MECHANICAL ENGINEERING | PHYSICS | PRESERVATION OF THE ARCHITECTURAL HERITAGE | STRUCTURAL, SEISMIC AND GEOTECHNICAL ENGINEERING | URBAN PLANNING, DESIGN AND POLICY | AEROSPACE ENGINEERING | ARCHITECTURE, BUILT ENVIRONMENT AND CONSTRUCTION ENGINEERING | ARCHITECTURAL, URBAN AND INTERIOR DESIGN | BIOENGINEERING | DATA ANALYTICS AND DECISION SCIENCES | DESIGN | ELECTRICAL ENGINEERING | ENERGY AND NUCLEAR SCIENCE AND TECHNOLOGY | ENVIRONMENTAL AND INFRASTRUCTURE ENGINEERING | INDUSTRIAL CHEMISTRY AND CHEMICAL ENGINEERING | INFORMATION TECHNOLOGY | MANAGEMENT ENGINEERING | MATERIALS ENGINEERING | MATHEMATICAL MODELS AND METHODS IN ENGINEERING

PhD Yearbook | 2025

Chair:

Prof. Andrea Caragliu

DOCTORAL PROGRAM IN ARCHITECTURE, BUILT ENVIRONMENT AND CONSTRUCTION ENGINEERING

Vision

The Doctoral Program in Architecture, Built Environment and Construction Engineering (ABC) was born in 2012 from the evolution of five prior programs, active since the institution of the Italian Dottorato di Ricerca (PhD) in 1988. The aim of the ABC-PhD Program is to represent a national reference for training researchers and experts in the following fields:

- the sustainable transformation and management of the Built Environment, interpreted as an environmental, economic, cultural and social ecosystem, as well as time and space series of Architectures and cultural landscapes;
- the Engineering of buildings and components, structures and infrastructures, materials and service systems those architectures and landscapes are part of;
- the organization of the Industrial Systems that design, realize, manage and transform them, and the Public Administration System that defines the rules for taking care of their value as social assets.

Program organization

The Program adheres to the following ten principles:

1) Selection of candidates through a transparent and fair procedure;
2) View of candidates as independent, mentored and monitored, researchers;
3) Setting up research plans tailored on each Candidate's research topics and needs;
4) Organization of training activities based on research practice;
5) Research practice closely connected to the ABC Department strategic research lines;
6) Transparent assessment of Candidates' scientific production;
7) Systematic assessment and open and supportive peer review of Candidates' advancements;
8) View of candidates as nodes of international research networks;
9) Systematic valorization of PhD holders and their research outputs among relevant stakeholders;
10) Interpretation of candidates as an active part of the Program's Quality Management System.

The awarding of the ABC-PhD title requires that Candidates, under the control of their Supervisors:

- plan and carry out a three-year, full-time, research activity;
- plan, attend and pass, with a positive evaluation, a number of Doctoral Courses, to complete her/his skills as researchers;
- develop a PhD thesis and defend it, in a Final Exam session certifying its original advancements on a specific topic.

The ABC-PhD Program offers a wide roster of diverse cutting edge specialized doctoral classes. The offer is continuously updated in order to meet the ever-changing demand of skills as the opportunities offered by the Department. This list is further strengthened with the possibility to borrow classes offered by Politecnico di Milano's PhD School, while it may also be integrated by the offer of all other Doctoral Programs offered at Politecnico di Milano.

Academic, industrial and social collaborations

Each Candidate is mentored by one main Supervisor and inherits her Supervisor's Scientific Sector as reference. However, thanks to the multidisciplinary nature of the ABC department, her activity may be supported by other co-Supervisors to strengthen her final research output. The main effort of the ABC-PhD Program Board is to keep research works by candidates constantly reviewed, borrowing from the wide range of skills and competencies available within the ABC Department, other Politecnico di Milano Departments, or other national and international Universities and Research Centers. Each Candidate is also assigned a member of the Program Board, which acts as individual Tutor with the aim of constant independent monitoring of her activity.

Moreover, each Candidate is progressively encouraged to confront her position, project, intermediate products and final results with any stakeholder that may acknowledge, enhance, valorize and exploit them through social or industrial collaborations. Our social and industrial collaboration starts often from the very beginning: in fact, roughly 50 per cent of ABC PhD candidates are thematic, and their main research topic is defined (and the Candidate selected) together with a firm or an international research institution as a fully, or partially, funding partner. Our mission is to train our PhD Candidates as self-sufficient and independent actors, able to gain – as scientist, as intellectuals, as professionals, as entrepreneurs – an outstanding position at an international level.

We are confident that our early-stage openness toward stakeholders and the whole scientific world and networks represents an asset to provide future PhDs with solid occupational opportunities for an academic career as well as for a job in research centers and other firms and public bodies looking for high-skills workforce, in particular of experts trained to innovate and to manage innovation processes.

The PhD-ABC Program deals with a wide variety of topics and related disciplines. The range of disciplines and topics address by the program is so wide that a shortlist would make little sense.

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SHEAR STRENGTHENING OF CONCRETE STRUCTURES WITH ORGANIC- AND INORGANIC-MATRIX COMPOSITES

Veronica Bertolli - Supervisor: Tommaso D'Antino

Tutor: Valter Carvelli

Fiber-reinforced cementitious matrix (FRCM) composites have gained popularity as externally-bonded (EB) reinforcement of structural members, as they represent an effective alternative to fiber-reinforced polymers (FRP) to strengthen existing concrete and masonry structures. Although failure of FRCM strengthened elements depends on several geometrical and mechanical parameters of the composite and of the substrate (Figure 1a,b), the main parameter influencing the effectiveness of FRCM is the composite bond behavior, i.e., the composite stress-transfer mechanism.

Among possible applications, EB FRCM composites can be applied to reinforced concrete (RC) elements to improve their shear strength (Figure 1c). FRCM composites are generally U-wrapped around the cross-section of RC beams and completely wrapped around the cross-section of RC columns. The shear strength contribution provided by the EB FRCM is computed following the Mörsch truss analogy, and the analytical models available in the literature compute the stress in the composite based on different hypotheses. In the first part of this work, the accuracy of analytical models available in the literature to compute the FRCM shear strength contribution is assessed with respect to a database of FRCM shear strengthened RC beams collated from the literature. The assessment allows for identifying the main parameters affecting the FRCM shear strength contribution. Based on these results, an experimental campaign is designed to clarify the effect of some of these parameters. Namely, four-point bending tests are performed at the Politecnico di Milano on five real-scale RC beams shear strengthened with U-wrapped PBO FRCM composites. Then, a new analytical model is proposed to compute the actual stress distribution arising in the composite intersecting the main shear crack. This model can account for the bond behavior of the specific FRCM-concrete interface studied and can follow the evolution of the stress-transfer mechanism as the crack opens. The model is first validated on a reference beam and then applied to the experimental results of the U-wrapped RC beams tested to shed light on the effectiveness of the FRCM shear reinforcement. The new model proposed is extended to the case of fully-wrapped members. Finally, a new design equation based on the FRCM bond behavior is proposed for the case of fully-wrapped FRCM shear strengthened RC beams. The results obtained pave the way for the introduction of a design equation for the case of fully-wrapped FRCM in the Italian guidelines CNR-DT 215.

The second part of this work investigates the shear strength contribution provided by glass FRP (GFRP) bars used as internal transverse shear reinforcement of new concrete members (Figure 2a). Indeed, the shear strength of FRCM-strengthened beams and of GFRP-reinforced concrete beams are topics that can be tackled in a similar way. Debonding of FRCM composites is characterized by large values of interface slips at the ultimate limit state, which entails large openings of substrate cracks. Analogously, reinforcement of concrete members with composite bars, which have elastic moduli smaller than that of steel, determines large openings of concrete cracks both at serviceability and ultimate limit states. Thus, the peculiarities associated with the concrete shear strength contribution observed in FRCM shear strengthened-RC beams can be extended to the case of FRP-reinforced concrete beams. The GFRP reinforcement shear strength contribution is computed using the Mörsch truss analogy and its effectiveness depends on the bond behavior at the GFRP-concrete interface. To improve the state of knowledge on this topic, four real-scale concrete beams reinforced with traditional steel bars and thermoset and thermoplastic resin GFRP bars are tested at the Politecnico di Milano (Figure 2b,c). A thorough mechanical characterization is performed on the newly developed thermoplastic GFRP bars, which can be easily shaped and are particularly suitable to realize transverse reinforcement. The tests performed allow for assessing the effectiveness of thermoset and thermoplastic resin GFRP bars as longitudinal and transverse reinforcement of concrete members. The focus is set on the GFRP bar shear strength contribution by discussing their behavior and comparing the experimental results of the beam tested with predictions of existing analytical formulas, providing indications on the accuracy of these formulas and on parameters that need further consideration. This assessment is particularly interesting because analytical models available in the literature provide formulations based on results of thermoset GFRP bars only and are applied to thermoplastic GFRP bars for the first time. The results indicate that bent GFRP bars provide for a reinforcement shear strength contribution lower than that provided by the same amount of steel reinforcement. Furthermore, the low elastic modulus and different bond conditions entail a higher opening of the concrete main shear crack, which in turn determines a decrease of the concrete shear strength contribution as the crack widens. The results obtained confirmed the effectiveness of GFRP bars with either thermoset or thermoplastic resin as reinforcement of concrete members.

Fig. 1 - a) PBO open-mesh textile, b) cement-based mortar, and c) RC beam shear reinforcement with PBO FRCM.

Fig. 2 - a) FRP bars with different surface finishes, b) bent thermoset and thermoplastic GFRP bars, and c) failure mode of a GFRP-reinforced concrete beam.

A PLACEMAKING FRAMEWORK FOR A SYSTEMIC CHANGE. HOW TO COMBINE PLACEMAKING WITH CURRENT PLANNING TOOLS TO CREATE INCLUSIVE, HEALTHY AND SAFE PLACES. STRATEGIES FOR THE CITY OF MANTUA

Stefania Campioli - Supervisor: Scira Menoni

Co-Supervisor: Carlo Peraboni - Tutor: Sara Cattaneo

The given topic of this research, related to a department scholarship, is "Activation co-design and shared decision process in the construction of inclusive, healthy and safe spaces. Strategies and lines of actions for the city of Mantua."
This research looks at cities as key players for a sustainable development to make them more inclusive, healthier and safer. In defining urban strategic actions, public spaces play a key role because they are the backbone of cities and communities, can promote a healthy lifestyle and improve the sense of belonging among citizens. To address the wide topic of this study, the research has been organised in three directions. The first is the leading theme about the participatory design approach that includes shared decision processes, participatory processes and co-design. The second is about the deep meaning of creating inclusive, healthy and safe spaces for the community and the city focusing both on the tangible and intangible values of places. The third is how to define the strategies and lines of actions to get more inclusive, healthier and safer cities. Mantua, then, represents a specific given context with its uniqueness related to the architectural heritage and the natural landscape in which to test and apply the investigated methodologies.
The specific objectives that this study has developed are: 1) investigating co-design and co-creation for the regeneration and improvement of public spaces with communities; 2) identifying qualities and hidden values of urban places in order to make them inclusive, healthy and safe; 3) identifying strategies for the city of Mantua that answer to the "how to...?" questions such as "how can we make placemaking real in a specific Italian context?" or "how can we integrate placemaking into planning?". Since the academic field of this study is "Urban and regional planning" the perspective on those themes and approaches is a systemic thinking to define technical and political processes that can better develop a sustainable built environment to serve an ever-changing society and to improve people's lives.
Among the many approaches that combine the direct involvement of citizens and the project of public spaces, Placemaking represents the most comprehensive and structured one, so it has been deepened through bibliographic study, a hands-on approach during the experience abroad and its direct application on several projects. Placemaking is working its way in developing cities around their communities and places, it applies a human-centred approach, it looks at citizens as the experts of the daily public life that happens in places and it has been developed as a multi-steps process with plenty of tools.
The outputs of this study are manifold. The first is an "Organised Placemaking Toolbox" with tools applicable at different design scales throughout the whole placemaking process (one out of three has been directly experienced by the author). The second output is the "Placemaking Framework", a 'meta-design' that combines the steps of the placemaking process and three design scales of urban projects together with the suitable placemaking tools. This frame of reference helps designers, facilitators and civil servants to interpret urban challenges and current urban plans through the lens of Placemaking, to implement it within urban policies. The third output consists of a proposal for the city of Mantua to implement Placemaking into future projects applying the "Placemaking Framework". To validate this proposal, the "Placemaking Framework" has been applied to the PEBA Plan (Plan for the Elimination of Architectural Barriers) of the city during its initial phase.
Thus, through its outputs, this study wants to propose a urban development model that can easily combine bottom-up and top-down initiatives creating a collaborative process that is socially and culturally inclusive, flexible and multidisciplinary.
The development of a conceptual framework represents an interesting step forward in the application of placemaking into urban policies and this is a way to easily combine bottom-up and top-down initiatives. Moreover, the re-organisation of tools with the steps of the Placemaking process and the spatial dimension is very useful when applying Placemaking from scratch.
To conclude, the development of this research and its outputs can be considered a progress in the scientific and academic research because they present a synthesis about the shared decision and co-design processes; a streamline of the placemaking process; a systematisation of existing tools; the addition of the spatial dimension to these tools; and a way to make placemaking more systemic.

Fig. 1 - Organised Placemaking Toolbox, the first output of the thesis

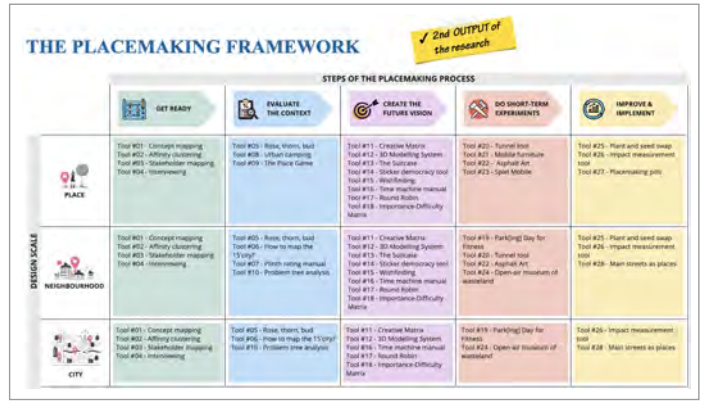

Fig. 2 - Placemaking Framework, the second output of the thesis.

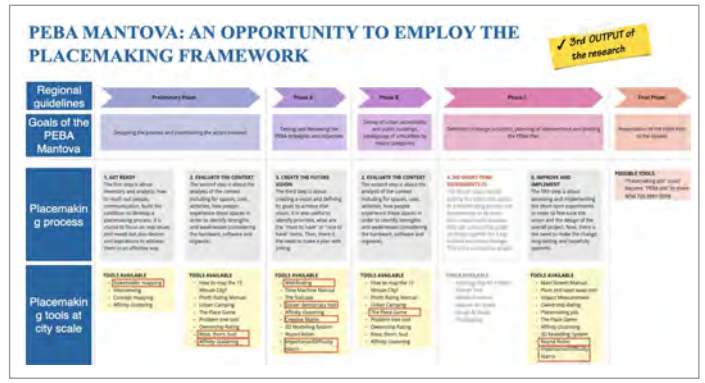

Fig. 3 - Chart of the application of the Placemaking Framework into the PEBA Plan of the city of Mantua, the third output of the thesis.

MECHANICAL VENTILATION FOR ITALIAN SCHOOL CLASSROOMS

Riccardo Cardelli - Supervisor: Simone Ferrari

Tutor: Claudio Del Pero

The recent COVID-19 pandemic has highlighted the key role of school classrooms' ventilation in reducing the infection risk of airborne pathogens, besides providing a general improvement in Indoor Air Quality (IAQ). Among the ventilation strategies, mechanical ventilation with heat recovery (MVHR) appears to be the only one that can provide adequate ventilation rates and thermal comfort during the heating season. The present research aimed to promote National strategies for equipping the existing Italian school classrooms with low-invasive mechanical ventilation systems. Hence, a set of archetype models has been defined. Based on these, different low-impact ventilation schemes have been considered and numerically simulated to evaluate their ventilation performances. The more effective solutions have been designed in detail and relative intervention costs have been assessed. Finally, dynamic energy simulations have been done, to define the potential energy and economic impacts on national school building stock.

As a result, it emerges that implementing mechanical ventilation systems in Italian classrooms has a potential positive primary energy impact. In particular, it has been estimated that the annual primary energy related to the Italian stock can be reduced by 30%. Analysis at the regional level revealed that more than 70% of the National savings is associated with classrooms in northern Italy. The national incidence reduces moving to the south, in proportion to both the mitigation of the climate and the decreasing of the building stock density.

On an economic level, however, savings on energy costs have been observed only in the harshest climate zones (zone E and zone F) with variations depending on the type of building construction and the installed power of the ventilation units. In particular, decentralised units reveal greater reductions in energy costs than centralised systems. However, all the analysed solutions are not cost-effective revealing a payback time longer than the useful life of the ventilation units.

In conclusion, this research demonstrates that, in the Italian context, implementing MVHR systems in classrooms is aimed at reducing primary energy consumption and improving the IAQ, without interfering with the thermal comfort of occupants. Furthermore, a reduction in public health costs associated with mitigating virus transmission can be expected. The overall results of this work offer valuable insight to support the definition of national policies for the implementation of MVHR within the Italian classroom stock.

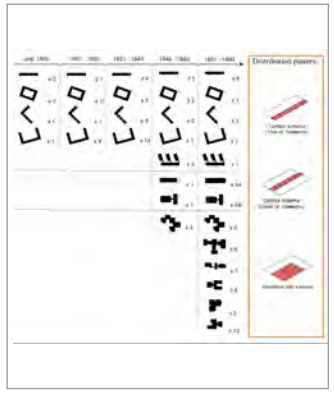

Fig. 1 - Italian classroom distribution patterns.

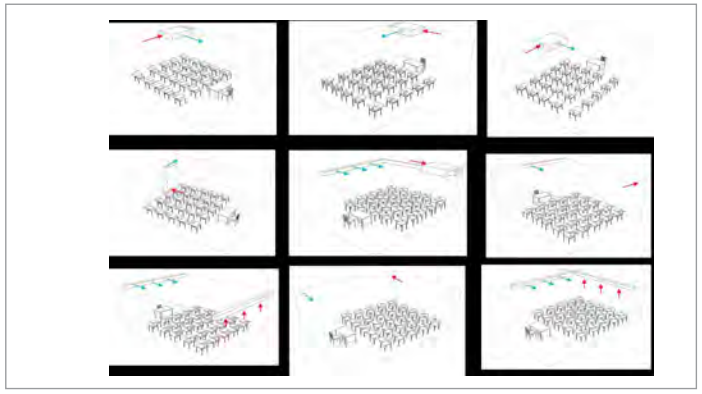

Fig. 2 - Low-impact ventilation schemes for school classrooms.

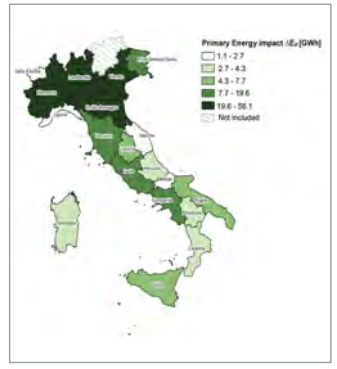

Fig. 3 - Annual primary energy impact at Regional scale, QGIS elaboration.

NOVEL PREFABRICATED BIO-BASED RETROFIT SYSTEM

Giorgio Castellano - Supervisor: Ingrid Maria Paoletti

Co-Supervisors: Laura Elisabetta Malighetti, Francesco Pittau - Tutor: Monica Lavagna

This PhD research aims to investigate novel applications of bio-composite materials and digital manufacturing technologies based on the circular reuse of agricultural waste to develop innovative building components to retrofit the existing building stock.
The research objective aligns with the European Green Deal and the Renovation Wave initiative, which underscore the urgent need to reduce greenhouse gas emissions and resource consumption in the built environment.
According to the Strategia Nazionale di Specializzazione Intelligente (SNSI) programme, the PhD activity is framed in the thematic area 'smart and sustainable industry, energy and environment' and is focused on the development of innovative high-efficiency production processes and industrial sustainability, innovative and environmentally friendly materials and technologies for biomaterials and biobased products.
The project aims to contribute to the preparation of a green, digital, and resilient recovery of the economy by reducing the impacts of climate change and promoting sustainable development. These objectives align with the national and European strategy to develop mass-customized production systems for adaptive technology using environmentally friendly materials. Moreover, looking at the PNR2021-27 strategy, the PhD develops Key Enabling Technologies to address at least three national interest areas: humanistic culture through heritage and built environment, the digital transition, and green technologies. Interweaving these areas of growing interest will help develop and upgrade the building stock more coordinately, avoiding resource losses and closed domains of interventions.
The work's objective focuses on the potential for large-scale retrofitting of the building stock and optimising the production and construction phase to comply with the EU renovation wave program and decarbonisation targets. If the deep renovation rate does not double by 2050, most of the existing European building stock will still be responsible for high global environmental, economic, and social impacts. Multiple challenges exist, from increasing renovation rates to bringing in deep renovation projects, emerging technologies and skills. The need for a more holistic process, resulting in innovative integrated (seismic-energy-architectural) renovation solutions, pushes construction production and assembly to be part of the design process from the early stage of the design. Within this context, the PhD was developed on designing, prototyping, and validating NoRS (Nature-based Retrofit System) as an innovative construction methodology that leverages agricultural byproducts, digital fabrication, and distributed manufacturing. The aim is to provide a sustainable, customizable, cost-effective retrofit solution that meets current and future demands for energy-efficient and low-carbon building renovations. Following the circular economic principles, agricultural waste may be a highly insulative building constituent, producing beneficial outcomes for the buildings and the environment. The utilisation of bio-based materials contributes to climate change mitigation due to diminished energy consumption and the ability to sequester carbon throughout their operational lifespan, offering an alternative fabrication model based on circular regeneration rather than an open emission process.
The structure of the dissertation is divided into three main sections. The first (Section A) presents the theoretical framework, state of the art in the three research fields (retrofit, bio-based materials, digital manufacturing) and an in-depth analysis of case studies from European and Italian perspectives. The second section (Section B) describes the design and evaluation of the NoRS system, illustrating the development phases of the mock-up, the issues encountered, the selected materials and assembly technology. A comparative Life Cycle Analysis (LCA) is also presented to evaluate the system's environmental impacts in terms of carbon emissions. The third section (Section C) includes the mock-up structural tests, supported by the Materials Testing Laboratory (Laboratorio Prove Materiali e Strutture per le Costruzioni) of Politecnico di Milano. To identify the maximum connection capacity of the system, four compression bending tests consisting of three NoRS elements were developed to evaluate pressure capacity. The final chapter discusses possible future developments and reflections on the system's patentability and scalability. The PhD research seeks a scalable retrofit methodology that could improve current retrofit issues in the market. Through continuous testing and refinement, NoRS aims to drive a profound shift toward low-embodied energy solutions and closed-loop resource use as an essential contribution to Europe's vision for a carbon-neutral future.
Key elements of NoRS are the use of fast-growing, bio-based materials, specifically rice straw, which offers an eco-friendly alternative to timber-based products and helps address the potential scarcity of wood fiber and other byproducts. By turning rice residues, a common agricultural waste product, into modular panels fabricated with CNC (Computer Numerical Control) machines, NoRS embodies the circular economy principles, maximising resource efficiency and minimising waste and a distributed manufacturing approach. From Design for Manufacturing and Assembly (DfMA) principles for advanced facade systems, a series of strategic design factors were considered, including materials and their properties, the geometry of the façade system, and production methods.
This minimises material use and labour and enhances the system's environmental footprint. The system is based on standardised modules for construction, layers, and joints. Modules change based on the size of the intervention (S-M-L) and are flexible in architecture, form, and cladding. In addition, modules can be combined with non-prefabricated (conventional) retrofit options.
The proposed solution will be achieved through the second-façade approach, which involves attaching the retrofitted façade to the existing one, integrating the system and fireproof elements, and using low-embodied carbon materials, such as bio-based ones. The design concept is to develop 'connection elements' within the facade that provide substantial load-bearing capacity, facilitating the assemble and disassemble procedures and guaranteeing performance behaviour in case of fire and thermal resistance.
These key points are crucial for enhancing the bio-based materials' characteristics, longevity, and resistance to fire in retrofitted buildings. Components can be produced locally, transported flat-packed to the construction site, and assembled without specialized tools or heavy machinery, lowering upfront investment costs, reducing transportation-related CO_2 emissions, and empowering local communities. The idea behind NoRS is a flexible use of on-site manufacturing facilities, referring to a lever-aging process regarding flexibility and accuracy in fabricating components on demand.
Answering the Sustainable Development Goals (SDGs) 09-Industry, innovation and infrastructure, 11-Sustainable cities and communities, 12-Responsible consumption, and 13-Climate action, this PhD research is the base for setting up a technological system of prototyping and validation in the laboratory with additional mock-ups.
Given its innovative nature, NoRS is undergoing a patent application process, managed in collaboration with Politecnico di Milano's Technology Transfer Office (TTO), which includes prior art and technology mapping.

SPORT AS AN ENGINE OF URBAN AND SOCIAL ENHANCEMENT BETWEEN OPEN SPACES AND FORGOTTEN PLACES

Marta Cognigni - Supervisor: Emilio Faroldi

Co-Supervisor: Maria Pilar Vettori - Tutor: Oscar Eugenio Bellini

The title of the thesis derives from the combination of the word "sport", which, in the current socio-cultural scenario, is an engine of development, given its inclusive connotation, which incorporates, the potential of functional and spatial qualification that expresses, the terms "open spaces, forgotten places", such as, within urban planning and design, remnants of the continuous changes and adaptations of the structure of the city in response to social demand.
This combination of terms constitutes, at the same time, the hypothesis and objective of the research, which, starting from the context of the study, the system of the so-called "open-forgotten spaces", present in the city, elaborates an articulated reading, and some strategies, so that the "problems" of these spaces can be solved and transformed into new open sports spaces.
The research is aimed at the study and dissemination of sport, in the contemporary city, as a "total social fact", an area in which urban and social regeneration policies based on the desire to promote actions of health education are applied, social inclusion and physical qualification programs for the built environment.

The primary objective of the work, therefore, is to develop tools and strategies for the re-functionalization and enhancement of unused spaces in the city, provoking an organic reading of the object of study and the different disciplines related to it. The research works through the connections between the theme of urban quality and the well-being of the citizen, understood as accessibility to the goods and resources of the city.
Research claims that the quality of a place depends on the interrelation between itself and the society that makes use of it.
For this reason, it is appropriate to adopt a multi-scale vision for the study of these unused places and allow the proposition of urban design solutions to impact not only quantitative (the number of citizens and visitors to that place, the number of events it can host, etc.) but also qualitative (considering the impact that such operations can generate on the components of the city system).
Through the identification of the different elements that make up a space, it is possible to establish new rules for the organization of urban functions, to create new formal relationships between them, while maintaining (and in some cases enhancing) the integration of the identity of the place and the prevailing specializations of use.
The unbundling of contemporary society requires the restoration of certain conditions that allow the recognition of meeting places, that reduce the distances between places, squares and streets and between spaces and objects, and that gaps are filled by spaces with well-defined roles and functions. Research, therefore, in response to these assumptions, after defining the types of contexts which, according to scientific literature, today are identified as unused spaces of the city and as spaces intended for the enhancement, finds in the context of European cities a benchmark of reference and privileged inspiration, under the spread and articulation of the types of heritage analyzed, about the consolidated social and cultural tradition linked to sport, as well as the degrees of innovation and experimentation in place about public sports planning.
It has come, through in-depth bibliographical studies, to the definition of what is today an interstitial, unresolved, empty, forgotten space; as well as the role and characteristics it has within the processes of urban transformation. Define to understand how to intervene consciously obtaining new scenarios of urbanity socially active and shared thanks to the "wedging" of urban sport. Types of sports, described in the final forms of research, do not have fixed dimensions but adapt to the space that the city offers.
The value of unstructured sport investigated in research is approached to the social reactivation of and in a place. We do not study and make applicable only the forms of sport but also its values. Sport affects people's lifestyles, ways of thinking, and mental attitudes; and the fact that it represents an ethical and educational system that can deeply affect society makes it necessary to read sport in a regenerative - educational.

The research path is divided into four parts. The state of the forgotten open spaces, which are identified as opportunities for urban regeneration, is defined after revisiting the weaknesses of the contemporary city. Sports disciplines from high social value, and educational identifies themselves as the object and subject of investigation.
Scientific data related to sports practice are of support in the second part to define the state of Italian about the widespread practice in Europe. From here a review, rereading, and analysis of paradigmatic cases on these issues made in the last ten years in Europe leads to the definition of the outcomes of the thesis.
What tools have been used to implement projects? What benefits have they brought to the community? What can be exported and replicated? Is there a city to model?
The consequence of these questions is answered by the results of the research through: the definition of a checklist, a useful tool to analyze the project in its phase of construction, realization, and perception.
The definition and classification of the most popular urban sports today.
The description of a virtuous project, in which a small Italian province, proves to be an experimental project laboratory between sport and urban regeneration and through.
The story of reference projects carried out in Copenhagen, a European city that today is more avant-garde in the implementation of projects on these issues. Here resilience, multifunctionality, and design sustainability are accompanied by the search for psycho-physical well-being and sociality.

The research is positioned in an innovative form within the disciplinary debate on the studies related to the urban complexity of open space, and unfinished places, of their value, promoting the opportunity to introduce innovative solutions for the regeneration and enhancement of the functions of the contemporary city.
The work promotes the potential deriving from a renewed cultural approach to the theme, making use of a potential future methodological and operational perspective, in a context such as that of our cities, usually not inclined to innovation and change and often lacking a real international vision.
In addition to presenting, in a systemic and up-to-date way, the state of the art on the subject, the thesis connects the Italian and European panorama, to identify design and process variants and invariants on the subject.
The methodological approach developed in the thesis allows us to systematize the emerging disciplinary issues in the international context, declining them to the specificity of the Italian context. This approach represents a relevant point of reference also for other European contexts with similar criticalities/ opportunities.

FOG HARVESTING TEXTILE ARCHITECTURE TO FACE THE HYDRIC CRISIS

Maria Giovanna Di Bitonto - Supervisor: Alessandra Zanelli

Tutor: Paola Caputo

Climate change is causing severe water scarcity issues, giving rise to water emergencies in many regions around the world. In this context, fog harvesting has emerged as a promising solution, especially in areas affected by persistent fog and low rainfall. Fog harvesting, a passive water collection system, not only reduces the energy demands of traditional water distribution networks but also presents a viable option in places where conventional water supply systems are absent or inadequate.

The primary source of clean water in underground basins is under threat due to unpredictable precipitation patterns. Consequently, the demand for alternative water sources is growing. Fog, harnessed through Fog Collectors, offers a sustainable solution. These devices, composed of a mesh and a supporting structure, have demonstrated their effectiveness in numerous field campaigns. However, it is worth noting that the design of these fog collectors has seen limited innovation since the last century, leaving room for substantial improvement.

This research project aims to significantly enhance the efficiency of fog harvesting by advancing the technology of fog collectors, with a particular focus on optimizing their individual components. The first stage of the investigation entails a comprehensive analysis of weather and geographical conditions that enable the system to function optimally. Subsequently, the mesh design undergoes thorough examination through a series of experimental campaigns to determine the specific characteristics that influence its water yield capacity. The supporting structure is similarly scrutinized and tested to ascertain its impact on fog harvesting performance. These in-depth analyses are critical for the development of a systematic approach for configuring the mesh and structure, based on the specific environmental conditions and functional requirements.

The ultimate goal of this research is to develop a design strategy for a novel fog collector that can be seamlessly integrated into the architecture of various functional constructions. This includes building facades, emergency shelters, and greenhouses, which have the potential to benefit from this technology. The challenge lies in customizing the design to serve multiple functions while promoting resilient construction practices and ensuring water self-sufficiency in these applications. By advancing the state-of-the-art in fog collector technology and integrating it into versatile structures, this research aims to contribute to sustainable water solutions and resilience in the face of water emergencies.

Keywords: Fog harvesting; Water self-sufficiency; Textile architecture; Resilient construction.

A DATA-DRIVEN AND AI-INTEGRATED FRAMEWORK FOR URBAN ENERGY PERFORMANCE: SUPPORTING ENERGY EFFICIENCY IN EARLY-STAGE DESIGN

Andrea Giuseppe di Stefano - Supervisor: Matteo Francesco Ruta

Tutor: Graziano Salvalai

Urban centers and their structures are central to economic, cultural, and developmental activities. Although these areas collectively occupy less than 10% of the global land surface, they are responsible for a significant proportion of global energy consumption. Furthermore, a substantial part of the limited amount of residual CO2 that can be emitted to limit climate change effects is likely to originate from urban buildings. Despite technical and political efforts to enhance urban resilience and reduce urban energy use, the path to buildings' decarbonization is extensive. In this context, the designers' role is crucial to the technical and social response against climate change, and providing a new generation of tools and instruments is central to guide their decisions towards sustainable cities. Designers and policymakers need streamlined methods and tools to achieve demonstrable levels of environmental sustainability from the earliest design stages without limiting design action, untying the energy efficiency from the cost of its assessment, and without oversimplifying the designers' evaluations. Data-informed digital tools offer a strategic approach for optimizing limited resources to assess energy consumption in buildings, allowing different stakeholders to make informed design decisions – especially in the early stages – and facilitating the formulation of relevant urban policies. This research project supports the large-scale adoption of digital tools for sustainable integrated design at city scale by the Architecture, Engineering and Construction sector. Despite growing attention to the topic, there remains a lack of a clear framework for integrating data-driven tools into the design workflow, particularly for practitioners actively involved in conceptualizing and conducting feasibility analyses for decarbonizing new urban spaces. The central gap is identified in the lack of methods, algorithms and tools to analyze and optimize urban performance in the early design stage, especially for multiple building scenarios. The overarching aim of this research is to provide a practical decision support framework that enables designers, policymakers, and various stakeholders to make informed decisions from the earliest design stages. It streamlines the design process by integrating advanced digital tools, including artificial intelligence and data-driven methods, to predict the energy performance of new urban areas with the limited information available at the early design stage. The primary goal is to reduce operational CO_2 emissions related to urban building operational energy consumption, shifting the focus from individual buildings to the broader urban context. First, a business-as-usual workflow is identified and streamlined for each actor involved in the early-stage design process. This workflow definition was developed through expert judgement and insights gathered from informal interviews with key practitioners, providing critical input for integrating data-driven tools.

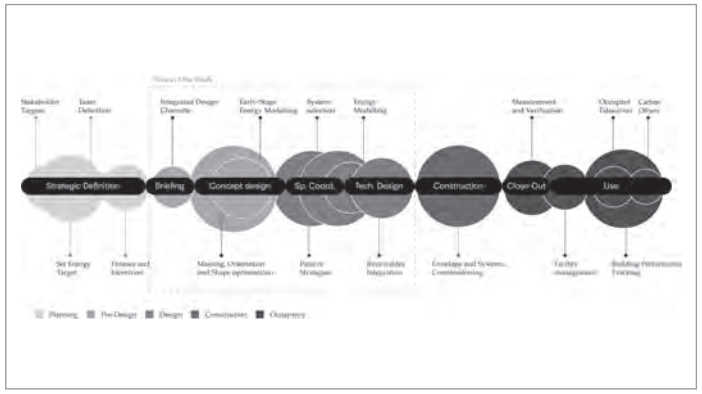

Fig. 1 - Overview of the integrated design process for sustainable neighborhood-scale design, detailing stages from strategic definition to building use with a focus on energy and sustainability targets.

Second, a user-centric framework was developed to streamline computational requirements, data, and calibration needs. This framework facilitated the swift development and application of tools for assessing building energy performance informed by geometric, weather, and context-defined data. Third, the framework was applied through the development of a digital tool to rapidly generate early-stage urban building performance simulation models. These models focused on pathways for reducing operational carbon, aiming to substantially decrease both the time and resources needed. Ultimately, this thesis compared two business-as-usual methods (physics-based and solely analytical) with the data-driven tool based on the framework through a hypothetical case study. This integration sought to enhance the understanding and inference of energy usage in urban buildings and cities. Each step was documented, and the findings were juxtaposed with those from conventional modeling practices. The major contribution is the development and validation of a framework that streamlines data requirements and workflow integration, rapidly generating and exploiting building performance simulations in an urban context scenario. This supports design exploration and helps designers develop carbon reduction pathways, achieving ever-higher levels of environmental sustainability. This research project presents a significant advancement in the field of urban sustainability by addressing the critical need for early-stage urban design tools and strategies that integrate data-driven methods to optimize building energy performance within urban neighborhoods. The intellectual merit lies in developing a scenario-modeling framework that leverages data-driven artificial intelligence tools within an industry-driven urban design workflow to predict and enhance the energy performance of clusters of buildings. By focusing on multiple building scenarios rather than isolated structures, the research provides a quantitative approach to decarbonization planning, essential for achieving significant reductions in operational CO_2 emissions. Working with both academia and industry partners across Europe and United States to build a user-centric framework further reinforces the robustness and applicability of the research outcomes. This project sets a precedent for integrating advanced computational tools within early stages of urban design workflows, thereby pushing the boundaries of sustainable urban design practices.

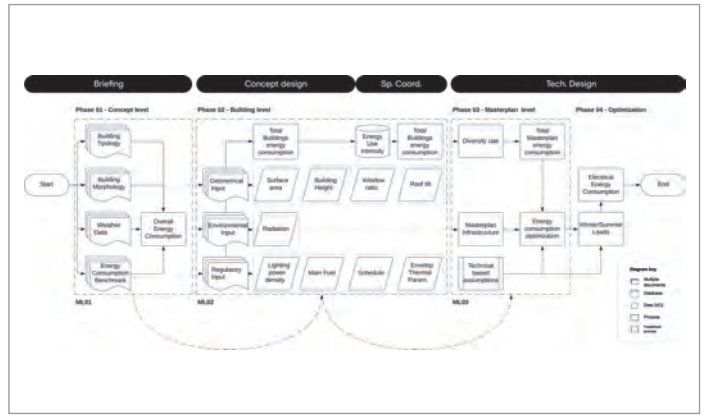

Fig. 2 - Framework Definition.

INNOVATIVE METHODS AND SOLUTIONS FOR EFFICIENT SUPPLY CHAINS IN THE MANTOVA AGRI-FOOD SECTOR

Silvia Falasco - Supervisor: Paola Caputo

Co-Supervisor: Paola Garrone - Tutor: Marco Scaioni

Almost one-third of overall greenhouse gas emissions are generated by the agrifood sector. Therefore, increasing food system sustainability has become critical, as encouraged also by the European Union with the Farm to Fork Strategy. The territory of Mantova and its surrounding areas (rich in tradition and gastronomic heritage) has been chosen to assess possible solutions to improve the environmental sustainability of the value chain, along its phases (i.e., production, distribution, and consumption). For the production stage, the use of the European Geographical Indication (GI) scheme is proposed. After a deep literature review, regarding their impacts on social, economic and environmental sustainability, a comparative Life Cycle Assessment (LCA) has been conducted to compare the environmental performances of two GI products to their conventional alternative. Results have shown that the GI scheme alone is not a synonym for better environmental performance. However, GIs can be used as a powerful instrument to promote and pursue higher sustainability in production, introducing environmental criteria inside their specification, avoiding the creation of a new dedicated mark. For the distribution stage the use of Alternative Food Networks (AFN) is proposed. After a literature review regarding the definition and the characteristics of AFNs, the LCA methodology is again used to compare the distribution system proposed by AFNs to the conventional distribution system, using a case study. Results show that for the up-stream logistics (from producer to point of sale) AFNs have better environmental performance, due to fewer actors involved. For the downstream logistic (from point of sale to consumers) AFNs have worse performances than conventional distribution systems, due to the limited quantity of products purchased by consumers. In this case an optimization scenario for AFNs has been evaluated, to make this distribution system more environmentally sustainable also on the downstream logistics. AFNs could therefore become a way to increase sustainability in food distribution, especially in context like the one analyzed. For the consumers part, the development of a decision support system (DSS) is proposed to help increase consumers' awareness regarding their personal food choices, leading to more environmentally conscious behavior. The DSS was developed to calculate the environmental impacts of the meals of one day, based on an LCA dataset. The DSS has also being tested in Mantova, receiving 104 responses, and will be converted into an online tool available for all. Results from pilot testing positioned the majority of people in the middle category and only 1 person in the most impactful category. Also, the impact of changes in consumers' choices is assessed, to find possible suggestions to be included in the DSS, to support consumers. The creation and testing of the DSS brought some reflection on the availability and reliability of datasets, a problem which affects all three phases of the value chain. Anyway, the LCA methodology was applied, although in different ways and with different aims, in the three stages of the value chain demonstrating its fundamental role in assessing environmental sustainability. To conclude, the territory of Mantova and surrounding areas, have a potential to improve environmental sustainability of their food system, which constitutes a fundamental part of their culture. Combining the strong traditional traits with technological innovations could represent the key toward a more resilient and sustainable area.

BIM/GIS INTEGRATION FOR IN-USE AND DISUSED RAILWAY LINES ASSET MANAGEMENT

Manuel Garramone - Supervisor: Marco Scaioni

Tutor: Fulvio Re Cecconi

Infrastructure asset management (AM) is receiving more attention as a result of greater awareness of climate change and contemporary urban challenges. The European Green Deal and the Sustainable Development Goals aim to create a sustainable global economy. Reducing transport emissions and their detrimental effects on the environment and public health is a significant task, as transport accounts for one-third of all final energy consumed in the EU. Since rail is sustainable, it has the potential to contribute significantly to the decarbonization goal. Additionally, more people are taking trains, which meets a growing demand for rail travel and raises the quality and quantity of services provided. Only in Italy, more than five million people travel by train to study or work each day, and this number is steadily rising over time. An increase in funding for rail infrastructure translates into more passengers. This is particularly evident when looking at regional rail transport: despite an overall growth of +5.1% between 2010 and 2019, the situation is extremely fragmented due to the individual regional policies. A management strategy is required for regular or local train transport, which is mainly utilised by commuters. Different intervention works, such as electrification and railway track adaptation, are required for most of them. Disused railways, which typically provide unique paths within cities and territories, are another railway sector area that could enhance sustainable mobility development. The railway heritage can play a significant role in sustainable development and landscape regeneration worldwide, particularly considering the conversion of abandoned railways into greenways, non-motorized transportation networks dedicated to soft mobility (such as that of cyclists, pedestrians, horseback riders, etc.). Enabled by new technology, the digital transformation offers numerous opportunities for a positive conversion of the transportation industry, and it is crucial in addressing the issue of renovation and management of regional railways as well as re-evaluation of disused railways. The main goal is to test the potential of an integrated system that combines Geographic Information Systems (GIS) and Building Information Modelling (BIM) for managing this kind of existing infrastructure. A three-step methodology is suggested to develop the integrated system, and to test the methodology two case studies in the South of Italy were examined: the in-use '*Ferrovie Appulo Lucane*' railway (see Figure 1) and the disused railway '*Potenza Inferiore Scalo*' – '*Laurenzana*' (see Figure 2). From the infrastructure AM perspective, the capacity of BIM and GIS for data management, analysis, and visualisation may offer additional insights for boosting asset value, identifying and minimising risks, and optimising decision-making in assets management, according to ISO, 2014a. Connecting the data produced by BIM and GIS makes possible the creation of an integrated digital model of the built asset, enabling advanced information management in the digital built environment.

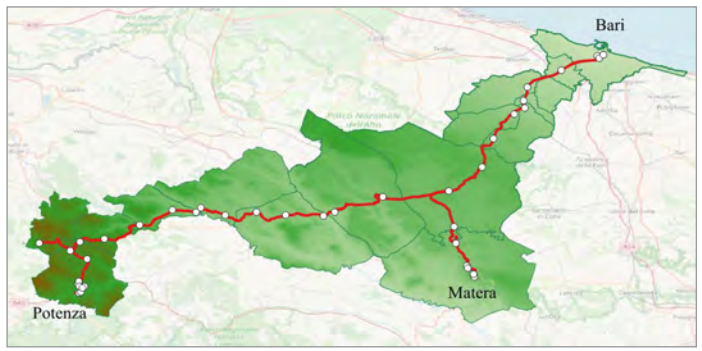

Fig. 1 - 'Ferrovie Appulo Lucane' (FAL) railway line with stations and stops.

Fig. 2 - 'Potenza Inferiore Scalo' – 'Laurenzana' railway line with stations and stops.

MAPPED HERITAGE: A METHODOLOGY FOR USING HISTORICAL CARTOGRAPHY IN THE VALORISATION OF MINOR WIDESPREAD HERITAGE IN LOMBARDY

Dina Jovanović Lombardo - Supervisor: Daniela Oreni

Tutor: Corinna Rossi

Historical maps are invaluable repositories of knowledge about spatial environments, transcending their status as mere artistic artifacts. They serve as physical archives for historical data, providing important insights into the evolution of the setting in particular context. These two-dimensional historical presentations are becoming increasingly significant in studying territorial transformations of minor widespread historic centres. Towns that experienced intense changes throughout the industrial era were left with undefined and discarded natural and built cultural heritage, making their valorisation and preservation considerably more challenging. The study focuses on the Lombardy region, which has many historically important towns, a dense infrastructure network, and various land use patterns, but has also seen numerous and impactful modification in the urban tissues. The intricate spatial historical stratigraphy underscores the necessity of employing diverse approaches and techniques to gather data from the past and present for future preservation and planning endeavours. Consequently, historical maps serve as instruments for researching and evaluating spatial relationships between coexisting elements in the past, often filling gaps in the meanings and significance of cultural and natural heritage. The transition from the common attitude of *viewing* historical maps to their *usage* is a core theme of the dissertation, highlighting the potentials that they carry when disassembled, compared to other sources, and ultimately visualised using spatial-temporal tools.

The dissertation methodology prioritise collection and examination of historical cadastral and topographic maps followed by their investigation, systematisation, and vectorisation. Prior their use, historical maps were georeferenced within the Geographic Information Systems software. The research methodology comprises two foremost approaches: the 'Deconstructive' and the 'Constructive' approach. The former involves the extraction and analysis of individual elements depicted on historical maps, by applying operational readings 'by typology' and 'by meaning'. The latter involves the construction of new knowledge by integrating processed historical information with current analysis of historical centre. Using a predefined workflow and guidelines, the research scale determines the vectorisation process. Vectorised single elements are organised in groups and linked with other historical records, including written documents, images, and illustrations. This process allows employment of map regressions across all historical layers alongside present-day data to establish a comprehensive timeline of urban changes. Structured datasets stored in the attributes of each vector file provide information about past and present qualities valuable for valorisation of elements composing investigated territory.

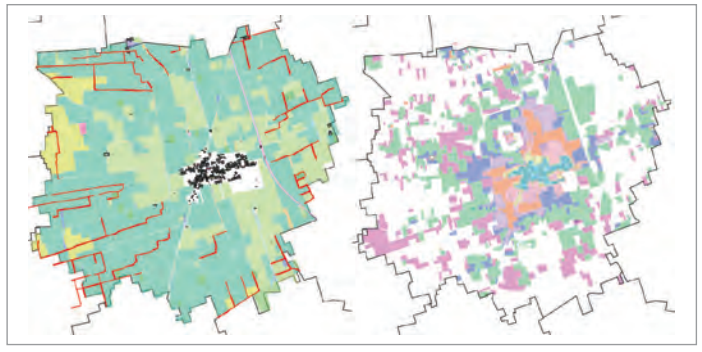

Fig. 1 - Municipality of Desio. Left: Evolution of built tissue by zones for the period between 1722 and 1998. Right: Vectorised parcels from the Lombardo Veneto cadastre (1865), classified by use, with municipal and local roads marked in red, which can still be recognized today in traces.

To examine the effectiveness and utility of the developed methodological phases, a case study involving the Municipality of Desio has been selected for implementation. Desio is a medium-small municipality in the province of Monza and Brianza. Its minor historical centre and landscape characteristics have undergone significant changes since the 1960s. Three sets of historical cadastres produced from the 18th to the 20th centuries at a scale of 1:2000 were utilised as the primary source of information in the urban studies. Their associated land register provide a substantial amount of information on land and building use. These cadastres, accompanied by other historical topographic and chorographic maps, were systematised, processed, and analysed using a developed methodology alongside contemporary data from municipal sources and geoportals. The study was steered by the recommendations for digitisation of historical materials and planning guidelines established by the regional, provincial, and local entities. The final outcomes demonstrated the large variety of information gathered and obtained through the proposed approaches. The created knowledge of spatial changes rediscovered landscape and cultural values, enabling the evaluation of the impact of newly proposed municipal projects.

The results of the vectorisation of historical cadastres, georeferencing of topographic maps, and integration of contemporary data revealed several distinct topics. The network of past road system today is reflected in traces of municipal and semi-private roads (known as *strade vicinali*), with much of their historical importance lost. Employing the methodology, it is possible to precisely determine their positions and propose potential areas for regeneration, integrating these roads into the routes of slow mobility initiatives. The study also examines the built heritage, farmsteads and villas, many of which have interconnection with these streets. Their evolution in form and function is tracked through the analysis historical cadastres, providing valuable insights into buildings' context and alterations significant for their preservation. Furthermore, the study highlights shifts in the nomenclature and arrangement of open spaces within the historical centre.

The dissertation methodology, workflow, and results will be applied in the development of the new Territorial Government Plan (PGT) for the Municipality of Desio. The creation of the document is scheduled for December 2024, during which the research will be employed for analysing, presenting, and describing the evolution of infrastructures, agricultural land, green elements, built heritage, services, and settlement. The remodelled structured database management system will specifically contribute to the study of urban tissue, the qualities of proposed regeneration areas, and the census of cultural heritage. The framework and systematised data obtained through this research will become the official part of the planning municipal document.

Final discussions are centred around the limitations and challenges inherent in examining information depicted on historical maps, establishing connections with complementary historical documents, and integrating past and present data within a digital environment. The methodology is meticulously designed for replication across diverse contexts and scales. Additional values of the study include increased administrative efficiency and enhanced participation of researchers, collaborators, and residents. The thesis provides guidelines for the use of historical maps in elaborated and contextualised projects.

SUSTAINABLE ACTIVE COOLING DESIGN FOR BUILDINGS WITH HIGH OCCUPANCY SPACES IN THE TROPICS: BALANCING THERMAL COMFORT, ENERGY EFFICIENCY, AND CLIMATE CHANGE IMPACTS

Jaqueline Estefanía Litardo Mosquera - Supervisor: Niccolò Aste

Tutor: Laura Elisabetta Malighetti

Providing indoor spaces with thermal comfort is critical, particularly in tropical regions, which accommodate more than 40% of the global population. Conventional air-conditioning (AC) technologies, i.e., window air conditioners and mini splits, predominantly meet the growing demand for space cooling in these regions, even in non-residential buildings. However, many alternative active cooling technologies remain underexplored despite their potential advantages in energy efficiency and environmental sustainability.

While numerous studies have examined active cooling systems, limited research exists regarding their suitability for extremely hot-humid climates, where dehumidification significantly impacts energy consumption. There is also an insufficient understanding of optimal indoor parameters (i.e., temperature, humidity, air velocity) necessary to ensure acceptable thermal comfort and energy savings in such conditions. Conventional setpoints typically range from 22-26 °C with relative humidity (RH) levels of 50-60%. However, these parameters may not always represent the best trade-off between occupant comfort and energy efficiency.

On top of it, future climate variations, including extreme heat events, are expected to exacerbate the demand for space cooling, emphasizing the urgency of identifying sustainable and resilient cooling solutions while maintaining indoor comfort standards.

Given these concerns, this Ph.D. thesis investigates practical solutions for space cooling in high-occupancy buildings in hot-humid climates. This research focuses on two real university classroom buildings in tropical developing regions (Fig. 1): one case study in Mogadishu, Somalia, and another in Guayaquil, Ecuador. This research begins by defining active cooling baselines for each case study to systematically assess potential strategies.

Case study A in Mogadishu is naturally ventilated, while case study B in Guayaquil is equipped with split-unit systems. The study then explores various indoor thermal conditions, analyzing different temperature, humidity, and air velocity settings through parametric simulations using the Integrated Environmental Solutions Virtual Environment (IESVE) software. These simulations aim to determine the optimal extended setpoint that balances thermal comfort with energy efficiency, reducing cooling loads without compromising occupant thermal comfort.

The study then quantifies space cooling and ventilation loads, assessing the feasibility of a 100% outdoor air ventilation mode as a potential approach to improving indoor air quality while maintaining energy efficiency. This step is crucial for evaluating the trade-offs between increased ventilation rates and the associated energy consumption in hot-humid climates. Additionally, the study compares air and ground as potential heat sinks, assessing their energy performance and viability for integration into cooling system designs.

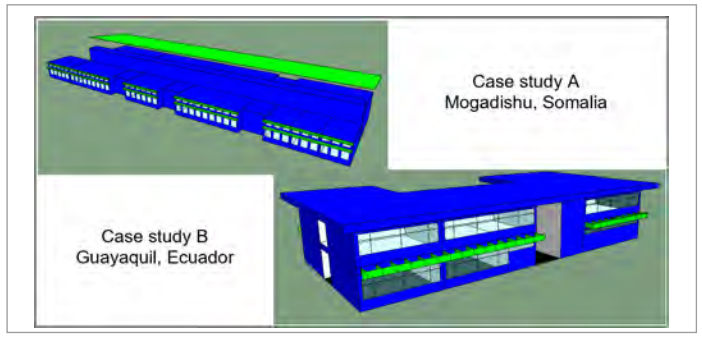

Fig. 1 - Virtual models of case studies A (top) and B (bottom).

Building upon insights from the literature review chapter, this study explores alternative AC configurations beyond traditional direct expansion (DX) units. Specifically, two technologies are examined (Fig. 2): (1) a variable air volume (VAV) system and (2) a radiant cooling system coupled with a dedicated outdoor air system (DOAS). These systems and the selected chiller are analyzed to assess their energy performance and initial cost implications. Based on a comparative analysis, the study identifies the most suitable active cooling approach for each case study, considering factors such as implementation costs and energy efficiency under present climate conditions.

Simulation results indicate that the VAV system best balances thermal comfort, energy efficiency, cost-effectiveness, and simplicity. In both case studies, the optimal indoor conditions were approximately 28 °C/70% RH with elevated air speed at 0.6-0.7 m/s provided by ceiling fans (hybrid cooling approach). The study further examines the impacts of climate change on future cooling demands by incorporating Shared Socioeconomic Pathway (SSP) scenarios. Results reveal that adopting an extended setpoint approach could mitigate the projected increases in cooling loads, keeping demand below baseline levels even under the worst-case future scenario (SSP5).

At the end of this research, key lessons learned from the literature review and case study analyses are synthesized into guidelines supporting sustainable cooling design practices. These guidelines provide valuable recommendations for AC practitioners in hot-humid tropical contexts, highlighting passive and active cooling strategies.

The findings emphasize the need for integrated solutions that leverage passive cooling, optimized indoor setpoints, and effective AC systems to achieve energy-efficient and climate-resilient building designs.

Overall, this research contributes to the growing knowledge of sustainable cooling solutions for tropical climates. It offers actionable insights for future building design, policy development, and climate adaptation by systematically evaluating alternative active cooling strategies and their performance in real high-occupancy buildings. In light of increasing global temperatures and rising cooling demands, identifying energy-efficient and cost-effective cooling solutions remains paramount for ensuring long-term sustainability in tropical developing contexts.

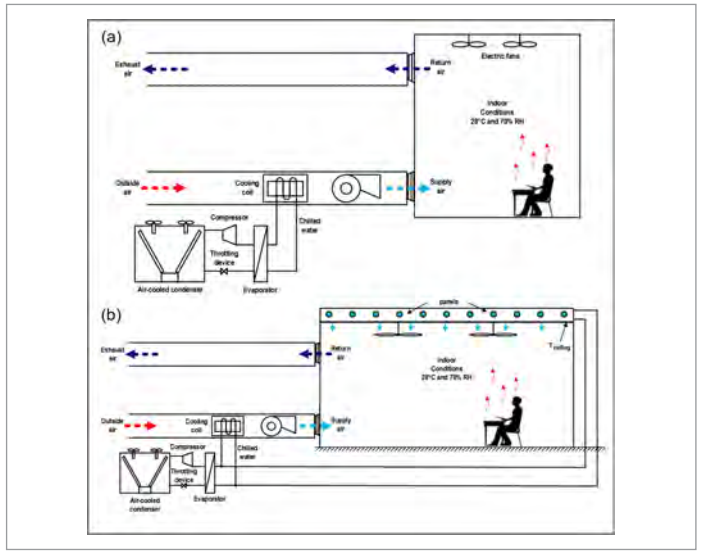

Fig. 2 - Simulated AC systems: (a) VAV system and (b) DOAS Radiant system.

SUSTAINABLE PRODUCTION OF PUBLIC SPACES IN SMALL HISTORIC CITIES IN CHINA

Qian Liu - Supervisor: Laura Anna Pezzetti

Tutor: Francesca Claudia Maria Belloni

Public space has been an essential part of Chinese cities in various types and forms throughout history. However, the turbulent 20th century has broken the long tradition of public space in urban China, bringing in new types, transforming existing types, and eliminating some old types. In contemporary Chinese cities, public spaces are facing problems, especially in small historic cities with valuable historic urban landscapes and typo-morphological characteristics but lacking sufficient funding and adequate professional design. They are more likely subject to damage by problematic public spaces.

The small historic cities constitute a unique category of cities in China. They are numerous, yet they face complex realities. On one hand, these cities possess valuable historical heritage, inevitably subjecting their urban development to constraints imposed by heritage conservation requirements. On the other hand, they significantly lag behind larger cities in terms of economic conditions but are compelled to accommodate urbanization from surrounding rural areas, leading to immense pressure for economic growth and improvement in residents' living conditions. In particular, within the context of China's overall economic transition, small historic cities tend to shift towards the tourism industry to promote local economic growth and increase residents' income. To foster the tourism sector and city marking, urban regeneration and construction efforts in small historic cities, under the dominance of capital and policy powers, have generated a substantial amount of public space. Capital power, especially the tourism capital, is over-exploiting such cities for more profit, and tends to reduce the unique historical characteristic to simple stylistic elements, without paying due attention to the real authentic historical urban morphology and identity. Policy power, on the other hand, is aggravating the situation by cooperating with capital power to produce large, "modernized", and symbolic public spaces as city marketing tools, which are not always suited to the urban context and the residents' real demand on public life. Such an unsustainable way of producing public spaces is sabotaging the unique historic urban landscape of these small historic cities while costing a huge amount of funding.

This thesis intends to contribute to the effort of addressing these problems in the public spaces in small historic cities. Thoroughly and comprehensively recognizing the complicated reality facing small historic cities, the research avoided one-sided emphasis on heritage conservation. Instead, it aimed at achieving a balance between cultural heritage preservation, public life, and economic growth.

To achieve the research objectives, historical references have been employed as the primary research strategy in this thesis, adopting a typo-morphological methodology. The urban public spaces in China's urban history have formed a continuous tradition of types and morphologies but were interrupted in the 20th century. These traditions were developed within flourishing public life and a continued culture. Referring to their characteristics can, on one hand, help align contemporary newly produced public spaces with the historical urban landscape. On the other hand, their unique historical and cultural attributes can sustainably attract tourists, which conforms well to the research objectives of this study.

The research started with a comprehensive and chronological overview of the public spaces in the history of urban China, focusing on their typo-morphological characteristics and the public life they accommodated. This beginning part figured out what inspirations the historical types may offer to contemporary interventions, and laid a basic research framework for the following work by identifying three critical issues that existed throughout the history.

Then in the second phase, the research introduced the main case study, the city of Zhengding, a small historic city in North China. Its typo-morphological characteristics were closely examined, both in terms of the whole city and of the public spaces within the city.

Next, the contemporary problems in public spaces in small historic cities were closely observed. Their causes and impacts were also analyzed in this part, so as to lay a foundation to better tackle them.

The last part of the research, cases in Zhengding were studied in detail to propose principles and strategies that aimed at reaching the expected balance between heritage preservation, public life, and economic development.

BUILT ENVIRONMENT AND DEMENTIA
EXPERIENCE-BASED DESIGN STRATEGIES FOR ALZHEIMER'S ARCHITECTURES

Silvia Mangili - Supervisor: Stefano Capolongo
Co-Supervisor: Marco Mario Trabucchi - Tutor: Francesca Bonfante

Introduction
In recent years, thanks to advances in medicine and the role of prevention that occupy more and more space in healthcare, life expectancy has experienced rapid growth, rising from 77.6 to 80.4 years in Europe from 2002 to 2020. Despite advances in medicine, as well as preventive approaches and the use of digital technologies, the aging population will lead to an increasing need for long-term care.
Dementia affects about 7 million people in Europe, and the number is set to double by 2050. About 60-80% of people with dementia have Alzheimer's disease. Dementia is a disease that brings serious changes in the cognitive sphere, altering perceptions of the living space. Due to the age and multimorbidity of the patient, is one of the most frequent visitors of healthcare facilities, and long-term care in many cases becomes their home. These structures often do not consider the real needs of the patient who, because of the pathology, relates differently to the environment than other kinds of patients. Multiple studies show that features of the built environment can impact characteristic aspects of people with dementia however, there is a lack of studies showing how there is a link between the quality of these environments and the quality of life and well-being of people with dementia living within them. Architecture must play a key role in creating places where the well-being of patients is the priority, both physical and psychological. To this end, Experience-based Design (EBD) needs to become a habit, a norm for designers who want to create facilities suitable in the best way for people with dementia. The research highlights the need for a transition from a prescriptive to a performance approach.

Research Objectives & aims
The built environment significantly impacts the health and well-being of vulnerable populations, including people with cognitive impairments. However, healthcare facilities are often not designed with the specific needs of people with dementia in mind. Dementia patients, as primary users of long-term care facilities, face challenges related to their physical, psychological, and cognitive limitations. Healthcare facilities for people with dementia are becoming increasingly important, particularly in countries with aging populations. A more holistic, experience-based approach is needed—one that moves beyond compliance with regulations to focus on measurable performance criteria. This research aims to develop a framework of architectural features in long-term care facilities that influence the health and well-being of people with dementia. These features will serve as the foundation for an assessment tool based on Multi-Criteria Analysis (MCA) to evaluate the quality of these environments and support decision-making in both new designs and renovations.
The evaluation tool will be capable to assess both existing and newly designed facilities for people with dementia (PwD). The tool is designed to measure architectural features that influence patient well-being and disease progression.
Its development involved a multidisciplinary team, including medical and technical experts, as well as patients with dementia, to ensure that user needs are accurately reflected.
The goal is to fill the gap in current guidelines and contribute to the design of healthcare environments that better support the well-being of people with dementia. The tool will also provide insights into design improvements and help decision-makers set priorities for facility upgrades. Additionally, comparing health outcomes among patients in differently scored facilities will help verify the connection between built environment quality and patient well-being.

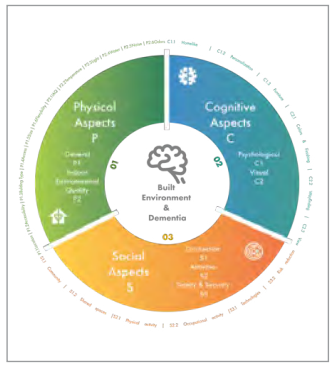

Fig. 1 - The framework of the DREAM-BE tool

Methodology
The study started by analyzing the state of the art (with systematic literature review, best practices, and analysis of existing evaluation tools). Based on these analyses, a framework of the most important architectural features was developed, and these are channeled into the evaluation tool. The design process of the assessment tool involved a multidisciplinary group of stakeholders, from medical and technical fields, and patients diagnosed with dementia, to thoroughly understand and consider the needs of the end user. The tool, named Dementia-Responsive Environmental Assessment Measure - Built Environment (DREAM-BE), consists of 3 macro areas, 7 criteria, 24 sub-criteria and 192 indicators. The sub-criteria were weighted with stakeholder involvement. The tool was validated by applying it first to a pilot case study and then to 11 facilities (8 Italian and 3 British). A second version of the tool was developed to analyze projects during the design phase and was applied to two new facility projects for PwD (one in Italy and one in the UK). The application in the UK was made possible during a research period at University College London. This allowed the indicators to be tested and validated in another country with a different health care system. Finally, an observational study was conducted on a sample of patients from two of the evaluated facilities to test the impact of design strategies on health outcomes in residents with dementia.

Results
Application and testing of the tool on structures revealed several common critical issues and well-established aspects for each building. The application of the revised version on two projects highlighted the scalability of the tool that can be used from the early design stages, and the indicators can serve as guidelines. Regarding the observational study on two structures, the research showed a possible dependence between the quality of the built environment and the implications in users. There were no significant differences in cognitive decline data between the two facilities, however, interesting results emerged regarding improvement in quality of life and depression in the facility that scored best from the application of the DREAM-BE tool.

Conclusions
The DREAM-BE assessment tool has proven effective in assessing the quality of facilities for PwD. The application of the tool can highlight critical spaces and provide strategies to eliminate them. The tool is a valuable system for both designers to guide them during the design stages and decision makers to identify areas and priorities for facility renovation. The observational study revealed interesting initial data for monitoring the health and well-being of residents. Future development of the research by expanding the number of data would provide a more robust statistical sample and define even more precisely the impacts of different aspects of the built environment.

Keywords
Dementia, Alzheimer, Nursing Homes, Long-term Care, Built Environment, Experienced-Based Design, Healthcare Design, Assessment tool, Health & Wellbeing

BEHAVIOR OF EXTERNALLY BONDED CFRP-TO-STEEL SYSTEMS UNDER FATIGUE LOADINGS

Tommaso Papa - Supervisor: Massimiliano Bocciarelli

Tutor: Marco Vincenzo Valente

Steel structures are sensitive to cracks nucleation and propagation when subjected to cyclic loadings, such as traffic-loads or wind-induced vibrations and waves, causing a consequent accumulation of damage typical of fatigue processes. In recent years, increasing concerns regarding the fatigue crack development in civil metallic structures led to the urgent need of efficient strengthening and repairing techniques to avoid catastrophic, social and financial losses, consequent to their possible collapses. This research problem concerns both the design of new structural elements and the strengthening of existing structural components, which are facing longer service lives, increasing load and generally need for reinforcement. Very recently, the application of Fiber Reinforced Polymers (FRP) composite materials on damaged steel structures, in particular of high strength Carbon Fiber Reinforced Polymers (CFRP), has been adopted as an effective solution to restore their bearing capacity or extend their fatigue life. Their application often resulted to be more efficient than the traditional strengthening techniques, in reason of their own features such as: a high strength-to-weight ratio, low invasiveness, less sensitivity to corrosion, and negligible increment of the dead load. Different strengthening systems have been proposed and new issues related to their application have arisen, which needed to be properly considered and investigated. In particular, the use of externally bonded (EB) CFRP reinforcements, directly applied to the substrate with specific epoxy-based adhesives, showed their effectiveness in reducing crack growth rate and extending fatigue life. The load is transferred from the substrate to the composite through shear stress exchange mechanisms occurring at the bonded interface. Therefore, in EB CFRP-to-steel joints the behavior of the interface is crucial in guaranteeing the effectiveness of the bonded system response and represents one of the main issues of such applications. Failure usually occurs due to cohesive debonding within the adhesive, and thus the system response strongly depends on the mechanical and physical properties of the structural adhesive employed to bond the two adherends, namely the composite and the steel substrate. Two main classes of structural epoxy adhesives are present in literature. The former is generally referred to as brittle adhesive, showing a brittle and an approximately linear behavior; while the latter, generally referred to as ductile, presents a tougher, more ductile non-linear behavior, which represents a valid solution for EB CFRP fatigue strengthening applications. When subjected to cyclic loadings, the constituents of the reinforcement system, i.e., the composite and the adhesive, can exhibit a progressive degradation of their properties, reducing over cycles their stiffness and strength and thus leading to the collapse of the bonded system. In this context, the present work proposes an experimental and numerical characterization of the fatigue behavior of EB CFRP-to-steel systems under cyclic loading conditions. Experimental tests aimed at investigating the bond behavior have been conducted at the Materials Testing Laboratory (MTS) of Politecnico di Milano. Single-lap direct shear (DS) tests have been performed under both quasi-static monotonic and fatigue cyclic loading conditions (Figure 1). A new toughened epoxy adhesive recently proposed for the fatigue strengthening of steel elements has been adopted and its performances investigated. Toughened adhesives resulted to be characterized by a more pronounced non-linear behavior, a lower elastic modulus and strength, but a larger ductility than traditional linear epoxy adhesives. This class of adhesives presents a larger fracture energy than that of standard ones, which leads to an higher CFRP-to-steel ultimate bond capacity. A numerical modelling strategy of these systems response has been investigated in the present work. In fact, the development of reliable computational models predicting fatigue crack propagation is desirable and still an open issue in literature. A cohesive zone model (CZM) approach is adopted, and proper cyclic cohesive zone models (CCZM) were introduced (Figure 2). One important aspect related to the use of a cohesive zone law refers to its parameter identification and calibration, which is necessary to guarantee a reliable use of the model itself. Consequently, proper parameter identification strategies based on stochastic inverse analysis procedures were developed for material and model characterization, dealing with fatigue crack growth both in a bulk element and at an interface between two materials. The cyclic degradation of the composite patch itself has been usually included in the nonlinear behavior of the adhesive interface. However, because of the presence of new structural adhesives with higher performances, larger loads and deformations can be sustained. In this context, the contribution of the fatigue damaging behavior of the composite element (plate or sheet) to the global system response plays a significant role and thus must be taken into account directly. Therefore, a preliminary experimental and numerical investigation of composite fatigue damage behavior and its possible influence on the bonded joint response is conducted. Tensile fatigue tests on rectangular CFRP laminate coupons have been first performed, on the basis of which a fatigue residual stiffness model was adopted and calibrated to describe damage initiation and propagation in the composite material. The fatigue response of bonded joint systems under single-lap DS tests was then numerically modelled by considering separately the damage at the bonded interface and in the composite material. Comparisons between the responses of different system configurations were provided, based on a numerical parametric analysis aimed at investigating critical configurations, where the effect of damage developing in the composite material plays a significant role on the bonded joint behavior.

The outcomes of this research can be of big impact regarding structural applications, as they can influence current design guidelines that, at present, do not account for the damage conditions of the composite in the evaluation of the structural performance of the retrofitting system.

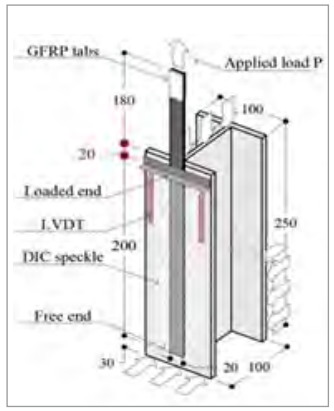

Fig. 1 - Single-lap direct shear test.

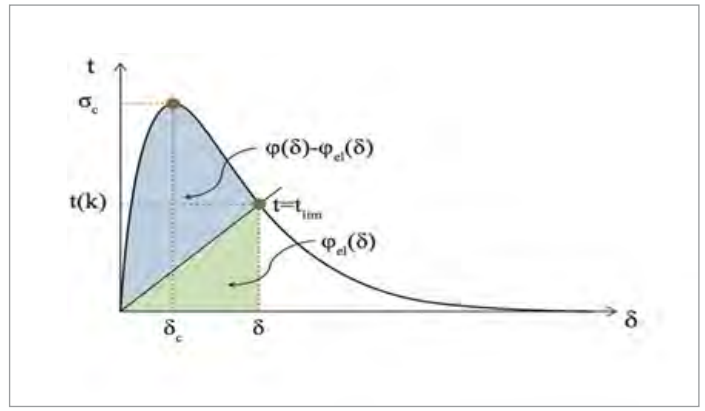

Fig. 2 - Exponential cyclic cohesive zone law.

REVITALISING THE ANCIENT SPACE. A MULTIDIMENSIONAL DISPLAY OF IMAGES OF ANCIENT PLACES

Andrea Pasqui - Supervisor: Corinna Rossi

Co-Supervisor: Nico Staring - Tutor: Marco Scaioni

Cultural heritage is of major importance in our society, but we should not consider it as untouchable *reliquiae*. When studying, surveying, or just even visiting archaeological sites or archaeological artefacts, we are tempted to treat them as something that represents a particular place frozen in time and made accessible to us today. From this point of view, we hence tend to conceive archaological objects – in a broad sense – as something fixed and given. Such a tendency is particularly problematic when referring to an ancient landscape which, in contrast, is a very dynamic and everliving feature.

The aim of this work is to shape an effective framework for the revitalisation of archaeological remains. This study seeks to realise a multidimensional display of images that might trigger the revitalisation of ancient places by illustrating the spirit of the place, the *genius loci* in Latin. A multidimensional display has to be intended as a palimpsest of images depicting a heritage site. Those *images* may be photos, drawings, maps, 3D reconstructions and whatsoever may feature the monument.

The main question that justifies this research is: how should archaeological site be exhibited and displayed far from their place? This issue entails a set of sub-questions that allows and imply an in-depth analysis of the matter. First of all, in order to answer to the primary enquiry, one should ask: what is an archaeological site? Or, as we will see in our particular case, what is Saqqara? This challenging question entails basically two other questions. On the first hand, after having carefully pondered what are those elements which characterise a certain archaeological site, we are prompted to think about which data – generally speaking, including eventually the material culture – should be presented to the public while talking about the site, and on other hand we should reflect on how we should do that. Ultimately, the target of this thesis is to produce a theoretical framework and a practical workflow aimed to make effective the use of images in the process of musealisation of archaeological sites. In a world overflowing with images is essential to take advantages of their existence by using them in the most suitable way: for this reason, in this thesis is searched and investigated a feasible way of merging scientific and emotional/artistic approach to images.

A crucial aspect that needs to be faced while studying archaeological sites is the concept of place. In fact, it differs from the space – to be intended as the physical substrate – insofar the place is a complex entity made of both cultural and tangible elements. This research pursues the revitalisation of the place by means of the recontextualisation of the ancient space. Such operation is intended to raise curiosity about the manufact – object, building, necropolis or whatsoever – and its *life*, and not just to create a sort of fetish: in this regards it is important to keep in mind Gustav Mahler's quote: 'tradition is not the worship of ashes, but the preservation of fire'.

The approach proposed in this study attempting to answer the above-mentioned questions, aims, essentially, at *going beyond the material culture*. The broad methodologic framework in which this research is entangled is that of post-processualism; far from rejecting the scientific method application to archaeology, a phenomenological approach is adopted to face some issues, with particular regards to the matter of landscape.

This study works with case studies from ancient Egypt, yet involves different disciplines, including cultural anthropology, philosophy, architecture, museology, and Egyptology.

Fig. 1 - The step-pyramid of Djoser, a central element in the landscape of Saqqara.

Fig. 2 -An imaginal representation of the methodology adopted. The 3D virtual reconstruction of the tomb of Meryneith is overlaid onto a film photo of the interior of the same. The human factor is central.

Fig. 3 - Holistic representation of the tomb of Meryneith within its context.

In addition, photographs and digital elaborations made by the author during two archaeological missions at Saqqara play a central part in the study.

If the primigenial aim of archaeology was the production of knowledge, it should be remembered that dissemination is a crucial part of this process: knowledge must not be reserved to scholars, but one way or another, it has to be shared.

The production of knowledge necessarily has to go through a process of imagination by means of which a visitor of an archaeological site, or exhibition, is led to ponder about how the life was *in* that place and how the life of that *place* was.

This research focuses both on theoretical background and on a practical application. Theory relies on some examples, by which is extracted a methodology that leads to the practical implementation of a specific case study.

DIGITALIZATION OF ADMINISTRATIVE PROCEDURES PROVIDED FOR BY LEGISLATIVE DECREE NO. 42/2004: IMPROVING BUILT CULTURAL HERITAGE CONSERVATION MANAGEMENT THROUGH DIGITAL PLATFORMS AND ICT TOOLS EMPOWERED BY AI ALGORITHMS

Anna Maria Pentimalli Biscaretti di Ruffia - Supervisor: Stefano Della Torre

Co-Supervisors: Francesco Trovò, Anna Chiarelli - Tutor: Elisa Boeri

The research deals with the digitalization of Public Administration processes, specifically concerning the management of administrative procedures for the protection of built cultural heritage. It focuses on the Soprintendenza Archeologia, belle arti e paesaggio (Soprintendenza ABAP), the institution responsible for enforcing Legislative Decree no. 42/2004, which governs the protection and enhancement of cultural heritage in Italy. Currently, administrative procedures are not fully digitized and rely on the GIADA system (Gestione Informatizzata Archiviazione Digitale Accessibile) for digital protocol and document management. However, this system does not ensure homogeneous organization of information or standardized data for project evaluation, resulting in a discretionary decision-making process that is not always transparent. The objective is to develop an innovative digital management model for authorization procedures, incorporating Artificial Intelligence (AI) to enhance data analysis, preservation, and interoperability. This approach aligns with the National Recovery and Resilience Plan (Piano Nazionale di Ripresa e Resilienza PNRR), which allocates substantial resources to the digital transformation of Public Administration, particularly through the creation of the Portale dei Procedimenti, a centralized platform being developed by the Ministry of Culture. The methodological framework is structured around three key phases. Initially, an in-depth analysis of the existing system was conducted to study the document flows within the Soprintendenza, assess the data currently managed through GIADA, and identify critical issues in the current administrative process. This was followed by the definition of a digital strategy aimed at establishing interoperability between existing platforms, while also setting clear parameters for data standardization in project submissions. This phase included the identification of objective indicators to improve the evaluation of restoration proposals. The final phase involved experimentation and validation through collaborations with the Direzione Generale Archeologia belle arti e paesaggio, the Digital Library - Istituto Centrale per la Digitalizzazione del Patrimonio Culturale, and Acca Software, a technological partner. The originality of this research lies in its contribution to the development of the new digital platform for administrative procedures, currently under construction at the Ministry of Culture: the proposed system aims to increase transparency and decision-making consistency by leveraging AI to analyze and classify restoration projects. It is designed to facilitate interoperability between digital archives across public administrations, reducing redundancy and improving information accessibility. Additionally, it introduces predictive analysis tools to assess project quality and detect potential issues before the authorization stage. This research takes a strongly application-oriented approach, made possible by direct engagement with public institutions and technological stakeholders actively involved in the digitalization of administrative processes. The expected outcomes include a comprehensive review of current procedures, accompanied by a concrete proposal for the digital transformation of built cultural heritage protection. Ultimately, this study represents a significant step toward a more efficient, equitable, and technologically advanced management system for cultural heritage, contributing to the sector's modernization and long-term sustainability.

STRATEGIES FOR THE REHABILITATION OF EXISTING BRIDGES BY SEISMIC ISOLATION

Carlo Pettorruso - Supervisor: Virginio Quaglini

Tutor: Sara Cattaneo

The PhD thesis presents an innovative and practical methodology for the seismic retrofitting of existing bridges using isolation techniques. The approach consists of two main phases: a preliminary feasibility assessment and the design of the isolation system. The goal is to create a methodology that is both precise and easy to implement, ensuring seismic safety while minimizing complex and costly interventions. The study combines structural modeling techniques, seismic response analysis, and real-world validation to offer a comprehensive framework for bridge rehabilitation.

The research begins by analyzing the seismic vulnerability of bridges, emphasizing their unique structural characteristics that differentiate them from buildings. Unlike buildings, bridges feature continuous spans, expansion joints, and bearing systems that can amplify seismic effects if not properly designed or retrofitted. Common failure mechanisms observed in past earthquakes include unseating of decks, shear failure of piers, and inadequate anchorage of bearings. To address these issues, the study reviews existing seismic regulations, highlighting discrepancies between building and bridge codes that can lead to inconsistencies in seismic risk assessment. Various international and national standards are examined to outline best practices for seismic evaluation and retrofitting of bridges.

A key focus of this research is evaluating different structural modeling techniques for seismic assessment. The study compares static and dynamic analysis methods, dividing them into linear and nonlinear approaches. Static methods include equivalent static analysis (ESA) and modal pushover analysis (MPA), while dynamic methods include response spectrum analysis (RSA) and time-history analysis (both linear and nonlinear). These methods are tested on three typical bridge configurations in Italy, representative of over 90% of the national bridge stock. The study assesses their effectiveness in predicting seismic response under three seismic scenarios corresponding to different risk zones in Italy: Reggio Calabria (high seismicity), Sirmione (medium-high seismicity), and Pavia (medium-low seismicity).

The results show that nonlinear time-history analysis (NLTHA) is the most precise method, capable of capturing inelastic behavior and complex structural interactions during an earthquake. However, it is computationally demanding and impractical for large-scale assessments. RSA provides a good trade-off between accuracy and computational efficiency, making it suitable for structures that remain within the elastic range or experience limited inelastic deformations. ESA, while cost-effective, is less reliable in predicting the true seismic response, particularly for continuous-deck bridges where it cannot model the interconnected behavior of piers. The study suggests that ESA is useful for preliminary vulnerability assessments, while more advanced methods should be used for detailed analysis of high-risk structures.

A major contribution of this research is the development of a systematic criterion to determine whether a bridge is suitable for seismic isolation. The process begins with assessing the structural capacity of bridge piers by calculating their moment and shear strength. A simplified single-degree-of-freedom (SDOF) model is used to estimate the acceleration at which failure occurs. This is then compared to the seismic demand imposed by the expected earthquake scenario. If the seismic demand exceeds the pier's capacity, the bridge is identified as a candidate for seismic isolation. The study also evaluates whether the substructures can sustain the new seismic forces after isolation. This decision-making framework is applied to various bridge configurations and seismic scenarios, producing suitability matrices that categorize bridges based on their potential for effective retrofitting. The findings indicate that in most cases, seismic isolation is a viable solution, but in certain configurations, additional reinforcement of the substructure is required.

The thesis then introduces a novel procedure for designing the isolation system, based on the Acceleration-Displacement Response Spectrum (ADRS). This methodology eliminates complex iterative calculations while ensuring precise determination of key isolation parameters such as stiffness and damping. The approach is based on a two-degree-of-freedom (2-DOF) model, where the deck mass is decoupled from the substructure's motion, allowing for more accurate modeling of seismic response. The procedure consists of six steps:

1) Collecting geometrical and material properties of the bridge.
2) Determining the capacity curve of the as-built structure through nonlinear static analysis.
3) Defining the target performance point (TPP) based on the bridge's displacement capacity.
4) Comparing the TPP with the elastic response spectrum to determine whether additional damping is required.
5) Selecting the appropriate isolation parameters (stiffness and damping).
6) Designing the isolation system to ensure compliance with regulatory requirements.

The methodology is validated through a parametric study, which applies the design procedure to various bridge typologies and seismic conditions. The results confirm that the proposed approach is effective in optimizing isolation parameters while maintaining simplicity in the design process. The key advantage of this method is that it does not require iterative adjustments, making it more efficient than traditional isolation design techniques.

To further validate the approach, the research includes two real-world case studies in Italy, where the proposed methodology is applied to assess bridge suitability and design the isolation system. The final validation is performed using nonlinear time-history analysis before and after retrofitting. The results demonstrate a significant reduction in seismic vulnerability, as the base actions on piers remain within the elastic range after isolation. The study also evaluates the displacement response of the bridge and the isolators, confirming that the retrofitted structures remain within acceptable geometric limits, ensuring both safety and serviceability.

The conclusion of the thesis emphasizes the importance of seismic isolation as a cost-effective and efficient strategy for rehabilitating existing bridges. The proposed methodology offers a structured and scalable approach that enables engineers to quickly assess bridge vulnerability, determine the suitability of isolation, and design the isolation system with high accuracy and minimal computational effort. The research highlights the need for updates to existing regulations, recommending the inclusion of specific guidelines for seismic isolation of bridges. This would facilitate the adoption of advanced engineering solutions that enhance the resilience of transportation infrastructure in seismic-prone areas.

By integrating advanced modeling techniques with practical design criteria, this thesis provides a valuable contribution to the field of seismic engineering. The proposed methodology not only streamlines the seismic retrofitting process but also ensures that critical transportation networks remain operational after major seismic events. The findings underscore the potential for seismic isolation to become a standard approach in bridge rehabilitation projects, promoting safer and more resilient infrastructure worldwide.

TEXTILE SKINS FOR RETROFITTING EXISTING FAÇADES.
BOOSTING TEXTILES PROPERTIES WHILE IMPROVING FAÇADES' PERFORMANCES.

Giulia Procaccini - Supervisor: Carol Monticelli
Co-Supervisor: Adriana Angelotti - Tutor: Valter Carvelli

The retrofitting of existing building façades is a crucial intervention strategy in the construction industry to improve energy efficiency, reduce environmental impact, and enhance the aesthetic and functional value of buildings. Conventional retrofitting techniques often involve rigid and heavy materials, leading to significant structural constraints and cost implications. Membranes represent an innovative alternative thanks to their lightweight nature, adaptability, and multifunctional potential. These materials allow for a less invasive application process, minimizing time and cost of building processes and the amount of use of construction materials.
Considering that to renovate a building is a complex process that require substantial expenses, significant structural modifications and a considerable amount of time (with the consequent disturbance for the building occupants), Textile Façade Retrofit Strategies (TFRS) have the potential to tackle these challenges, additionally enabling the coverage of vast areas, making them ideal for retrofitting expansive façade on a large scale.
Textile materials offer several methods to enhance building performance and aesthetics. If their application in façade can be classified in two main categories as Structural Membranes or Enclosures [Figure 1], their employment in façade retrofit applications [Figure 2] can be categorized according to the main retrofit strategy, by replacing the existing façades or elements of them, adding a new finishing over existing façades, either internally, as an insulated textile layer, or externally, as a sun-shading device; or wrapping the existing building façade(s) and creating a thermal buffer zone.
Based on their retrofit strategy and the specific method of implementation, nine Textile Façade Retrofit Strategies [Figure 3] have been identified. Each strategy presents distinct advantages in terms of aesthetic enhancements, energy efficiency improvements, and structural interventions:

- Tensioned Membrane and Cushions make use of the Replace strategy and are ideal for comprehensive façade transformations, offering significant aesthetic changes and potential thermal improvements, suitable for complete overhauls;
- Finishing, Adding, and Covering represent less invasive strategies that require to add a layer to the existing façade, allowing for both interior and exterior enhancements without substantial structural alterations, effectively improving insulation and reducing solar heat gains across various settings;
- Wrapping, Double Skin, Enclosing and Nesting require to wrap the entire building or parts of it: they are particularly effective in creating buffer zones that enhance both thermal and acoustic performances.

Among the nine identified strategies, Covering, Wrapping, and Double Skin stands out thanks to their ability to enhance the thermal performances of the existing façade by adding a sun-shade element to it and /or creating an additional air gap.
Each strategy balances energy and aesthetic benefits, requiring careful design to manage weight and structural integration. While material selection influences both appearance and performance, all TFRS provide flexibility in design, offering solutions that address energy efficiency, sustainability, and architectural expression. Their adaptability to different materials and retrofitting needs makes them valuable tools for upgrading existing buildings.
The use of textile skins in façade retrofitting demonstrates several significant advantages in terms of (i) flexibility and adaptability, being easily shaped and customized to fit any building design, allowing for creative and innovative architectural solutions; (ii) aesthetic versatility; (iii) environmental and economic benefits.
Specifically, compared to traditional retrofit strategies, these solutions consistently demonstrated lightweight properties, with environmental impacts varying based on the quantity of material produced and replaced over a 50-year period. Despite their polymeric nature and limited lifespan, they reached a maximum impact of approximately 130 kg CO_2e.
Moreover, the research highlighted the potential of textile materials as versatile sun-shading devices, which can be implemented either temporarily or permanently on façades. The findings achieved through accurate digital energy simulations indicated that applying these materials over existing façades could reduce the annual energy demands for buildings in Milano (Italy) by 27% to 32%, depending on the retrofitted building stratigraphy, primarily by minimizing summer cooling system consumption. These results may vary according to the building's location, construction, retrofitted strategy design, and specific material properties used.
When analyzing the environmental impact of these strategies taking into account the building use phase (B6), it can be highlighted that the use of these materials for retrofit purposes achieve lower $kgCO_2e$ that the building without any retrofit intervention. It is possible to conclude that the additional use of materials for achieving the retrofit intervention can be offset both economically and environmentally within a 50-year lifecycle scenario.
In conclusion, the integration of TFRS offers a novel and promising approach to retrofitting existing façades. By addressing the multifaceted considerations associated with TFRS and by an appropriate design of the retrofit interventions, architects and building professionals can effectively harness the potential of these innovative strategies, driving the future of sustainable and resilient urban environments.

TEXTILE FAÇADE APPLICATIONS

	STRUCTURAL MEMBRANES			ENCLOSURES		
	DEFINING	WRAPPING	NESTING	DIVIDING	FINISHING	COVERING
Description	The membrane defines the whole space. It works both as a structure and as façade.	The membrane embraces the building structure. It creates an exterior buffer zone.	The membrane is enclosed within the building structure. It creates an interior buffer zone.	Separation between the interior and the exterior through one single layer.	The membrane is used as finishing layer of the façade system.	The membrane is used as a covering layer of the façade.
Relation with the enclosure	Main façade - In line	Main appearance - Additional layer	Interior façade - Additional layer	Main façade - In line	Main façade - In line	Main appearance - Additional layer
Function and Application	Structuring layer: Configuration and Separation between the building interior and the exterior	Second layer: Protection of the building façades components; buffer zone	Second layer: Creation of an interior space; interior buffer zone	Separation layer: Separation between the building interior and the exterior.	Finishing layer: Improvement of the thermal performances	Second layer: Protection of the building façades components; Sun-shading
Hermeticity of the layer	Fully enclosed	Fully enclosed	Fully enclosed	Fully enclosed	Closed layer	Open layer

Fig. 1

TEXTILE FAÇADE RETROFIT APPLICATIONS

	STRUCTURAL MEMBRANES			ENCLOSURES		
	DEFINING	WRAPPING	NESTING	DIVIDING	FINISHING	COVERING
Refurbishment strategy	Replace	Wrap it	Add in	Replace	Add on Add in	Wrap it Add on
Benefits	+ Limited additional weights; ± Total change of the appearance of the existing building.	+ Embracing of the whole building; + Creation of a new intermediate space / buffer zone + Self-supported (new) façade; ± Total change of the appearance of the existing building.	+ A new structure into the structure; + Preservation of the existing façade; + Self-supported (new) structure; ± Relevant trasformation of the interiors.	+ Limited additional weights; ± Total change of the appearance of the existing building.	+ Exterior and Interior application; ± Total change of the appearance of the existing building	+ Partial attachment to the structure; + Embracing of the existing façade; + Sun-shade; ± Partial change of the appearance of the existing building.
Limits	– Replacement of the existing façade.	– Increase in the thickness of the existing façade.	– Reduction of the interior space.	– Replacement of the existing façade.	– Application onto the existing façade; ± A little increase in the thickness of the existing façade.	– No buffer zone; no additional space; ± A little increase in the thickness of the existing façade.
Key component	Walls	Walls; Balconies; Windows	Walls	Walls	Walls; Balconies	Walls; Balconies; Windows

Fig. 2

Fig. 3

DRAWING AND PROJECT IDEA. REFLECTIONS ON THE DIGITAL TRANSITION OF THE IDEATIONAL PROCESS IN ARCHITECTURE

Cecilia Santacroce - Supervisor: Maria Pompeiana Iarossi

Co-Supervisor: Giorgio Buratti - Tutor: Leopoldo Sdino

The thesis reflects on the role of drawing within the ideational phase of the design process and explores the possibility and means of preserving its cognitive and maieutic value even in the digital transition.
The research focuses on how drawing fosters the development of design thinking in the germinal phase of the architectural idea, which Renato De Fusco defines as "auroral." The first part of the thesis, therefore, examines the purpose of drawing in the conceptual phase, distinguishing it from the technical-prescriptive function of graphic documents or the communicative role of project outcomes. Instead, drawing acts as a mediator between the idea and its progressive formal definition.
Drawing is a cognitive tool for understanding the existing reality and its potential transformations, allowing designers to express design intentions and formulate critical judgments about reality—both in its physical-material sense and as a repository of formally defined responses. This reservoir of knowledge provides designers with a reference from which to develop their own response to the design challenge.
Drawing is a space for the expression of compositional theoretical paradigms and the manifestation of design intentions, both when the choice of a specific representation system reflects a defined theoretical perspective on architecture and when critical representation and design proposal intertwine to the point of convergence, highlighting the inherently analytical and synthetic character of drawing.
In order to assess how digital tools can support the design process with the same effectiveness as analog drawing, the research investigates compositional trends and operational methods specific to computer-aided design. Despite its widespread use in the technical-constructive detailing phase and in project communication, the adoption of digital tools in the conceptual phase has marked a rupture in the theoretical conception of architecture, driven primarily by the introduction of three-dimensional modeling. This shift has, in some way, disrupted a long-established tradition, replacing the synthesis of two-dimensional line drawing projections with an increasingly accurate and realistic virtual model—one that, however, lacks the ability to formulate a synthetic judgment on reality.
This has led to the consolidation of formal approaches based on a self-referential use of digital tools, excluding the potential of drawing from the design process. Within these tendencies, it is possible to distinguish the performative approach, which sacrifices expressive values in favor of mere performance efficiency, and, conversely, the generative approach, where the morphogenetic process of architecture is entirely shaped by a sculptural-plastic conception. Most significant among these is the theory of Parametricism by Patrik Schumacher, which is based on the concept of autopoietic architecture, conceived as a complex network of parametrically interconnected subsystems.
Instead, considering architectural design as an interpretive exercise that, in the auroral phase, relies on the interpretation and modification of a context, drawing from the established forms of History, the research explores the possibility of finding in digital tools valid supports equivalent to traditional analog representation systems, examining their applicability to the conceptual phase in relation to their manipulative potential in line with a specific design intention.
These questions introduce the second and more experimental part of the thesis, in which the genetic process of a selection of projects, developed by the authors through analog representation before the advent of digital tools, was digitally retraced within the design tradition characterizing the Milan School. The choice of case studies was guided by the variety of design approaches and methods of formal manipulation (iconographic manipulation, geometric manipulation, manipulation through decomposition and recomposition of constructive elements, and manipulation guided by dynamic perceptual simulation), a variety shaped both by the different nature of the authors and by the diverse education they received, resulting from the evolution of the pedagogical process between the 1920s and 1960s at the School of Architecture of the Politecnico di Milano.
These projects, proceeding through the manipulation of the reference models using the fundamental tool of drawing, made use of historical knowledge and experience as formal starting material, and their manipulation through specific systems of analog representation, adopted according to the different ways of conceiving the design.
The experimentation thus digitally retraced the design process of four projects developed between the 1920s and 1960s by authors trained at the Milan Polytechnic School – the Municipal Building of Sesto San Giovanni by Piero Bottoni, the Church of Sant'Ildefonso by Carlo De Carli, the kindergarten of the Olivetti Center in Merlo by Marco Zanuso, and the urban planning project "Da Diocleziano a Caracalla" by Vittorio Introini—having previously identified in each of them the historical references taken as starting materials.
To this end, for each designer, the historical and cultural context was reconstructed, thus providing an overview of the evolution of the role of drawing in the formative process of architects at the Politecnico di Milano, starting from 1865, when it—according to the specific imprinting established by Camillo Boito, founder of the Technical Higher Institute of Milan—served as the maieutic discipline of design, and continuing through to the 1970s, noting its gradual reduction in favor of the rise and consolidation of other disciplinary knowledge.
The results of the research have suggested the potential for a conscious experimentation, even in the educational field, with the use of software to support architectural design (fig. 1), promoting the transition to digital representational systems, provided there is a solid understanding of the logical constructs of drawing, the foundational principles of representation, and the specific potential of each digital tool. This transition would make all the competencies and disciplines involved in defining architectural design more interoperable, also ensuring that digital representation takes on the transversal and maieutic role previously performed by analog drawing.

Fig. 1 - Structure of the design process in the phases of data collection, ideational phase, 2D drawing, 3D modeling, and communication of outcomes. The ideational phase can correspond to a whole range of software tools designed to support a specific compositional approach and modification of the reference model.

Keywords: drawing; representation; software; design education; Politecnico di Milano

MIXED REALITY APPLICATIONS AS SUPPORT FOR THE MAINTENANCE OF MONUMENTAL ARCHITECTURES

Simone Teruggi - Supervisor: Francesco Fassi

Tutor: Marco Scaioni

This research investigates the innovative application of Mixed Reality technologies to enhance the maintenance of monumental heritage architectures. It specifically addresses several critical challenges arising from the need to operate effectively in complex and large-scale cultural heritage sites. The project, developed through a structured and interdisciplinary collaboration with both the Veneranda Fabbrica del Duomo di Milano and the 3D Survey Group (ABCLab - Department of Architecture, Construction Engineering and Built Environment at Politecnico di Milano), is rooted in the operational necessities highlighted by heritage conservation professionals. These experts emphasize the pressing need for a robust, dynamic, real-time, and on-site digital information system capable of facilitating long-term maintenance planning, supporting day-to-day operational execution, ensuring the effective fruition of complex data, and enabling the efficient archival and retrieval of maintenance records across the entire life cycle of conservation activities.

The urgency and relevance of this research stem from the increasing complexity of managing monumental heritage sites such as the Milan Cathedral, a vast and intricate architectural organism whose maintenance requires constant, highly coordinated effort. Traditional maintenance methods and documentation processes—often based on static data and disconnected from real-time operations—demonstrate substantial limitations when applied to such intricate contexts. These conventional approaches are typically inadequate for enabling timely decision-making, rapid intervention on-site, and comprehensive understanding of ongoing maintenance requirements. In highly stratified heritage sites, where historical, artistic, and technical considerations intersect, the absence of an integrated digital support system can lead to inefficiencies and hinder preservation outcomes.

Addressing these critical requirements, the study initially focuses on resolving the challenges posed by the management and interpretation of vast, complex spatial datasets, such as dense 3D point clouds acquired through terrestrial laser scanning and photogrammetric surveys of heritage sites. Through the implementation of advanced Machine Learning algorithms, the research achieves the automatic classification and semantic enrichment of these datasets. The result is the transformation of raw, unstructured data into structured, meaningful 3D digital point cloud models that are reality-based and semantically aware. These enriched tri-dimensional datasets offer actionable and contextually relevant information, significantly improving the accessibility and practical usability of large-scale heritage data for conservation professionals operating directly in the field. The integration of these models within an MR environment enables intuitive interaction with spatially contextualized data, which, until now, had remained primarily confined to desktop-based GIS or BIM systems.

Fig. 1 - Real scale alignment of the point cloud model over real-world objects.

A second major challenge addressed by the research concerns the precise and seamless alignment of digital holographic content within complex and geometrically articulated physical environments. The monumental scale, geometric intricacy, and unique construction techniques of buildings like the Milan Cathedral present a substantial technological obstacle in achieving accurate alignment between virtual holograms and the physical structure. To overcome this limitation, the research implements an advanced system combining Microsoft's HoloLens 2 headset with its spatial mapping capabilities, World Locking Tools and the Iterative Closest Point algorithm. This hybrid approach addresses both large- and small-scale alignment issues, ensuring the stability and contextual correctness of digital overlays. As a result, virtual information is precisely superimposed on the real-world structure, providing users with a reliable and consistent MR experience that is essential for practical on-site applications, including inspection, annotation, and data collection tasks.

Fig. 2 - Hand gestures to interact with high resolution point clouds.

The third focal point of the research concerns the usability, ergonomics, and operational functionality of the developed Mixed Reality system. Recognizing the importance of user-centered design in heritage maintenance workflows, the study includes rigorous evaluations and iterative refinements of the MR application's interface and interaction methods. The result is an intuitive and efficient system that enables professionals to directly insert, manage, and retrieve spatially contextualized maintenance data in real time. Users can navigate complex high-resolution point cloud models on-site, conduct visual inspections, record maintenance interventions, and benefit from voice-command capabilities integrated with Azure Cognitive Services. These features greatly enhance the interactivity, accessibility, and user experience of the system, reducing the learning curve and enabling operators with varying degrees of digital literacy to efficiently perform their tasks within the MR environment.

The final outcome of this research is a sophisticated and highly intuitive MR prototype specifically designed to enhance and optimize maintenance workflows, operational efficiency, and information management within complex heritage environments. The system has been rigorously tested on-site at Milan Cathedral in real operational scenarios, demonstrating its potential as a powerful, reliable tool for heritage preservation. By providing operators and decision-makers with immediate access to critical maintenance information, offering intuitive interaction with spatial data, and supporting data-driven maintenance planning, the MR system represents a substantial advancement in heritage conservation practices. It facilitates more informed, timely decision-making processes and supports better long-term preservation outcomes, ensuring the sustainability and resilience of monumental cultural heritage for future generations.

SEISMIC RETROFITTING OF MASONRY STRUCTURES WITH POST-INSTALLED SYSTEMS

Navid Vafa - Supervisor: Sara Cattaneo

Co-Supervisor: Pietro Giuseppe Crespi - Tutor: Tommaso D'Antino

Masonry is one of the oldest and most widely used structural systems for building construction around the world. Despite its historical importance and enduring cultural significance, masonry structures are inherently vulnerable to seismic forces due to material properties and traditional construction practices that emphasize compressive capacity over tensile and shear resistance. This research addresses the urgent need to enhance the seismic performance of unreinforced masonry buildings by investigating innovative retrofitting techniques that improve both in-plane and out-of-plane behavior.

Retrofitting with Reinforced Plaster:

Retrofitting with reinforced plaster represents a promising technique to enhance the in-plane seismic resistance of masonry structures. In this study, a series of masonry specimens were retrofitted with reinforced plaster applied directly onto the wall surface. The experimental program involved diagonal cyclic testing on specimens with varied plaster thickness and anchorage patterns. Results demonstrated that the reinforced plaster system significantly improved the load-carrying capacity and energy dissipation of the walls. Finite element models were developed in ABAQUS to replicate the experimental behavior and to conduct a detailed parametric study. The analysis revealed that even modest increases in plaster thickness lead to a substantial enhancement in ductility and strength. By effectively bridging discontinuities between masonry units, the reinforced plaster contributes to a more uniform stress distribution and delays the initiation of cracking under seismic loads. The ease of application, low invasiveness, and compatibility with existing construction practices underline its practical advantages. Detailed comparisons between unretrofitted and retrofitted specimens showed a marked improvement in deformation capacity, energy absorption, and overall structural integrity. This approach offers a pragmatic pathway for upgrading vulnerable structures without the need for extensive demolition or reconstruction, reducing economic disruption in seismic regions.

Helicoidal Anchors:

Helicoidal anchors represent an innovative advancement in retrofitting techniques, designed to improve the connection between different masonry walls. These twisted stainless steel bars are engineered to provide enhanced mechanical interlock and bond strength with the substrate. A comprehensive experimental investigation was performed to evaluate the performance of individual helicoidal anchors under direct tension, pull-out, and cyclic loading conditions. Key parameters such as embedment depth, pre-hole diameter, installation angle, and surface treatment were systematically varied to determine their effects on the anchorage performance. The experimental results indicated that the helicoidal configuration promotes a more uniform stress transfer along the embedded length and delays the onset of local failures. Finite element simulations complemented the experimental work by replicating the stress distributions and deformation patterns observed during testing. The unique geometry of the helicoidal anchor increases the effective surface area in contact with the masonry, thereby enhancing frictional resistance and bond performance. Moreover, the spiral form facilitates a progressive engagement of the anchor under load, resulting in improved energy absorption capabilities. These characteristics make helicoidal anchors particularly effective in scenarios where traditional anchoring systems may fail due to stress concentrations or premature debonding. The studies also highlighted the importance of proper installation techniques and quality control in achieving optimal performance. Overall, the innovative design of helicoidal anchors offers a robust alternative for strengthening masonry structures, contributing to enhanced seismic resilience and longevity.

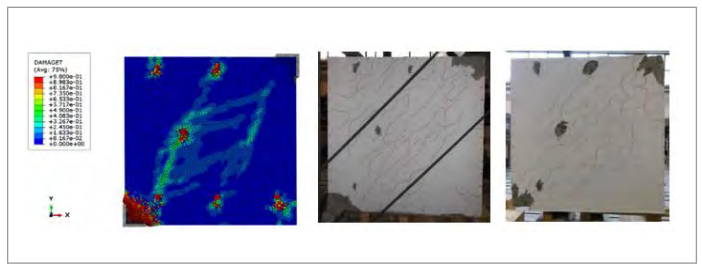

Fig. 1 - Damage pattern on the front and back side of MR250-RP30 mm.

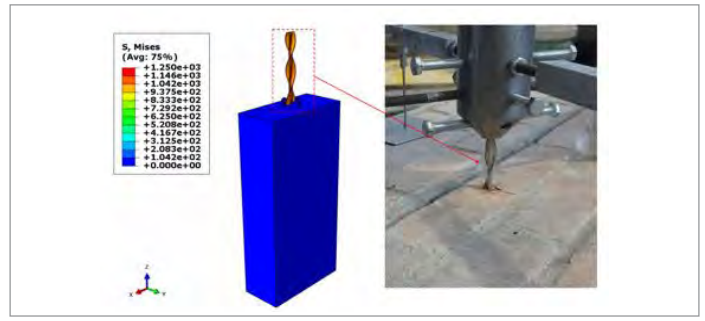

Fig. 2 - Untwisting of Heli-Brick.

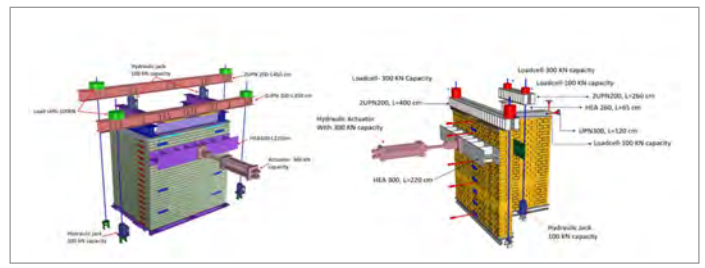

Fig. 3 - U and T shape wall.

Out-of-Plane Retrofitting with Helicoidal Anchors:

Addressing the vulnerability of masonry walls to out-of-plane seismic forces, the application of helicoidal anchors as a retrofitting measure has shown considerable promise. This approach was specifically applied to T-shaped and U-shaped masonry walls, where out-of-plane behavior is critical to the overall stability of the structure. Experimental tests under out-of-plane loading conditions demonstrated that the integration of helicoidal anchors leads to a significant increase in flexural strength, stiffness, and ductility. The retrofitted walls exhibited delayed cracking, reduced displacement amplitudes, and a more gradual failure mechanism compared to unretrofitted counterparts. Detailed finite element models, calibrated with experimental data, were developed to simulate the complex interactions between the helicoidal anchors, the reinforced plaster layer, and the masonry substrate. These models successfully captured the enhanced load-displacement response and the progressive damage patterns observed during testing. Parametric studies underscored that optimal anchor spacing, proper embedment depth, and the synergistic use of reinforced plaster are crucial for maximizing out-of-plane performance. The integration of these systems not only provides additional confinement but also redistributes stresses more evenly across the wall, thereby reducing the likelihood of catastrophic failure. This combined retrofitting strategy offers a cost-effective and minimally invasive solution for upgrading existing masonry structures in seismic regions. It serves as a practical tool for engineers to enhance structural safety while preserving the historical and cultural value of traditional masonry buildings. The successful implementation of this method can play a pivotal role in mitigating seismic risks and ensuring the long-term resilience of vulnerable structures.

LOCAL PARTICIPATION AS A TOOL FOR THE VALORIZATION OF MINOR CULTURAL HERITAGE. A NEW MODEL FOR THE REACTIVATION OF CULTURAL DISTRICTS

Nour Zreika - Supervisor: Daniele Fanzini

Tutor: Stefano Della Torre

The Cultural Districts model has emerged as a tool for achieving the sustainable development of territories. Rooted in the Marshallian Industrial District model, this concept highlights the shift from globalization to localization, ultimately fostering a form of 'glocalism' (localized globalism). This shift acts as the motivation behind the adaptation of the Industrial District model into the Cultural Districts model, where intangible attributes, such as knowledge and social significance, are acutely highlighted as a source of social and economic benefit. As a result, the Cultural Districts model has been realized across Europe generally and Italy specifically, where it has been officially endorsed in various Italian laws. Several years after its implementation, the Cultural Districts model faces several challenges related to social, economic, management, policy, and the covid pandemic. Despite the fact that this model has seen widespread support and adoption in the Italian context, its concept has not undergone thorough assessment or adequate redesign. While the concept itself has received great attention, its regulations have been subject to criticism. Based on the findings of a survey conducted by Nuccio & Ponzini in 2017, the primary challenges facing the cultural districts model are the absence of specialized cultural activities, the decline of community participation, and the lack of an appropriate governance model. Cultural heritage valorization has become widely adopted and recognized in local and regional policies, documents, conventions, and declarations. This growing recognition has led to the exploration of a new 'transdisciplinary' role for cultural heritage, capable of delivering advantages that expand beyond the cultural sector. By harnessing the cultural resources present in territories, this approach contributes to sustainable development and long-term socio-economic growth. We understand that cultural heritage possesses the capacity to deliver benefits on both the social and economic levels and inversely, these values promote the conservation and valorization of cultural heritage. In many ways, cultural heritage can embrace the creation of identity, the adoption of sense of belonging, the formation of social cohesion, as well as the engagement of local communities. It can also support the attraction of investment, the promotion of tourism, the improvement of quality of life, and the creation of jobs.

Among the many aspects of cultural heritage, its relationship with community participation remains a subject of great interest. We understand that successful development is one which creates strong links to community participation; this is to say that effective change cannot be achieved without the empowerment and participation of local communities. Thus, participatory approaches enable citizens to recognize the problems facing their territories and explore the best solutions, fostering long-term benefits and effective transformation. This also applies to cultural heritage valorization, as local communities are tightly bound to their cultural heritage and are determined to safeguard it. We have seen how active participation of individuals and groups in cultural heritage can impact the cultural, social, and economic development of communities.

Therefore, active participation can generate values for cultural heritage by creating and transferring knowledge, strengthening social cohesion through intercultural dialogue and shared experiences, and facilitating the allocation and distribution of economic resources and services. As an attempt to encourage community participation, we witness the increasing shift in managerial power from a top-down to a bottom-up approach. As a result, several initiatives have been formed to highlight the increasing appreciation for bottom-up approaches. A notable example is the LEADER approach, established by the European Union to address the issues of Europe's rural areas by encouraging the involvement of public, private, and third sectors in all stages of the development process. Community participation has undoubtedly become a focus of social innovation, showing an ability to foster capacity building, skills training, aptitude advancement, and experience sharing within the cultural sector while also encouraging cross-sectoral collaborations to generate innovative solutions and ideas. In many cases, digital tools have been used to enrich community participation in cultural heritage by transforming it into a more accessible and inclusive process.

Although local participation is a considered a prospective approach, issues concerning participation and impact assessment have been encountered and must be addressed. Administrative and governmental bodies are often hesitant to transfer their authority to the people and include them in decision-making processes. When participatory approaches fail to follow a decentralized form of management, they become difficult to operate. In most cases, community participation requires more time and funding to prosper. Therefore, it may be a challenge to ensure their financial support. Moreover, finding the best methods for applying participatory approaches remains difficult. Local communities lose interest in participation once they perceive short-lived gains. As a recent challenge facing local participation, the pandemic has left all levels of involvement operating in an atmosphere of great uncertainty. With respect to assessing the impact of participatory approaches, the main obstacle is the identification of accurate methods to measure this impact in real-time.

Recent attention has been shifting towards the enhancement potential of 'minor' cultural heritage, making it the main focus of this research project. Aligning with cultural heritage principles, the valorization of minor cultural heritage can lead to the conservation of this lesser-known heritage, the contribution of local communities and stakeholders to its preservation and safeguarding, the awareness raising of its cultural, historic, social, and economic importance, and the advancement of innovation through the increased adoption of ICT technologies and digital tools. To begin addressing the challenges of local participation in cultural districts, we will explore the importance of minor cultural heritage. In this case, we will consider minor cultural heritage as a catalyst of community involvement and territorial enhancement. Thus, with the suitable methods and tools, minor cultural heritage can enhance community participation and, in turn, reactivate the Cultural Districts model.

However, minor cultural heritage, unlike major cultural heritage, is not subject to legal and regulatory protection and enhancement. They are at risk of deterioration and loss as they do not attract enough funding. Minor cultural heritage is underrecognized by its local and regional authorities, making it difficult for their local communities to perceive its actual potential. Therefore, a better understanding of minor cultural heritage, its definitions, and its benefits as present in legislation and policies is attempted through the analysis of European and international case studies.

In order to recognize 'minor' cultural heritage as a valuable resource for the reactivation of Cultural Districts, this research project aims to design a methodology for the enhancement of minor cultural heritage through participation and co-design processes. This methodology will outline the processes, instruments, and possible indicators for assessing and appraising the outcomes of such interventions. The use of this methodology in the context of some on-field research experiences has enabled its partial validation. The results of the research work, in addition to filling some of the gaps in the existing literature, provide tools for communities, policy makers, and stakeholders to encourage the enhancement of 'minor' cultural heritage.