Figure 7).

The third scenario, which foresees the reuse of recycling materials on-site, after suitable treatment, is the most advantageous profile as it allows to obtain, overall, a reduction in demolition, logistics and transport costs, up to compensate the gap between the costs of the traditional site (mod.1) and the costs of the site prepared for rewarding CAM (mod.2). These results are graphically represented in the graphs in Figure 7 below.

5. DISCUSSION AND CONCLUSIONS

The approaching the end of life phase of some building complexes dating back to the first half of the 20th century makes the problems connected with the demolition and disposal of waste materials more topical than ever. Current legislation requires the drawing up of a plan for the selective disassembly and demolition of the work at the end of its life, requiring compliance with environmental requirements in terms of recycling and reuse of materials.

This approach determines new scenarios regarding the adoption of the most suitable site organisational strategies in order to achieve the set objectives, imposing targeted choices, aimed at the selection of materials, in the demolition process. The expected reduction in 'indirect costs' (i.e. relating to the reduction of environmental impact) translates into an increase in 'direct costs' linked to the demolition process.

The study showed an increase in direct costs (intuitively expected) between the organisation of the traditional site and the organisation of the site prepared for the basic CAM, in the measure of 8.6%, for the achievement of the threshold of 70% recycling or reuse of materials from the demolition process. Exceeding this threshold, in order to obtain the rewarding requirements (to the maximum extent obtainable for the case study), on the other hand, can determine an estimated cost increase of about 35% compared to the traditional demolition site.

However, a scenario of economic compensation through recovery/recycling of on-site demolition waste has been assumed, which would result in an overall economy of 36%, i.e. a negative balance of 1% compared to the traditional site. These scenarios, therefore, make it possible to cancel the economic gap of the experimental site, which is not only adequate to the current environmental standards but organised to achieve the rewarding CAM, to the extent of 24 percentage points, with a view to achieving the rewarding scores when the contract is awarded.

This approach encourages the current growth trends of entrepreneurship in the environmental sector. Many European experiences, in fact, highlight the start of new entrepreneurial activities dedicated to specialised supply chains in the sector, with a consequent reflection on the increase in employment. The study, developed with the objective of quantifying the trend of direct costs, in the transition between the hypothesised scenarios, can evidently be implemented through the estimation of indirect costs, i.e. related to reductions in environmental pressures resulting from the dynamics hypothesised for the development of the experimental model (mod.2). It is evident, in fact, that the latter approach has a lower impact in terms of exploitation of primary resources [18], as well as in terms of reduction of CO_2 emissions [19-20].

Future research perspectives are aimed at defining possible technological scenarios that will allow optimising the reuse and/or recycling of materials, coming from the demolition process, within the on-site reconstruction project, thus defining a technological continuity in the transition 'from grave to cradle', according to the logic of a circular building economy.

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RETHINKING THE (NEAR) FUTURE OF POSTWAR BUILT ENVIRONMENT: A SYSTEMIC APPROACH THROUGH FAÇADES-ONLY REPLACEMENT

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Highlights

The difficult heritage of postwar residential building stock because of its progressive loss of value, functionality, performances, and closeness to the end-of-life. The limits of a general demolition & rebuilding. Facing decarbonizing perspectives with an all-embracing view on carbon footprint (both operational and embodied carbon). The necessity to consolidate a methodology to correctly upgrade these buildings by increasing their micro-resilience and environmental value. The façades-only replacement as a systemic retrofit strategy to improve long-term carbon footprint, functionality, and environmental sustainability.

Abstract

There is a noticeable portion of the Italian building stock, typically concentrated in suburban areas, whose performance obsolescence and vulnerability are worsening its value and urban image as well. Even though a large-scale construction replacement seems to be apparently the expected way to solve the problem, current global strategies towards the built environment demand different approaches. The paper identifies envelope replacement as a systemic and feasible tactic to extend the service life of such target buildings and to enhance their resilience towards climate change and users' needs, also with positive fallouts for the environment and urban image.

Keywords

Carbon footprint, Embodied carbon, Postwar residential buildings, Envelope, Façades.

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1. INTRODUCTION

Data collected in the 2011 census by ISTAT (Italian statistic center) return an overall overview of residential buildings' consistency and, albeit in a concise way, their state of preservation. Among the whole censused residential stock (12,187,698 buildings), it is particularly significant to highlight that nearly 48% (5,869,320 buildings) was built during the postwar period, precisely between 1946 and 1980, and the 32% of it (1,887,191 buildings) concerns multi-story residential buildings with reinforced concrete structural frame. This study is focused on this last segment, that is to say at least 40 years old buildings, most of them at the end of their (designed) service life, usually affected by performance obsolescence, high seismic vulnerability, and living discomfort, especially for that substantial quota with inadequate maintenance status, which reaches about 70%. The criticalities mentioned above are always accompanied by lexical poverty of the facades lowering the urban image as well, especially in suburbs and past fast-growing areas where these low-quality buildings have been the answer to the growing real estate demand of postwar period, generated by a substantial increase in the population of urban areas.

This current performance obsolescence and vulnerability issue is not only age-related, but can be traced back also to the particular historical context of these buildings construction: within a few decades, a vast residential stock has been built, without no need of any particular urban planning or compositional care, but only by ensuring a minimum indoor quality standard threshold. Furthermore, the lack of thermal and anti-seismic strong regulations of that period (about 77% of the whole Italian building residential stock was built before 1981 when only 25% of territory was classified as seismic; even 88% of it was built before the first framework law with thermal insulation requirements of 1990 [1]) contributed to give back today buildings with hard structural and thermal deficiencies, mainly due to envelopes' energy waste and obsolete facilities.

This worrying situation is also spread in whole Europe: data collected by national Energy Performance Certificates (EPC) show that substantially all European buildings built before 1990 have energy-inefficient envelopes, as illustrated in Fig. 1, as well as structural deficiencies with respect to both static and seismic actions [2].

By now, there is no doubt about how much this residential building stock represents a difficult heritage, because of the progressive loss of its value and stiffness in meeting the new housing needs. Outlining a near future for these buildings inevitably involves a choice between replacement and retrofitting. It is not easy to outline a one-sided answer. Retrofit strategies on this kind of buildings are a recent and developing issue, somewhat lacking a systemic approach, but there are indisputable criticalities that could make a construction replacement inapplicable in many cases. An Italian apartment block usually involves very fragmented ownership, which hardly manages a decision-making process in a synergistic way: different goals and expectations make the total replacement decision almost impossible, also because the demolition phase is not even regulated by the condominium legal framework (Italian Civil Code only considers total or partial "destruction" due to accidental causes and not a planned demolition of the building for reconstruction purposes [3]). In addition, there is an objective difficulty to temporarily relocate all the residents (owners more than tenants) for the entire rebuilding period.

On the other hand, disjointed ownership usually tends to favor only single and autonomous remedial services,

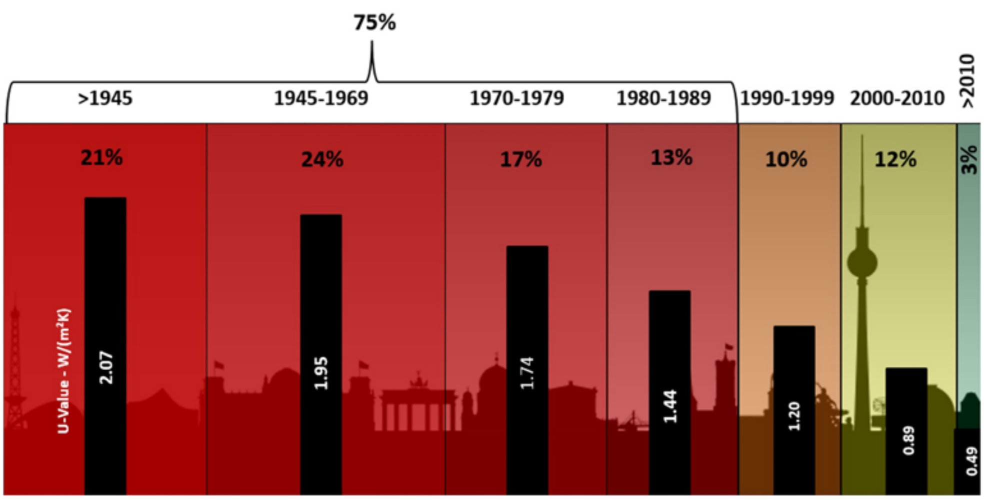

Fig. 1. *Age of EU building stock and corresponding average U-value for building envelopes. Source: BPIE Building Performance Institute Europe, 97% of buildings in the EU need to be upgraded. Factsheet (http://bpie.eu/wp-content/uploads/2017/12/State-of-the-building-stock-briefing_Dic6.pdf)*

mostly for emergency or purely monetary purposes (e.g. tax relief, volumetric premiums, etc.), to the detriment of more organic and systemic renovation strategies.

In order to offer an alternative to irreversible degradation, it is necessary to overcome the mentioned criticalities with really feasible strategies that need to be found halfway between total replacement and random retrofit attempts.

This research explains why a selective facade-only demolition could rebuild the envelope no more like a simple closure, but rather as an active, dynamic, and multifunctional interface. This can open up to new scenarios of a systemic reorganization of the entire building, with the aim to enhance not only indoor comfort and building performance, but also a functional improvement, environmental footprint and its resilience towards climate and users' needs, also with positive fallouts for the environment and urban image as well.

2. REPLACEMENT VS RETROFITTING

According to the 2019 Global Status Report for Buildings and Construction of the International Energy Agency (IEA) [4], the built environmental sector is responsible for 39% of global energy-related CO_2 emissions. Nevertheless, "operational" emissions concerning buildings in-use phase e.g. fossil fuel combustion for heating, cooling, or power generation for electricity, are only a part of the above percentage (28%). The other share, fairly substantial (11%), concerns process-related emissions during manufacturing, transportation, construction, and end of life phases. These emissions, commonly called "embodied" carbon, have been largely overlooked in the balance of built environment impact in the past, but the current climate emergency demands global strategies to achieve full decarbonization of construction sector, as pointed out, for example, in the recent World Green Building Council's report of 2019 "Bringing embodied carbon upfront" [5], even if Energy Performance Certification of Italian buildings does not consider embodied energy yet.

Moreover, embodied emissions footprint appears to have recently become an important key factor also in buildings lifecycle assessment, especially for those at the end of their service life, which feed the debate "retrofitting vs. demolition & rebuilding". Even if it is not easy to correctly quantify embodied carbon footprint in the two different scenarios due to data shortage, the majority of the literature review [6, 7] found that refurbishment strategies generally have lower embodied carbon emissions (and lower environmental impact) than demolition and new build.

Besides the importance of tackling embodied carbon emissions growth, with regard to the considered building stock, further reasons could make challenging to apply a general replacement (in addition to the problem of a decision-making process put into a fragmented property's head) such as the European waste framework Directive 2008/98/EC, which implies the recycling of at least the 70% of construction and demolition waste (CDW). The problem lies in the typological and material characteristics of those buildings: LCAs on real building demolitions and disposal phases highlighted the extremely predominance of inert materials (about even 97% for 60's and 70's multi-story residential buildings with a reinforced concrete structure and brick infill envelope [8]). It seems obvious that the only way to respect the Directive is to recycle (or at least "downcycle" by re-using on-site) inert wastes, but, in a typical replacement operation of such buildings, which usually take place in high-density urban areas with very limited site area size, it is almost impossible to keep and re-use on-site the 70% of inert waste. Thus, the alternative is to manage recycling activities, which require source separation and energy supply. Here comes another problem: because of the heterogeneity of common building structural frame (i.e. the presence of clay blocks in reinforced concrete floors), it has been proven that more than 60% of total inert waste consists of non-separable concrete, brick, mortar and ceramic [8] (or separable only with processes requiring high charges also for energy). The traditional "wet" technology, which characterizes the considered building stock, does not seem to facilitate recycling processes of complete demolition waste.

It is then inevitable to adopt different strategies oriented towards an extension of these buildings' service-life, with a significantly lower impact on C&D waste and CO_2 emissions.

A very first sustainable way to respect the waste framework Directive is to minimize material waste, to get it as less heterogeneous as possible, and with higher waste quality. In this frame, a concrete strategy is particularly suitable for the reference building stock: applying selective demolition processes, mainly to the building envelope.

3. METHODOLOGY

Considering all the issues associated with postwar apartment blocks, a change of perspective can widen the façades-only replacement potential largely. Their global upgrading can be considered as a best practice, improving long-term carbon footprint, practical feasibility, and getting several "side-related" favorable goals.

3.1. EMBODIED CO_2 IN FAÇADES

Globally addressing total carbon footprint is now a must also with reference to the building stock we are considering. Now a fair approach shall focus on embodied carbon impact too since strategies to reduce operational emissions are already underway. It is not easy at all to give real and comparable data about embodied carbon, mainly because of the wide variety of input data in LCA studies and, above all, their different boundary conditions (i.e. cradle-to-gate, cradle-to-grave etc.). Chastas et al. [9], for example, give evidence of that by identifying a wide range indeed of embodied carbon emissions (179.3÷1050 $kgCO_2e/m^2$) upon 95 residential buildings case studies based on 50-year building lifespan. Other reviewed literature [10-12] narrow that range between 300÷600 $kgCO_2e/m^2$ instead. The LCA of Grönvall et al. [13] is particularly significant because they take into account a hypothetical apartment block with an on-site cast reinforced concrete frame (four-story building with 16 flats in total) quite parallel to the reference stock. Their results show a total embodied carbon of 344 $kgCO_2e/m^2$, split as follows: 86% raw material extraction, building material production, and transportation; 2% construction phase; 12% end of life phase. Since this study refers to existing buildings with a reasonable possibility to undergo a service life extension, the end of life stage is not considered, thus assuming a reference "cradle-to-construction" approximate value of 300 $kgCO_2e/m^2$. Thus, a 5-story apartment building measuring e.g. 26x12x15(H) m, has embodied about 468 tons of CO_2e after its construction.

Material	Thickness [m]	Surface [m²]	Volume [m³]	Density [kg/m³]	Total mass [kg]	Embodied Carbon [$kgCO_2$/kg]	Total material Embodied Carbon [$kgCO_2$]	Incid. [%]
gypsum plaster (int)	0.015	390.00	5.85	1120.00	6552.00	0.12	786.24	3.29
general clay brick	0.12	390.00	46.80	800.00	37,440.00	0.22	8236.80	34.47
air gap	0.13							
general clay brick	0.12	390.00	46.80	800.00	37,440.00	0.22	8236.80	34.47
cement plaster (ext)	0.015	390.00	5.85	1760.00	10,296.00	0.12	1235.52	5.17
cement screed (balconies)	0.1	35.00	3.50	2100.00	7350.00	0.21	1565.55	6.55
ceramic (balconies)	0.02	35.00	0.70	1700.00	1190.00	0.59	702.10	2.94
cement plaster (intrados balconies)	0.015	35.00	0.53	1760.00	924.00	0.12	110.88	0.46
iron (parapet)		53.00		20.00 [kg/m²]	1060.00	1.91	2024.60	8.47
windowsills (limestone)	0.04	11.00	0.44	2180.00	959.20	0.017	16. 31	0.07
windows (wood frame with single glazed, no coating)		70.00				14.00 [$kgCO_2e$/mq] [15]	980.00	4.10
						existing façade embodied carbon	**23,894.80**	100
						Incidence on the assumed total building embodied carbon	**5.11 %**	

Tab. 1. *Assessment of existing building facade embodied carbon incidence.*

In this frame, what is the embodied CO_2 share of e. g. a street-side façade? The following Fig. 2 table estimates this value on the basis of the University of Bath's ICE Database [14]. The boundary conditions of selected material shown in Tab. 1 and Tab. 2 are all "cradle-to-gate". In both existing and new façade embodied carbon evaluation, the materials' transportation to site and construction phase incidences are disregarded.

Since the evaluation is referred to a façade replacement, the above embodied CO_2 value needs to be increased by a certain amount (12% according to Grönvall et al. [13]) to take into account CDW wastes disposal: this value could be lowered through a smart managing of recycling activities or selective de-constructions.

In the same frame, the embodied CO_2 impact of the new envelope (with its optimized and updated performances) can be assessed, as shown in Tab. 3.

As predictable, the new façade shows an almost double value of embodied carbon mainly due to process-related emissions for high-performance windows and some of selected mineral-based and fossil-based building materials.

However, the whole building carbon footprint modification due to the facade-only replacement needs to be considered. The reference building has slightly increased embodied carbon footprint (which is the sum of existing façade demolition incidence increased by some percentage to take into account also CDW disposal, and the new façade realization), but there is a significant decrease of the operational carbon, thanks to the lower energy demand for heat generation and the higher thermal comfort performance of the new façade. Considering a thermal transmittance decrease from 2 W/m²K (existing façade) to 0.19 W/m²K (new façade, as detailed in Fig. 3) and a traditional fossil fuel-based heating system, the building carbon dioxide operational savings can be appraised in 7800 $kgCO_2$ per year This saving will balance the increased embodied carbon (approximately 70.000 $kgCO_2e$) within about 9 years, which is a relatively short period of time compared to the achieved building service life extension (at least another 50 years).

The façade-only replacement in such a kind of buildings showed to be very effective in reducing their long-term global carbon footprint. Nevertheless, how is this feasible?

Material	Thickness [m]	Surface [m²]	Volume [m³]	Density [kg/m³]	Total mass [kg]	Embodied Carbon [$kgCO_2/kg$]	Total material Embodied Carbon [$kgCO_2$]	Incid. [%]
gypsum plasterboard (int)	0.025	390.00	9.75	900.00	8775.00	0.38	3334.50	7.71
plasterboard counterwall steel framing	0.075	390.00		10.00 [kg/m²]	3900.00	1.71	6669.00	15.42
rockwool panel	0.04	390.00	15.60	23.00	358.80	1.05	376.74	0.87
air gap (plant passage)	0.28							
precast concrete panel	0.04	390.00	15.60	2400.00	37,440.00	0.215	8049.60	18.61
polystyrene panel	0.140	390.00	54.60	20.00	1092.00	3.400	3712.80	8.59
cement plaster (ext)	0.02	390.00	7.80	1760.00	13,728.00	0.12	1647.36	3.81
cement screed (balconies)	0.1	35.00	3.50	2100.00	7350.00	0.21	1565.55	3.62
ceramic (balconies)	0.02	35.00	0.70	1700.00	1190.00	0.59	702.10	1.62
cement plaster (intrados balconies)	0.015	35.00	0.53	1760.00	924.00	0.12	110.88	0.26
iron (parapet)		53.00		20.00 [kg/m²]	1060.00	1.91	2024.60	4.68
windowsills (concrete)	0.04	11.00	0.44	2400.00	1056.00	0.215	227.04	0.52
windows (2x glazed, krypton filled, aluminum framed)		70.00				211,80 [$kgCO_2e$/mq] [15]	14,826.00	34.28
						new façade embodied carbon	**43,246.17**	100
						Incidence on the assumed total building embodied carbon	**9.24 %**	

Tab. 2. *Assessment of hypothetical new building facade embodied carbon incidence.*

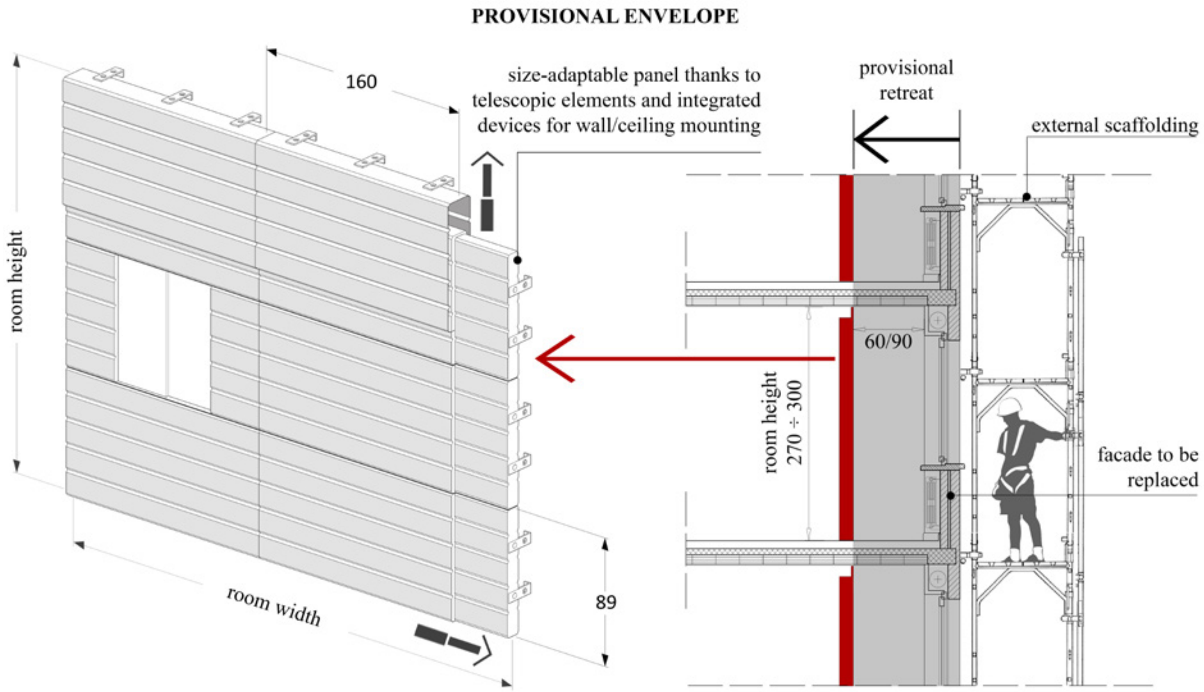

Fig. 2. *Easy-mount and telescopic low-mass prefab elements for the "provisional envelope".*

A building envelope-only replacement requires specific techniques to manage the site, mainly because of the intrinsic difficulties to operate in a sensitive context such as highly-density urban environment, which involves limited available space for the site, logistical and handling difficulties and last but not least the users' & owners' life very close to the working site. This requires specifically trained operators and entrepreneurs also concerning the demolition phase, where a selective de-construction is certainly the correct strategy to respond to the project goals properly and to improve the CDW management.

The whole envelope replacement process will keep the building usage ongoing and fairly compatible with the working site, thus overcoming the problem of relocating occupants. This feasibility goal is based on provisional works, basically by realizing a "provisional envelope", consisting of easy-mount and reusable low-mass prefab elements (a sort of sandwich panels with tongue-and-groove joints and high soundproofing capacity), which would also be size-adaptable thanks to specific telescopic elements, as illustrated in Fig. 2.

This provisional closure should be mounted directly inside the rooms, close to the envelope to be replaced (approx. 60÷90 cm back from it), thus creating a sort of usable gap where operators can also gradually work as the selective demolition goes on.

Some of the panels could provide a sliding window made of unbreakable synthetic material and internal shutters, to assure fresh air and light control, especially when staffs are not working on that room's envelope.

If the building envelope's substitution is limited to the outer layers, the provisional closure may be unnecessary: this is certainly a low-cost compromise solution, moreover with a faster site timeline. In this case, the inner envelope is kept in place with some adjustments to fit the new windows and facilities.

3.2. THE REAR FAÇADE: AN OPPORTUNITY FOR A FUNCTIONAL IMPROVEMENT

In addition to performance, obsolescence, and vulnerability criticalities, second postwar buildings have a qualitative deficit primarily. It heavily weighs on the environment, user comfort, and proxemics: an important role is played by "non-functional" building envelopes (meaning they do not offer any kind of dynamic interaction), thus related to simple idle closures. The building culture of that period was used to create a hierarchy that rather became a "visual" antithesis, between a (not even always) properly designed street façade, which living spaces stood on, and a simple "window-holder" closure of the rear one, with no whatsoever formal dignity. This has contributed to giving buildings with an increasing loss of today's value and functionality.

Despite that, rear facades themselves, which are usually less normatively restricted because they insist on private courtyards, have favorable conditions to receive a more organic retrofit intervention, aimed firstly to functional improvement. In order to maximize and join functional and performance enhancement, a systemic approach is needed. If rear façade replacement is recon-

Fig. 3. *Post-war residential building (built in 1960-1961) in Kapfenberg (Austria) before (a) and after renovation (b); Rear counter-façade with new spatial arrangements (c). Source: https://architizer.com/projects/renovation-residential-building-kapfenberg/.*

ceived with a greater degree of freedom, for example, by adding a multifunctional counter-façade, new scenarios open up, even to operate indirectly on the whole building.

Such intervention could create e. g. new spatial arrangements, both private and communal, like wider balconies or even covered spaces like loggias; new update horizontal and vertical distribution, as well as a more congenial access system for apartments, which would benefit from a rise in value thanks to the new private transitional in/out spaces. A rear counter-façade also has huge potential in terms of new grid-connections, renewable energy technologies integration, and solar shading control; the latter may be favorably oriented towards greenery systems to take advantage of "free" benefits deriving from vegetal-based materials (i.e. carbon dioxide absorption, cooling through evapotranspiration).

This kind of multi-benefit approach (functional, performance, imagery etc.) has already consolidated in various research fields [16-18], which originated from some European experiences of existing façade over-cladding (overlapping) and re-cladding (replacement), like in the case illustrated in the following Fig. 3.

It is also important to highlight this kind of approach can better convey adaptive and subject-oriented interventions, with a positive return for users' well-being and quality of life.

3.3. THE STREET-SIDE FAÇADE: A KEY ELEMENT FOR ENVIRONMENTAL SUSTAINABILITY

Most of these postwar buildings are located in high-density urban areas, where climate change due to global warming intensifies air pollution, peel temperatures and heat island effects (UHI): this is a non-negligible factor and, moreover, their street-side facades' impervious surfaces are partly responsible for harmful microclimates increasing e.g. for the urban canyon effect.

Every building can do its counteracting part by enhancing its environmental sustainability, much more if it is part of a well-balanced urban scale green planning based on vegetation improvement. Street-side façade rethinking can be a concrete solution: no longer a traditional closure, but rather an active and dynamic interface capable of giving an added value to environmental quality e. g. by integrating vertical greenery systems (VGS). More precisely, indirect VGS framed on external light structures made of trellises, meshes, cables, or wired ropes for climbing plants development, are very well suited to these buildings because of their over-cladding propensity.

According to reviewed literature estimations [19], VGS CO_2 absorption capacity depends on many factors but is around fairly low values like 1 $kgCO_2$ per year (and would weigh very little in the balance estimated in par. 3.1). The real strengths of these systems are rather related to other intrinsic skills like shading and evapotranspiration cooling since they have higher values of *albedo* than most of the common building materials.

Thus, VGS proved to give a real contribution to UHI mitigation [20], especially in high-density urban areas where the availability of vertical surfaces (façades indeed) for greening is much more potentially usable than horizontal spaces at street level [21]. Obviously, this mitigation effect needs to be evaluated at a neighborhood scale, considering each building contribution, as well as these measures, should be encouraged by urban planning and tax-incentive mechanisms. It might be useful to introduce an indicator at building scale, a kind of UHI mitigation performance (P_{UHI}) for an indirect green façade system, to be evaluated through the capacity to change the balance between paved or impervious surfaces and greenery-cooling surfaces, considering the portion of the built environment in front of that façade, as drafted in the schemes of the Fig. 4.

The increase of cooling surfaces due to indirect green façade implementation is evaluated as the delta value Δ_{UHI}:

The formula (1) is illustrated in Fig. 4 considering different situations: street only; UHI-worsening façade; façade already fully or partially covered with indirect green façade systems (in this last case it is possible to evaluate benefits of increasing the vegetal layer on the indirect façade system).

The resulting delta parameter (1) needs to be related to the built context (different kinds of suburbs, middle town etc.) and decreased with a reduction coefficient when the greening façade takes place in rural

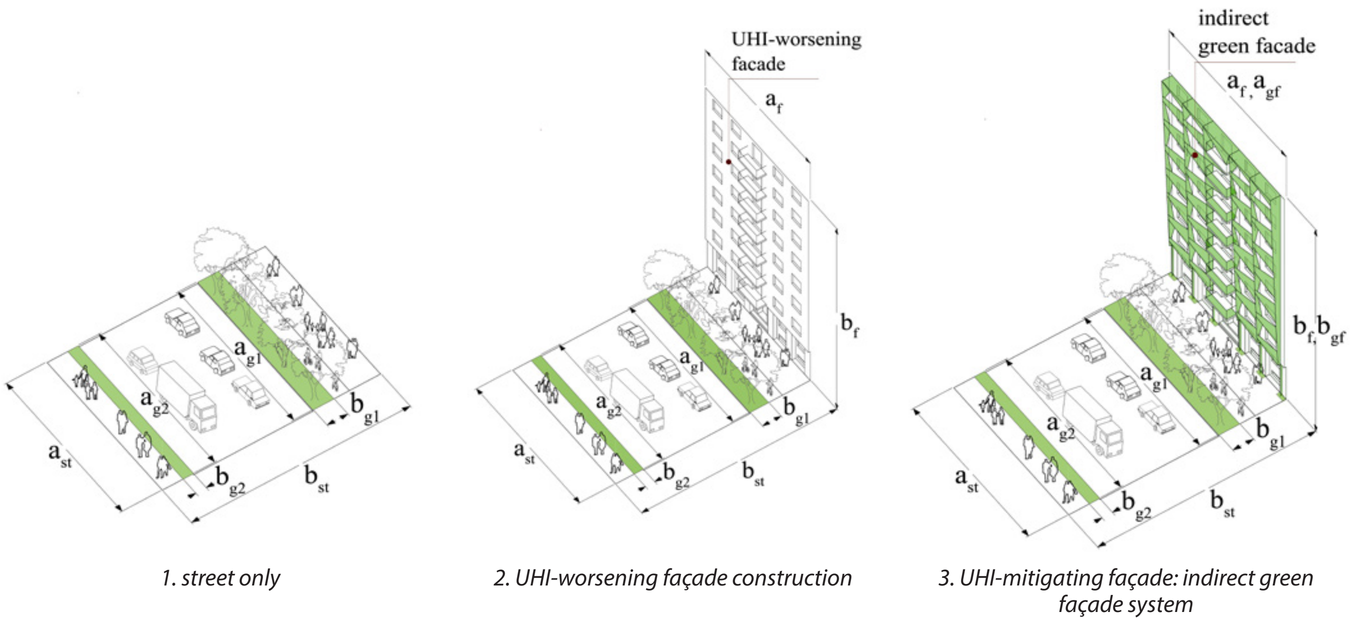

Fig. 4. *Axonometric cross-sections of a built environment according to three configurations: 1. no building; 2. UHI-worsening façade; 3. cool façade optimization with indirect green façade.*

$$\Delta_{UHI} = \left[\frac{\Sigma(a_{gi} * b_{gi}) + (a_{gf} * b_{gf})}{(a_{st} * b_{st}) + (a_{f} * b_{f}) + (a_{gf} * b_{gf})}\right]_1 - \left[\frac{\Sigma(a_{gi} * b_{gi}) + (a_{gf} * b_{gf})}{(a_{st} * b_{st}) + (a_{f} * b_{f}) + (a_{gf} * b_{gf})}\right]_0 \quad [0 \div 1] \qquad (1)$$

Where:

$\Sigma(a_{gi} < b_{gi})$ existing cooling surfaces in the street portion

$(a_{st} < b_{st})$ façade-related street portion*

$[\ ]_1$ final situation

$(a_{gf} < b_{gf})$ façade portion with an indirect green façade system

$(a_{f} < b_{f})$ façade portion without indirect green façade system

$[\ ]_0$ initial situation

*The façade-related street portion considered must never exceed the area of the façade itself. In these cases, the street portion to be considered is represented by the façade overturning on the ground.

or peripheral areas that are marginally or not at all affected by UHI effects. Since there is a recognized relation between UHI effect and population density [22], the following diagram (Fig. 5) adapts the coefficient mentioned above for rural (scarcely populated) and peripheral (intermediated populated) neighborhoods. The product between the reduction coefficient $C_{r,UHI}$, and the Δ_{UHI} generates the urban heat island (UHI) mitigation parameter P_{UHI} (2).

$$P_{UHI} = C_{r,UHI} * \Delta_{UHI} \, [0 \div 1] \qquad (2)$$

The population-weighted density thresholds shown in Fig. 5 diagram derives from the European Degree of urbanization DEGURBA [23], which provides am harmonized classification of thinly, intermediate, and densely populated areas.

This behavioral and performance parameters approach could be favorably extended in order to value many different aspects of an indirect VGS, thus going so far as to define a global performance indicator [24].

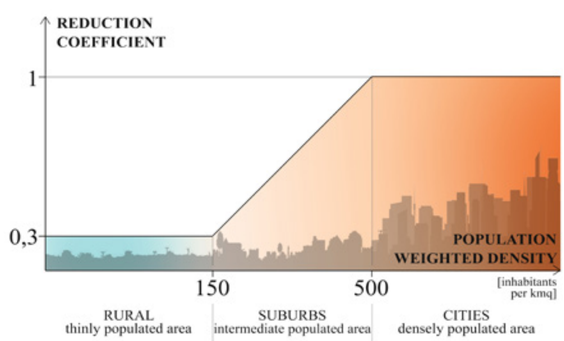

Fig. 5. *Graphic illustrating a reduction coefficient Cr for ΔUHI (2), compared to the population density.*

4. RESULTS

The typical assessment on the carbon footprint balance depending on façade-only replacements on post-WWII buildings has a rather low increase of the embodied carbon (around 15% compared to the total embodied carbon) and instead of significant weight on operational carbon savings, thanks to new façade thermal performances. Such interventions appear, therefore, particularly virtuous, so that the balance point between embodied carbon increase and operational carbon saving can be reached in 9 years only, after which the new façade system starts lowering the building's long-term CO2 footprint.

The sustainability of such works could be enhanced by expedients and strategies, like the selective de-construction of the existing façade in order to properly manage recycling activities of CDW wastes, here less heterogeneous, in compliance with the Waste Framework Directive; more quick and efficient site management, for example implementing a "provisional envelope", can feasibly keep ongoing the building usage in spite of a good compatibility with the working site.

According to the authors, particularly interesting and worthy of more in-depth analysis in the future are also some "side effects" e. g. the inward/functional rear-façade importance and the outer/environmental street-side value.

5. CONCLUSIONS

Rethinking the sustainable housing renewal facing a decarbonized EU building stock by 2050 requires a real focus on postwar buildings, because of their anything but negligible amount and their closeness to the end-of-life. General demolition & rebuilding seems to be the right choice to achieve the goal of an updated and environmentally friendly building: better energy rating and CO_2 footprint. At a closer look, the common way to assess the CO_2 footprint neglects the carbon embedded in the building: it is an "on duty-only" rating. But if we consider the whole carbon footprint balance (construction, service life, de-construction) a new option comes into the limelight: demolition & rebuilding of the vertical envelope only: quicker works, no need to reallocate inhabitants, less waste impact and a great improvement for thermal performances and building functionality with a better fallout on the environment.

Façade-only rebuilding showed to be an effective strategy to increase the micro-resilience and the environmental value of post-WWII building heritage. In doing so, a methodology to correctly upgrading these buildings needs to be consolidated and encouraged above all.

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STUDY ON SOLAR SHADING SYSTEMS FOR DESIGNING NZEB KINDERGARTENS IN ITALY

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Highlights

Solar shading energy and environmental performance for kindergartens are evaluated.
The visual link between classrooms and the external environment is guaranteed.
Different types of control for automated internal blinds are studied.
Overhang and internal automated blinds are advisable for southern configurations.
The illuminance uniformity and average daylight factor are verified for classes.

Abstract

The use of solar shading in buildings necessarily affects the energy balance and energy demand. The aim of this study is to evaluate the efficiency of the most common solar shading for kindergartens to improve their energy and environmental performance. The research considers different types of solar shading for a southern orientation, their possible implementation with automated control systems, the relation with the window-to-wall ratio and finally the addition of vertical solar shading for eastern and western orientations.

Keywords

TSchools, nZEB, Solar shading, Energy savings, Low carbon.

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1. BACKGROUND

The use of shielding systems in buildings necessarily affects the energy balance and the energy demand for heating, cooling and lighting [1]. Evangelisti et al. calculate an index dependent on the surface temperature of the window glazing and demonstrate that a 38.7% reduction in the energy demand for cooling is obtained during the summer season using a shading system characterised by horizontal louvres [2].

As for lighting, the use of solar shading could also lead to a significant reduction in energy requirements, and this is obviously linked to the intended use of the building as well. Most of the studies pertaining to solar shading are related to office buildings since their energy demand for artificial lighting is significant. David et al. demonstrated that the use of a large number of vertical sun shadings for windows on eastern and western facing façades results in a daylight illuminance index (UDI) value below 20%, leading to an increase in the energy demand for artificial lighting to ensure proper indoor visual comfort [3]. Zuo et al. [4] also use the value of the UDI to optimise a control system for automated solar shading to minimise the glare and to maximise the natural lighting, by reducing the annual energy demand.

Furthermore, solar shadings are one of the most important bioclimatic passive strategies for a façade. Salva et al. define such passive solar shadings as those that do not consume any energy [5]. Based on this, the construction of an nZEB (Nearly Zero Energy Building) kindergarten in Italy cannot ignore the use of shading systems since they inevitably contribute to guarantee internal comfort, significantly affected by the entry of natural light and solar gains, and to help both visual comfort and hygrothermal well-being [6, 7]. Their proper design can avoid overheating problems through the regulation of the solar gains inside the rooms during the summer season [8, 9]. In a building where visual activities are carried out at predetermined workstations, visual and hygrothermal comfort strongly influence the productivity of the occupants. Therefore, this aspect is essential for school buildings.

There are different types of solar shading systems: the active systems change the ratio between the incident and transmitted solar radiation, the passive fixed systems are mainly used in climates where the incident solar radiation does not change significantly during the year, and finally, the dynamic systems change their position through an automated control mechanism [10]. Many studies favour active or dynamic shielding systems, that can adapt to real external climate conditions [11], to improve both the building energy performance and internal visual comfort for the occupants [12]. However, other studies claim that such systems could lead to glare problems [13]. Some studies also state that it is essential to consider the possibility of using active systems, especially in relation to users' satisfaction with respect to their internal comfort and the opportunity for them to adjust the solar shading system according to their needs, which is essential for visual comfort [14, 15]. Finally, other authors link the use of automated solar shading systems to the evaluation of a building environmental impact. Al Touma et al. consider the use of an automated solar shading in an office building with South-facing openings and they state that it is possible to reduce CO_2 emissions due to the consumption during the operational phase by 24 $kgCO_2/m^2a$ [16].

2. RESEARCH AIM

First, solar shadings are an element that strongly characterises the appearance of the buildings' fronts. Furthermore, by regulating the entry of solar gains into rooms, they necessarily and significantly influence the energy balance. Finally, their proper design ensures the hygrothermal and visual well-being of the occupants. For a school building, it is essential to maintain adequate internal conditions to ensure the comfort of students both during school time and during periods in which extracurricular activities or neighbourhood activities are carried out. Due to the "2030 climate & energy framework", the "2050 long-term strategy" and the obligation to build new nZEB buildings starting since January 1st 2019, it is necessary to properly define all the features that characterise and influence buildings energy and environmental performance, especially during the preliminary design phase.

Consequently, the main objective of the study reported in the article is the evaluation of the efficiency of the most common solar shading systems for the new typological models of nursery schools in Italy [17], which were defined in a previous phase of the research. Three different models for kindergartens were identified. These represent the synthesis of the analysis of the environmental and technological system of many sustainable school buildings built from 2003 to 2015. The identified models meet the current morphological, dimensional, aggregation and spatial distributional needs and requirements of both new teaching and pedagogical methods and the public administrations that build schools. The survey included the assessment of the energy efficiency of each different model that was defined and the different technological solutions that can be adopted in relation to the different Italian climate zones, with reference to the primary energy demand and environmental impact through the calculation of the Global Warming Potential. This also allowed to establish which model is the best performing in each climate zone according to the main design features. The study described precedes the one proposed in this work, and it has been the subject of some publications.

The analysis is aimed at reducing the energy demand of the typological models in question, which is represented by the sum of the energy needed for heating, cooling, lighting, auxiliary systems, internal equipment, and domestic hot water. Furthermore, it is essential to understand, in relation to the intended use of the building, whether a fixed shielding system or an automated movable one, with a relative control device, is better in terms of energy requirements and CO_2 emissions. Furthermore, it is necessary to evaluate: the natural lighting conditions inside classrooms to establish the most advisable arrangement of the openings in the façade; the optimal configuration of the shielding systems to ensure the proper amount of daylight; the uniformity of the lighting to avoid glare in the areas where visual tasks are performed. The study has been developed considering the models located in five cities (Milan, Florence, Rome, Naples, Palermo) belonging to different Italian climate zones.

3. METHODOLOGY

Initially, the analysis applied to the 3 new typological models for kindergartens [17] compared the most common shielding systems for a southern orientation, where indeed the classrooms are located:

- internal venetian blinds with slats with a high reflection coefficient and control of the incident solar radiation – 120 W/m^2;
- fixed shielding made with an overhang equal to 2.00 m;
- horizontal louvres;
- a combination of an overhang and internal blinds with slats with a high reflection coefficient and control of the incident solar radiation – 120 W/m^2;
- external venetian blinds with control of the incident solar radiation – 120 W/m^2.

The influence of the different solutions was assessed not only in relation to the energy demand, but also considering the specific heating, cooling, and lighting contributions as well. Subsequently, the possibility of using a fixed or automated system with horizontal slats with different types of control was analysed, as illustrated in Table 1. The study was performed considering both the primary energy demand and CO_2 emissions in the atmosphere, with respect to each type of control. This analysis was carried out for the city of Florence, and it also considered the variation of the window-to-wall ratio. Indeed, in order to perform a comparison, the study was also developed with respect to the advisable WWR (Window-to-Wall ratio) for the southern orientation of an nZEB kindergarten in Italy, as defined by previous studies (southern WWR = 50%) [18].

Type of solar shading control system	Control definition (Design Builder contents)
Always on	Shading devices are always activated
Schedule	It is defined by a time using a schedule (if the schedule is equal to 1, then the shading operates)
Solar	Solar radiation > 120 W/m^2
Glare	Maximum glare index > 22
Outside air temperature	External temperature > 24°C
Inside air temperature	Internal temperature > 24°C
Cooling	Shading is on if zone cooling rate in the previous time step is non-zero
Night outside low air temperature	Air temperature < 0°C
Night inside low air temperature	Air temperature < 15°C
Horizontal solar	Solar set point >120 W/m^2

Tab. 1. *Definition of different types of solar shading control systems.*

The influences of vertical shields to the East and West and the variation of the WWR for the different typological models also were considered on the evaluation of energy performance of a building. The study that was carried out allows determining the advisable solar shading system that should be adopted during the construction of nZEB school buildings in Italy.

Finally, to evaluate the proper natural lighting inside the classes, the natural light maps of the classes were built. The daylight factor was calculated in order to verify the minimum value that complies with the UNI (Italian National Agency of Unification) 10840 [19] for schools. In addition, the uniformity ratio was calculated using the minimum and average values of the daylight factor and according to the different façade openings positions and the advisable WWR value, previously determined for each city. Since the classes have the same shape and planimetric organisation in all the models, the analysis was carried out considering two of the three typological models to evaluate the natural lighting for June 21st and December 21st at 12:00 with the sky model of the CIE (International Commission on lighting) (clear sky) and a worktop height of 75 cm. The energy simulations in the dynamic regime with hourly steps for calculating the total energy demand and the different contributions and the simulations for making the maps of the illuminance and the daylight factor of the classes were conducted using Design Builder. The primary energy demand was calculated with the following conversion factors for the different energy carriers: gas $f_{P,tot}$ = 1.05 and electrical energy from the public grid $f_{P,tot}$ = 2.42 ($f_{P,nren}$ = 1.95 and $f_{P,ren}$ = 0.47). The calculation of the CO_2 emissions in the atmosphere was carried out considering the following conversion factors: 0.210 $kgCO_2/kWh$ for gas and 0.544 $kgCO_2/kWh$ for electrical energy from the public grid.

4. MODELS AND INPUT DATA

As already specified, the analysis has been carried out considering 5 different cities belonging to different Italian climate zones, as reported in the Decree of the President of the Republic 412/93, and they were identified using the number of heating degrees days. Florence, characterised by a temperate climate with hot summers and cold and humid winters, may also be representative of Milan and Rome with reference to the results reported in this paper. On the other hand, Palermo, with a temperate Mediterranean climate with dry summers, is also representative of the city of Naples. Three basic typological models for kindergartens (Figure 1) were considered in the study: one with a compact shape with three sections (I1) and an area of approximately 890 m^2, and two with prevalently linear shapes with three (I2) and six sections (I3) and areas of approximately 950 m^2 and 1730 m^2, respectively [17].

A construction system with a wooden structure with cross-laminated timber (XLAM) was used for both the vertical perimeter wall and the roof. This solution has been utilised because the technological analysis, which has been carried out on many example buildings, has shown that it is one of the most recurrent for the construction of kindergartens in the Mediterranean area. Table 2 shows the main characteristics of the materials that constitute the stratigraphy of the technological solution adopted for the wall and the roof. The table shows the minimum thickness of the insulation necessary to meet the thermal transmittance of the reference building, as defined by the current Italian regulations, and the value of the thermal transmittance of the wall and roof for each respective climate zone. After comparing it with other materials, wood fibre insulation was chosen since it is a natural material that obtains low CO_2 emissions for the construction phase, and also allows to guarantee a proper value of the thermodynamic characteristics of the wall, without using a high thickness.

For the ground floor layers, the solution with plastic formwork for the underfloor ventilation was used, and it was completed with an expanded polystyrene (EPS) insulation layer. Finally, an aluminium thermal break frame was adopted (Thermal transmittance U_f =1.7 W/m^2K) for the windows, completed by double glazing with different properties depending on the climatic zones to comply with the thermal transmittance required for the reference building. The minimum value of the WWR was defined according to the current health-hygiene regulations in Italy. In all the models, a fixed solar shading system built with an overhang of 2.00 m for each southern functional unit was used. For each different thermal

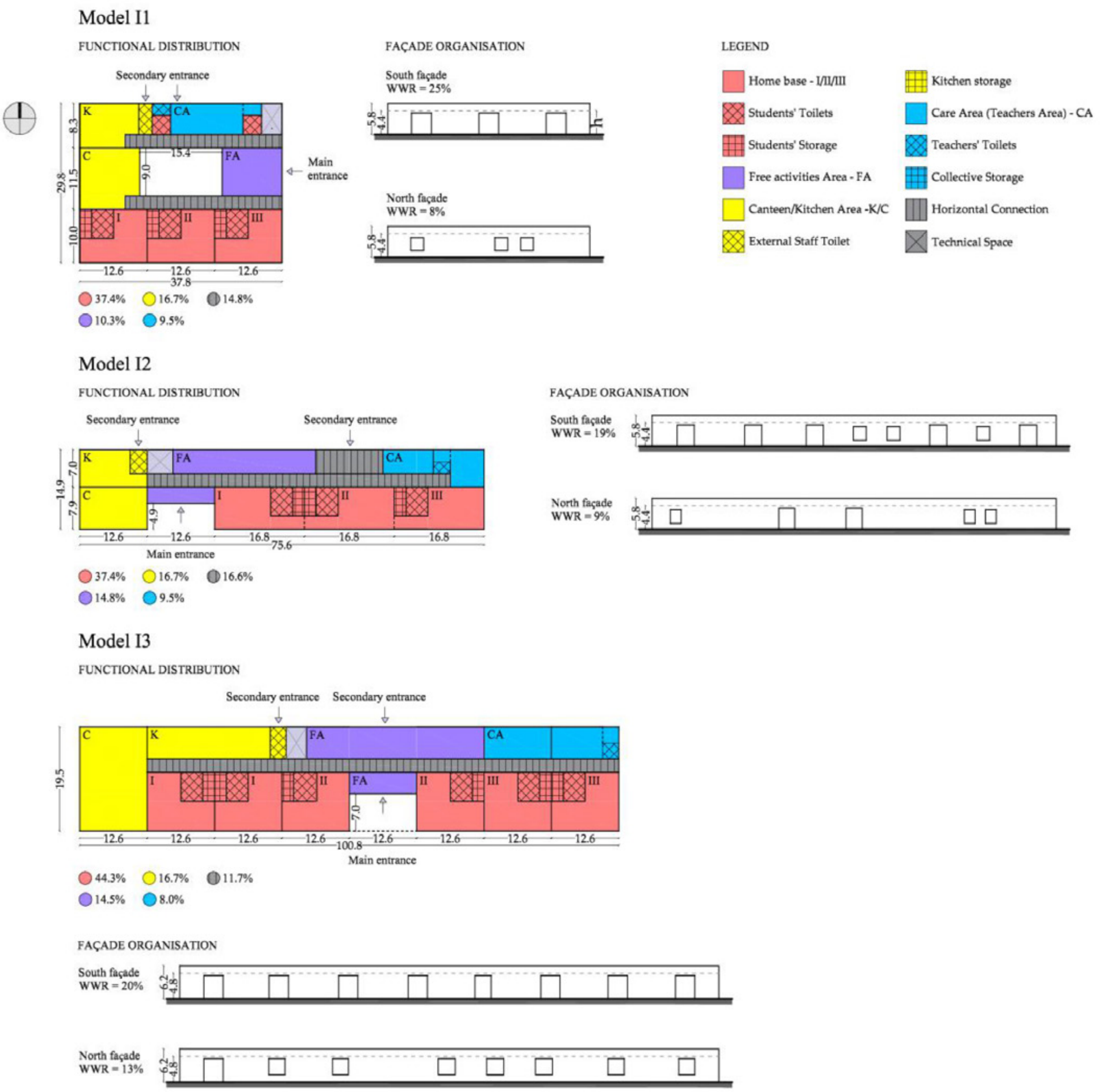

Fig. 1. *Three new typological models for kindergartens.*

zone, in which the building was divided, the occupancy (person/m^2) is determined according to Appendix A of UNI 10339 [20], the minimum airflow rate is taken from the same legislation in Table III, and finally, the internal gains are taken from UNI/TS (Technical specification) 11300-1 [21]. Regarding the level of illuminance, UNI EN (European Standard) 12464-1 was considered [22]. The lighting efficiency was considered to be equal to 120 lm/W. Regarding the simulations, the lighting control was used with the maximum glare allowed. The system was simulated using a simple HVAC (Heating, Ventilation and Air Conditioning) system with a condensing gas boiler with efficiency equal to 90% for heating, a heating pump for cooling with an energy efficiency index equal to 2.5 and a mechanically controlled ventilation system with heat recovery equal to 50%.

	Layer	Material	Climate zone	t [m]	λ [W/mK]	U [W/m²K]
External wall	1	External plaster		0.025	0.9	
	2.1	Wood fibre	B	0.04	0.038	$U_B = 0.42$
	2.2	Wood fibre	C	0.08	0.038	$U_C = 0.29$
	2.3	Wood fibre	D	0.10	0.038	$U_D = 0.25$
	2.4	Wood fibre	E	0.10	0.038	$U_E = 0.25$
	3	XLAM panel		0.13	0.12	
	4	Air cavity		0.05	-	
	4	Gypsum board		0.015	0.21	
Roof	Layer	Material	Climate zone	t [m]	λ [W/mK]	U [W/m²K]
	1	Metal sheet		0.00005	1.07	
	2	Air cavity		0.5	-	
	3	Waterproof sheet		0.004	0.2	
	4.1	Wood fibre	B	0.06	0.038	$U_B = 0.30$
	4.2	Wood fibre	C	0.06	0.038	$U_C = 0.30$
	4.3	Wood fibre	D	0.10	0.038	$U_D = 0.23$
	4.4	Wood fibre	E	0.12	0.038	$U_E = 0.21$
	5	Vapour barrier		0.0003	0.17	
	6	XLAM		0.125	0.21	

Tab. 2. *External wall and roof stratigraphy.*

5. RESULTS

To demonstrate the influence of the use of solar shading (fixed overhang of 2.00 m) on the energy demand for heating, cooling and lighting for the South-facing functional units of the different typological models, a comparison was made with the models with the same characteristics, but without the inclusion of a solar shield. The results of this analysis show that the use of shielding on the South-oriented façade significantly influences the energy demand for cooling in both climatic zones (climate zones D and B), especially for model I2, while it affects the need for lighting to a lesser extent. By contrast, in model I1, the most significant highlight is the decrease in the energy demand of approximately 55% for the city of Palermo. Regarding the city of Florence, the energy demand for heating decreases by approximately 3% for the I2 model. It is necessary to stress that the use of southern solar shading is required by the current Italian legislation on energy and it allows to obtain an adequate value for the ratio between the equivalent summer solar area of the building ($A_{sol,east}$) and the useful surface of the building ($A_{sup,useful}$), in relation to the summer performance of the external envelope.

With regard to the variation in the type of shielding on the southern front, the simulations carried out on the 3 typological models in each city show that this change has a negligible influence (~1%) on the energy demand of the building models analysed, compared to the corresponding reference model. However, for the sake of completeness, an analysis was carried out with respect to the individual contributions of the energy balance in order to understand which parameters have been mainly influenced by changing the type of solar shading, considering the three models located in the cities of Florence and Palermo. Figure 2, referring to the city of Florence, shows the variation in the percentage of the energy demand for cooling and heating for the three typological models, with respect to the model with fixed shading (overhang of 2.00 m), considering different alternatives of solar shading that can be adopted for the southern façade.

It is possible to notice that for the models with mainly horizontal development (I2 - I3), the use of an internal

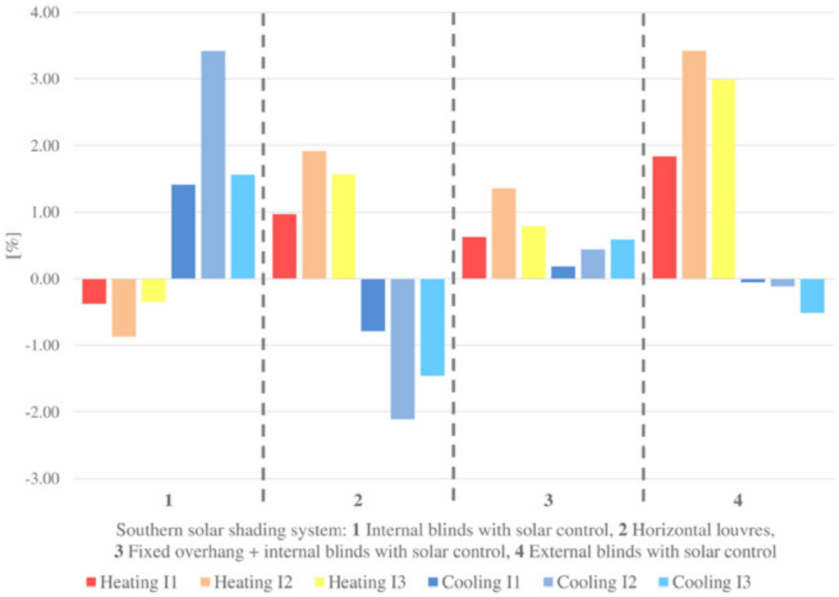

Fig. 2. *Variations in the percentages of the energy demand for heating and cooling for Florence for the 3 models and different solar shading systems.*

shield with solar control (120 W/m^2) involves a significant increase in cooling (~ 3.5%), while the use of the same external shielding implies an increase in the heating requirements on the same order of magnitude. For cities belonging to the climate zones E and D, where the contribution of the energy required for heating prevails in the energy balance, the optimal solar shading for the southern façades is the internal one with control of the maximum solar radiation (120 W/m^2).

Figure 3 shows the percentage change in the energy demand for heating and cooling compared to the reference model with the overhang in the city of Palermo. The graph shows that for cities such as Naples and Palermo, which are characterised by a mild climate with very hot summers, especially for the models with elongated floor plans (I2 and I3) in the East-West axis direction, the recommended solar shading for the southern façades is the one with an overhang of 2.00 m and internal venetian

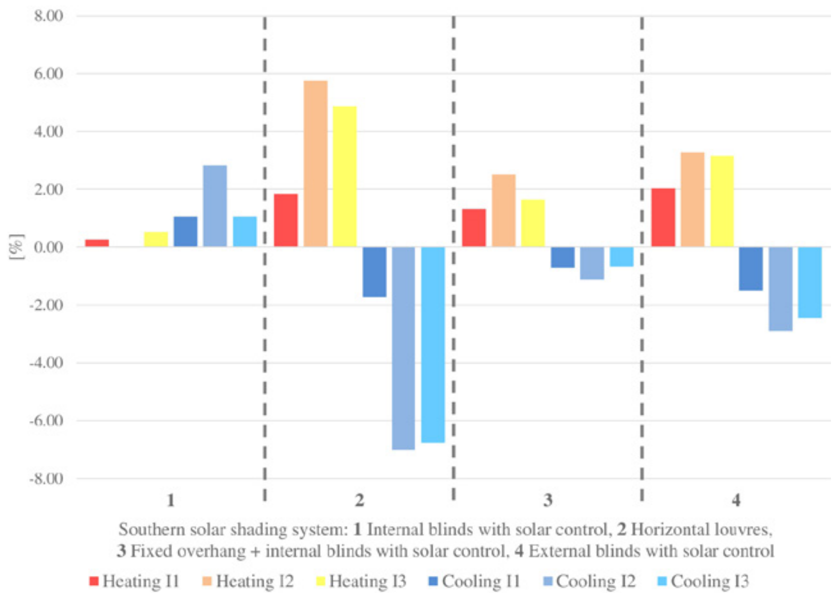

Fig. 3. *Variations in percentages of the energy demand for heating and cooling for Palermo for the 3 models and different solar shading systems.*

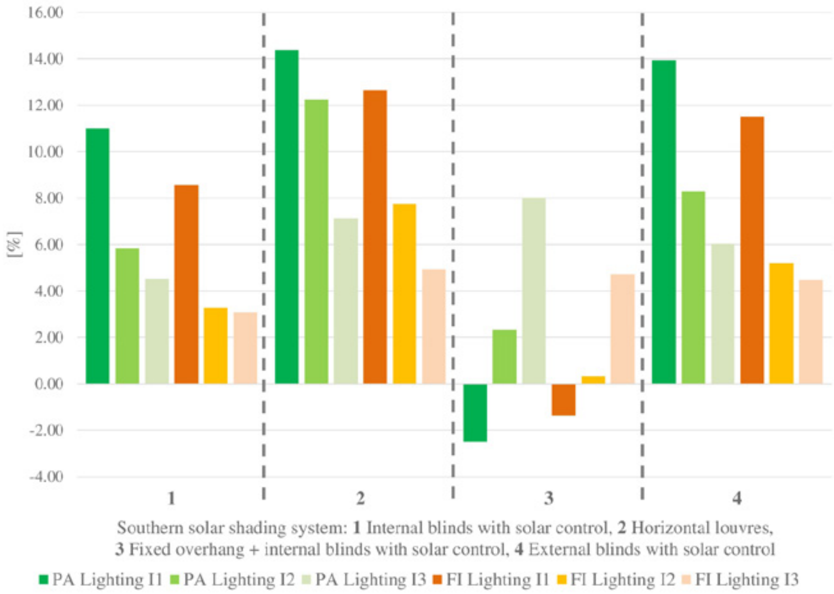

Fig. 4. *Variations in the percentages of the energy demand for lighting for Florence and Palermo for the 3 models and different solar shading systems.*

blinds with control of the incident solar radiation (120 W/m^2) since the energy needs for cooling decreases by approximately 6.5%.

Finally, compared to artificial lighting (Figure 4), the use of a 2.00 m overhang is the solution that allows for greater savings in all the models studied and for all the considered climate zones. It is important to stress that for a school building, the energy demand for lighting is a contribution that minimally affects the energy balance compared to the needs for ventilation, heating, and cooling.

With regards to the different control systems, horizontal slatted shielding was considered for the Southern oriented classes and the study was carried out only on the model I1 located in the cities of Florence and Palermo. From the energy simulations and the calculation of the environmental impact [kgCO_2/m^{2}a] for the operating phase only, it can be seen that for both climate zones, the use of an automated movable shading system results in a decrease in the energy demand compared to the reference fixed solar shading (always on) and a reduction

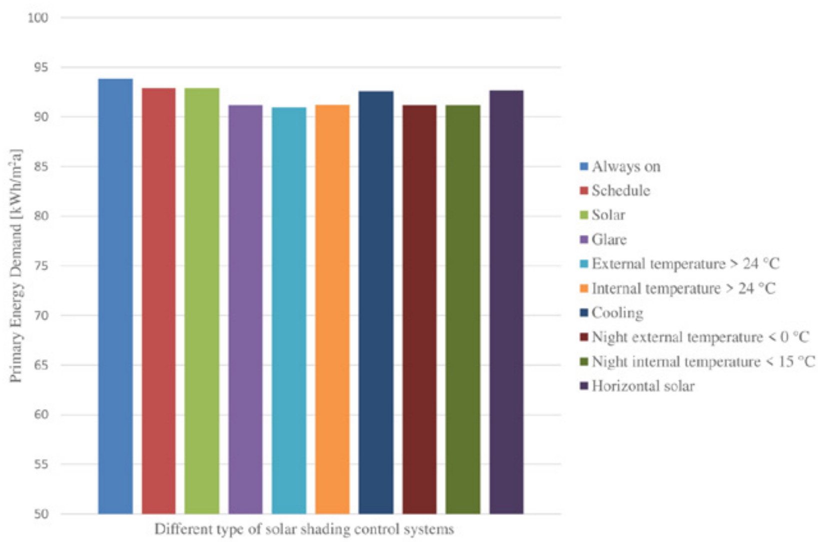

Fig. 5. *Primary energy demand for the different types of solar shading control systems for Florence for model I1.*

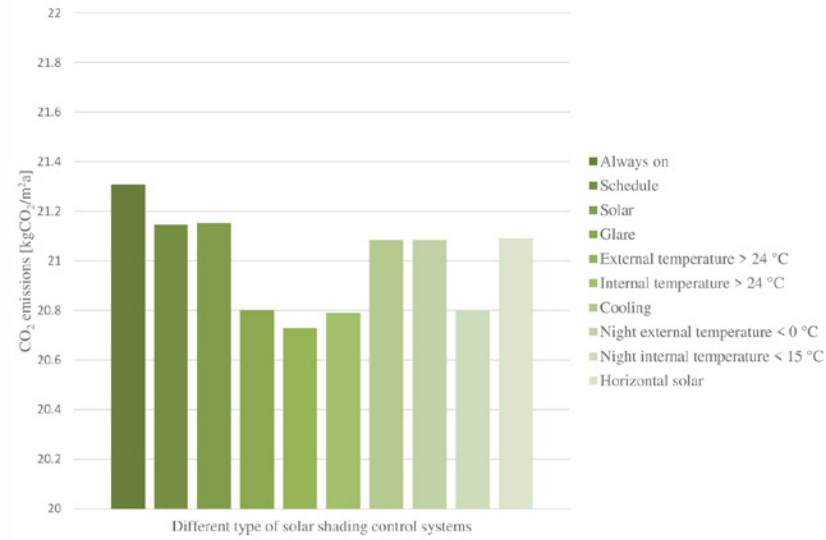

Fig. 6. CO_2 emissions for the different types of solar shading control systems for Florence for model I1.

in CO_2 emissions. This happens for any type of control analysed. Figures 5 and 6 respectively show the variation of the primary energy demand and the CO_2 emissions produced during the operational phase for each type of control system considered for the city of Florence.

The best type of control system for automated shielding is for both climate zones, the one which imposes a limit on the external temperature equal to a maximum of 24 °C. The assumption of this outdoor temperature limit value for the control of the shielding system is independent of the climate zone. In fact, the choice of the value is closely linked to the conditions that must be maintained inside the rooms. Since the internal temperature is one of the parameters that have the greatest impact on the comfort conditions of the rooms, which is conventionally equal to 26°C, the activation of solar shading at 24°C outside avoids to use the systems to compensate for the heating from direct solar radiation, in addition to the inevitable heating from direct heat exchange. Therefore, this is independent of the climatic zone.

For climate zone D, the second-best solution, in this case, is the one that controls the glare with a Discomfort Glare Index (DGI) [19] equal to a maximum of 21 according to the regulations for kindergartens.

For climate zone B, which is characterised by warmer summers and a more limited heating period, the second-best solution is the one with cooling control.

To complete the study of the shielding for the classes, the ideal value of the WWR, which was calculated in a previous phase of the research, was considered for each climate zone and the analysis on the type of control to be adopted for the horizontal slatted shielding was repeated. The study was carried out only for the cities of Milan, Florence, and Rome, in which the recommended WWR for the southern façades is 50% and is therefore different from the minimum required by the current health-hygiene regulations in Italy. In this case, as well, the trend of the variation in the energy demand compared to the control systems used is the same as in the previous case, even if the decrease in the energy demand is slightly higher.

The simulations concerning the use of vertical shields to the East and West, for the compact typological model with an internal courtyard (I1), show that their use does not entail significant benefits in terms of energy consumption for heating, cooling and lighting (<1%). This situation is more evident in models I2 and I3 that have most of the openings along the East-West axis. It must be emphasised that the results presented are inevitably influenced by the orientation and distribution of the functional bands and units in the floor plan in the various models, and by the high ventilation flow rates required by the regulations for buildings with this intended use.

To assess the visual comfort within the classes, maps of the natural lighting have been built for the daylight

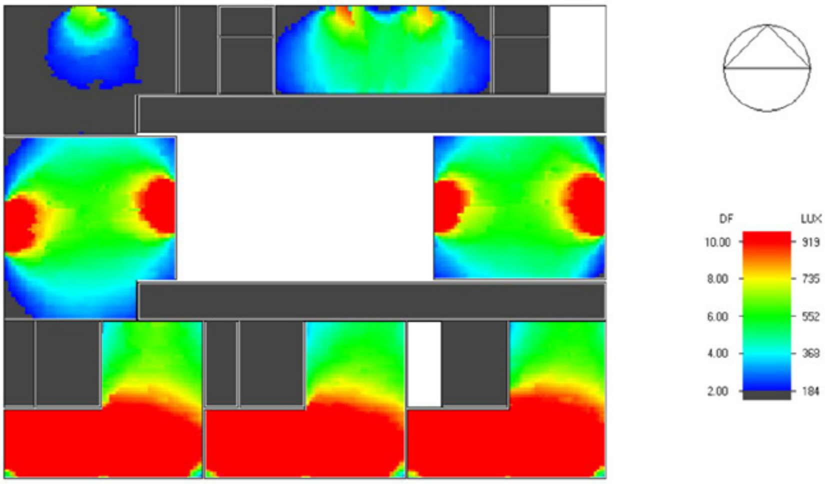

Fig. 7. *Maps of the natural daylight for the model I1 in the city of Florence for June 21st with the advisable WWR and 2 windows.*

factor and illuminance uniformity [23]. The analysis was carried out, taking into account the solar shielding with a 2.00 m overhang for the southern front for 2 typological models (I1 – I2). The choice of this shielding is, even if only slightly, the most advantageous in terms of energy consumption and it allows to maintain continuous visual contact with the external environment as well, as required by the current pedagogical methods. Furthermore, to face the glare problem, internal solar shading with blinds with control for the DGI was considered in order to ensure the proper illuminance of the area where visual tasks are performed. The WWR considered for making maps for natural lighting is the advisable one: the southern WWR = 50% (I1 – I2) for Florence, Milan, and Rome; and the southern WWR = 25% (I1) and 19% (I2) for Naples and Palermo. Figure 7 illustrates the natural illumination map for the I1 model for the functional bands of the classes on June 21st at 12 noon for Florence.

Table 3 shows the values of the average daylight factor (η_m) and the illuminance uniformity (η_{min}/η_{med}) related to models I1 and I2 for each class in Florence and Palermo considering the advisable value of the southern WWR. For the sake of brevity, only the data relating to these two cities are reported, since they are also representative of other climate zones. The values of the illuminance uniformity are calculated based on the area of the entire class and not where the visual tasks are mainly concentrated.

		η_m [%]		η_m Uniformity [η_{min}/η_{med}]		η_m [%]		η_m Uniformity [η_{min}/η_{med}]	
		Model I1				Model I2			
City	Class	21.06	21.12	21.06	21.12	21.06	21.12	21.06	21.12
Florence	1	14.50	20.40	0.20	0.10	15.70	24.00	0.14	0.09
	2	13.90	19.80	0.16	0.08	17.60	24.90	0.125	0.09
	3	13.77	19.90	0.18	0.085	18.00	25.40	0.13	0.10
Palermo	1	5.70	8.50	0.15	0.06	5.90	9.40	0.10	0.05
	2	5.50	8.30	0.11	0.07	6.50	10.00	0.145	0.07
	3	5.30	8.20	0.12	0.06	6.40	9.70	0.10	0.05

Tab. 3. *Daylight factor and illuminance uniformity for the 3 classrooms with the advisable WWR.*

Table 3 shows how the minimum value of the average daylight factor required by UNI 10840 [19] is followed in each class, and for both models, it is higher than 5% in the two climate zones considered. As it regards the illuminance uniformity within the classes, especially during the winter season and mainly for the city of Palermo, it must be guaranteed through the use of artificial lighting mainly due to the closure of the internal solar shading. However, it is important to underline that the minimum value of the illuminance during the winter season takes place in the corners of the classroom, on the side of the windows, and in the furthest part of the classroom from the window where the children's rest area is usually organised, as shown by the map above. By observing the values for the two models, it can be seen that, although both have two openings for each class, the I1 model has more advantageous performance in terms of natural lighting since it guarantees better illuminance uniformity and an appropriate value of the average daylight factor in both climate zones (B and D).

6. CONCLUSIONS

The use of the fixed overhang allows obtaining a summer performance of the external envelope equal to the medium standard according to the requirements imposed by the Ministerial Decree of June 26th 2015 [24] for the construction of nZEB buildings. It also permits to comply with the requirements of the new teaching and pedagogical methods, that prefer a visual link between the classroom and the external natural environment. In addition, the inclusion of interior sun shading in the South-facing classrooms is done to avoid glare and, at the same time, it guarantees an appropriate average daylight factor. The adoption of a double opening in the façade for each class allows for the correct illuminance uniformity, in both seasons, in the area where the visual tasks are carried out. By using an automated shielding with control for the external temperature for the southern front, energy savings and reduced environmental impacts are achieved in every climate zone considered, even with a WWR higher than the regulatory minimum. Finally, as it regards the eastern and western façades for the typological models considered, the use of vertical shading does not lead to an improvement in the energy performance of the building, not even increasing the WWR.

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THE ENHANCEMENT OF LOCAL RESOURCES: RESEARCH, TEACHING AND EXPERIMENTATIONS IN L'AQUILA

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Highlights

The paper illustrates how to valorize the territory of L'Aquila through the analysis of the climatic and material context and the identification of local resources (including waste), the management of selective demolition, the identification of appropriate technology, and the performance of materials/components. A path of research, training of construction sector operators and experimentations, through the design of temporary modules that reuse waste materials from post-seismic reconstruction in L'Aquila. The paper highlights how sustainability in the building process also passes through the training by the university of technicians who, after completing their studies, will work in companies.

Abstract

The construction sector has a major impact on current environmental issues. Through cost-effectiveness, it is possible to encourage construction sector operators to trigger voluntary environmental protection mechanisms. The use of local resources (including waste materials) is one of the possible strategies but requires specific and interdisciplinary training involving many aspects, including context analysis, demolition management, durability and reversibility control, and the ability to identify the performance of the construction system. The paper illustrates a path of research, teaching and experimentations concluded with the design and realization in self-construction of temporary modules, reusing waste materials from post-seismic reconstruction in L'Aquila.

Keywords

Reuse, Self-construction, Waste materials, Economic development, Sustainability.

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1. COST-EFFECTIVENESS AS A TRIGGER FOR ENVIRONMENTAL PROTECTION

"Whatever you do in the world, you do it to yourselves." This is the slogan of a global campaign on environmental protection launched by Advertisers Without Borders that well expresses the correlation between human action and direct and indirect effects on the environment. Think that in these months (January-May 2020), the reduction of human activities and in particular of mobility worldwide, due to the COVID19 pandemic, has produced a cascade reduction in the concentration of nitrogen dioxide with an improvement in air quality [1] (Fig. 1).

Environmental sustainability depends on the actions that each individual takes in his or her daily life, choices related to private and working life (number and mode of travel, choice of workplace, type and mode of use of resources such as water and electricity, food and consumer goods choices, etc.). The choices are, however, conditioned by each individual's knowledge of reality, according to the principle that "everyone sees what he knows" (Bruno Munari). Environmental awareness campaigns and, more specifically, the training of operators in the various sectors are therefore aimed at broadening knowledge and skills in order to allow a better understanding of reality (cause and effect) and to encourage a more responsible attitude.

an economic advantage. Taking a leap of scale and considering the industrial processes (which have always been accused of a great responsibility towards environmental pollution), one example of industrial symbiosis [3] is the industrial district of Kalundborg located in Denmark [4]. Since 1972 it has progressively developed thanks to the economic advantages deriving from the sharing and circularity of water, energy, and material cycles and which allows environmental advantages in terms of saving resources and avoided emissions.

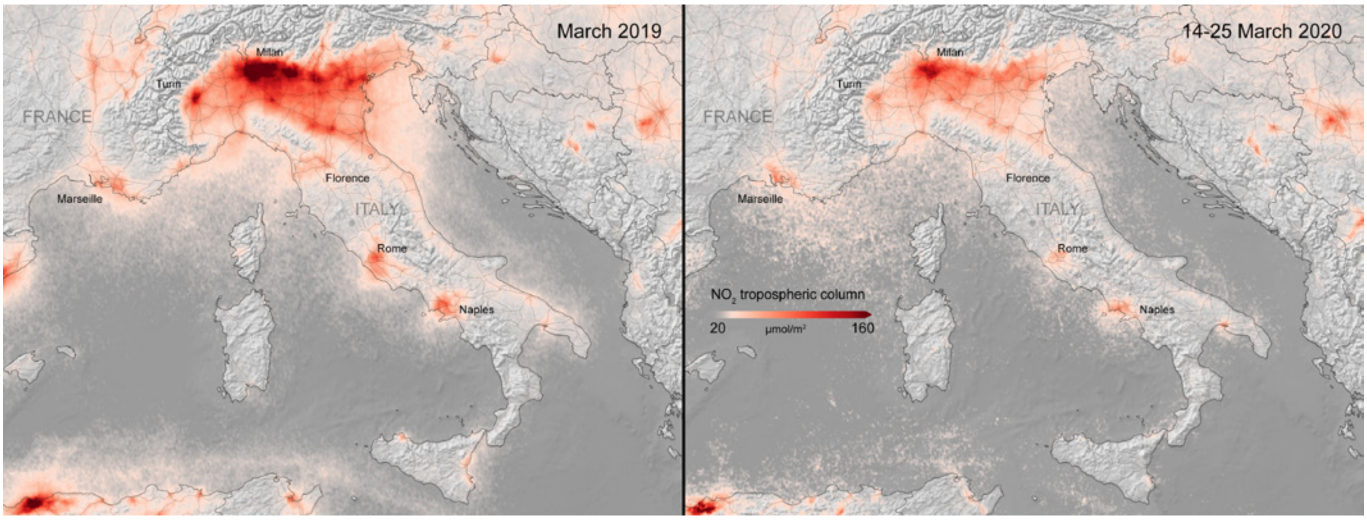

Fig. 1. *Nitrogen dioxide concentration over Italy – ESA European Space Agency.*

The assumption of responsibility clashes, however, with the perception of the shift in time of the effects of today's action, which sometimes leads to consider the existing environmental problem, but not necessarily conditioning. Suffice it to say that the study of the causes of global warming at government level began in 1988 with the formation of the scientific forum Intergovernmental Panel on Climate Change (IPCC), but operationally the Kyoto Protocol (1997) and the Paris Accord (2015) have not produced the desired effects [2]. The need to overcome environmental problems often does not seem to be a sufficient motivation to trigger responsible action by the community. In contrast, when an environmental benefit is associated with economic advantage, voluntary environmental protection mechanisms are developed. An example related to everyday life is represented by the plastic bottle compactors, which in return for the separate collection of plastic bottles by the user, give him/her a voucher and thus

According to a report prepared by IEA and UNEP and presented at COP24 (2018), buildings account for about 40% of global greenhouse gas emissions, 36% of total energy consumption, and are responsible for 50% of raw material extraction and 1/3 of drinking water consumption. Given the environmental importance of the construction sector, it follows the need to identify actions that they are economically advantageous, produce a cascading environmental benefit. By analyzing the life cycle of the building (construction, use, demolition) for each phase, it is possible to identify actions that bring both economic and environmental benefits. The use phase of the building is all the more convenient from an economic and environmental point of view the more energy-efficient the building is and the more it has been designed and built taking the climate context into account. In the construction and demolition phases of the building, on the other hand, convenience is linked to the materials and construction systems used, a consequence of the availability in the territorial context. The more the materials and chosen building systems allow to trigger local cyclical processes by optimizing grey energy (associated with the product during its entire life cycle), the more an economic and environmental advantage is obtained. The increase, in fact, of the life span of any consumer goods allows decreasing the incidence that in a given period of time (annual, monthly, etc.) the production of that object has had on the environment. In the construction and demolition phases, the construction method used and, in particular, the energy contribution of the means and machinery used also has an impact. In this regard, the use of construction systems in which assembly/disassembly is easy and quick allows the use of unskilled labor and the construction of the building in self-construction. The result is a reduction in construction costs due both to the reduction in labor costs and to the prevalent use of manual equipment (more suitable for unskilled labor), also obtaining an environmental advantage.

2. THE NEED FOR SPECIFIC TRAINING

The environmental and economic optimization of the building process, in all phases of the life cycle, is linked to the construction equipment and related materials. The suitable technology (right tech) is opposed to the choice a priori of low-tech or high tech, identifying the most suitable technology after the analysis of the territorial context and the performance required by the building. The choice of a suitable technology allows in the use phase to obtain appropriate performances and to guarantee the environmental comfort and, in the construction and demolition phases, to safeguard resources, especially materials. The identification of suitable technology is an operation that requires, however, specific, and complex training that involves many interdisciplinary aspects.

2.1. THE TERRITORIAL CONTEXT: CLIMATE AND MATERIALS

The territorial context can be divided into two macro-categories: the climatic context and the "material context". The analysis of the climatic context makes it possible to identify the microclimate in which the building is located (temperature, sunshine, ventilation, rainfall, etc.) in order to define the performance that must be achieved by the building according to its intended use with the aim of ensuring environmental comfort [5]. The "material context" identifies, instead, the characteristics of a given territory in terms of resource availability within a specific mileage. The analysis of the material context makes it possible to define in a local dimension [6, 7] what resources are available. Among the latter, must be considered local materials that allow the environmentally friendly production of components and waste materials that can be sent to a new life cycle. Operationally it is necessary to carry out a mapping of the territory identifying for each resource the distance from the place where the building is located. In some territorial areas, online platforms/markets have been created where it is possible to identify the availability of materials at a given time [8, 9].

2.2. DEMOLITION MANAGEMENT

Among the local resources, waste, materials/components that have already undergone one or more life cycles, but which have sufficient residual performance to be reused again, are particularly important. Among the waste materials that can be used in the building industry, there are both materials from other sectors (tires, pallets, bottles, etc.) and materials from the building industry (tiles, wooden beams, doors, and windows, etc.). In the latter case, the materials are actually reusable only if they have remained intact during demolition operations. The demolition of the building must, therefore, be carried out selectively: the building must be progressively demolished starting from the components which, compared to the construction method, have greater integrity (radiators, tiles, fixtures, railings, etc.) to the components which have less integrity (wet partitions, screeds, etc.) [10]. Selective demolition requires a thorough knowledge of demolition techniques, machinery/equipment, and the building [11]. The construction site must be dimensioned and organized, considering different storage for each product fraction and, at the same time, organizing its transport. The technician must have the skills to identify the residual and potential performance of the materials making up the building and define the demolition plan according to the building's construction characteristics and in such a way as to guarantee the integrity only of the actually reusable components. Not being able to understand whether material is actually reusable entails the risk of additional work during demolition (in order to ensure the integrity of the component), which is not economically viable with subsequent reuse.

Moreover, the analysis of the territorial context is necessary to identify the end-of-life possibilities present in a given territory. The choices in the planning of selective demolition must, in fact, also be made on the basis of the distance of the processing, recycling, or disposal plants and the reuse possibilities present in the specific territory.

2.3. IDENTIFICATION OF RESIDUAL AND POTENTIAL PERFORMANCE OF LOCAL RESOURCES

Among the local resources, it is necessary to identify the materials that, combined with each other, enable the building to achieve performance that guarantees environmental comfort. The technician must be able to identify the residual performance of a given material/component and evaluate the various performances potentially achievable with possible reconditioning operations. In addition, it is essential to know the environmental and economic impact of each operation in order to assess whether its cost offsets the advantage obtained in terms of performance. If it is an economically viable operation, the possibilities and methods of reuse can be identified. Being able to identify the residual and potential performance of the materials/components individually and combined, means being able to define which construction elements can be derived from the local supply chain and which, instead, must be supplied outside the local context, in order to achieve the desired performance for building.

2.4. DURABILITY AND REVERSIBILITY: REQUIREMENTS TO BE DESIGNED

Among the requirements, durability is particularly important. In order to use local resources, including waste materials, it is necessary to know the durability of the individual components in relation to the time of use of the building. For example, in the design of a temporary building, it can also be used untreated wood elements as a finish, provided that their durability is not less than the time of use of the building. Conversely, in the design of a building with a useful life of 50 years, treated wood elements we can also use as a finish, with the intention of replacing them when due to degradation, their performances are lower than the minimum performances established for the building.

The durability of the components must also be assessed. The optimal condition would be to use materials/components that have the same durability coinciding with the time of use of the building, in order to dismantle the building and the components at the same time, making maximum use of the grey energy of each building element. Since this is a condition of impossible realization due to the diversified nature of the single materials which, thanks to their different characteristics, can combine to guarantee complex performances, it is necessary to foresee a maintenance plan, through which, during the time of use of the building, the construction system guarantees the achievement of the required performances [12].

The reversibility of the building allows advantages from an economic and environmental point of view. During use, facilitating maintenance operations, it is a prerequisite for durability control [13]. In the demolition phase, the reversibility makes it possible to divide the materials/components into homogeneous product fractions, starting each one at the most appropriate end-of-life scenario with respect to its residual performance. The type of connections between the building elements is the only factor that, by nature, conditions reversibility. In order for it to be possible to carry out backward the path that led to the construction of the building, the connections must be dry (bolting, screwing, seaming, nailing, etc.).

The design of reversibility also concerns the way in which the building is connected to the ground, allowing the protection of the soil, which is a vital and "fundamentally non-renewable" resource of the Earth. In 2017 in Italy, there was a land consumption of 15 hectares per day. Overall, Italian soil consumption is 23,062.5 square km [14].

3. RESEARCH, TEACHING, AND EXPERIMENTATIONS

The University of L'Aquila, in collaboration with other institutions (Universitat Politècnica de València, Ente Scuola Edile L'Aquila (CPT), ANCE Giovani L'Aquila, Filauro Foundation), has promoted an experience of experimentation and training of specialized technicians through the design and self-construction of temporary modules.

The analysis of the material context in L'Aquila has highlighted the availability within a narrow radius of 10 km of resources that can be used in construction (Fig. 2), both linked to territorial peculiarities such as wood, fibers linked to agriculture (straw), waste from the zootechnical industry (sheep wool) and to the current post-seismic reconstruction phase (rubble, pallets, materials deriving from selective demolition such as tiles, solid bricks, etc.). In particular, previous research [15] has highlighted the availability of a significant amount of waste resulting from the disassembly of safety systems including scaffolding, pallets, steel beams, etc., materials whose transport to landfill and disposal involves significant logistical, economic and environmental costs for the community [16, 17].

The training and experimental experience had the task of preparing in international context technicians who will work in the reconstruction in the crater of L'Aquila on how to transform such waste into an environmental and economic advantage, in a resource at no cost. The skills of specialized technicians can, in fact, make it possible, through their choices, the activation of a spontaneous reuse chain. The experience has been divided into three parts: theoretical, design, and self-construction.

3.1. THE THEORETICAL PART

The theoretical part allowed the technicians to learn the knowledge about the topics previously described,

Fig. 2. *Harvest map L'Aquila.*

Fig. 3. *Theoretical training (prof. Di Carlo), practical training (CPT L'Aquila) and field visit to the construction sites in the "red zone" in L'Aquila.*

through frontal lessons with experts in the sustainability field at the national and international level and, consequently, the direct contact with consolidated approaches and methods in different territorial contexts (Fig. 3). In order to identify the construction techniques and technologies used in the post-seismic reconstruction and to understand the implementation of virtuous practices related to the environmental sustainability of the construction site, the students visited some reconstruction sites located in the red zone of L'Aquila. The theoretical part was also fundamental to acquire knowledge about the characteristics and actual and potential performance of the available local materials to be used in the project.

3.2. THE PROJECT

The design part involved the students divided into groups led by tutors in the design of temporary modules to be used for different functions: an info-point, a bathing establishment for restricted contexts, a temporary residence, a space for music, a bike-sharing and an exhibition area. The functions have been hypothesized considering the possibility of using the temporary modules within a maximum mileage of 100 km (local dimension for the Ithaca Protocol) with respect to the place where the materials are found. The materials used in the projects derived exclusively from post-seismic reconstruction and were donated by ANCE Giovani L'Aquila and CPT L'Aquila. The students, in particular, interfaced with the system of innocent tubes, pallets, and wooden boards, with dimensional (and modular) characteristics already defined in advance. The presence of different modules required the students to think about the dimensional coordination of the components. The projects also had to comply with the reversibility requirement, and reasoning on durability control was carried out. The project deepening has reached a level of executive detail, necessary for the next phase of self-construction. For example, in the project concerning the bathing establishment

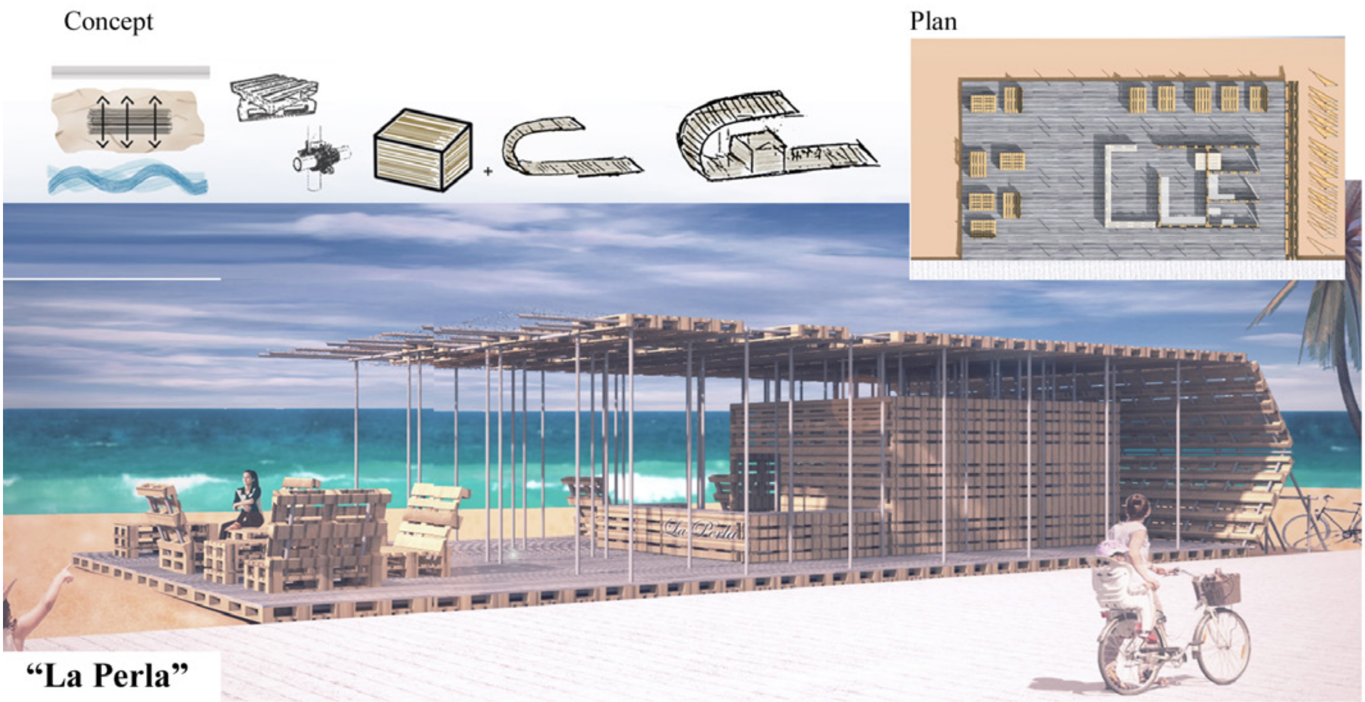

Fig. 4. *Design part. "La Perla" bathing establishment. Concept, plan, and render.*

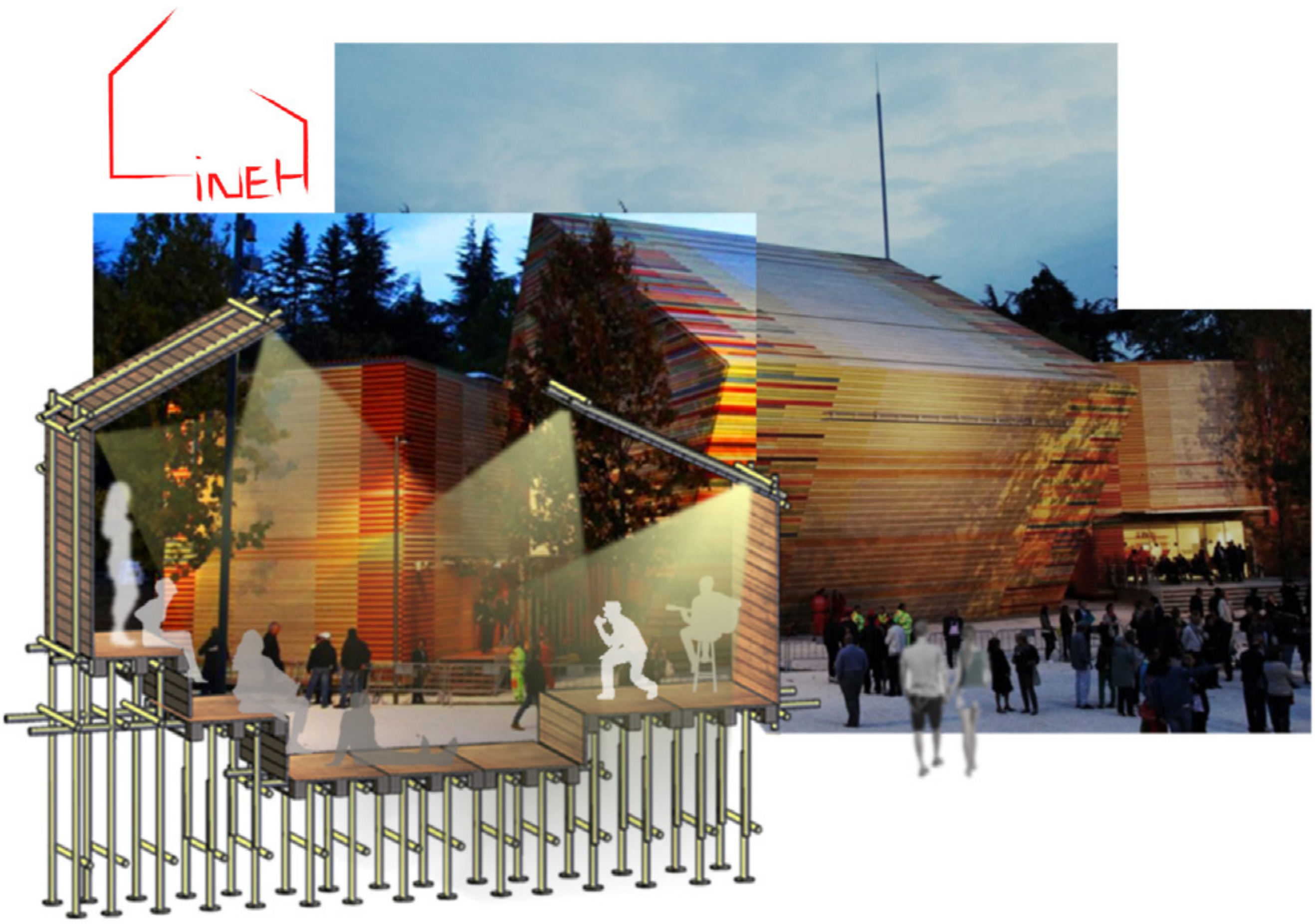

Fig. 5. *Design part. A temporary space for music. Render in the Castle Park, L'Aquila.*

for restricted contexts, called “La Perla “ (Fig. 4), the waste materials of the reconstruction were integrated with easily available waste materials such as ropes, canvas, and bottles. Attention to the intervention sustainability is also highlighted by sustainable mobility systems integration of such as bicycles into the building organism.

In the design of the music space (Fig. 5) for temporary summer installations, the value was given to the flexibility of the construction system and its ease and speed of modification, characteristics typical of systems traditionally used on sites such as pipes and joints.

3.3. THE SELF-CONSTRUCTION

The realization part involved the students guided by the tutors in the self-construction of their project (Fig. 6). This choice was a tool to make the students understand the construction techniques necessary for the realization of what they designed, to verify the operational and logistic difficulties related to the design choices and the construction times of unskilled labor. In the initial phase of self-construction, each group identified the construction phases, the materials needed and divided the tasks among the members of the group.

Each group also had to provide for the organization of the construction site, especially with regard to aspects related to the handling of materials and the availability of limited space for maneuvers also due to interference with neighboring groups operating in the same area.

The self-construction time was equal to two working days. It should be noted that, although these are temporary structures of medium complexity, no variations were made during the self-construction work, a sign of the effectiveness of the training that has ensured successful projects and studied with competence in detail.

4. CONCLUSIONS

The considerable impact of the construction sector on environmental issues requires specific skills in design and construction choices, such as to be able to manage and control the entire life cycle of the architectural organism. It is, therefore, necessary to provide interdisciplinary training for operators in the sector, first of all, technicians. Experience has shown that through specific training and comparison with international realities, it is possible to change the traditional design approach from the idea to the choice of materials/components in an experimental approach. The latter starts from the parallel analysis of the requirements necessary for the building and the resources and operational possibilities dictated by the territorial context (climatic and material) and identifies, based on them, a compatible project, and appropriate technology. It increases the degree of complexity of the project but also increases the sustainability of the intervention.

The realization of temporary modules in self-construction with reused materials has, moreover, carried out an action of sensitization of the local enterprises, with respect to the possibilities that the materials considered waste can offer with a direct economic advantage for the enterprise and environmental advantage for the community. The university, through training and research, has therefore been a vehicle of knowledge and awareness of the territorial context, which currently interfaces daily with post-seismic reconstruction.

A cascade phenomenon that started from research passed through training and arrived at companies, an operational arm on the territory that translates the needs of the client into architecture, mediating them with those of the community. Only through cooperation between universities and companies is it possible to apply the innovations deriving from research to the territory.

5. ATTRIBUTIONS

Stefania De Gregorio has conceived and structured the paper and had the managing supervision and the scientific coordination of the educational and experimental experience. Pierluigi De Berardinis and Luis Palmero have supervised the paper and had the scientific responsibility for the educational and experimental experience.

The figure 4 was elaborated by: tutor: Valentina Michini, students: Oscar Mico Cerdan, Marta Pezzi, Pablo Puchol Herreros, Federico Ratini, Nacho Romero Hernandez, Carlo Sciamanna. The figure 5 was elaborated by: tutor: Arianna Tanfoni, students: Daniela Cerasani, Adolfo M. Moltó Vidal, Jorge Moltó Vidal, Federica D’Orsogna, Laura Garribo Abalos, Sara Zaccaria.

Fig. 6. *Self-construction phases (tutor: S. Balassone, L. Capannolo, D. Di Donato, E. Laurini, V. Michini, A. Tanfoni, A. Tata).*

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THE ROLE OF VERTICAL FARMING IN RE-THINKING AND RE-DESIGNING CITIES WITHIN A CIRCULAR PERSPECTIVE

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Highlights

Vertical farming as a new paradigm to connect urban and rural settings.
Urban agriculture sets a new layout for contemporary cities, giving new purpose to urban voids through innovative solutions.
Trento AgroFarm is based on vertical farming as a flywheel to recover an abandoned area of the city in a circular perspective.
Circuits – concerning production, water, energy, social engagement, and the circular economy – are proposed as a means of intervention.
The local community is actively involved in the sustainable food cycle production where architectural fields support this process.

Abstract

One of the key issues of the contemporary city is “urban voids”, characterized by disused buildings. Such spaces can be the starting point for a new urban setting, where the city reconnects to the rural environment. Vertical farming can be a new paradigm connecting these often-opposed concepts, bringing several advantages. This paper presents an experimental case study about a typical situation in a peripheral context of the city of Trento. An industrial building under decommissioning is restored as a vertical farm through a circular economy perspective, combining natural resources with ICT, consumption, and reuse processes.

Keywords

Food Innovation, Urban agriculture, Vertical farming, Urban regeneration, Circular economy.

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1. FOREWORD

For centuries, rural and urban settings have been two opposing realities, although strictly interrelated. Today, however, the nature of this relationship is fading. Echoing the words of Andrea Branzi (as paraphrased by Buonanno, 2014, p. 12 [1]), city and countryside are now “sclerotic” concepts: the world is no longer divided in two since the city itself represents a seamless system. Thus, the contemporary city [2] can be read as a unique and inseparable system of constructions and nature, and as such, it needs to be investigated and designed. In fact, urban dynamics are increasingly linked to environmental and ecological issues [3]. The consequences of human activities are not fully understood yet, in particular regarding the effects of settlements and infrastructures on nature, as well as the excessive and uncontrolled abuse of natural resources. 1.7 planet Earths [4-5] would be needed to meet humankind’s current needs and absorb its waste. The main crucial factors are above all the urban sprawl high use of land, the agriculture depletion of soil, the pollutant emissions released into the air, soil and water, the waste, and consumption of millions of water liters.

In addition to environmental and ecological problems, the contemporary city has to deal with numerous abandoned and unused buildings and factories: numerous warehouses are underutilized despite being infrastructured. In Italy alone, more than 700 km^2 of factories and 2100 km^2 of surrounding areas are purposeless [6]. This is the result of the profound economic crisis that has affected the country since the late 2000s, but the trend of abandoning large industrial areas is also part of a larger process: as a result of the 19th-century city, human activities are now going to retract.

The research project presented in this paper defines a methodological framework useful to provide solutions to these issues and is applied to an existing warehouse in the city of Trento. The transformations proposed are centered on a system of circuits based on circular economy principles. Urban agriculture, especially in the form of vertical farming, is the key driver of other environmental and social dynamics. Thus, the regeneration phenomenon is accompanied by a development of the area also in terms of energy, water, economic and social sustainability.

2. STATE OF THE ART: BACK TO AGRICULTURE

Within this complex framework, the concept of urban resilience [7] can be applied to the agricultural field, in order to define a strategy able to answer specific questions posed by the contemporary city. The challenge is, therefore, to change direction to a more sustainable and adaptable urban planning towards greener cities. Currently, the experiences of urban and peri-urban horticulture are going in this direction (Food and Agriculture Organization of the United Nations (FAO)) [8]. Food production goes beyond the rural limit, towards something that is increasingly occurring within the city limits or in its immediate suburbs. Today agriculture can play an important role in giving new purpose to urban voids through innovative solutions, thus being an inner component of the contemporary city.

The framework proposed so far is not only a green infrastructure or ecological corridor but also a reality that begins to stand beside the city, supporting and feeding it. To reduce social and environmental costs of industrial agriculture, permanent cultivation initiatives, also called permaculture, are increasingly widespread. The first principle of permaculture is that food has to be produced close to consumers: urban agriculture goes into this direction. Urban farms are becoming more prominent and tend to shorten the distance between the place of production and consumption. Pioneers in this field are the cities of New York and Detroit. In the case of the latter, the city, in crisis for years due to deindustrialization, has managed to reinvent itself through urban agriculture. Similarly, in Italy, the significant increase in the number of municipal gardens stands out among the different types of urban green; in three years, from 2011 to 2014, there was an increase of 30% in the uncultivated public areas assigned on loan for agricultural use to citizens [9]. In Trento, for example, a real *Bank of the Earth* [10] has been set up: it is a collection of uncultivated public and private lands, which owners can temporarily lease to new farmers.

The fusion between urban and rural has so far been hindered by the rigid regulatory constraints imposed by urban zoning, according to which each function is located in a specific area of the territory. The overcoming of this planning model is prevented by an uncertain cultural and social condition, by the industrial crisis, and by the need to transform the consolidated urban territory. Today, urban agriculture provides cities with unique opportunities: it refers not only to the social gardens' trend but also to the multiple possibilities for urban renovation by promoting:

- urban redevelopment, utilizing new production technologies, spatial devices, and design skills that integrate vegetable production at the different scales of the city;
- urban renewal and social inclusion in terms of re-functionalization of space through the creation of social gatherings and new environmental solutions to face climate change;
- educational activities and sustainable processes of the food supply chain through the physical, symbolic, and cognitive approach between producer and consumer.

Among the different forms of urban agriculture, vertical farming [11-15] is becoming a widespread cultivation technique. As a particularly articulated form of cultivation without soil, vertical farming brings agriculture itself to its extremes: it emerged with the development of cultivation techniques becoming the synthesis of the urban and the rural worlds. Vertical farms are food self-production centers: climatic conditions suitable for the production of different types of plants are recreated inside the buildings so that vegetables can grow out of the soil through nutritious watery solutions and with the light transmitted through a LED lighting system.

While many revolutions have changed human lifestyles over the last century, agriculture has remained behind as compared to other sectors. Technological and industrial improvements took over, however, we can only speak of horizontal development, as Peter Thiel defines it in his book *Zero to One* [16]. The indoor vertical cultivation technique aims instead to develop the first process innovation in agriculture, a "vertical development". Some advocates of vertical farming define this technique as the third green revolution, comparing it to the upheaval launched by Apple and Tesla in their respective sectors. "Food is one of the final frontiers that technology has not tackled yet. If we do it well, it will mean good food for all": this is what Elon Musk's brother says (as quoted by Severson, 2017 [17]). In fact, this type of agriculture is a strategy to recover unused buildings, allowing the cultivation on different overlapping vertical levels and guaranteeing the progress of a sustainable approach: food safety, reduction of human activities' impact, containment of land use and emissions of harmful substances into air and groundwater.

The interest shown in this research field by different professional profiles is growing. Some "vertical greenhouses" have already been built in Japan, South Korea, Singapore, the Netherlands, the United States, while others are under construction, for example, in Sweden, Canada, Saudi Arabia, and Italy. In 2012, the first vertical farm in the world was built in Singapore: *Sky Green Farms*. Starting from the very high number of inhabitants and from the hectic lifestyle that has little to do with the rhythms of the natural environments, the construction of a vertical farm in this context aims at making some areas of the metropolis food self-sufficient. One of the peculiarities of this system is the rotation of the greenhouse at the speed of one millimeter per second to allow solar lighting to all plants.

Urban farming [18], and in particular the indoor technique, does not solve the production issue related to the primary sector alone, but it offers unforeseen opportunities integrating food production and architectural renewal in a circular perspective. *Trento AgroFarm* is an experimental project that aims at highlighting how these innovative aspects can be integrated through vertical indoor farming (Fig. 1).

Indeed, agriculture can contribute to developing a circular urban management process, in which the continuous expansion of cities is curbed by exploiting and redeveloping the existing building heritage. Moreover, it can play a crucial role in coordinating water and waste flows. By also focusing on cultural and social aspects, vertical farming becomes more than just one technological innovation. *Trento AgroFarm* uses vertical farming as a flywheel for the recovery of an abandoned area of the city of Trento. Therefore, it represents an excellent example of the circular economy, able to funnel natural resources, technological inputs, consumption, and reuse (Fig. 2).

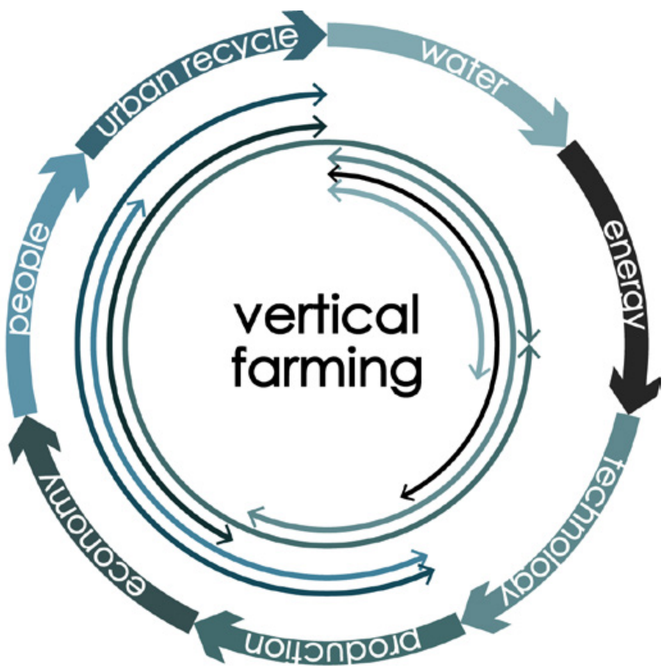

Fig. 1. *Vertical farming. A circular process.*

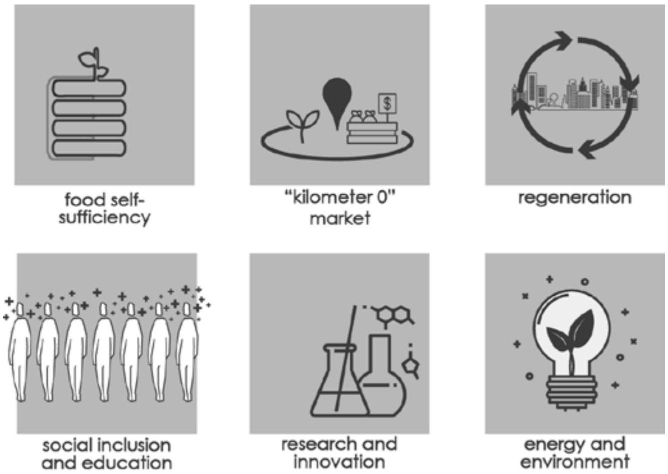

Fig. 2. *Trento AgroFarm goals.*

3. TRENTO AGROFARM: TOWARDS A NEW SCENARIO OF URBAN AGRICULTURE

Trento AgroFarm is an experimental design project that envisions and tests how an industrial urban void can offer an opportunity for urban regeneration and circular economy. This is done by addressing the challenges of water and energy resource efficiency, reduction of the ecological footprint, and empowerment of social dynamics. First, the knowledge framework was settled on a regional and urban scale, in order to describe the environmental, productive, social, and cultural context in which the city of Trento is set. Afterward, the suitable area to this type of intervention has been defined: it has to be an area already characterized by a construction and developed substrate, ready to be converted into a new productive and cultural landscape. A multi-criteria analysis has been drawn, focusing on a series of parameters central to the activity [19], such as the population density, the presence of commercial activities and the real estate value [20], and it was finally decided to intervene on Casa Girelli: the headquarter of a historic Italian wine company, founded in 1959 in Trento (Fig. 3). Casa Girelli, which extends for about 18150 m^2, is located in the Clarina district, a residential neighborhood in the southern area of the city. It is able to offer a large user base for future planned activities, as well as being close to the city center. The place can also weave a network with the other food poles in southern Trento and connects with the vast surrounding green areas and open spaces.

Fig. 3. *Casa Girelli.*

In 2014, the sale of the site and the reclassification of a larger area became a matter of discussion. Despite the solicitation of the property itself, the timeline for this substantial change is still not known and will probably take a long time. Considering the many abandoned areas that receive only *ex-post* buffer solutions, the desire to prevent this abandonment process drove to the choice of this area as the design idea, planning a new life cycle before the site is actually decommissioned. The main goal of the project is to reconcile multiple functions, which support and complete the merely productive aspect, thus designing a pole that catalyzes the interests of a wide part of the population. In addition, agricultural production is drawn back into the urban circuit, making the city more self-sufficient from a food production point of view: a *zero-km* consumption possibility is offered, and educational and research programs lead to forms of inclusion and awareness. The project starts a redevelopment process, from the architectural to the urban scale, which aims to achieve a high level of energy and environmental sustainability. For these reasons, a layout of multiple sustainable cycles has been developed. The different natural and social resources involved work together, following the circular economy philosophy. All the aspects are then summed up into the architectural new design of the site: *Trento AgroFarm* (Fig. 4).

4. AREAS OF INTERVENTION: THE CIRCUITS

A series of circuits (Fig. 5), regulating the development of a vertical farm based on production, water, energy, social, and economic sustainability, have been identified. These aspects have been put into context with the architectur-

Fig. 4. *Trento AgroFarm site plan.*

al qualification of the spaces. Through the intersection of these circuits, it is possible to create a dynamic and resilient structure, fitting within the urban system, feeding it, and at the same time, drawing strength from it.

As for the recovery design of the existing structure, a series of small interventions have been defined to preserve the original feeling of the area, adapting it to the new features and enhancing its characteristic elements (Fig. 6). In particular, the natural elements of water and sunlight provide the project with energy and are transformed into real architectural components. For this reason, among the various aspects analyzed, the focus has been placed on the water and energy circuits, as highlighted below.

4.1. THE WATER CIRCUIT

One of the basic components needed for vertical hydroponic cultivation is water. This technique grows plants with a 95% water saving compared to traditional cultivation, an important aspect considering that the food sector plays a crucial role in assessing the water footprint. The project aims to make the production cycle autonomous from the point of view of water supply. For this reason, *Trento AgroFarm* is equipped with a system for the recovery and collection of rainwater: after having been processed, it is destined to the fertigation system, to undrinkable internal uses, and for the air treatment unit (Fig. 7).

A forecast model of the city's rainfall was created. The statistical-probabilistic study of the data [21] provided the maximum rainfall height values *h* for a predetermined return time *T* (20 years) and an annual, daily, and hourly duration. Thus, the SCS (Soil Conservation Service) method was applied to calculate the volumes of water falling on the waterproof surfaces, such as roofs and paved areas. These volumes are then conveyed through a channeling system, which marks the external flooring, into an underground collection infrastructure, made of "first flush tanks". These ensure a first purification step of water from polluting agents. The tanks were sized according to the crops' water needs and to collect the water volumes in case of extreme weather events.

Part of the overall water volume, calculated in approximately 14500 m^3 per year, is stored inside some already existing tanks. Once intended to house the wine, they are thus preserved and re-valued. A percentage of the collected water is destined for hydroponic cultivation. The total stored volume is compared with the water needs of the crops to verify the possibility of water self-sufficiency. In order to have the first indication, all the calculations were referred to a cultivated type-species, lettuce: it has been selected because it is an intermediate-range species and for data availability. The consumption of water is not only related to the intrinsic needs of the plant, but also

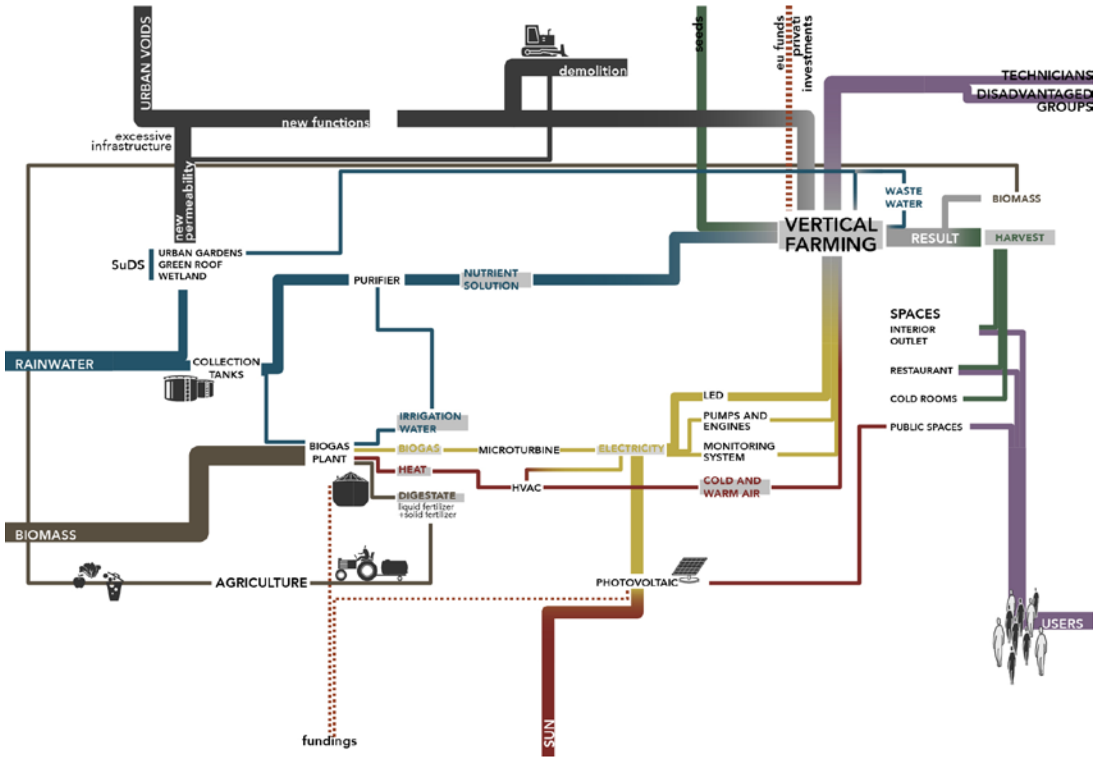

Fig. 5. *Trento AgroFarm sustainable circuits.*

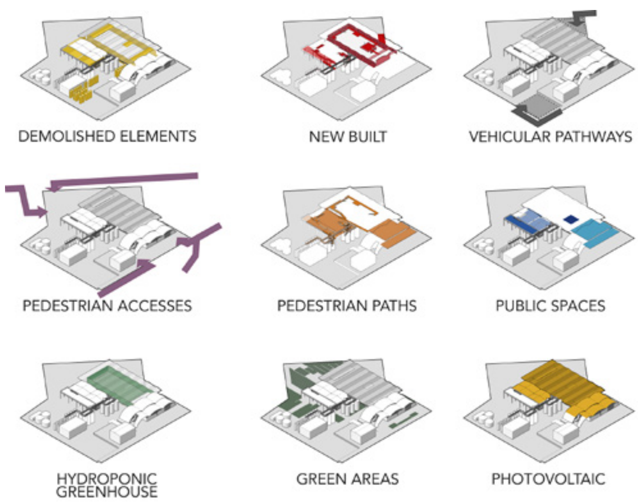

Fig. 6. *Trento AgroFarm architectural strategies and devices*

climatic parameters. Thanks to the control of the internal conditions, it is possible to have a precise estimate of the quantity of water necessary for the growth of the plants.

The water destined to cultivation, about 1100 liters per day for a total cultivated area of 4600 m^2 (surface used on the ground equal to 385 m^2), is managed by the fertigation unit. It is then further treated, distilled, and enriched with nutrients to generate the stock solution. The irrigation system is a closed cycle: in this way, the water that is not absorbed by the roots and does not evaporate is not dispersed but returns to the circulation. The system gets completely emptied only after a certain number of cycles, and the watery solution can be used to irrigate the external green areas and urban gardens within site.

In order to wrap up, the sustainability of the designed water cycle is demonstrated by comparing water needs with rainwater volumes collected. The water that is not necessary for internal uses is released into the municipal white-water network. In this way, the annual water load weighing on the network is about 75% reduced thanks to internal uses and the absorbed water by the permeable soil. The project site, now completely impermeable, is ecologically reconnected with the external spaces, thus increasing the permeability of the surfaces. In particular, in addition to public green spaces, the lot opens up toward the west, granting direct access to a new system of urban gardens. On the other hand, the surfaces still waterproof are used to collect rainwater, as previously described.

4.2. THE ENERGY CIRCUIT

One of the most critical aspects connected to a vertical farm is electricity consumption. In fact, one of the main variables related to the growth of plants is light. The natural source of the sun is replaced and integrated with artificial light. With this in mind, the choice of using a LED system is drawn by several advantages. First of all, the LED allows selecting and transmit to the plants only the wavelengths they actually need, in particular the blue and red spectrum, which are around 400 and 700 nm in the visible range. Moreover, compared to traditional lighting techniques, the use of LEDs leads to high energy saving (up to 70%), as the light is consumed almost completely by the plants themselves. In addition, the light emitted by the diodes produces way less heat than traditional systems, avoiding overheating and the risk of burning the plants. Finally, LEDs are very durable, thus allowing a profitable long-term investment: they have a product life cycle of 7-8 years. On the basis of the plant species' needs, the type of LED system was identified, and therefore the energy consumption related to its use was calculated, with reference to a daily duration of 18 hours.

The second aspect that weighs on the energy bill of the vertical farm is the internal air conditioning system, necessary to maintain a constant and controlled temperature of the cultivated environment. As a point of reference, a 20°C average temperature and 50% relative humidity were con-

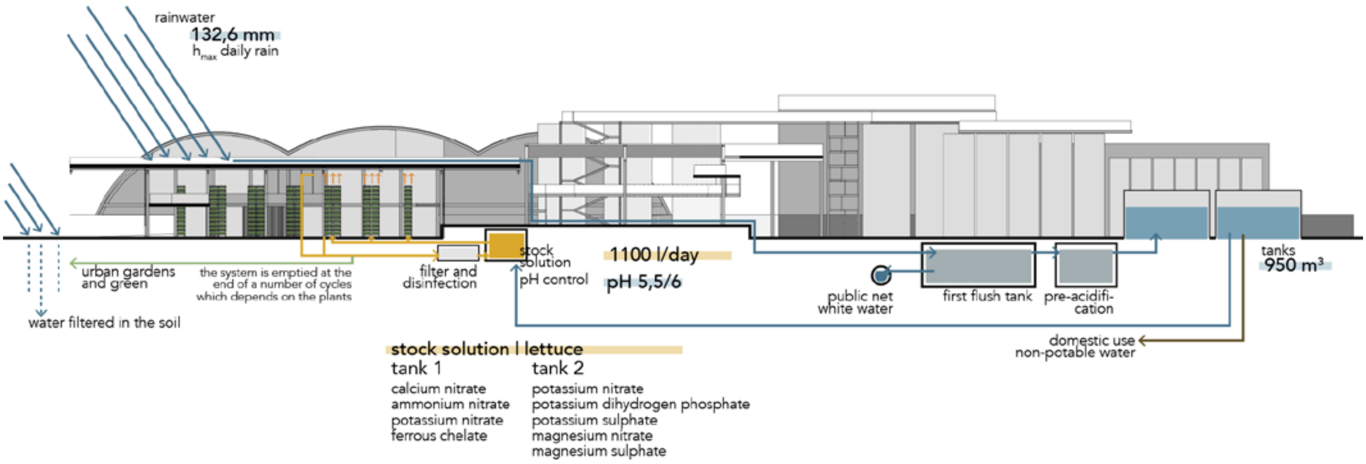

Fig. 7. *Trento AgroFarm water circuit.*

sidered. The hydroponic greenhouse energy requirement has been calculated in the different months of the year for heating and cooling according to current regulations [22-25] so that the power necessary for the operation of the air treatment unit (AHU) was identified. In order to increase the project's energy sustainability, the goal has been to cover the high estimated consumption through renewable energy sources, and in particular, a photovoltaic system integrated with a biomass plant. Photovoltaic has undergone considerable development in recent years, producing an important share of electricity from renewable sources in European countries [26]. On the one hand, the project envisages the installation of a traditional photovoltaic system, which produces the most significant share of energy deriving from solar. This is joined by an integrated photovoltaic system: Building Integrated Photovoltaic (BIPV) is the set of technologies designed to be applied to buildings as an integral part of their envelope. The BIPV also assumes a role in the architectural language. As part of the project, the distance between the photovoltaic cells allows sunlight to filter through into the rooms below with games of light and only a limited reduction in energy efficiency. For this reason, the BIPV was chosen to replace the roof in correspondence with the internal inhabited spaces and the covered external square. The design of the plant has therefore evolved hand in hand with the architectural project.

The photovoltaic system was designed to optimize the energy produced throughout the day, positioning the panels on the surfaces that determine a meaningful yield thanks to their exposure [27]. The approach followed is the one reported in the paper "Effect of module orientation and batteries on the performance of building integrated photovoltaic systems" (Lovati et al. 2017) [28]. Once the different design parameters required were supplied to the free software "POW" (Photovoltaic Optimization Ware), the simulation was started. The result of the process indicated that it was not economically efficient to cover with photovoltaic part of the north-facing roof, because it would have resulted in a minimum contribution in terms of electricity production (Fig. 8).

In general, the results provided have been limited by the area: a sufficient photovoltaic surface has not been provided to the program to cover the high electrical consumption. In particular, the sum of the traditional and integrated plant covers 23% of the vertical farm's energy consumption, with an average installed power of 888.1 kWp. Through the hourly, day-by-day monthly calculation, it was possible to optimize the production in

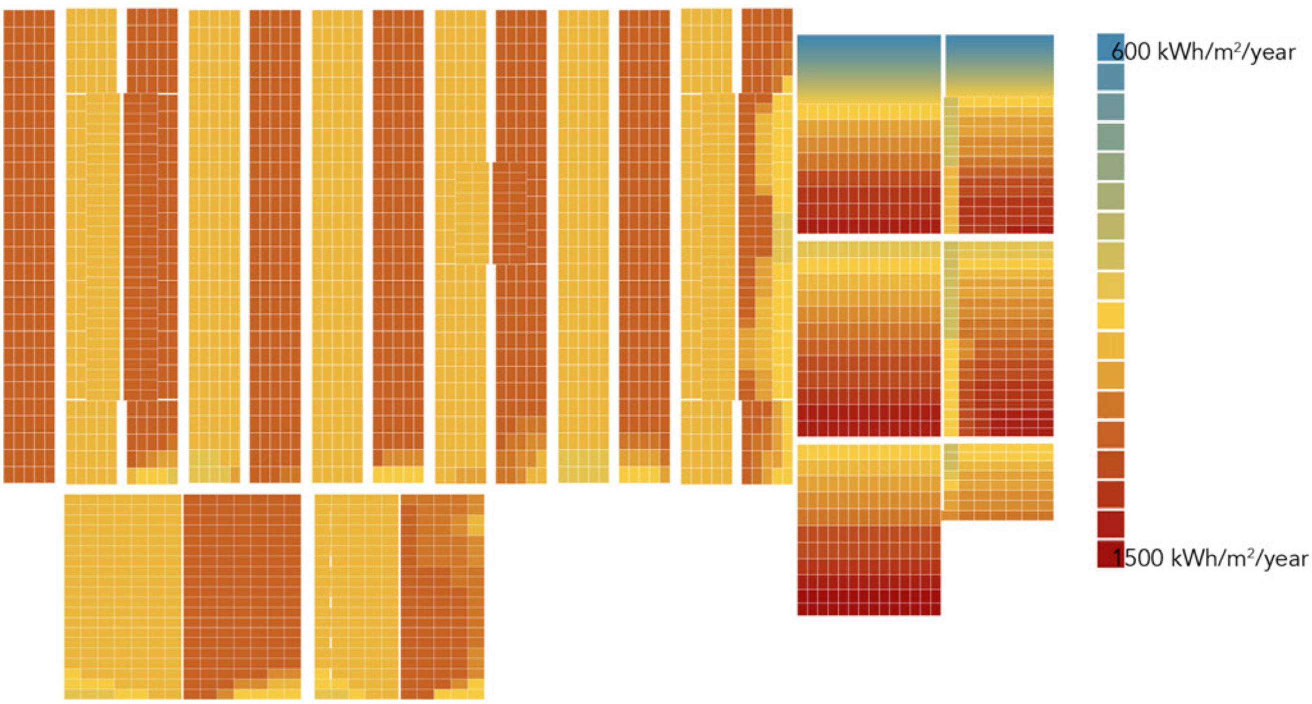

Fig. 8. *Cumulative annual radiation produced by Trento AgroFarm photovoltaic system – rooftop view.*

such a way that almost all the energy supplied was also self-consumed by the building. This result is clear from reading Figure 9.

The energy demand not covered by photovoltaics could be virtually met with biomass: the advantages linked to this choice are manifold. In fact, through the biomass plant, the waste deriving from hydroponic crops would be recovered and integrated with the organic waste produced by the city of Trento. In this way, the discarded waste becomes a starting point for a new production cycle able to generate the energy necessary to make the food circuit work. In addition to the production of electricity, the system also generates heat, generally unused, which also warms up the internal cultivated environment, thus reducing consumption related to the mechanical ventilation system.

4.3. THE SOCIAL CIRCUIT

In addition to the more strictly engineering aspects, *Trento AgroFarm* engages a series of important effects in the urban area, involving the community within the food chain and not only at the end of the cycle, at the time of consumption. Even to a lesser extent, a phenomenon of decentralization of the agricultural function with respect to urban spaces happened in Trento. *Trento AgroFarm* is an opportunity to restore centrality to production, weaving a direct link between the population of the neighborhood and the entire city. In fact, the architectural design aims at creating a strong relationship between cultivated spaces and public paths (Fig. 10). In addition, *Trento AgroFarm* develops programs about consumer orientation and nutrition education. Last but not least, it offers job opportunities for the local population. Taking up the model proposed by *Vertical Harvest*, *Trento AgroFarm* provides innovation not only in agriculture but in the social field, playing a key role in answering the demand for employment by disadvantaged social groups.

5. CONCLUSIONS

This contribution aims at proposing a complex and integrated design path, within which a new possibility of urban regeneration was developed through a renewed link with the rural environment. *Trento AgroFarm* represents a circular system, in which each resource is the starting point or integration of another cycle, affecting different aspects that concern the life of the city and its future. It prefigures the possibility of a new urban productive landscape capable of recovering and generating resources. Blue and green infrastructures for the collection and purification of water and the permeability of the soil [29] are combined

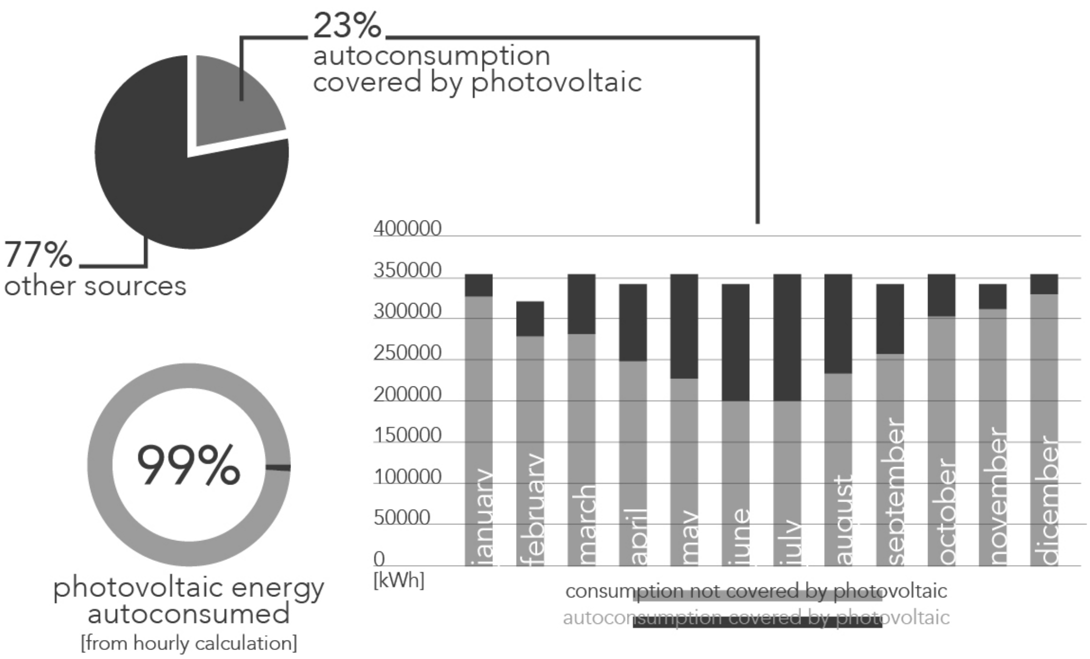

Fig. 9. *Trento AgroFarm. Daily production-consumption of photovoltaic energy.*

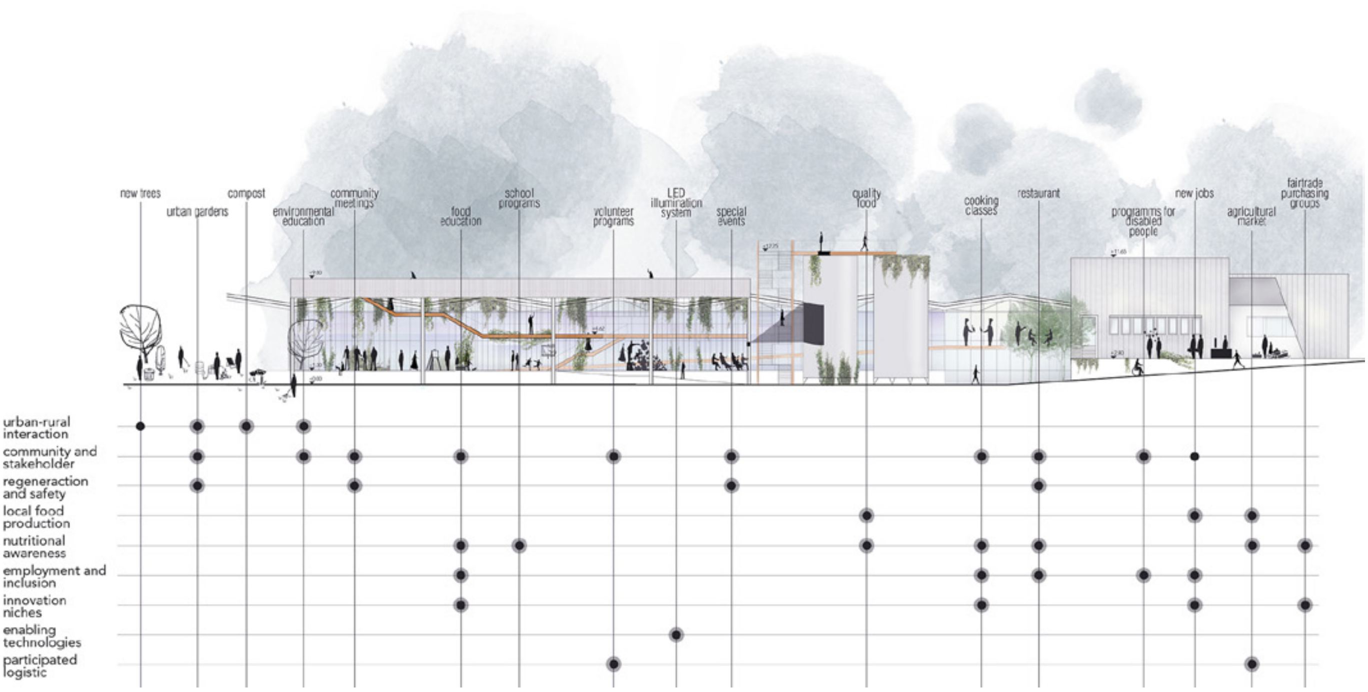

Fig. 10. *Trento AgroFarm. Social development.*

with productive aspects related to food and energy, engaging community, research, and urban renewal. In order to preserve the quality of the urban texture anticipating the abandonment of the buildings, the regeneration process is addressed through different time phases, developing from the beginning basic and pop-up actions able to enliven the site and make the population feel part of the transformation process. In this way, the project offers an innovative system to create conviviality by introducing vertical farming as processes of recovery and transformation of the urban fabric as well as an opportunity to achieve a higher quality of life for sustainable urban development.

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