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Chair:

Prof. Marco Scaioni

DOCTORAL PROGRAM IN ARCHITECTURE, BUILT ENVIRONMENT AND CONSTRUCTION ENGINEERING

Vision

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

- the sustainable transformation and management of the Built Environment, holistically viewed 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 pursues the following ten pillars:

- 1) Selection through a transparent open process.
- 2) Candidates as independent, mentored and monitored, researchers.
- 3) Training plans tailored on Candidate's research topic and needs.
- 4) Training activities based on research practice.
- 5) Research practice hinged on the framework of Department activities.
- 6) Transparent tracking of Candidates' scientific production.
- 7) Systematic assessment and open and supportive peer review of Candidates' advancements.
- 8) Candidates as hot spots of international research institutions.
- 9) Systematic valorization of PhD holders and their products among stakeholders.
- 10) Candidates as active part of the Program's Quality Management System.

The award of 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 positive evaluation, a complementary series 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.

For what concerns courseware, ABC-PhD Program boasts a wide (more than 20 titles/yr), diverse, educational assortment on cutting edge, specialized, research topics. It is an open list of courses that changes, year after year, following Candidates' needs as well as the opportunities offered by the Department. This list is further enriched with the transferrable skills courses offered by the PhD School and may be integrated by the offer of all the university Doctoral Programs.

Academic, industrial and social collaborations

Each Candidate is mentored by one main Supervisor and inherits Supervisor's Scientific Sector as reference. Due to the multidisciplinary nature of our wide research field, nevertheless, his/her activity may be supported by other co-Supervisors to make stronger, more sound and reliable his/her final research product. The main effort of the ABC-PhD Program Board is to keep Candidates research works constantly reviewed, involving every useful, available competency from the ABC Department, other Departments or other national and international Universities and Research Centers. Each Candidate is also assigned to a member of the Program Board, which serves as individual Tutor with the aim of constant independent monitoring of his/her activity.

Moreover, each Candidate is progressively encouraged to confront his/ 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 beginning: approximately 50% are thematic and the topic is defined (and the Candidate selected) together with an industry or an international research institution as funding – or co-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 sure that our early stage openness toward stakeholders and the whole scientific world and networks is the best way to provide future PhD Holders with solid occupational opportunities for an academic career as well as for an employment in research centers and in any other enterprise, public body or private societies in need of highly qualified personnel, 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. It is not possible to list them in few rows (see our site, here: <https://beep.metid.polimi.it/web/abcphd/milestones>) and it is even useless, due to our fluid, adaptable nature: we look for new research questions (in the wide ABC sector) and for good ideas to give answers to them. A complex set of cutting edge, scientific and humanistic, disciplines and experts are at Candidates' service to support them to make their efforts three-time-winning (Researchers, Stakeholders, Academy) intellectual products.

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MONITORING HERITAGE AND URBAN CHANGE ALONG THE RED SEA ... QUSEIR AND SUEZ AS CASE STUDY

Manar Al Gammal - Supervisor: Cristina Pallini - Co-supervisor: Nora Lombardini

Tutor: Enrico De Angelis

We are on the verge of fast-paced urban development. It is important to understand that urban and architectural heritage may bear tangible processes of borrowing and adaptation. Port cities and their historic centres are the world's most important settlement through history. They are highly rich with resources and potentials.

This research is focused on the port cities along the Red Sea coast, whose future is currently being discussed in relation to national projects such as the New Suez Canal Project and the Golden Triangle project. While cultural exchange across the Mediterranean has been the subject of much scholarly work, the Red Sea as an area of cross-cultural research has been largely overlooked. A timely study of these port cities may help provide Egyptian planning authorities with the opportunity to promote a better future. Along this line of thinking, this research aims at understanding the specific urban identity of these port cities in the broader context of cultural exchange between Egypt and the trade network across the Red Sea and beyond.

It is important to achieve an understanding of urban and architecture heritage of Red Sea port cities to support further conservation and development strategies. Red Sea coastal cities are historical transit

points of long-distance trade. This research is based on urban and architectural heritage which may bear tangible evidence of processes of borrowing and adaptation between Egypt and Saudi Arabia, Yemen, etc.

Architecture is not just about technology. Architecture and the urban context are physically shaped by traditional cultures which are ingrained in the design and construction of old cities. Such urban patterns and architecture rely on a rich and unique quality, rhythm, and cultural affinity, as well as on practical considerations such as behavioural patterns, function, topography and local building material. All these factors combine in shaping the city's structure and morphology.

The research aims to set a methodology of mapping to study the Red Sea port cities' heritage, urban change and transformation. The final product will be an "academic record" and an "urban atlas" of heritage in the Red Sea's oldest port cities, Quseir and Suez, which have played a crucial role in the trade and pilgrimage routes from Asia through Africa to Europe.

MULTI-SCALE MODELLING APPROACH FOR URBAN OPTIMIZATION: COMPACTNESS ENVIRONMENTAL IMPLICATIONS

Carlo Andrea Biraghi - Supervisor: Massimo Tadi

Tutor: Michele Giovanni Caja

The research tries to clarify the relationship between urban form and environmental performances identifying that urban morphology characterisation has room for further investigation. Its objective is to develop a multi-scalar and multi-metrics methodology capable of objectively representing some morphological properties of the city considered as a Complex Adaptive System investigating in particular Porosity and Permeability, how they concur in the definition of the Compactness of an area and their environmental implications.

The work is contextualised within the actions to fight climate change acting on the urban environment, quantifying the urgency of this issue by examining current urbanization trends and the related challenges for cities. This heterogeneous and complex scenario can't be addressed with a ready-made solution to be used as a panacea for sustainable development, but requires instead an adaptive modelling approach generating customized answers while posing the same to any existing context.

The key relationship between urban structure and its environmental performances is targeted starting from rating systems, moving from the results achieved at the building scale, exploring the applications at the neighbourhood one and

understanding their limits. The ability to quantify and handle morphological qualitative features of the context appeared as the weakest part of those methodologies. The field of urban form is so explored to find principles able to fill this gap, deepening concepts as urban morphology and architectural typology, stressing the importance of classification. Finally, system theory is faced and assumed as a framework allowing to integrate the previous approaches. The city is considered a Complex Adaptive System (CAS) and that allows to work on it in a holistic way, exploiting the knowledge transfer from other disciplinary fields (hydraulics) and scales working in a systemic way. Despite the agreement in the literature on the role of Compactness (together with Complexity and Connectivity) as a system Determinant able to match structural and performance aspects, its impact on city environmental performances and the lack of a theoretical framework for its qualitative measurement and representation emerged.

Integrated Modification Methodology (IMM), an innovative operative theory developed at Politecnico di Milano ABC Department, was considered the most appropriate theoretical framework to work within. Inside its multi-layer structure, Compactness is defined as the result of the integration of Porosity and Permeability Key

Categories (KC), which, in their turn, are seen as the integration of Volume and Void Components. This methodology, to be considered a CAS on its own, was the perfect room for the practical implementations glimpsed by the author. After an introduction of IMM phasing and elements, the research proposes some implementations aiming to drive the theory to a more operative stage in a software perspective. This started with a data-oriented reconceptualization of IMM Components identifying four hierarchical levels: one or more input layers (raw data), gathered in some instances, each of them with a large set of attributes to be combined for the creation of spatial metrics. This allowed to base a measurable urban diagnostic process on morphological units (building, blocks) including less used one as courts, studying new absolute and relative geometrical attributes generated through the creation of ancillary layers. This enlarged set of parameters encouraged the creation of additional spatial metrics measuring especially qualitative well debated aspects visually emerging from the maps but hardly transformable into numerical values. 37 new metrics based on the integration of Volume and Void Components are introduced and a selection of 60 metrics, including the best found in the literature, is tested on a very large sample to extract the

most complete, valid, consistent and non-redundant ones. In addition, the selected metrics have been assigned to one or more IMM KC, even the ones out of this research investigation like, i.e., diversity.

Pursuing multiplicity, identified as one of the main drivers to defy simplistic approach and increase modelling capability to describe complexity, a combination of maps, metrics and graphical patterns is proposed as the output of the urban structure understanding process.

New maps emerged from the above mentioned metric-related geometries offering synthetic representation of complex morphological phenomena. After an analysis of the existing software landscape highlighting the empty space existing in between GIS and BIM, analysis and simulation, a set of algorithms in between GIS and 3d modelling is developed as a first step towards a City Information Modelling (CIM) software.

The improved morphological investigation approach is then used to define a calculation and a

representation method for Porosity and Permeability Key Categories as a first step for Compactness understanding. Both properties are approached justifying their right to be considered systemic properties, reviewing existing definitions and measurement methods, proposing a set of heterogeneous metrics able to describe them from both quantitative and qualitative aspect and validating this method on a sample of nine case studies from three different cities.

Then, performances are taken into account starting from indicators in general as an instrument able to assess them, moving to the evidence of correlation between performance indicators and quantitative simple spatial metrics, to finish by explaining IMM indicators logical structure and accepting them as the tool for assessing performance within the research framework in accordance to United Nations Sustainable Development Goals (SDGs). An application to 88 district-like areas in Milan (NIL) is performed to test the proposed approach and discuss

the first results. It showed that the best performing areas for the city of Milan are those in between the two opposite extremes of centre and suburbs, mostly planned in the first half of the XXth century.

This have design implications because positive aspects hardly found together in existing cities, can be easily be combined for the construction of new areas with the support of recent technological innovations. The Eco-District approach goes in this direction as by setting ambitious performance goals, they are planned to facilitate the adoption of sustainable behaviours and to have a positive impact also not only locally but also on the larger urban system they are part. An overview of most promising examples worldwide is provided together with a critic of the current improper use of this label in the Milanese context.

Research learnings have been used for the development of an Eco-District project for Porto di Mare in Milan. This gave us the opportunity to explore IMM retrofitting phase measuring the structural and performances aspects of different stages of the same system. The final masterplan, developed during a research activity involving three universities during two international workshops, is compared with the initial configuration and with an alternative transformation scenario with the same techniques used for the Milanese neighbourhoods' analysis. In conclusion the dissemination activity to promote the Eco-District project is presented.

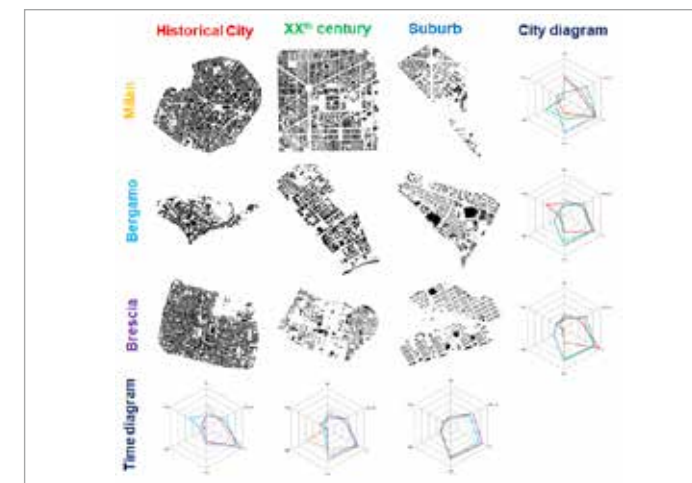


Fig. 1 - City-Area Matrix for Permeability assessment

HUMAN EYE KINEMATICS FOR ADAPTABLE VISUAL COMFORT ASSESSMENT

PERSONALIZED RESPONSIVE CONTROL STRATEGIES TO INTEGRATE BUILDING ENVELOPE AND ARTIFICIAL LIGHTING

Juan Diego Blanco Cadena - Supervisor: Tiziana Poli

Tutor: Valeria Natalina Pracchi

A significant gap has been identified between modelled and real building performance, which can be partly attributed to the user-building interaction. Total energy consumption computed throughout building energy modelling tends to be largely deviated from the actual energy use measured during functioning. Also, occupants' comfort hours forecast differ; the definition of comfort state conditions established by building design regulations, and/or suggested by guidelines, seem to be scant or their approximations too coarse to satisfy the occupants' real preferences. Being comfort disruption the incentive for most of occupant-building interaction, their frequency shall be minimized to shorten the existing gap between modelled and real building performance owed to cognitive human action. Nevertheless, Comfort is not an elementary issue to address; some aspects cannot be managed directly by designers, allowing variance and uncertainty growth due to humans' volatile behaviour. Hence, it has been studied either as an overall perception of the indoor environment likeness (encompassing every aspect known to make part of it) or dedicating all efforts on only one of its constituents. But, the broader the comfort consideration is, the lower is the prediction accuracy of its rating.

This work has been done on the framework of the Doctoral thesis to

obtain the PhD degree of Architecture, Built environment and Construction Engineering at Politecnico di Milano. It comprises a screening on sustainable design assessment strategies, with an especial focus on proper indoor comfort provision. It has deepened in how the building could adapt to the variability of building occupants, proposing an innovative control logic of building systems (or components) for daylighting influx control and/or lighting provision. This control logic proposal is based on the occupants' response and adaptive capability to the ever-changing surrounding environment. Starting from an exhaustive inspection of traditional and emergent comfort assessment, inspecting, as well, their performance indicators which aim to express accurately the occupants' comfort sensation; followed by an inquiry

to identify the parameters altering the overall comfort perception. Subsequently, supported by the knowledge gathered and presented within the state of the art, the project scope was narrowed down to assess only the visual comfort. Afterwards, a deep study was carried out on how these perceptions vary among different occupant types; accompanied by an investigation on how these parameters, or occupants' distinctive features, can be correlated or clustered for predicting more consistent environmental preferences.

All this intensified the efforts for giving an answer to the debate on how to accurately communicate the actual occupant visual perception to the building managing systems to trigger an adjustment when necessary; it is intended that this information transfer

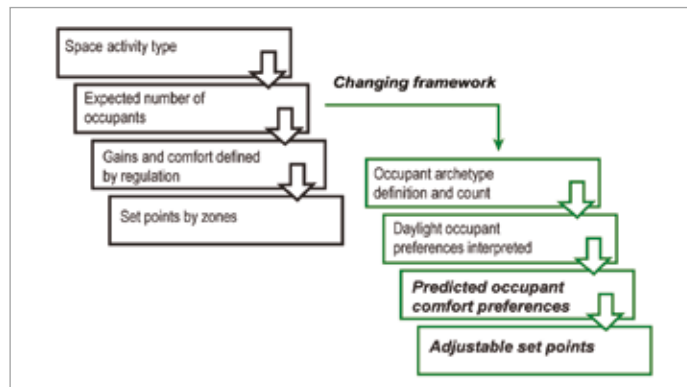


Fig. 1 - Proposal for a boost on current BMS approach by modifying current framework paradigm

is conceived throughout a dynamic straightforward comfort index. Thus, this research has concentrated in deeply assessing visual comfort disturbance by developing a dynamic visual comfort metric based on the interpretation of the saturation degree of occupants' adaptability

(later translated to indoor condition preferences, see Figure 1). This metric is intended as input and feedback for the control scheme of different building passive and active systems, boosting their operation efficiency (Figure 2). The metric can be computed for both existing and

new buildings, by employing image processing analysis for running buildings (Figure 3), and a correlation with vertical illuminance for the design of new ones. Further work on this metric is proposed for adding potential useful modules that could increase the metric's accuracy, plus deciphering the overall comfort condition of the user. The latter is planned to be achieved by introducing thermal comfort evaluation and, even more challenging, by consolidating both the emotional and physical aspect that shape the state of mind of satisfaction.

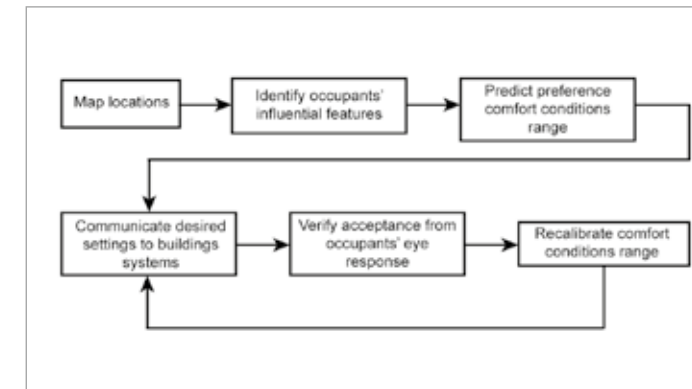


Fig. 2 - Proposal of the new conceptual framework for a control system to deliver proper lighting indoor

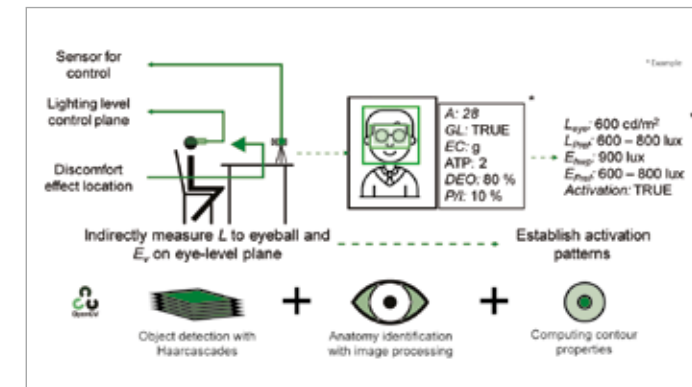


Fig. 3 - Explanatory schema of the process carried out for assessing and adapting to occupant visual comfort perception

TALEAH TECNOLOGIE ADDITIVE IN LEGNO PER EDIFICI ACTIVE HOUSE. A BIM-BASED MULTI-DIMENSIONAL ANALYSIS FOR THE DECISION-MAKING SUPPORT OF THE BUILDING PROCESS. THE APPLICATION ON TIMBER ADDITIVE SOLUTIONS FOR THE SUSTAINABLE TRANSFORMATION OF THE BUILT ENVIRONMENT

Federica Brunone - Supervisor: Marco Imperadori

Tutor: Sara Cattaneo

TALEAH is the acronym of “Tecnologie Additive in Legno per Edifici Active House” (wood-based additive technologies for Active House buildings) and represents a vision for the sustainable management and development of the built environment, referring to the application of timber construction systems as additive solutions for the multi-purposes improvement of existing buildings.

The research project aims, indeed, to translate this vision into an innovative methodological approach for the management of the construction process and the assessment of timber-based construction performances, across the entire building life-cycle - from design to production, operation and maintenance.

It is based on a multi-dimensional analysis, which refers to information-integrated environments and multi-criteria evaluation methods, such as BIM (Building Information Modeling) and the DO (Design Optioneering) approaches.

By the application of this methodology, the research work proposes to identify innovative models of process, products, and design (project) of wood-based construction technologies, suitable to satisfy the needs of the 2D/3D construction layering for the sustainable transformation of the built environment.

Therefore, the research methodology

has focused on the definition of several sustainable principles and related evaluation criteria, displayed through quantitative parameters and indicators, and derived from the investigation of timber systems’ applicability to additive retrofit design.

This investigation has included, indeed: i) the review of the state of the art about the built environment transformation strategies, through the analyses of the current trends of the AEC sector and the related potential of additive retrofit design; ii) the definition of a new creative breakdown taxonomy of the most widespread wood-based construction systems, including innovative products and industrial processes, already oriented to 4.0 revolution (BIM-oriented and CNC-based); and iii) a wide survey on real case studies, from the technical literature and a capillary network of industries and stake-holders, collecting a portfolio of design strategies and good practices of the existing building stock transformation with timber-based construction technologies.

The results of these analyses integrates with new criteria and parameters the validated Active House certification system, which already considers the three principles of Comfort, Energy and Environment, by validating qualitative and quantitative data related to constructions’ features, as referred to specific parameters. Therefore, the additive criteria of Structural Loads, Construction

Feasibility, Industrial Construction, and Economic Affordability, and the related parameters and indicators, aim to satisfy the assessment procedures over timber-based additive solutions for retrofit design, acquiring input data from different sources, as related to each stage of the construction process.

The research outcome is, therefore, a dynamic and active tool to support the decision-making process, which collects the so-defined principles, parameters, and indicators, being thereof able to give a holistic and comprehensive evaluation of the construction across the consecutive stages of the building process, and here specifically applied to wood-based additive solutions.

During the design stage, it can dynamically analyze and compare different design choices (e.g. different construction systems as different options), according to the DO method, until the definition of the “as-built” step and its validation; during the



Fig. 1

operational phase, instead, it is capable to read sensors-retrieved data and show the evolution of the building behavior, accounting for real users’ interaction, building performances decay and needs of maintenance, through the definition of the building digital twin and toward the realization of a real cognitive building.

Finally, this new innovative approach has been tested on two real case studies: 1+1 house, a volumetric doubling of an existing one-story family house representing the feasibility of a densification aim that could involve the Italian small residential stock as a strategy of building renovation; and n+1dome, a project that aims to guess the potential transformation of urban areas, centers, and suburbs, overcrowded of mid-rise and high-rise condos, by adding over them a smaller volume to circularly create renovated economies in terms of real estate value, energy efficiency, and urban regeneration.

In particular, the two case studies have represented the possible transformation

strategies for two opposite stereotypes of half of the Italian existing buildings, proving the high catching potential of timber-based additive solutions on the building market, and the impact of the proposal.

In conclusion, since the main focus of the research work has been the development of a new and innovative approach to the whole life cycle building performance evaluation, specifically applied to the field of additive retrofit in timber constructions, its application on two real case studies, and the retrieved results, have helped to prove and outline the great potential that timber-based technologies have, as a varied portfolio of solutions for the transformation of the built environment.

The outcomes have confirmed the initial guesses of the research objectives and the first insights of the case-history survey: structural

lightness, positive environmental footprint, and high prefabrication potential are the key features that drive the decision-maker towards timber-based solutions. Those features embody the natural potential of wood as a construction material to reduce the impact of new interventions on existing buildings and, thereof, to ease the related structural verifications; finally, the natural high-recyclable content, and the capacity to store the CO2 of wooden products and timber-based technologies, with a considerable GHG emissions cut-off, contribute to reduce the environmental impact of the built environment, towards the envisaged sustainable development.

Keywords

Wood-based construction technologies; Building Transformation; Building Information Modeling; Design Optioneering; Cognitive Building; Multi-dimensional analysis; Evaluation process; Active House

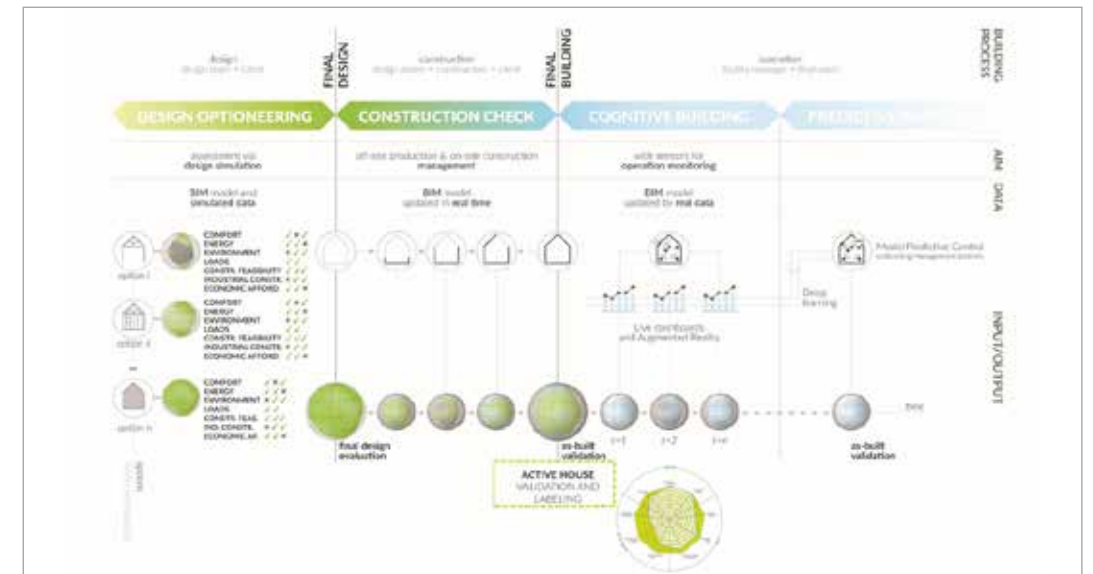


Fig. 2

SUBSIDIARY INFRASTRUCTURE STRATEGIES FOR THE ENHANCE OF ECCLESIASTICAL HERITAGE: THE SYSTEM OF AMBROSIAN PARISH COMPLEXES

Francesca Daprà - Supervisor: Emilio Faroldi - Co-supervisor: Maria Pilar Vettori

Tutor: Massimo Ferrari

The title of the dissertation derives from the juxtaposition of the term “infrastructure” – which refers to the concept of “network”, of “mesh”, and, even more, of what is “between”, and “supports” urban life – with the term “subsidiary” which, in the context of planning and designing services, refers to a “collaboration” between “civil parties” and the public administration, for the provision of services of collective interest. This expression constitutes, together, the “hypothesis” and “objective” of the research: starting from the object of study considered – the system of the so-called “parish complexes” – the dissertation elaborates an articulated reading, and some strategies, aiming that the “nodes” of this system – which innervates the Italian city in a capillary way – integrate their offer of collective services, already present and active on the territory, within the panorama of urban services, in a subsidiary logic.

The interest in the particular type of ecclesiastical heritage, pertaining to the parishes, derives, first of all, from multiple inputs, collected from the disciplines that in recent years have addressed the topic of sacred architecture and its socio-cultural implications within the city; secondly, it stems from the observation of the physical structure of this institution, which is now passing through a phase of transformation and

re-consideration, and which it poses a series of problems relating to the functionality of its large spaces – they constitute a large part of the entire Italian built heritage –, as well as the effectiveness of its services within the system of the “public city”, of maximum relevance.

The primary objective of the work presented there is, therefore, to develop tools and strategies for a re-signification and enhancement of the parish heritage in this direction, passing through an organic reading of the object of study and of the different disciplines which deal with it. The research finds in the city of Milan a privileged area of study, by virtue of the diffusion and capillarity of the analyzed heritage, of the consolidated social and cultural tradition linked to it, as well as of the degrees of innovation and experimentation in progress related to the subsidiary planning of services.



Fig. 1 - (left) The city of Milan and its parishes. Map edited by the author.

The first part of the dissertation is conceived to build the theoretical framework of the research, aiming at conducting an organic reflection on the nature of the “parish”, and of its implications with the city and contemporary society, through a multidisciplinary reading. Part I frames the research topic and its object, underlining three aspects: the nature of the parochial institution – of which the object of the research is a material expression – read from a historical and pastoral point of view; the architecture of parish complexes in Italy – focusing especially in some Italian experiences held in the twentieth-century period of the great urban sprawl; the knowledge and management of the ecclesiastical heritage, of which the parochial one is part. The research does not exempt itself from reflections on the heritage analyzed as a “cultural asset”, with the various implications – conservative, regenerative, real estate



Fig. 2 - (right) The city of Milan, its NIL and parishes. Map edited by the author.

– that derive from it. Regarding these topics, the dissertation provides the main references for the construction of an organic State of the Art. The second part of the dissertation reports on the analytical phase of the research. It consists of an analysis at the urban scale of the relationships between the services and the territorial organization of the public and ecclesiastical city, and an analysis of fifteen complexes in the city of Milan. The analyzed complexes, belonging to three territorial portions, synthetically defined as “central belt”, “intermediate belt”, “peripheral belt”, are intended to constitute a significant sample, in order to carry out reflections applicable to the rest of the urban complexes and to other types of heritage with similar characteristics. The analysis does not focus on the architectural artifacts per

se, but rather it structures a complex analytical methodology that includes several factors, to photograph above all their “presence” – materially and immaterially – within the urban fabric and the network of services into the city. Among the topic analyzed for each parish: the main actors and users of the complexes, their spatial and functional articulation, their state of maintenance and the relationship with the neighborhood. The analysis, although focused on the Ambrosian center, raises topics that make it replicable in different contexts and areas.

The third part of the dissertation reports the results of the research proposal phase. It intends to make most of the reflections of the previous parts in order to propose tools and strategies to define the

parish of the future. In particular, an analysis tool of the parish heritage is developed, capable of identifying its characteristics and potential, through criteria and indicators not only related to the building but also to a series of factors connected to it. In the last chapter, a series of issues are addressed, considered to be of fundamental importance in order to innovate parish complexes. The third and final part of the dissertation shows, on the one hand, the possibility and potential of a deep knowledge of the parish heritage, and on the other hand, its prospects for innovation.

The dissertation has only led a small step towards the consideration of the urban, social and real estate potential of the heritage considered, with the hope of encouraging other researchers of the disciplines involved to study these three aspects in greater depth.

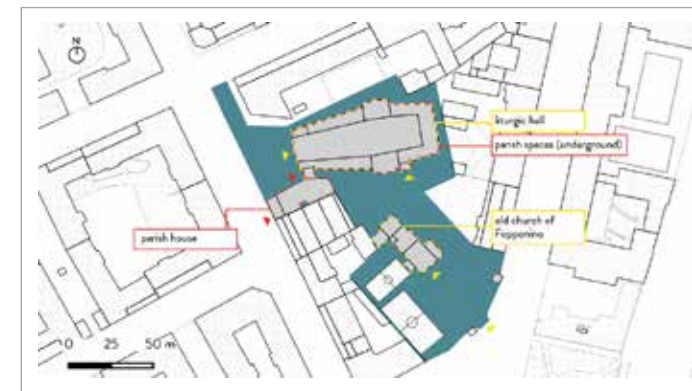


Fig. 3 - Example of the representation of spatial and functional analysis held for each parish analyzed. Parish of San Francesco al Foppino. Edited by the author.

PROTO-TYPE FOR THE MUSEALIZATION AND PROTECTION OF ARCHAEOLOGICAL EXCAVATION. THEORETICAL AND PRACTICAL PRINCIPLES

Annalucia D'Erchia - Supervisor: Massimo Ferrari - Co-supervisor: Claudia Tinazzi

Tutor: Andrea Campioli

A renewed sensibility towards the ancient has led to the growth, accelerated in the last fifty years, of the debate on the future of the past, especially with reference to architecture.

A proto-type, a theoretical model, rather than a practical one, of an exhibition system imagined for the places of archeology, which, through the opening of the archaeological yard and the protection during the excavation activity, is the translation of a possible understanding between the disciplines of archeology, architecture and engineering. A thinking that takes shape through an imagined dialogue between Andrea Carandini and Franco Minissi. The first, witness of that complex structure of the archaeological investigation, is a pioneer, maker and convinced supporter of a renewal of making research, especially on field, in archeology. *Allo sterro presto viene sostituito lo scavo stratigrafico, e l'attenzione all'eccezionale viene sostituito dalla cura per il piccolo oggetto, che messo in relazione al contesto e strato di rinvenimento racconta più dell'opera bella esposta in un museo.* The second, called to confront and interpret in a new way the complex relationship between the contemporary and everything that preceded it, first in close contact with the Istituto Centrale per il Restauro after the Second World War, then at School, with students, invents the

concept of in situ musealization by translating this theme in the forms of architecture through a blind trust in technology and new materials. The works to protect Villa del Casale in Piazza Armerina in 1957 thus become, together with the other Sicilian experiences of the same years, prototypes of musealization and "solved exercise", which translates to the general principles that are still found today in all those architectural interventions for the archeology. Thus, the strength of the context is also recognized by architecture and, "no longer the existing structures goes to the museum, but the museum is going to the existing structures, particularly to the archaeological sites.[...]Continuing to worry about and take care of two things for which the museum worries and occupies: to conserve, but at the same time using the asset as a tool for the dissemination of culture" (Minissi, 1988). Thus, in the Italian context, the firm reflections of Carandini and his School and the audacious translations by Minissi will lead to the recognition of the place and time of the yard as the strategic protagonist of this speech and of this interpretation, as it is in other disciplines, where archeology and architecture are not so far. Both of them, starting from two different points of view, have tried first to theorize and then to translate into architecture a need that comes from

archeological yards. Starting from these premises, the development of the relationship between a theme and its necessity leads to the need to identify a concrete case to focus on. The choice of the case, as a result of various second thoughts, becomes the methodology to come to imagine a possible translation, the search for convenient forms for an open archeological yard, which do not yet care to interpret the site, but take care of making it, through the its fruition, place of exhibition and learning. The choice fell on a portion of Roman residential tissue in Aquileia, whose digging has been completed on several occasions, as it usually does. A development that has been imagined and conducted, from the beginning, according to a double theoretical and practical register which mingling makes itself available in addition to a discursive and consequential reading, with two independent and, in some ways, episodic readings. The value, the discovery, the safekeeping, the preservation and the protection of the ancient is recognized. Two necessary insights bring to our contemporary age and deal with one of the knowledge of the ancient today, linked to archaeological research and its methodology with its changes and the other of the communication of the ancient, anchored instead to the

interpretation of meanings through the definition of a critical anthology of architectures built for archeology and of some projects left on paper. The theoretical rib that tells the methodological questions of research and their connection and dependence on historical-political and social contingencies is a necessary construction for the arch which, in this context, translates into the variation of the excavation practice, in the interpretation of the site, in the recognition of an insufficiency - today - in the relationship with time, in the forms of the architectural project at the service of archeology, and the search for the necessary elements organized in the best way to pursue the ultimate goal of spreading culture when it is being built. Imagining a temporary museum on the excavation means putting the organization of the structures already in use at the archaeological sites into the system and the need to overcome

the excavation by crossing it at a height. The act of crossing at altitude translates figuratively into the ideal construction of an aerial passage, a light bridge, which must meet a series of requirements, which, in turn, must take into account two specific features that the study a posteriori of the excavation of Aquileia has highlighted: the planimetric unpredictability, although preliminary investigations today give quite precise information about it, and the altimetric irregularity. These two physical variables lead to support the impossibility of studying a structure with a rigid module, both in plan and in elevation, which supports the parts of this air path. It cannot be imagined as a single span, as it must comply with the principles of lightness, facilitate transport, assembly and disassembly which make clear, through their pieces and their way of assembling,

and therefore through itself, the theme of temporary nature of the intervention. Despite this, it is also necessary to consider the impossibility of touching the archaeological ground too much but only in discrete and necessary points. A superstructure capable of modifying its development by following the archaeological text and not by imposing the rules that allow its construction.

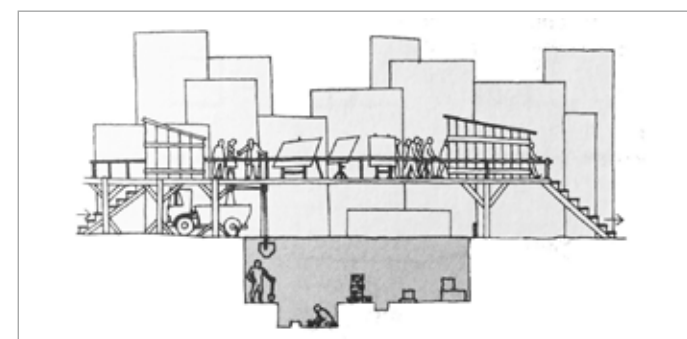


Fig. 1

“URBAN NEIGHBORHOOD MOSAIC” DOES MAHALLE PROVIDE LONG-LIVED NEIGHBORHOOD PRINCIPLES?

Derya Erdim - Supervisor: Cristina Pallini

Tutor: Adalberto Del Bo

Taking Istanbul as a case study, this thesis focuses on the neighborhood as a specific problem of urban planning and architecture. Notably, this thesis aims at showing how Istanbul, considered in its historical evolution, may provide original perspectives on how to address problems of neighborhood layout, place identity, and design of community-level institutions.

At present, the debate on neighborhood and community revival is gaining momentum from different viewpoints. Town planners, urban historians, and experts in town-planning history are showing a renewed interest in the neighborhood concept, seen as a tool to recover a “sense of place” in fast-growing metropolises.¹ At the same time, architects are increasingly interpreting the idea of “community center” in different urban and cultural contexts.²

Over the last decades, the real estate market has often used concepts such as community, identity, and sense of belonging as a branding strategy for the success of gated communities in many parts of the world. More recently, even public authorities are looking back at the traditional neighborhood structure as a system available for future reinterpretations.³ The growing interest in the topic of the neighborhood has led many writers and scenarists to develop their narratives on this basis.⁴

The reinterpretation of the idea of neighborhood entails different disciplinary approaches and may be traced back to various precedents. In this sense, the concept of “neighborhood unit,” as established by Clarence Perry in New York of the 1900s, is often taken as an unavoidable term of reference by both town planners, who have repeatedly

tried to update its principles, and architects, who have revisited the civic center as a community center, idea-store, anti-coffee, and co-working (namely a “qualified space” aimed at promoting new fruition schemes and new levels of functional integration that would be possible through relations with the surrounding urban context).

This thesis argues that Istanbul may be considered a “book of stone” when approaching the notion of the neighborhood in relationship with a broader urban structure and inner logic, that is its “anatomy” where the architectural public space and community-level buildings play a crucial part. In fact, Istanbul was a metropolis long before London, Paris, or New York. According to the French journalist St. Marc Girardin, Istanbul is “natural and necessary” due to its strategic geographical position along

long-distance routes.⁵ Moreover, due to this key geographic role, Istanbul has always been a haven for people from far and wide.

During the Ottoman period, this multiethnic cultural makeup manifested itself in the administrative organization and the physical environment of the city: Istanbul consisted of a system of long-distance routes approaching the constellation of ports located along the Golden Horn and on the Marmara shore; it was also a mosaic of the neighborhood, the so-called *mahalle*. Centered around a cluster of religious institutions (mosques, churches, and synagogues) and community-level functions (soup-kitchens, public baths, etc.), the *mahalle* brought together people from the same religion (and place of origin). As such, it constituted a semi-autonomous physical and social entity collectively responsible for paying taxes, hence the basic administrative unity of the city.

Focusing on the anatomy of the *mahalle*, this study aims at identifying a context-specific notion of the

neighborhood and civic center that has been in place for over five hundred years (resilient) and could well feed new interpretations. Along this line of thought, this research took as reference the maps of the 19th and 20th century, a crucial time when the city was undergoing a fast-paced process of Westernization.⁶ However, this was a moment in time when the *mahalle* mosaic was most vital and even expressing the attempts of modernization.

The detailed information included in these maps (German Blues and Pervititch), cross-examined with additional visual and bibliographical sources, has been fundamental to the examination of the traditional structure of a number of *mahalles* facing the Golden Horn. These maps have been taken as a basis for a patient work of interpretative mapping: identifying the focal point/points of the *mahalle* (clusters of public buildings at two different levels; *mahalle* as an organ that differs based on the community it hosts) and its main open places (be it a street or a square). Finally, this system of *mahalle* has been seen

as grafted onto the age-old urban structure (the Egnatia, the road coming from the Danube, the Mese, Topkapi, etc.). The last part of the thesis explores the Republican period (1923–1945) when the old community structure was subverted by a new society based on a shared national identity. This is the time when the notion of Western-style neighborhood replaced the *mahalle*.⁷

The thesis work concluded in a project (in appendix) to show compliance with the notion of the neighborhood in both architecture and urban designs. It is the project that was produced in the early stages of the thesis for the neighborhood design competition, winning the first prize, where the traditional Ottoman principles of the *mahalle* were reinterpreted for the contemporary designs.

1. **Urban Forum 2014** titled “Neighborhood: The Measure and Meaning of an Urban Ideal,” hosted by the University of Chicago Urban Network in April 2014. The event aimed to explore the definitions, designs, and theories behind the neighborhood. Seventeenth IPHS conference hosted by Delft University in June 2016 introduced a section titled “Housing and Neighborhoods”.

2. **Venice Biennale 2016** organized the theme for the civic center to improve the quality of life. The theme was examined mutually as an intervention for the community design and that of the community itself, presenting cases where organized communities and empowered citizens, sometimes without any formal training in design, managed to improve their built environment.

3. TOKI, the housing production institution affiliated to the Prime Ministry of the Republic of Turkey, cannot ignore the problems that arose following the creation of considerable gated community housing. For instance, Toki organized **two competitions in 2014** (titled “From Tradition to the Future”) and **in 2017** (titled “Mahalle”) to introduce the traditional neighborhood, mahalle, as a future urban growth strategy. The purpose of the competition was the creation of a “mahalle” and its principles that could be applied to future designs.

4. The neighborhood **Çukur**, located in Istanbul, was transformed into a movie set in 2019. It has become the most-watched series in Turkey with a script narration influenced by the *mahalle*. The interdependence of the neighborhood community has been shaped like a family tie. The whole neighborhood is perceived as a home by neighbors. In his book, ***A Strangeness in My Mind***, published in 2014, Orhan Pamuk, the Turkish novelist who received the 2006 Nobel Prize in literature, explains the strange cultural formations that emerged on the side of the *Gecekondular* neighborhood, illegal houses, which created new articulation of urban life in which man belonged to space with a sense of community sense.

5. **Girardin, S. M.** (1840). De La Destinée Des Villes. **Constantinople**, Alexandrie, Venise Et Corinthe, *The Destiny of the Cities*, A Revue des Deux Mondes (1829–1971), 24(6), 830–838.

6. Because the foreign communities were granted the privileges, which the Ottoman Empire gave to the communities from different religious and ethnic backgrounds to build and operate their places of worship, schools, and recreation and entertainment areas.

7. The period referred to the creation of the neighborhood based on the reclassification of workers’ neighborhood, civil servants’ neighborhood, or factory settlements. New types of buildings, new residential typologies, and social facilities were added to the neighborhood layout.

IN PLACE AND IN TIME. FOR AN ENVIRONMENTAL HISTORY OF TOURIST INFRASTRUCTURE IN THE FRENCH-ITALIAN ALPS (1945-1975)

Caterina Franco - Supervisors: Catherine Maumi, Emilio Faroldi

Tutor: Elena Germana Mussinelli

The work is the result of a conjoint thesis, developed in the laboratory "Les Meties de l'Histoire de l'Architecture, édifices-villes,territoires" of the Ecole Nationale Supérieure d'Architecture de Grenoble, Ecole Doctorale SHPT, Université Grenoble Alpes and in the Department ABC Politecnico di Milano. The Thesis has been financed by a Contrat Doctoral of French Ministry of Culture and by a mobility bourse of the Université franco-italienne. The research has been supervised by prof. Catherine Maumi (MHAevt) and prof. Emilio Faroldi (dABC).

The thesis studies ski resorts planned and built at high altitude after the Second World War in the Franco-Italian Alps. The two national contexts, different for economic history, politics and geographical location, now share similar problems, which look to the future of a tourism model based on mass attendance, long stays and an offer concentrated around skiing. Indeed, climatic hazards, changes in the modes and times of tourist use, ageing of structures and infrastructure, are only some of the challenges which these places are facing today. Several researchers from various disciplines then suggested that the station could be rethought in continuity with the territory, the latter included in its economic, geographical or administrative nature.

The research aims at investigating these questions in the field

of architecture and through a historical study. By questioning the relationships established between the station and the territory (in its spatial, environmental and landscape components) during the design, construction and evolution process, the wish is to go beyond a reading of high mountain tourist establishments as de-contextualized objects. Working on the spatial coordinate of the territory, we formulate the hypothesis that the establishment of winter sports resorts has led to large-scale transformations, and that, at the same time, the environmental, historical, economic and geomorphological characteristics of the sites concerned have played an active role in the design and construction process. Working on the temporal coordinate of the territory, we assume that the

history of the winter sports resorts built in the 1960s and 1970s is only one step in the long process of transforming high-altitude sites for tourism. In this perspective, the history of activities preceding tourism, located in the same places, plays a decisive role.

We rely on a method developed by environmental historians such as William Cronon, who considers the history of a territory as the result of interactions between human actions and natural data over a long period of time. The work is carried out through the study of four cases: Pila and Sansicario, in the Italian Alps; Chamrousse and La Plagne in the French Alps. We mobilise a corpus mainly constituted by documents belonging to different archival collections (local authorities, architects and urban planners,

technicians), which we process by analysing textual, graphic and cartographic documents, as well as by re-drawing and constructing chrono-systemic timelines.

In addition to give a contribution to the understanding of the history of tourism development in high mountain areas, we hope, through this work, to contribute to the debate on the methodological issues of research in the history of architecture.

Keywords

landscape construction ; tourist infrastructure ; French-Italian Alps ; Post-war ; environmental history.



Fig. 1 - Service des Ponts et Chaussées, Berrier Roger et Dosse Raymond, « Projet du Département de l'Isère pour une station de sports d'hiver dans le Massif de Chamrousse, Projet d'aménagement », 1:1.000, avril 1944. Archives départementales de l'Isère, 7093 W 107.

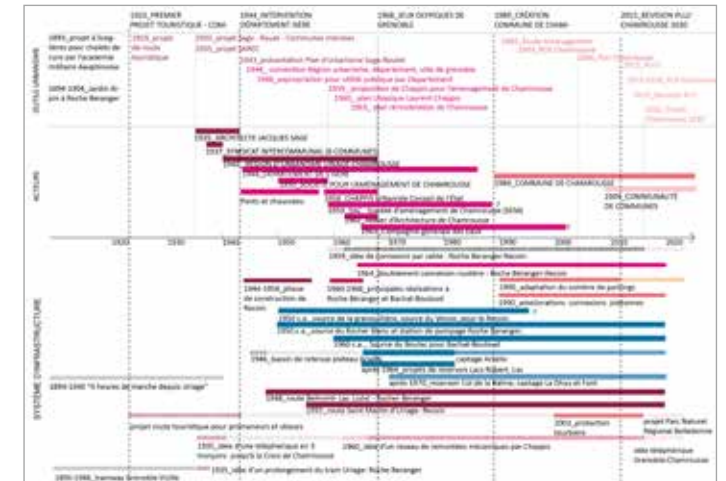


Fig. 2 - Chrono-systemic timeline made by the author representing the territorial transformation provoked by tourism in Chamrousse, during the XX century.

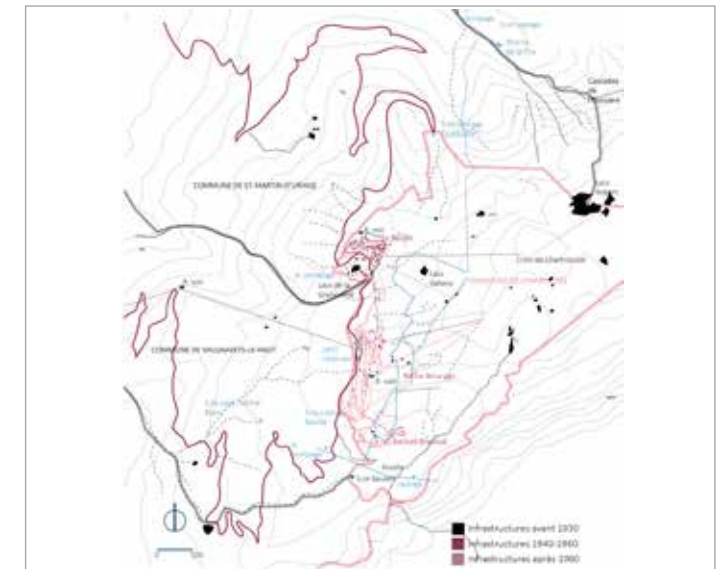


Fig. 3 - Map made by the author revealing the actual palimpsest of the successive territorial transformation provoked by tourism in Chamrousse.

APPLICATION OF BUILDING INFORMATION MODELLING TO COLLABORATIVE PROCUREMENT IN ORDER TO MANAGE AND CONTROL AECO PROCESSES

Paolo Ettore Giana - Supervisor: Giuseppe Martino Di Giuda

Tutor: Marco Scaioni

This research aims at managing and controlling BIM processes set in a collaborative framework through a digital platform. This data-driven approach allows (i) clients to obtain the improved value from the integration among parties, (ii) to manage information workflow and (iii) to better understand the contract performance each step of the way; (iv) professionals to share information and manage the process assuring the quality of the outcomes through a BIM approach.

This research starts analysing into the principal inefficiency of the peculiarities of AECO (Architecture, Engineering, Construction and Operation) market. A cross-country analysis of differences and similarities with other economic fields provides a solid background to understand the impact of fragmentation on construction sector performance, especially in the Italian context. The construction industry is deeply fragmented and has been designated as a very litigious and conflictual environment. The research investigates the problem of AECO sector and limits its scope to collaboration as one of the main problems affecting the sector performance.

During this analysis of the reasons of low collaboration in AECO sector, Information Asymmetry (IA) rises

as one of the main causes that enhance opportunistic behaviour in contractual parties. The presence of IA occurring in the AECO market sets the foundation of the paradox of traditional contracts. The construction sector is requiring a more collaborative approach to reduce information asymmetry. Traditional contract typologies increase segregation among project teams. In this sense, several studies have been analysed to understand contract framework performance by a comparison of the results achieved in different projects. This approach provides a quantitative foundation that collaborative arrangements can produce greater certainty of results and, above all, less variance of results. An analysis of the result of non-collaborative approaches shows a need for restructuring the sector, especially through different contractual frameworks. The contracts set the framework in which the interactions grow. Thus, a change in the contract standard imposes a switch in the approach. The research analyses the application of collaborative procurement (RPDAs) in a worldwide scenario in a cross-country analysis. Common features and peculiarities of different approaches are presented. Framework Alliances provide a soft-landing approach to collaboration and a decreasing of the burden for public administrations.

The proposed approach set a framework alliance to create a collaborative environment to manage the overlapping integration of (i) a Document Management System (DMS), (ii) BIM methodology and (iii) a Performance Management System (PMS) as illustrated in fig.1.

In this sense, the proposed approach for the reduction of relational problems consists in the change of the contractual interactions. Framework agreements allow removing opportunistic behaviour moving to collaborative attitudes and a soft-landing approach in importing collaboration in AECO sector. In this sense, the researcher imported the Framework Alliance Contract into the Italian legislation helped by a multi-disciplinary group. A change in the contractual framework allows reducing the segregation of BIM methodology. BIM methodology requires a collaborative framework. The alliance contract provides the legal framework involving and integrating parties. This agreement provides also the legal framework to set a common guideline to manage the BIM methodology. In this sense, best practice for developing and managing the approach are attached as guidelines to the agreement. The client can use these guidelines to set a common practice to define its own data-driven process and manage its portfolio.

Even though, BIM methodology can support the integration among parties, processes of information exchange can't be controlled within this approach. In this sense, a Document Management System can embed and control the information exchange along the construction process. Setting a data-driven process allows the stakeholders to understand the actual performance of the entire system, having on going measurement of the system. The proposed approach provides a legal foundation for information modelling, giving value to data exchanged. Guidelines define the rules to exchange information as an attachment to the framework agreement. The DMS platform allows sharing structured information among parties based on predefined workflows. Instead, BIM methodology allows elaborating and storing data both in the model and in the external database created according to the Client policy for Asset Management. This approach allows Clients to continue with their traditional approach, but having consistency in the asset and operational information.

Once created the foundation for the collaboration, the information has to flow in a structured environment. Predefined workflows are set to share information and catalogue documents in the repository to facilitate maintenance works. The shared platform provides a different level of information according to user profiling. This method of sharing information allows decreasing the problem of incoherence among documents.

Thanks to the predefined structure of data, indicators can be used to make the decisions and take action that are best suited to achieving the objectives of the process as set in the collaborative agreement. On the basis, this computational method provides a Decision Support System to evaluate project behaviour and forecasting its trend. Therefore, professionals can use this Project Management technique to control the project and, if necessary, to apply procedures to realign the project with Client expectations evaluating different alternatives.

The researcher tested and validated the methodology through the application in a real case study, a middle school in Liscate (Italy). A great added value was achieved using a collaborative framework agreement that allowed a change in the behaviours of the stakeholders. Thanks to the collaborative platform (DMS) controlled by the framework agreement, the parties were able to manage information in a collaborative way. The proposed approach demonstrated to increase efficiency in the information exchange, effectiveness of process' decisions and the economizing the information management, reducing information asymmetries of the process.

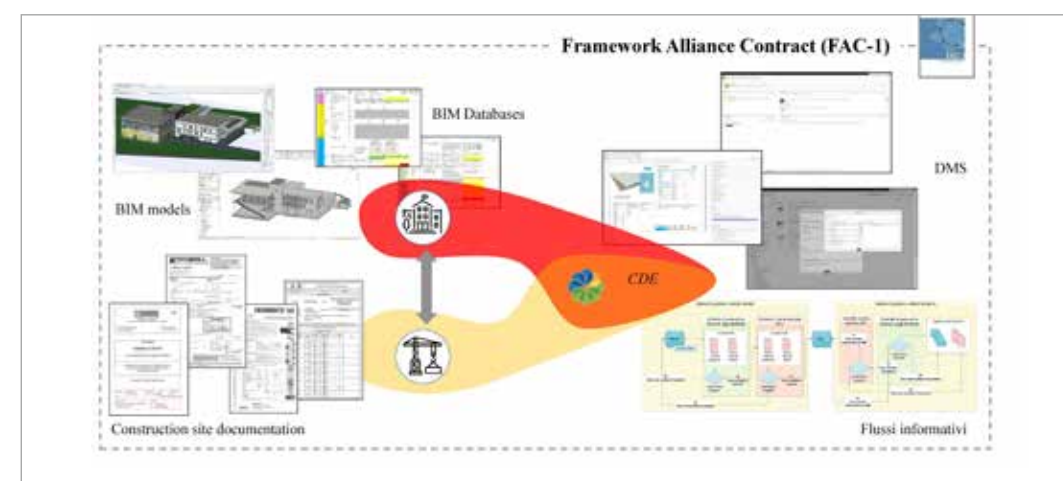


Fig. 1 - PhD methodology

CIRCULAR ECONOMY AND REGENERATION OF BUILDING STOCK.

POLICY IMPROVEMENTS, STRATEGIC PARTNERSHIPS AND LIFE CYCLE DECISION-MAKING TOOLS

Serena Giorgi - Supervisor: Monica Lavagna - Co-supervisor: Andrea Campioli

Tutor: Laura Daglio

The current European strategy of Green New Deal calls for the transition from the current linear economy (take-make-use-dispose) towards a circular economy (closed loop of materials), which aims at avoiding the generation of waste and reducing the extraction of raw materials, in order to preserve the planet's limited resources. To achieve this transition, the building sector, and in particular the regeneration of existing building stock, plays a crucial role, in fact it represents the first sector for the production of waste quantity, and one of the major sectors for the consumption of resources.

However, at present time, the application of circular economy at building level, towards a sustainable circular building process, are thwarted by political and economic barriers. Not all countries have the same starting point and the same resources and that some of them are moving slower than others.

In this context, the scientific communities have the duty to identify the correct strategies to suggest to the policy-makers, which have to define legislative actions to enable the transition. Consequently, the PhD research gives important support to the policy-makers, identifying a set of recommendations necessary to encourage a sustainable and circular transition in the building sector, in particular within the regeneration of existent building stock, defining

the framework for a sustainable and circular building regeneration process. The recommendations are articulated to identify the important policies improvements, stakeholder networking and environmental and economic life cycle assessment tools for supporting the decision. The recommendations are useful at European level and, when necessary, some specifications are defined at the Italian level.

Hence, the thesis result is an important support to the policy-makers, who want to change the legislation regarding the building sector towards circular economy and to the stakeholder of the building value chain who want to identify and open up new networking for the activation of sustainable circular profitable business.

This thesis in particular focuses on the activation of sustainable circular dynamics during the building regeneration process, showing which are the current obstacles, which are the opportunity for the transition and, consequently which are the necessary improvements towards a sustainable circular process.

The circular economy strategies are treated not only from the point of view of construction and demolition waste management (downstream approach) but focusing on the importance of avoiding the waste (upstream approach) in order to achieve a sustainable model. Therefore, the

thesis encourages the strategies that aim to extend the service life of existing buildings (giving back new function and value), to repair and maintain the elements, to remanufacture and reuse the replaced products and, only finally, to recycle any demolition waste generated by requalification processes. Moreover, the thesis treats the fundamental issue to support the decision-making of circular strategies by environmental and economic sustainability assessment, within a life cycle perspective, in order to promote not only circular practices, but sustainable circular practices.

The thesis is structured in three parts. The first part of the thesis focuses on the analyses of the circular economy concept, conducted throughout literature reviews of scientific publications. Through this analysis, the thesis identifies the three main areas of development of strategies (waste management, design, business models) to apply circular economy at building level. Moreover, the thesis highlights the necessity to link the circular strategies to the sustainability assessment, analysing the effectiveness of LCA and LCC application in the decision-making of circular practices.

The second part of the thesis regards the field research phase, aimed at defining the best practice of circular economy applied at the building level at European context and the

identification of the opportunities and current barriers (knowledge not yet present in the state of the art). This investigation permits to identify the further improvements towards a circular and sustainable process (not yet applied and identified by the thesis). The methodology includes the analysis of case studies regarding circular practices applied at building regeneration process and qualitative interviews to experts/stakeholders (designer, contractors, manufacturer etc.).

The third part of the thesis consists in the outcomes of research, which are the definition of the **framework for a sustainable and circular building regeneration process**, useful in particular for operators in the construction process, who want to implement circularity actions, and the definition of **recommendation for achieving the conditions for the transition** towards circular economy at building level. The framework for a sustainable and circular building regeneration process shows how the process phases, the operators' relationships, the materials and information flows and the used tools should be change. The recommendation identifies the necessary: i) policy improvements; ii) strategic partnership and business models; iii) life cycle decision-making tools, to achieve the change. The outputs derived from the critical analysis of current practices

and policies, the identification of obstacles and best practices during the stakeholder interviews, the original implementation of further improvements.

RECYCLED RUBBER-FIBER REINFORCED ELASTOMERIC ISOLATORS FOR SEISMIC PROTECTION IN DEVELOPING COUNTRIES

Ahmad Basshofi Habieb - Supervisor: Gabriele Milani

Co-supervisors: Virginio Quaglino, Marco Vincenzo Valente - Tutor: Pierluigi Colombi

It is an unfortunate fact that many developing countries with huge population are located in high seismicity regions. As many residential or public buildings are not designed properly nor sufficiently protected against earthquakes, the number of deaths is always feared high when the earthquakes strike. In the last two decades, severe earthquakes were recorded causing thousands of casualties in Indonesia. In December 2004, an earthquake with large magnitude 9.3 Richter scale (RS) struck Aceh and Northern Sumatra, followed by a huge tsunami wave, killing 170.000 people. In Java island, the most important land in Indonesia, an earthquake 5.0 RS hit Jogjakarta city in May 2006, causing 6.500 dead, and 1.115 people were killed due to Padang earthquake in September 2009. In August and September 2018, two big earthquakes stroke Lombok Island and the city of Palu, causing 555 and more than 2000 casualties, respectively.

Confined or unreinforced masonry buildings are commonly found in developing countries, particularly in rural areas. Without resisting moment frames, masonry can withstand seismic loads only thanks to the in-plane shear and flexural strength of piers and spandrels, but unfortunately, conventional brick masonry exhibits poor tensile strength, so its capacity to carry horizontal loads is

considerably lower than standard reinforced concrete.

Generally, in order to reduce the damaging effect on building due to earthquake, some techniques commonly used are; (a) increase the seismic-resistant capacity of the structure (b) involve bracing system (c) use of added damping system and (d) reduce the seismic demands on the structure by incorporating the base isolation system. Increasing a seismic-resistant capacity can be done by increasing the dimension of structures and upgrading the quality of materials used to achieve the expected target strength. Undoubtedly, this attempt will increase the total cost of structures significantly. The second option, bracing system, enhances the horizontal stiffness of the building and can localize the plastic hinge to improve the seismic behavior of structure, but does not decrease the seismic force on the structures. For an economical reason, it is not suitable

to implement the bracing system for ordinary residential buildings. Use of damping devices can be a solution to reduce the seismic force at the upper structure but increase the overall cost significantly, so cannot be adopted for common buildings.

In the last decades, the interesting topic is towards the reduction of seismic demand rather than increasing the seismic resistant capacity of the structure. The seismic demand of structure can be reduced by installing the devices having a low horizontal stiffness to provide a certain degree of flexibility in the structure. The elastomeric isolator is considered as the most widely used device to isolate the seismic energy propagation in the building. The elastomeric isolators are produced in different types such as laminated rubber bearings, lead rubber, and high damping rubber bearings. This technology satisfies well the need of seismic isolation for certain kinds of



Fig. 1 - Collapse of a residential building in Yogyakarta, Indonesia, after an earthquake in May 2006.

buildings and remains an attractive research topic among the construction engineers. However, the cost of commercial elastomeric isolators is relatively expensive and not so suitable for residential buildings.

This study focuses on the development of fiber reinforced elastomeric isolators (FREIs) made from recycled rubber, see Fig. 2. The cost of such a device is expected one tenth of which of the commercial rubber isolators

with similar dimension. When implemented in unbonded condition, the displacement capacity of the FREIs increases significantly when compared to the commercial devices.

The research starts with the characterization on the rubber compounds made from recycled rubbers. Then, a series of experimental tests and numerical simulation are performed on the prototypes of FREIs. The appropriate model of the proposed devices is

then developed to be implemented in structural analyses of an isolated building using FREIs, see Fig. 3. The results show that the proposed low-cost isolator devices can mitigate fairly the damages due to earthquakes on several types of masonry buildings.

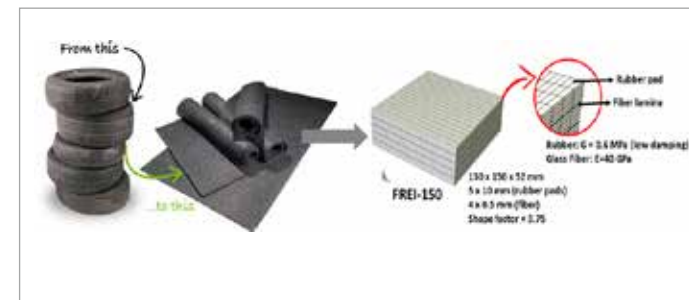


Fig. 2 - Proposed fiber reinforced elastomeric isolators made from recycled rubbers.

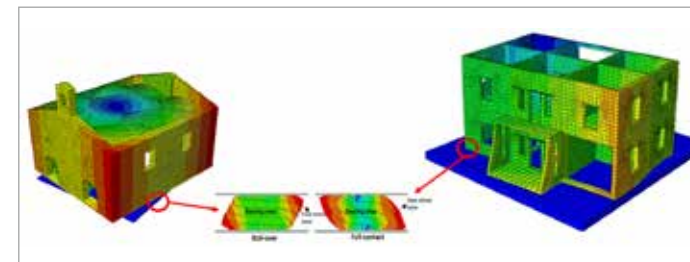


Fig. 3 - Application of the proposed FREIs on several types of masonry buildings.

VALIDATION OF HISTORICAL BUILDINGS ENERGY MODELS: A METHOD BASED ON MICROCLIMATIC CONTROL PARAMETERS

Harold Enrique Huerto Cardenas - Supervisor: Fabrizio Leonforte

Tutor: Claudio Del Pero

The awareness on the importance of energy efficiency in the building sector is increasing and with it the debate on sustainability about conservation and management of historic buildings. In such respect, building energy simulation software represents a powerful tool able to predict the building's energy and environmental response and can be used as diagnostic and prognostic tools. Thanks to the amount of data received from smart meters and devices and the advancement made in both energy software and computers, the quality of energy models are gradually improving and, hence, also the suitability of their output. However, due to the complexity of the built environment and prevalence of large numbers of independent interacting variables, it is difficult to achieve an accurate representation of real building operation, particularly in historic building where the uncertainty increase. This disagreement between simulated and measured data represents a common issue in the field of building simulation, therefore, by reconciling model outputs with the real measurements it is possible to achieve more accurate and reliable results. The reconciliation process is known as model calibration, meanwhile the verification of the model reliability is known as validation. Currently, three are the existing protocols that define

general criteria to validate building energy simulation models, through the comparison of the simulation results with the building energy consumption collected from bills. However, none of these protocols establishes a methodology to validate models without energy information that often miss in historic buildings which haven't an operative Heating, Ventilation and Air Conditioning system. In these cases, the model validation is carried out through the comparison of microclimatic data, often monitored in such buildings. In the literature, is increasing the number of studies that face the model calibration and validation through microclimatic parameters and since do not exist a collective and unified procedure to validate such models, each researcher follow an own methodology. Moreover, adopt the tolerances defined by the existing

protocols seems not to be adequate for the validation of historic building models in the context of preventive conservation. This thesis presents a detailed review of the current approaches to perform historic building models calibration and validation with microclimatic control parameters, highlighting the main issues and shortcomings. Finally, a method to calibrate and validate building energy simulation models will be provided. In detail, such method is focused on the selection of the most suitable microclimate control parameters, statistical indices and the related thresholds for the evaluation of model uncertainty combined with the analysis of residuals to verify the reliability of the results achieved. In this regard, the proposed method will be tested on two important historical buildings located in Italy.

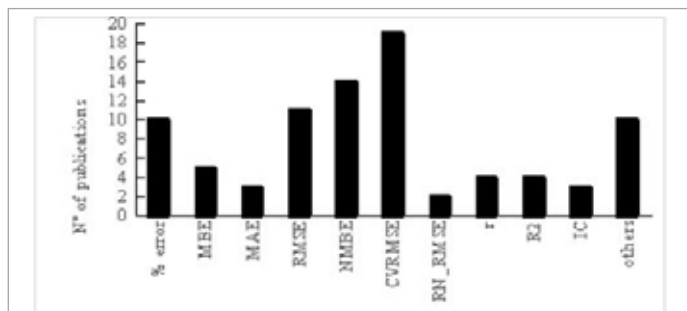


Fig. 1 - Most used statistical indices in historical building simulations (MBE: mean bias error, MAE: mean absolute error, RMSE: root mean squared error, CVRMSE: coefficient of variation of the RMSE, RN_RMSE: ranged normalized RMSE, r: Pearson coefficient, R²: coefficient of determination, IC: inequality coefficient).

The main outcomes from this work are summarized hereafter:

- To properly validate a hygrothermal building simulation model, temperature with a humidity parameter should be used (e.g. MR, SH, etc.), particularly in historical buildings context;
- Using RH for validation, due to its dependency on temperature, may cause an increase in the error when the simulated temperature is far from the real one; on the contrary parameters such as AH, SH, MR and Pv should be preferred because they are independent of temperature. It should be underlined that, after model validation, the RH can still be useful for an accurate assessment of thermal comfort, risks of material degradation, etc.;
- The MBE and NMBE are affected by the cancellation effect; then, it

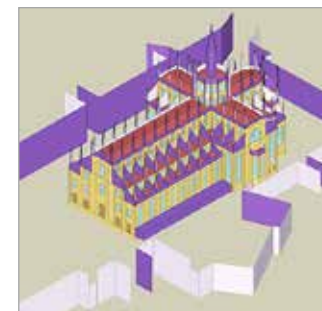


Fig. 2 - View of the simulation model carry out in EnergyPlus.

is advisable that they should be used in combination with other more reliable metrics. However, MBE and NMBE can still be useful to understand when the model is close to being validated and to verify if simulated data generally over or underestimate the measured one;

- The results provided by normalized indices (NMBE, CVRMSE and RN_RMSE) can be misinterpreted due to the variability of the mean and range used in their calculation;
- Statistical indices as the MAE and the RMSE can avoid misinterpretation due to the normalization process. Among such indices, the RMSE is very widespread in the literature; in most cases keeping RMSE below 1°C for temperature is considered a reasonable degree of reliability;
- The frequency analysis of the residuals method is able to carefully evaluate the model accuracy; in this work, suitable thresholds for model validation with microclimatic parameters are defined based on the literature. They consist in two different ranges of accuracy: the range between $\pm 1^\circ\text{C}$ and $\pm 1\text{g/kg}$ (considered as "excellent"), and the range between $\pm 2^\circ\text{C}$ and $\pm 2\text{g/kg}$ (considered as "acceptable") for temperature and mixing ratio respectively. Of course, the

required accuracy level depends also on the simulation objective;

- In the field of cultural heritage conservation, taking into account also the RH daily cycles is a pivotal step; thus, further verification of the simulation results through the Qv ratio should be carried out.

In conclusion, the information collected in this work may be useful to different subjects (e.g. designers, energy auditors, researchers, conservators, buildings' owners and policy makers), and can drive suitable maintenance interventions to prevent possible damage problems. Moreover, the improvement of the validation results allows decreasing the uncertainty about the outcomes and can offer a significant contribution to the development of new rules and strategies.

THE PROJECT OF THE “CITY FOR ALL” IN CULTURAL HERITAGE SITES

Sebastiano Marconcini - Supervisor: Valeria Natalina Pracchi

Co-supervisor: Alberto Arengi - Tutor: Laura Elisabetta Malighetti

This research addresses the topic of inclusion and inclusive design approaches, investigating the role of the built environment in enhancing human well-being and social participation. Particularly, the work focuses on cultural heritage sites, given their importance as a source of life and inspiration to which everyone should have access.

Although this topic has been analyzed in its different aspects since the second half of the eighties, the current design practice reveals multiple criticalities in managing inclusion in the design process. What has just been said is particularly relevant for cultural heritage sites, given the complexity of interacting with both inclusion and preservation needs. Starting from these issues, the thesis aims at identify inclusive design strategies, supported by appropriate instruments that ensure their implementation and effectiveness.

In order to achieve the set objectives, this work has been divided in two principal parts, the first mainly theoretical and the second focused on the empirical investigation of a case study.

“**Part I - Theoretical framework**” has been aimed at define the necessary knowledge of the complexity of the human needs and the features of the built environment that influence

the ability of a person to access and participate in the public realm. First, it has been attempted to reconstruct the cultural path that have led to tackling important social issues, such as disability, but evolving from the latter and trying to define the role and objectives that inclusion has today in contemporary society. Within this process, the role that cultural heritage could play and what it means to guarantee its accessibility has been investigated, as well as defining the needs to which an inclusive planning process should be able to answer. Subsequently, the further goal has been to reconstruct the set of knowledge currently available to deal with the topics that are the subject of this research. Particularly, this phase of the work has been sustained by the literature review and they have been analyzed the methodological approaches which, although with their peculiarities, seek to build an environment suitable for all and the regulatory framework of reference on these issues. Finally, they have been analyzed a collection of best practices learned from the observation of multiple European experiences in the field of inclusion. The result of this first phase has been the recognition of the components that characterize the inclusive project, especially its multi-scale and management dimensions.

“**Part II - Empirical investigation and research proposal**” has been

aimed at develop an empirical investigation applied to the case study of Mantua, in order to validate and calibrate the results of the first part of the work in relation to the real issues faced in managing inclusion, especially while preserving the cultural heritage values. The purpose has been to understand and overcome the reasons behind the discrepancy between the theoretical advances on inclusion and the design practice. After the introduction of the case study of Mantua and the motivations behind its choice, they have been defined the methodology for the development of the on-site surveys and the necessary tools for its implementation. Following an initial observation of the policies and strategies already implemented in the city for the development of physical



Fig. 1 - Scheme showing the meaning the term inclusion assumes in the research, through the definition of its two main components; one related to its physical dimension and the other to the socio-cultural one – © Sebastiano Marconcini

accessibility, they have been analyzed the results of the surveys, which have allowed the limitations that still characterize the built environment of a cultural heritage site like Mantua to emerge. On the basis of these observations, have been proposed some project-related reflections on how to deal with the issues identified during the surveys phase, highlighting how it is mainly at the level of project management that new proposals can be made to guarantee the promotion of better inclusive conditions. In particular, the thesis suggests a new governance model that would be able to detect and involve all the necessary stakeholders and concerns that must enter into the policies and strategies enhanced within the city. In order to do so, the introduction of operative tools, namely an interactive map and a quality label, was the further required step to guarantee the needed support in the development of



Fig. 2 - Top view of the city of Mantua, highlighting its cultural and environmental heritage – © Andrea Bonacini

an inclusive methodological approach and the concreteness of this research proposal.

The conclusions of the research focus on the complexity of the issues addressed by the target of inclusion, especially the limitation that characterized cultural heritage sites. Methodologically, the specificities in the approach to inclusion in heritage contexts are linked to the intervention modalities. These, along with the needs for renovation, must guarantee observance of the authenticity of the building, expressed by its material consistency, assessing a multiplicity of factors when defining solutions with the lowest possible impact and maximum performance. For this reason, reconsidering design strategies and policies according to coherent multi-level and multi-scalar solutions was considered the most appropriate proposal to respond to

the urgencies that contemporary society is facing. The outcome of the research highlights the need for a methodological shift from an approach to inclusion as a set of individual solutions to a system that answers to the complexity of the urban environment with a long-term planning vision and the coordination among a high number of actors.



Fig. 3 - Scheme showing the different components of the city and cultural heritage, tangible and intangible, that must be taken into account for the development of a fully inclusive design approach – © Sebastiano Marconcini

VIBRATION-BASED STRUCTURAL HEALTH MONITORING OF CIVIL ENGINEERING STRUCTURES: AUTOMATED OPERATIONAL MODAL ANALYSIS AND DAMAGE DETECTION

Gabriele Marrongelli - Supervisor: Carmelo Gentile

Tutor: Maria Adelaide Parisi

The continuous aging of important and strategic infrastructures that has severely affected the Italian Transport System during the last years and the structural degradation of many historical Italian buildings highlights the need for an adequate strategic plan for the maintenance of the structural integrity of civil structures and the preservation of monumental buildings in our country. In the last decades, these aspects have gained great relevance in Italy because the seismic hazard that adds to the normal deterioration of constructions and makes more difficult the protection and preservation of both modern structures and ancient buildings.

In the last twenty years, many efforts have been made to find appropriate solutions to these issues and an increased interest has been manifested by designers and owners of structures on dynamic tests and vibration-based Structural Health Monitoring (SHM) projects aimed at enhancing the safety of old and new complex constructions. Many efforts have been made to merge available technologies with efficient methodologies and to encourage the development of automatic tools to prevent the occurrence of catastrophic events, especially for those constructions subjected to high seismic risk. In the last years, the efforts in this field have intensified remarkably

providing good improvements in the development and application of several techniques mainly devoted to obtaining information about monitored structures in *operational conditions*.

The structural assessment of each investigated system starts with a dynamic test performed to extract the modal parameters (i.e. natural frequencies, mode shapes and modal damping ratios) from the output response collected during the in-service condition and under ambient excitation without measuring the input source. This strategy is defined Operational Modal Analysis (OMA) and implies the use of different techniques to analyze signals recorded during single tests as well as in continuous dynamic monitoring, involving efficient algorithms able to manage and handle a large amount of data and, from them, to extract those meaningful features that are going to be monitored. This task is not always straightforward, and some calibrations have to be made to clearly obtain the evolution of modal parameters over time.

This work focuses firstly on the implementation of various state-of-the-art algorithms for modal identification. Specifically, two methods in the frequency domain (PP and FDD) and two parametric methods in the time domain (SSI-Cov and SSI-Data) were implemented. Since the

parametric techniques are suitable to be automated due to their algebraic nature, they have been adopted in the development of automated tools for OMA purposes. It is worth noting that in OMA applications a lot of time is usually spent on manual analyses, necessary to tune the input parameters implying relevant user interaction. This is in clear contrast with the purposes of permanent dynamic monitoring, which require complete automation. Conversely, the removal of human intervention in OMA methods is still one challenging in this research field.

Accordingly, this Thesis is devoted to providing an improvement in the development of automated tools. Specifically, a first strategy for Modal Parameter Estimation (MPE) based on the interpretation of the stabilization diagrams was implemented with the aim of providing a well-founded array of modal estimates from single test data. The algorithm involves three consecutive sub-routines aimed at: a) removing most of the spurious poles, b) performing the clustering approach and c) improving the accuracy of modal parameters, reducing the uncertainty of the obtained estimates. The efficiency of the presented algorithm was proven using dynamic tests data of a lively footbridge and an ancient masonry bridge. Afterwards, an alternative MPE algorithm based on the construction

and the automated interpretation of tri-dimensional stabilization diagrams was developed. The validation of this algorithm was demonstrated with the extraction of the structural modes and the subsequent analysis of short monitoring period of important outstanding infrastructures: the *Infante D. Henrique bridge* in Portugal and the *San Michele bridge* in Italy.

As stated, in the context of vibration-based SHM it is mandatory to develop efficient and robust tools to perform the on-line and automatic processing of large amounts of collected data, avoiding any user interaction. Hence, in order to complete the implementation of a robust OMA methodology, capable of automatically providing the evolution in time of the monitored features, a new Modal Tracking (MT) procedure was developed and then integrated with both MPE algorithms previously described. In particular, the implemented tool is able to follow the seasonal fluctuations and unexpected variations of the modal features due to extreme environmental conditions. The validation of the tool in the monitoring of two important Italian Cultural Heritage structures (the *Gabbia Tower* in Mantua and the *San Michele bridge*) was proven with satisfactory results.

Since the structural degradation or the occurrence of damage is often associated with a reduction of the

global stiffness in the structure and with a subsequent decrease in frequency values, an accurate characterization of the modal parameters variations (especially natural frequencies) can be a robust way to detect structural problems. Despite this, in the classical SHM approach, damage identification is not always easy because the extracted modal estimates are subject to the effects of environmental factors, which could mask the damage. Therefore, the modal estimates are normally post-processed by routines that minimize the effects of external factors in order to obtain results that might depend only on structural conditions. This task is performed by applying multivariate regression models and/or principal component analysis models, which should be established using the time evolution of the features under a significant range of variation of environmental and operational factors requiring a long period of training.

The SHM approach developed herein discards the classical approach and performs the structural assessment using the identified modal parameters without removing the external effects on them. The removal of this relevant key-step from the methodology creates a clear distinction between the classical approach and the alternative OMA-based SHM strategy. Thus, a novelty damage detection approach

was developed to identify possible structural anomalies through slight frequency shifts and it was developed with two different strategies, based on: a) the Continuous Segment Analysis (CSA) strategy, defining the undamaged and damaged state of the system with two consecutive segments of data, and b) the Separate Segment Analysis (SSA) strategy, based on a reference segment of data used as undamaged condition. The validation of the damage strategy was demonstrated using experimental data collected during a seven-month of monitoring of the Gabbia Tower. During the monitoring period, the tower was subjected to a far-field earthquake that slightly damaged the structure. The occurred damage was clearly identified by the application of the novelty strategy.

The present work is completed with the application of all implemented algorithms in the continuous assessment of the San Gottardo bell-tower. The OMA algorithms were used to perform the continuous identification of the structural modes and the continuous assessment of the tower demonstrating its structural integrity for over two years of monitoring. Furthermore, some damages were simulated to test the sensitivity of the alternative SHM approach in the identification of small damages providing evidence of its usefulness and robustness.

ULTRA-LIGHTWEIGHT TECHNOLOGIES FOR TEMPORARY ARCHITECTURE. DEFINING NEW MINIMAL MASS AND EFFICIENCY-ORIENTED DESIGN STRATEGIES THROUGH AN EXPERIMENTAL APPROACH.

Carlotta Mazzola - Supervisor: Alessandra Zanelli

Tutor: Monica Lavagna

The thesis aims to investigate the use of ultra-lightweight technologies as a promising and effective option for minimal temporary building applications. Even if membrane architecture is taken as a point of departure, the study refers to lighter solutions, i.e. ultra-lightweight structures, with the intent to partially overcome the state of the art of membrane structures – already extensively studied starting from Frei Otto in the middle of the last century – to get to innovative and unexpected aesthetics, using new material combinations, tools and technologies. In particular, the thesis explores the possibility of using ultra-lightweight technologies for buildings with a short (i.e. ephemeral, temporary or seasonal) lifespan. Temporary buildings - characterized by specific constraints and requirements - are very common in the built environment but information and studies that provide a more complete view on the topic are still missing. The analytical part of the thesis (Chapters 1 and 2) explores the literature around temporary and lightweight architecture and presents the good and bad practices in the contemporary panorama to bring out the characteristics, critical issues and knowledge gaps. The critical part of the work (Chapter 3) focuses on two design challenges that arose from the path toward the realization of more efficient

buildings, namely adopting a time-based design approach and qualifying the architectural space. A Key Performance Indicators (KPI) matrix was built and used to analyse a series of significant case studies of significant lightweight and ultra-lightweight (Chapter 4). The issues that emerged from the first part of the thesis are at the same time defined and validated with prototypes, applying an experimental approach typical of the architectural technology discipline (Part B). The pilot project “TemporActive” - an ultra-lightweight temporary bending-active structure with a performing translucent envelope - was developed by the author in the role of project manager in collaboration with experts in the field from the conceptual design phase up to the occupancy phase and the predicted multiple cycles of use. In particular, three experimentations were

carried out on the pilot project to investigate and test both the design challenges and the aspects related to the construction phase which are generally poorly treated and about which little information is available. The experimental phase of the thesis led to the development of an ultra-lightweight temporary architecture that facilitates transportation and (un)installation and that, at the same time, consistently responds to specific project’s requirements and user’s needs. To find the optimum solution, the criteria taken into account were the feasibility and eco-efficiency aspects, the simultaneous weight minimization and maximization of the structural form efficiency and spatial architectural and comfort aspects. Based on the findings and lessons learned of the pilot project and analysis of the state of the art, generalized design strategies addressed to the

designer to create more efficient and coherent ultra-lightweight temporary architectures which are highlighted in the concluding part (Part C).

Keywords

Ultra-lightweight technologies, temporary buildings, membrane-based structures, architectural technology, prototyping, minimum, efficiency, performance, feasibility, form, structure, materials, sustainability, time-based design, envelope, comfort.



Fig. 1 - Pilot project “TemporActive” (a hybrid bending active ultra-lightweight temporary structure), developed as experimental part of the doctoral thesis.

A SYSTEMIC MODELING METHODOLOGY FOR EVALUATING BUILT ENVIRONMENT PERFORMANCE

Mohammad Hadi Mohammad Zadeh - Supervisor: Massimo Tadi

Tutor: Laura Elisabetta Malighetti

In today's world, built environment plays the key role in socio-economic relations and the environment is being affected most dominantly by urban life. Cities are growing fast, and faster are growing the numbers of urban inhabitants. At present, more than half of the world's population lives in cities and it is estimated that this ratio will increase to 70 percent by 2050. It means that if they are not managed now, the urban-related issues we are facing today will be taken to much more intensity tomorrow and even more severe environmental risks and socio-economic conflicts are yet to arise. Currently, about 80 percent of the global primary energy is being consumed in urban areas, cities are being guilty of emitting more than 60 percent of the total world's greenhouse gases, and the list of social issues in urban arrangements are endless. On the other hand, cities are the economic engine of the world, and by being on average responsible for more than 75 percent of a country's Gross Domestic Product (GDP) their further expansion is an inevitable perspective. In this situation, and as sustainability becomes the main development framework for all parts of economic communities, adopting innovative approaches towards development in the built environment is becoming urgent. In the recent decades, there have been many attempts to

define all-inclusive strategies and act globally for sustainable development.

In 2015, the United Nations General Assembly issued the Agenda 2030 as the standard framework for sustainable development ("Transforming Our World: The 2030 Agenda for Sustainable Development" 2018). One hundred ninety-three countries agreed to the document as the globally shared perspective of the near future in 2030. Currently, the main universal framework for approaching sustainability is the UN Agenda 2030 which defines the Sustainable Development Goals for the year 2030 and offers a comprehensive set of indicators for measuring the improvement. Since the socio-economic and environmental relations form a highly complex integrated matrix, all the Sustainable Development Goals are fundamentally linked together. Thus, the only possible approach to the UN Program would be through a profound systemic interpretation that highlights the linkage between the goals. This demands an elevated level of interdisciplinarity in all the attempts directed to meet the Sustainable Development Goals.

Although each and every target introduced by the Agenda 2030 is socially acceptable and politically correct, the totality of the SDGs

suffers from a severe problem of approach. Thus, it is incapable of identifying the roots of today's difficulties. The UN Agenda does not deliver a comprehensive and knowledge-based diagnosis to support its proposed plan. Moreover, it appears that the UN identified the goals and the targets within them independent from each other. One can argue that the problems in some specific Goals are rooted in others.

However, it is conventional for the first methodological steps to be taken in monodisciplinary research laboratories working only one goal or even few targets within the SDGs. Therefore, it is crucial for institutional and research bodies to consider the entire perspective when they develop methodological platforms to approach sustainability in their field. Such consideration requires a deep holistic understanding of the field of study and the overall obstacles of sustainability involving systemic synthesis with the usual scientific methods. In other words, any methodology defined to approach each one of the UN SDGs should be defined in a robust structure able to scientifically communicate to other fields involved. For this, the methods cannot be limited to analytical thinking but must adopt a clear system-thinking approach in their theoretical formation.

The built environment is composed of various morphological, typological, and technological subsystems from which the performing manner of the entire system is originated. Claiming sustainability in urban establishments demands a comprehensive understanding of cities as complex systems and clear identification of the role player subsystems within them. The majority of current trends and design methods adopt simplified analytical approaches and practically deal with the subsystems as independent entities; hence neglect the importance of phenomena resulting from their interconnections in different scales. With the aim of developing a better understanding of the built environment's systemic structure, the intention of this Ph.D. research is to offer a holistic methodology for studying the behavior of the built environment and investigate the methods for measuring the effect of urban structure to the performance. This goal will be pursued through an inquiry into the morphological components of the urban systems and the complex relationships between them. Particularly, this research focuses on the morphological patterns that might influence the non-motorized traffic. The measurable morphological values will be investigated and an automatizing calculating methodology will be developed.

Then, a theoretical platform for studying the pattern of relationship between the mentioned values and performance indicators will be argued.

Cities as CAS involve many systems, including energy, water and sewerage, food, transport, health and biodiversity. This network of systems, interconnections and flows can be described as a system of systems.

All the findings and applied methods in this thesis will be applied on the following case study: As it is predicted by UN that by 2050 around 70 percent of the urban population would live in informal settlements, it seems appropriate that the mentioned methodology will be tested in such a context. Therefore, PolomiParaRocinha which is a 2016 Polisocial award-winning project is selected as the case study. PolimiparaRocinha is a project with a theme of environmental performance and social inclusion for Rocinha, the biggest Favela of Rio de Janeiro, Brazil of which the author of this thesis is the coordinator of the operative team. For the case study adaptation, the non-motorized traffic patterns and parameters induced within the local morphological is being studied and their effects in terms environmental performance is being investigated both in the local

and city scales. The core value of this research is demonstrating that the direct relationship between action and behavior can be scientifically measured. This highlights the necessity of similar approaches for studying the built environment leading to developing decision support tools able to predict the behavior of the urban arrangement after certain modification scenarios from a sustainable point of view.

Keywords

Built Environment, Sustainability, Ecology, Systems, Complex Adaptive Systems, Sustainable Indicators, Urban Morphology, Key Categories, Morphological Attributes, Structural Tools, Evaluation Tools, Operational Facet, Modelling Methodology.

TOWARDS A DIGITAL-BASED MANAGEMENT OF SERVICISED ASSETS. A FRAMEWORK FOR ASSET MANAGEMENT BUSINESS PROCESS INNOVATION

Nicola Moretti - Supervisor: Mario Claudio Dejaco

Tutor: Fulvio Re Cecconi

Research background

Management of the Built Environment (BE) is characterised in the last years by the increasing complexity of physical assets, as well as the high number of stakeholders and the pervasive use of Information Communication Technologies (ICTs), due to the digital revolution. Assets can be considered as complex system featured by tangible and intangible performances, aiming both at providing a high-quality BE and advanced services to the users (servitisation). These dynamics raise the problem concerning how the digital processes can be harnessed in fostering Asset Management (AM) and which tools and methods should be employed to gather the new complexity of the digital BE. Therefore, the research

triggers process innovation in AM, exploiting established and new tools and practices, combined and reshaped to achieve enhanced performances of the BE.

Asset Management open questions

A set of problems emerging from the renovated real estate management context can be highlighted:

- engineering Asset Management targets change because of the servitisation principle. Therefore, effectiveness must be achieved through the combination of a more complex and wider array of targets (cross-domain), which enable the characterisation of the building as a service. Accordingly, traditional AM business processes must be reengineered;

- the digital asset provides asset managers with great amount of information. Thus, new asset management processes must be exploited for management of information flows, enabled by innovative ICT tools;
- the definition of digital BE can be extended from the single building, to buildings' portfolios, to the infrastructures, until the wider urban context. Therefore, management systems should be modular and scalable, in order to be reliable according to the scale of intervention.

These issues open to a new discussion on how to gather the complexity featuring the renovated BE paradigm and how to redefine the Asset Management business process,

identified before, providing innovative procedures for managing the digital BE. The outcomes of the BPR are new digital AM processes, that have been validated in 6 case studies.

Research methodology

The BPMa step allows to identify 14 core AM functions, classified by decision-making level strategic, tactical, operational (Figure 1). The BPMa is the first step to achieve a strong knowledge of AM discipline and to define its boundaries. Through the second step, the BPMo, the sequence of input, processes and output has been modelled for each core function and the main flows (relationships) and transformations (activities) have been defined. The BPMo enables the digital-based servitised innovation. The third phase, the BPR, concerns the business process innovation (reengineering) of some processes modelled in the previous methodological step, thanks to improved information management allowed by advanced ICTs. Reengineering means the optimisation or creation of new

business processes, to achieve a digital-based and servitised outcome, able to gather the new complexity of the digital BE. This operation leads to the redevelopment of the processes previously employed by the organisation. In this step, the identification of some additional key features of the processes is crucial. This basic information is: the typology of the organisation; the operating context; the organisation's constraints; the organisational goals and the involved stakeholders. These five features allow to shape the reengineering of processes and outcomes. A sixth feature must be added to five mentioned: the organisation's data availability and accessibility. This is a key driver for the BPR and for the achievement of the derived benefits (i.e. more efficiency and effectiveness, reduced uncertainty, increased reliability etc.) This approach allows to identify the sub-processes, input and outputs to be innovated through improved information management allowed by advanced ICTs. Eventually, the BPR takes places according to the

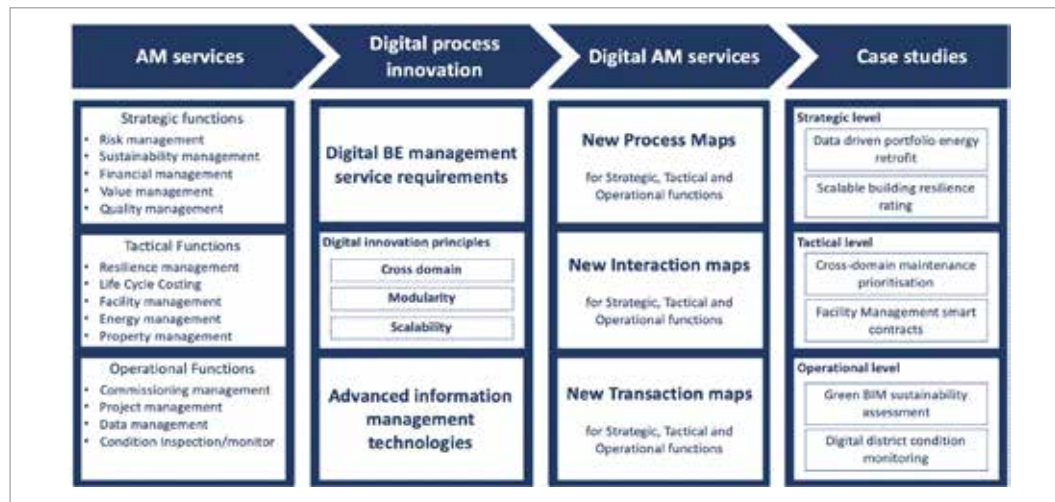


Fig. 1 - The PhD research schema

in order to contribute to a future proof framework for management of the digital BE.

Aim of the research

The research aims at enhancing AM business processes, through information management methods enabled by the availability of ICTs tools. Thus, a methodological framework for the AM innovation has been defined. This allows the development of innovative business processes to manage digital and servitised assets. The framework is articulated in three phases bringing from a strong knowledge and understanding of the traditional AM, to the development of new digital AM processes. The three phases are: Business Process Mapping (BPMa), Business Process Modelling (BPMo) and Business Process Reengineering (BPR). The aim of the first two phases is to identify the processes with the highest innovation potential. These processes are those more impacted by the digitisation and the servitisation. The aim of the third phase is to reengineer the processes

Case study	ICTs	Business context	Scale	Goal
Data driven energy retrofit	BIM, GIS, ANN	public portfolio management (school buildings)	Region	Evaluate building's energy savings potential, using the Certificazione Energetica degli Edifici (CENED) database to define an effective retrofit policy
Building resilience rating system	BIM	private/public portfolio management	Building portfolio	Measuring and rating resilience of assets for asset and portfolio management decisions
Maintenance prioritisation	BIM, GIS, AR	private/public buildings and infrastructures	Building, infrastructure and equipment	Maintenance planning and budget allocation with limited economic resources
District condition assessment	BIM, GIS, AR	Public/private Urban OM&R	district/ neighbourhood	Community involvement in urban condition assessment for urban OM&R prioritisation
Green BIM	BIM	Building assessment and rating	Building	Achieve sustainability rating through COBie on existing buildings
Blockchain and smart contracts	BIM, AR, DLT	OM&R contracting	Building/ district	Disintermediation between client and contractor through smart contracts for OM&R

Table 1: Case studies and enabling ICTs.

principles of modularity, scalability and cross-domain, needed for addressing the new complexity of the digital BE. The innovated processes shape the services delivered through digital AM.

Case studies and digital AM tools

Innovative services developed, are summarised in Figure 1. According to the scalability principle, service can be applied from a single asset to the asset portfolio. Also, in some cases, the focus is the BE as a whole. In the BPR step, different core digital AM areas have been innovated, in order to address contemporary cross-domain problems in management of the digital BE. Table 1. summarises key information of the case studies developed for the validation of the proposed methodological approach.

Conclusions

Through the proposed case studies, it has been demonstrated how digital AM processes can be developed according to a digital-based and servitised approach. These six case studies can be considered as advanced services with an immediate business application. The methodological framework has been defined and organised in three steps which bring from the deep knowledge of the AM processes to their reengineering, thanks to the employment of the improved information management

offered by advanced ICTs. After identifying current AM needs and, six new services have been proposed through the implementation of the BPR step, corresponding to the innovation of nine core AM functions. The innovation takes places the modularity, scalability and cross-domain principles, allowing to address the new complexity of the digital BE, therefore they can be considered as processes to be implemented in the digital AM sphere.

Also, some next development and further open questions can be identified. When a great amount of data and information is exchanged among parties, data property and reliability become primary issues. Therefore, further research efforts should be done for providing the tools and techniques able to ensure that information management and, ultimately the data-driven decision-making process are activated over reliable and secure datasets. The development of an error-proof data repository for AM would be appropriate. The data availability and reliability would enable the development of secure digital twins (and ultimately digital smart cities). However, for achieving a reasonable maturity level in the adoption of such tools, further confidence should be achieved also in industry and corporate world. Indeed, in this context, the adoption of advanced digital information

management tools seems not to be completely embedded in the value chain. Therefore, a further research effort should be done towards the quantification of the value of adoption of such data-driven approaches resulting, for instance, in the measurement of the value of the information. Altogether these are possible research lines which could find a common ground in the present PhD research.

EARTHQUAKE DAMAGE ASSESSMENT IN MOMENT-RESISTING STEEL FRAMES

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The most commonly used approaches for seismic design of Moment-Resisting (MR) Steel Frames, i.e. Lateral Force Method (LFM) and Modal Response Spectrum Analysis (MRS), are based on the use of the behaviour factor (q) to account for plasticity. They often do not lead to an accurate prediction of the seismic response and of the structural damage neither in the design phase nor in the post-earthquake condition. Nowadays, non-linear analysis methods as Pushover Analysis (PSV) and the most sophisticated Non-Linear Time History (NLTH) are admitted by the design codes. They provide a more precise assessment of the seismic performances, but designers rarely use them because of the complexity of their application.

In the first part of the PhD research, all the methods admitted by the European Seismic Design Code (EC8) have been considered to appraise, with reference to a set of cases of interest for practical applications, the differences in terms of design quantities. In particular, a set of 9 regular MR steel frames including Low, Medium and High ductility classes has been analysed by considering 9 Italian earthquakes. The output analysis data in terms of internal actions, inter-storey drift (θ_i) and total base shear (F_b) are obtained by linear methods assuming the maximum behaviour factor (q) admitted by the design code. The results of this investigation show

that the linear analysis approaches underestimate the internal actions and the seismic base shear values up to 40% respect to the results obtained by the non-linear approaches. Moreover, linear approaches lead to inter-storey drift values up to 25% higher than of those computed by NLTH, especially when second-order effects are accounted, while results of PSV and NLTH are quite close to each other. As a general conclusion, it can be stated that very different design results can be obtained depending on the method chosen by the designer, which also means different weights and therefore different costs as well as level of safety.

In the second part of the thesis, a numerical approach based on the integration between Non-Linear Time History and Low Cycle Fatigue (LCF) theory has been presented and applied for the assessment of the residual properties of a MR steel frame damaged by seismic action, basing on Non-Linear Static Analysis. As an example, reference can be

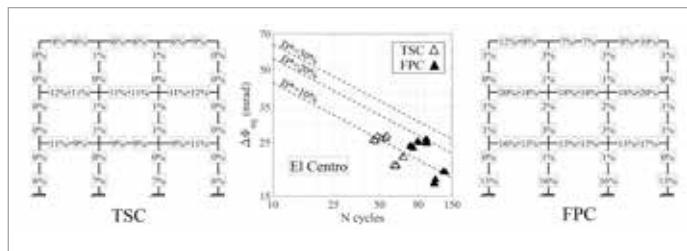


Fig. 1 - Local damage (%) distribution and Whöler's representation of semi-rigid joint damage (rotation amplitude vs number of cycles $N \cdot \Delta\Phi_{eq}$)

made to figure 1 where the damage is proposed for the for TSC and FPC frames together with the iso-damage lines.

After the calibration of the numerical models by using experimental data available in literature, the proposed procedure has been applied to two semi-continuous frames with top seat angle (TSC) or flush end-plate beam to column connections (FPC) and subjected to four different earthquakes.

Research outcomes show that the fatigue analysis results are strongly influenced by the structural response under a specific ground motion. Furthermore, another aspect, not adequately considered from the designer point of view, is the post-earthquake load carrying capacity, significantly influenced by the residual drifts, strongly depending on the cyclic joint behaviour. As a conclusion, accurate calibration of the numerical models basing on experimental data seems necessarily required to develop a safe design.

Further investigations are carried out by applying the proposed numerical procedure in a parametric form via Incremental Dynamic Analysis (IDA) considering an extended set of earthquakes. Numerical analyses are performed on the previously analysed frames, considering also a low ductility (DCL) and a Medium Ductility (DCM) frame. The damage level is statistically evaluated on IDA curve by means of the following three damage intensity measures (DMs): the maximum residual inter-storey drift, the maximum LCF local damage index and the residual load carrying capacity (Fig. 2).

From the analysis results, it appears clearly that the proposed procedure provides a more exhaustive evaluation of the damage state of the steel frame respect to the standard IDA application, which considers only the maximum transient inter-storey drift as damage intensity measure.

As a general conclusion, it can be stated that traditional seismic analysis methods do not provide an accurate and safe estimation of the seismic performances. Therefore, as proposed in this thesis, more sophisticated approaches should be applied in routine design to obtain more precise

evaluations of the design quantities and of the seismic behaviour of MR steel frames.

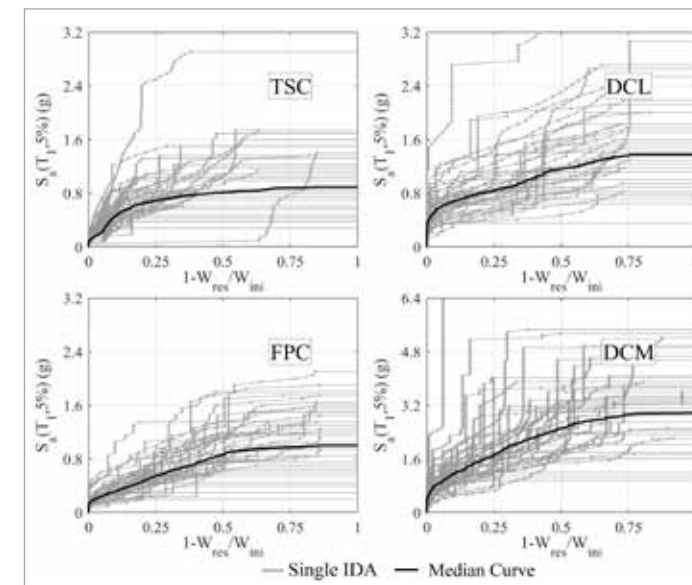


Fig. 2 - IDA curve of load carrying capacity reduction ($1-W_{res}/W_{ini}$) versus earthquake acceleration (S_e)

A PLCP FINITE ELEMENT CRACK MODEL FOR THE IN-PLANE ANALYSIS OF MASONRY

Manuela Alessandra Scamardo - Supervisor: Alberto Franchi

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Masonry buildings represent the great part of the world's historical heritage. During the past, these structures have proved their high vulnerability with respect to seismic actions and the structural safety of these constructions became a primary problem for both heritage preservation and life protection. The performance of masonry structures under seismic conditions is strongly influenced by cracking phenomena that have to be taken into account to obtain a reliable evaluation of mechanical behavior.

The present work presents a non-standard finite element (FE) method, coupled with a mathematical programming (MP) procedure, to simulate initiation, growth and propagation of cracks in masonry. The material is studied at the macro-level and modelled as a homogenous continuum by means of triangular shell elements. This hypothesis makes

the method suitable also for other quasi-brittle material. The analysis is limited to the in-plane behavior. Tensile and shear cracks (i.e. sliding) are taken into account. The method distinguishes between micro and macro cracks. Micro-cracks develop in the initial phase of damage and are simulated by means of plastic deformations spread in the elements, according to the classical theory of plasticity. Macro-cracks are represented instead as localized plastic deformations, which develop along the FE mesh edges. Some pictures from the simulation of an in-situ diagonal compression test are reported in Figure 1 to show the different phases of damage. Cracks opening is detected at each node by a specific limit value of the tensile/shear force normal/tangential to a potential crack direction. When the limit value is reached, a cohesive crack starts to open, following a linear

softening branch as proposed by Hillerborg. According to the Colonnetti approach, the non-linear response of the structure is obtained as the superposition of the linear-elastic responses to given external actions and to plastic strains (representing the crack opening) conceived as unknown imposed strains. The unknowns of the problem are the nodal displacements of the elastic model (as in standard FE method) plus the inelastic non-compatible nodal displacements representing the crack openings named crack multipliers. The values of the crack multipliers are found by solving a parametric linear complementarity problem (PLCP), assuming as parameter a load factor. The main advantage of using an LCP method is its ability to deal also with configurations in which a multiplicity of solutions is possible (e.g. softening behavior).

Different procedures and algorithms of MP have been developed to manage all the peculiar structural configurations (e.g. unloading, bifurcation point, inversion of load, etc.). Some numerical examples are presented to validate the method.

Keywords

Masonry; Finite elements; Cracking; Parametric linear complementary problem; Softening.

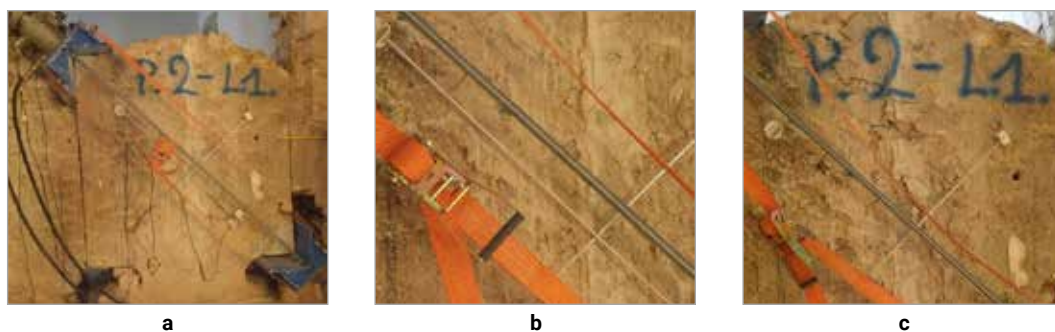


Fig. 1 - Figure 1 (a) Layout of an in-situ diagonal compression test. (b) Initial phase of damage with formation of micro-cracks. (c) Formation of macroscopic cracks.

“SPIRITUAL DISUSED” SPACES AND ECCLESIASTIC ARCHITECTURE AS MARKETABLE REAL ESTATE ASSETS: A POTENTIAL SOLUTION FOR RUSSIA’S ABANDONED SACRED HERITAGE ARTIFACTS UTILIZING ADAPTATION BEST PRACTICES

Anastasiia Sedova - Supervisor: Andrea Ciaramella

Tutor: Valeria Natalina Pracchi

Since ancient times, Russian Orthodox churches have been considered important objects of cultural heritage, which played a landmark role in the urban/rural fabric of Russian settlements, while the Russian Orthodox Church has played a key role in the social life of the country. The ecclesiastic architecture of this faith gave birth to the development of contemporary architecture in Russia, became city-forming elements, and instigated the self-organization of spaces around them. Despite this, the Soviet Government, upon its ascendance to power, in 1917, subsequently persecuted the Church, along with executing numerous demolitions, functional conversions, and closures of many Orthodox churches nationwide, which lasted until the collapse of the USSR, in 1991. Today, 28 years later, Russian society still has a vast amount of post-Soviet handovers – thousands of obsolete and abandoned religious buildings, and due to the fact that many of them are unique pieces of architecture, their desolation will be an irreparable cultural forfeiture for the nation, and the world at large. Considering the importance of these churches, and the imminent need to make a decision for their conservation, this thesis studies known adaptation strategies for religious properties worldwide, and how they can best be applied to the Russian context, while stressing their innate values, and planning for

impacts which could be facilitated through adaptation.

The Author raised two Research Questions, the first “How to reintegrate obsolete and abandoned Orthodox churches to the urban/rural fabric and social life?” addressed topics of architecture and conservation, and the second Question dealt with the governance and management of religious cultural heritage, inquiring “What is a conceptual circular adaptation management and governance model for stakeholders, incorporating a Decision Support System, based on multi-criteria methodological framework and recognition of multiple forms of Obsolescence and given Values?”

The study was divided into three Parts: The Introduction, Observation of Best Practices In Adaptation, and Adaptation of Abandoned Russian Orthodox Built Assets.

Part 1 gave an introduction to the state of contemporary Russian sacred real estate, explained where the problem were rooted, and were concluded with a “call for action” statement, that if conservation solutions are not be found, the churches mention will be at risk to collapse in the near future.

Part 2 dealt with observations of best practices in Adaptation

worldwide, through explaining what the Adaptation is, what Decisions of Adaptation can be taken, what New Uses were applied to International Case Studies of obsolete and abandoned religious properties, what the Life-cycle of built heritage properties are, what Values cut across churches and what Impacts can be obtained after Adaptation, who are potential Stakeholders and how much do they value these properties, along with the mechanisms to Partnerships, which allow introducing Stakeholders to each, and match different funding sources, in order to provide churches with sustainable conservation solutions, which could prolong their Life Cycle. Part 2 culminated in the formulation of findings about adaptations.

Part 3 focused inside the Russian context and aimed to find solutions to the Adaptation of obsolete and abandoned churches within the country, based on the most valuable aspects of best practices worldwide. The Author made a sourcebook of 146 cases which total 2% of all the “spiritual disused” Russian Orthodox religious properties and clustered them according to five chosen criteria. Later in this Part, the thesis amplified the national Stakeholders of Adaptation, and the ways in which they can partner. After, the thesis moved to a simulation and analysis for adaptation of a Case Study,

which was based of the findings and recommendations given after best practices’ observations. Finally, this dissertation gave recommendations for the adaptation of obsolete and abandoned Orthodox churches in Russia, and indicated the areas of potential further research, which could potentially further sophisticate the principles of adaptation, on which this thesis focused on.

This thesis is a first research on the Adaptation of obsolete and abandoned religious buildings/objects in Russia, which saw churches as real estate items, apart from their Spiritual trails, have other types of Values. Thus, this study makes an important contribution to Architecture, setting up a Decision Support System for Adaptation, which can be a role model when planning the conservation of Russian Orthodox churches at the “Concept Development” and “Project

Preparation” stages. The System is based on the recognition of both given Value and planned Impact, which laid out the identification of the Stakeholders of Adaptation. The division of the Stakeholders into groups according to what role and “power”, when taking the Decision of Adaptation, they can contribute to it, is applicable to, as well as for the Russian context, and worldwide. Also, the research contributes to the study of Multi-stakeholder Partnerships, explaining three types, which made possible the cooperation of Stakeholders in church Adaptation all around the world.

The thesis contributed to Architecture in a way, showing the feasibility of Adaptation, and explaining a framework for it, that the Decision Support System can be applied to any among the 7,323 obsolete and abandoned religious buildings in

Russia. The flexibility of this System was achieved by putting together only fundamental aspects of Adaption, such as the recognition of Values, or cooperation of Stakeholders, when essential aspects of it, such as what are the “weight” of each type of Values, or what type of cooperation should be chosen, will need to be defined for each single case. The main advantage of this developed System is that the aspects of it give birth to many areas of potential further research.

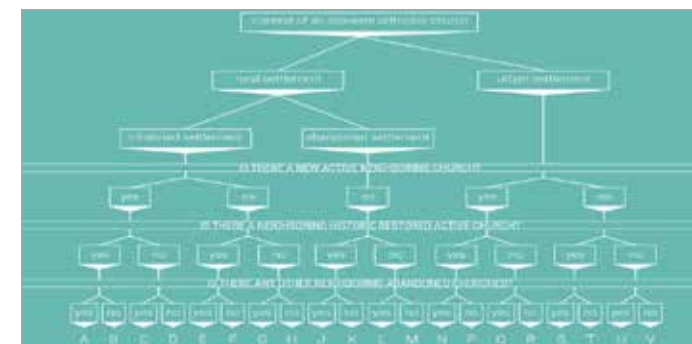


Fig. 1 - Decision Support System: The Context Scenario Selection.

SEISMIC VULNERABILITY OF CHURCHES: A TERRITORIAL KNOWLEDGE APPROACH

Gessica Sferrazza-Papa - Supervisor: Maria Adelaide Parisi

Co-supervisor: Marie-José Nollet - Tutor: Sara Cattaneo

This doctoral dissertation focuses on the seismic vulnerability of churches, proposing a territorial approach for its assessment.

Historical masonry churches constitute a large part of the Italian Cultural Heritage. They are extremely at risk in seismic prone areas, due to their constitutive structural characteristics. Several studies on the seismic damage and vulnerability assessment of these buildings have been carried out by the Italian scientific community since the last decades of the 20th century, stimulated by strong earthquakes that have occurred in the period. This line of studies interprets the church building as an assembly of structural units, called macro-elements that have been associated with recurrent failure mechanisms. The availability of effective computational tools has allowed providing numerical interpretations on the structural behavior of buildings subjected to earthquakes in support of empirical considerations from observational data. The different macro-elements and the associated damage mechanisms have become a reference among the experts of the field, becoming a sort of common vocabulary. This common language has favoured reaching a consensus on a first approach post-earthquake damage interpretation and vulnerability analysis and has brought to the development of corresponding

procedures and tools. At the present state of knowledge, a form for seismic damage survey was issued by the Ministry of Cultural Heritage, together with the Civil Protection Agency in 2006, widely used in subsequent earthquakes, as well as guidelines for the seismic assessment and risk reduction for Cultural Heritage in 2011.

The approach proposed in this dissertation is the identification of the so-called territorial specificities, that is, local characteristics of construction practice and tradition that can change from one territory to another and that may affect vulnerability increasing or decreasing it. They have, thus, to be considered within a vulnerability analysis to complement the current assessment procedures, which are based mainly on recognition of general possible damage patterns. The method obtained for the seismic vulnerability assessment of churches is specifically related to the territory and the building characteristics, keeping as a reference but advancing the basic procedure that is currently available. The proposed procedure is addressed to the medium scale, that is, to those Authorities which operate in the territory and that have a mediator role between the practitioners, who operate in it, and the national codes and guidelines for preventive actions. The practical consequence of such an approach is obtained, here,

developing a form called Territorial Aspect Form (TA-Form), which is a proposal of template to be used for guiding the vulnerability assessment, considering the territorial aspects that could be vulnerability modifiers.

The development of the research originates from analyzing a sample of churches from two Italian territories affected by important seismic events, occurred in recent years. One treated area is Eastern Lombardy, with specific reference to the case of the province of Mantova, which was affected by the Pianura Padana earthquake in 2012; the other one is the province of Macerata where many churches were damaged by the seismic sequence of the Central Italy earthquake occurred between August 2016 and January 2017. For the Italian territory, the investigation continues treating a church case structurally similar to a fortress or a palace that recurs in another Italian territory highly prone to earthquakes, that is, Eastern Sicily. While in the first two cases, the focus is on the occurred damage and the implication of the territorial specificities in the structural response, in the last case, the study was performed in a preventive phase, interpreting the structural behavior of a church-fortress that, along the years, was subjected to interventions and modifications that affected its seismic vulnerability; specific attention is paid to a reinforced concrete

column introduced in a restoration and strengthening intervention. Indeed, for the first aspect, this church typology represents an example that is not very frequent in the national territory and consequently not reflected in the reference situations or easily transferable to them; for the second aspect, the focus is on the structural interventions performed over the years, influenced by the common restoration practice of their time. They constitute an important phase in the life of the building that in case of an earthquake could change significantly the structural response compared to the original configuration. Such example has contributed to develop a methodology able to catch such territorial specificities, in order to better interpret its structural vulnerability. The Italian examples treated in the research have been the basis for the elaboration of the methodology; this has been, finally, transferred and tested in Montreal (Québec), in the occasion of a collaboration between the École de Technologie Supérieure (ETS) in Montreal and the Politecnico di Milano (POLIMI). The city of Montreal is one of the cities with the highest density of buildings in Canada and is close to the seismic Western Québec zone exposed to moderate seismicity. These aspects contribute to making the unreinforced masonry churches (URM) highly at risk; just for the Catholic Diocese of Montreal in

Montreal Island, 109 churches were inventoried. Churches, here, show some similarities with the Italian ones, which justifies the exportation of the Italian seismic vulnerability assessment in this different context with its own construction culture and awareness of seismicity. Starting from the inventory, the seismic vulnerability of a set of churches was initially assessed according to the current Italian methodology, but some difficulties of interpretation occurred. The churches were then subdivided into categories based on the façade configuration that includes the bell tower macro-element in a characteristic position according to the typology. First considerations on the associated seismic vulnerability were formulated and, in a second stage, one typology among those identified, the néo-roman, was investigated in depth. The néo-roman was selected for further analysis because of the characteristic central position of the bell tower in the façade and the mixed-use of timber and masonry for the church structure. Timber is used for the bell tower, the colonnade and the roof structure and masonry for the curtain walls. Considering a church case study for this typology, the numerical analyses have brought to recognize and to quantify the effects of its main stylistic characteristics on the seismic response. Results have been used to adapt the TS-Form to

the néo-roman typology, as a first step for the development of a TS form for the region. The adaptation of the methodology to the Canadian context has opened new scenarios of investigation now in progress on local church typologies, beyond the néo-roman typology investigated in this work. The Conefroy typology is locally investigated from a group of researchers starting from the approach proposed in this dissertation in order to assess its seismic vulnerability.

The application of the territorial approach proposed for the seismic vulnerability assessment of churches has shown the capability to interpret the vulnerability of churches also in the Canadian context.

At the end of the research, a layout for collecting the information in a GIS workspace is presented. This tool, characterized by flexibility and adaptability, is used both in the development of the thesis for intercorrelating information and at the end as exemplification of collecting the acquired territorial specificities and connecting them with the existing knowledge. Such characteristics of flexibility and adaptability reflect the character of the proposed approach.

KINEMATIC EQUILIBRIUM, BLACK BOX ANALYSIS, AND THE CHARACTERIZATION OF DRY-STACK MASONRY ARCHES

Gabriel Lee Stockdale - Supervisor: Gabriele Milani

Tutor: Marco Vincenzo Valente

Structural masonry and its supporting stability-based design techniques have the potential to become a viable and advantageous method for new constructions. This technique however requires a modernization of the design and an accessibility to the analysis for engineers and other practitioners. Sudden failure must be removed. Simplified engineering equations and procedures must be established, and the model must be economically competitive. Limiting the conversation to the masonry arch, this research presents a black box analysis approach for dry-stack masonry arches. Through the application of kinematic equations of equilibrium and the kinematic admissibility of their solutions, a simple and effective strategy is developed for the analysis of dry-stack masonry arches subjected to mechanical joint control. The kinematic equations of equilibrium are established through the inclusion of an applied loading variable into the free-body diagram that defines the kinematic condition which generates a determinant system and a single solution. The results of the solution are then used to establish the resulting thrust line that represents the theoretical concentration of compressive forces through the system. This thrust line is then evaluated against the boundaries of the defined kinematic state to establish admissibility of

the combined kinematic and loading conditions.

Incorporating this approach into the developed Kinematic Collapse Load Calculator (KCLC) establishes an accessibility and efficiency to the analysis through the visual representation of the condition under analysis and its solution with a back-end isolation of the supporting mathematics. Expanding beyond the traditional four hinged mechanism, the KCLC is adapted to incorporate limiting condition assessments for multi-mechanism analyses introduced from the inclusion of slip-joints. The inclusion of slip is accomplished through the incorporation of the coefficient of static friction. The inclusion of friction is balanced with a moment at the slip joint and the relationship between normal and parallel reactions at the mechanical joint. The resulting thrust lines from kinematically admissible statically unstable conditions are then evaluated against an arch geometry to establish the required joint reinforcements to maintain rigid elements between mechanical joints. The reinforcement magnitudes are calculated by determining the required moment or surface tension necessary to shift the thrust line back to the boundary of the arch. The accessibility and efficiency are then further expanded through the incorporation of a CAD based data

extraction technique that allows the analysis structure to be applied to any drawn arch model. Lastly for the black box analysis structure, the single degree of freedom motion of the kinematic condition is incorporated to evaluate mechanical deformations and their effect on capacity. This expands the kinematic equilibrium to static deformations and allows for the evaluation of conditions such as a hinge stiffness from a non-ideal joint reinforcement.

The transformation from the focus of stability to kinematic admissibility also allows the characterization of an arch to be established. This characterization is demonstrated by the development of collapse load diagrams (CLDs) and the adaptation of the analysis model to experimental conditions. CLDs are developed from calculating the minimum mechanisms for the admissible configurations of the base hinges for a given arch and plotting the capacities against the negative tangent of the angle between the base hinges. These diagrams establish a first-order assessment strategy for comparing arches and establishing quantitative values for project development stages of construction. This family of mechanisms also highlights the behavior between capacity and hinge sets. This behavior provides the comparison structure necessary to establish a capacity adjustment

equation that directly adjust the theoretical model to a real arch. This process was repeated with two experimental campaigns, one for an in-scale arch and the other for a full-scale arch, both subjected to a tilting plane.

Lastly, the evaluation of statically deformed conditions is expanded into a seismic modelling structure. The kinematic equilibrium of mechanical deformations combined with the equivalent single point representation of deformation establishes required work-paths necessary to propagate the kinematic arch to collapse. The definition of conservative work then links these work-paths with kinetic energy for accelerations that exceed the static limit, or when the arch is in a kinematic state. The spatial establishment of kinetic energy in turn allows the formation of the time domain for the kinematic condition. This establishes the time-step propagation of position and kinetic energy through an acceleration sequence.

Therefore, this work establishes an analysis foundation that addresses both the static and dynamic conditions of dry-stack masonry arches subjected to hinge control. It formulates a single theoretical structure that can be employed for every stage of a project's

development from inception and selection to contract execution. It links design with structural analysis and maintains a simplicity that can extend masonry arch analysis from the academic to practicing engineer. From this point the modernization of masonry has begun.

IN- AND OUT-OF-PLANE HOMOGENIZED LIMIT ANALYSIS OF NON-PERIODIC MASONRY WALLS BASED ON A NOVEL PIXEL/VOXEL STRATEGY

Simone Tiberti - Supervisor: **Gabriele Milani**

Tutor: Tommaso D'Antino

Homogenization is a meso-scale averaging procedure that has been widely used over the past decades to derive the macroscale mechanical characteristics of periodic masonry starting from those of its constitutive materials. Both the in- and out-of-plane behaviors have been reliably assessed, in either the linear or nonlinear range but also through the use of limit analysis. The application of homogenization techniques to old masonry structures was early recognized as interesting and promising. However, historical masonry buildings sometimes display a quasi-periodic, if not wholly random, arrangement of units which is sometimes also coupled with the presence of multi-leaf walls. This is apparently in disagreement with the very idea behind homogenization, i.e. the identification of a Representative Element of Volume (REV) able to generate a periodic pattern when translated. Nonetheless, few past works have attempted and eventually succeeded to overcome this issue. Still, the lack of a comprehensive model for non-periodic masonry is rather evident. This PhD thesis presents an innovative approach that comes from the combination of homogenization and limit analysis. This aims at investigating the in- and out-of-plane collapse behavior of non-periodic masonry walls through the derivation of homogenized failure surfaces, which represent

homogenized macroscopic failure criteria for the considered wall. The deformed shapes at collapse for selected in- and out-of-plane load conditions can also be extracted. Moreover, an automated procedure is introduced in this PhD thesis that enables the creation of a 2D or 3D finite element mesh directly from the image file representing the rasterized sketch of a generic masonry element. This PhD thesis is structured as follows: after the initial introductory chapter, the second chapter offers a deep insight into the state of the art concerning the numerical strategies for modelling masonry. An extensive literature review is presented, focusing on homogenization applied to masonry and with special attention given to its pairing with limit analysis. Several classic works in this field are recapped and summarily described. The third chapter offers a detailed description of the strategies adopted for creating a finite element mesh from the rasterized sketch of a generic masonry element. The first part of this chapter is devoted to presenting the “pixel strategy” conceived for generating a 2D finite element mesh. The basic idea behind this strategy is the transformation of a pixel into a planar finite element, so that the mesh is automatically created from the source image in very few steps. These are listed in a logical fashion and are eventually transcribed into a MATLAB script. Similarly, the

second part of this chapter is devoted to presenting the “voxel strategy” conceived for generating a 3D finite element mesh. Here, the basic idea is the transformation of a voxel (the 3D equivalent of a pixel) into a solid finite element. Again, the logical steps that allow the creation of the 3D mesh are eventually transcribed into a MATLAB script. The third part of this chapter describes the so-called “coarsening strategy”, which enables the reduction of the number of finite elements in the mesh when the source image contains a huge number of pixels. The fourth and final part of this chapter briefly describes the strategy adopted for the creation of a 3D finite element mesh of a multi-leaf wall. The fourth chapter is devoted to the full description of the procedure developed for assessing the in-plane collapse behavior of non-periodic masonry walls. The first part of this chapter broadly describes the approach on which this procedure is based, which combines the upper bound theorem of limit analysis and homogenization. This is then synthesized into a standard-form linear programming problem, subjected to equality constraints that directly come from the very mathematical formulation of this problem. Eventually, this problem is implemented into a MATLAB script that also contains the 2D mesh generating tool. This part also describes the method for constructing the in-plane

homogenized failure surfaces and the deformed shapes at collapse extracted for in-plane load conditions. The second part of this chapter presents the numerical application of the procedure previously described. This application is represented by an extensive investigation on six case studies, which actually are six non-periodic masonry walls that are part of existing buildings located in Tuscany and Emilia-Romagna. The resulting in-plane homogenized failure surfaces and deformed shapes at collapse for each case study are critically commented and compared. The fifth chapter is devoted to the full description of the procedure developed for assessing the out-of-plane collapse behavior of non-periodic masonry walls. The first part of this chapter broadly describes the approach on which this procedure is based, which employs a Kirchhoff-Love plate model for the out-of-plane kinematics, and which again combines the upper bound theorem of limit analysis and homogenization. This is then synthesized into a standard-form linear programming problem, subjected to equality constraints that directly come from the very mathematical formulation of this problem. Eventually, this problem is implemented into a MATLAB script that also contains the 3D mesh generating tool. This part also describes the method for constructing the out-of-plane homogenized failure

surfaces and the deformed shapes at collapse extracted for out-of-plane load conditions (set as flexural/torsional moments). The second part of this chapter presents the numerical validation of the procedure previously described: here, the out-of-plane homogenized failure surfaces are extracted for two periodic masonry bonds (namely, running bond masonry and English bond masonry), which are then compared to those available in literature for the same masonry bonds, obtained with the use of two different methods. The third and final part of this chapter presents the numerical application of the procedure here described. This application is represented by an extensive investigation on the six non-periodic real case studies already inquired in the previous chapter. Once more, the resulting out-of-plane homogenized failure surfaces and deformed shapes at collapse for each case study are critically commented and compared. The sixth chapter is devoted to the study of the out-of-plane collapse behavior of multi-leaf walls, using a modified version of the procedure developed in the previous chapter for single-leaf walls. The first part of this chapter describes the modifications needed in the mathematical formulation of the linear programming problem to account for the presence of several layers in the wall thickness. The second part of this chapter presents

the numerical application of the modified procedure. This application is represented by two custom-built case studies, consisting of three-leaf walls that are created starting from two of the six real case studies previously investigated. Specifically, a rubble three-leaf masonry wall and a quasi-regular masonry wall are created and inquired in terms of their out-of-plane collapse behavior. In the latter case, the influence of the transversal interconnection (simulated by the presence of bricks that spread throughout the whole thickness of the wall) is also investigated. Again, the resulting out-of-plane homogenized failure surfaces and deformed shapes at collapse for each case study are critically commented. The seventh and final chapter is mainly devoted to discussing the future developments that may possibly be originated by this work.

INTERDISCIPLINARY DIGITAL PROCESSES TO SUPPORT THE VALORISATION OF CULTURAL HERITAGE. THE UNESCO SACRI MONTI APPLICATION FIELD.

Cinzia Tommasi - Supervisor: Cristiana Achille - Co-supervisor: Daniele Fanzini

Tutor: Marco Scaioni

The valorisation of Cultural Heritage is a relational dimension of safeguarding and conservation. In this vision, it includes each intervention that improves the conservation condition of a building/site/monument, requiring an aware behaviour to access the heritage, also considering the restitution of a utility value contemporary to the society and territory where the building belongs. This scenario requires an interdisciplinary profile: all the actors involved should cooperate in integrating their different methods and information. The quantity of data and digital content is growing exponentially, together with the potential of digital technologies. The range of technologies to capture, represent, and share the Cultural Heritage made huge advances, varying in terms of costs, scales, purposes and outputs: they become more democratised in terms of both economic and practical accessibility of equipment and techniques, and access to models and information with internet portals. The employment of 3D models that describe the tangible parts of the heritage and contain the related information become mainstream, mostly for planning and monitoring the restoration activities. Within a consideration of Cultural Heritage, however, it is necessary not to lose sight of the need to capture and understand the social aspects of the heritage. It always owns an

inner meaning, traditions, stories, and cultural resonance, which constitute the kind of information needed for its fruition and valorisation. The question is: how is it possible to use an information model not only as a tool made for expert and oriented to restoration but also for valorisation purposes? In which way is it possible to combine tangible and intangible aspects inside a digital information system to engage people and produce cultural value? In this complex framework, Cultural Heritage definition assumes a holistic view, and the challenges for ensuring its valorisation, management, preservation, and promotion address to these lines: the communication between different actors and different disciplines, the technology that can be the mean to deal with the large amount of data and can connect people, widening the public through

participatory processes, and the quest for a “standard” cultural practice that can be shared at national and international levels. So, the research project aims to create an intermediary role between the field of digital technologies and the socio-cultural aspect bonded to the intangible elements of the heritage. In this sense, this professional figure has to be able to plan a valorisation program of a selected case study, having in mind all the multiple aspects of an enhancement process, and being able to manage them. In particular, the main features to consider are: Recording the tangible aspect of the case study, identifying the most appropriate methodology and technology for surveying the case study and modelling the data, according to the needs and purposes of the work.

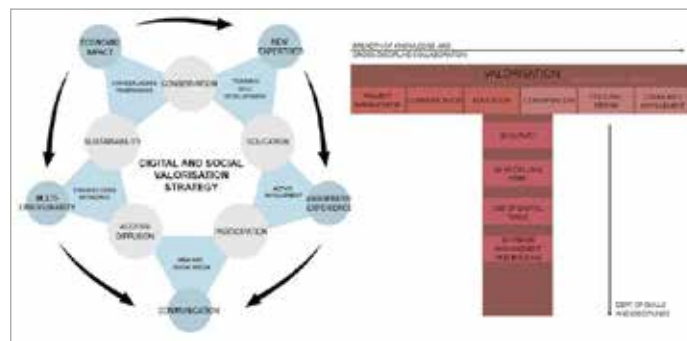


Fig. 1 - The criteria founded for a valorization project, and their relationships (On the left). The t-shape diagram of the competences touched by the topics of the research (on the right).

Acquiring the intangible aspects of a building/site, considering all the layers of information. Making an in-depth analysis of the data acquired (tangible and intangible) and combine them to create strategies of interventions and products. Community interactions with heritage, considering a heritage community as \people who value specific aspects of Cultural Heritage which they wish, within the framework of public action, to sustain and transmit to future generations Engaging and exploiting with stakeholders and local communities. The effectiveness of this work lays on the way that I use the data at disposal (tangible or intangible) of a selected case study to create value and participatory fruition of Cultural Heritage. The benefit and the difficulty are to conduct an interdisciplinary work, being aware of all the multiple processes contained in each point of the bullet lists for reaching communication goals between different disciplines, connecting digital technologies with humanities, in other words combining the technical advances and skills within a social

science context. The responsibility and the future of the Cultural Heritage are not only of the professionals who deal with its study, management, and conservation, but it is a broader matter that includes many subjects as the full citizenship. A research project operated and accessed only by experts is out of date and without future, in as much as its effectiveness is measured in terms of social and cultural impact on society. For this reason, the thesis investigates how to use digital in Cultural Heritage to achieve a valorisation project, looking to 3D models, their outputs, and information systems as a tool to engage people, produce cultural value and development.

The thesis applies the theoretical principles listed above in a practical case study, the UNESCO Sacri Monti Circuit, a diffuse heritage made by nine sites located between Lombardy and Piedmont, where each site contains a variable number of chapels, a Sanctuary, and other buildings. The focus of their conservation and management plan are the chapels, which are regularly monitored, inspected,

and restored. However, from the UNESCO's Periodic Reporting activity on this site, it emerges the need of a structured conservation database, and the necessity to increase the relationships with local communities and stakeholders. For these reasons, the research proposed and tested a new method for the daily management, improving the conservation process through an online tool capable of sharing 3D models and handling a structured information database, making all these kinds of information accessible to people with different skills and background. The ad-hoc platform is created following a real multi-disciplinary and co-creation approach, actively involving all the actors included in the conservation of Sacri Monti. The findings of the work individuate the “minimum” and sufficient information for creating a standard management methodology sharable among the Sacri Monti circuit and building a cultural practice for the site's conservation. Moreover, it opens to a future development scenario, where these same data could involve and engage other types of public (non-expert users), sharing them through other channels and languages of communication.



Fig. 2 - One web-platform, many possibilities: the final outcome of the thesis is an online platform that collects 3D models and information (on the left), capable of managing on site restoration and monitoring activities (in the middle), and that opens to future developments where these data can involve and engage with other types of public (on the right).

ENERGY FLEXIBLE BUILDING CLUSTER

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In response to the urgent threat of climate change, decarbonizing the energy systems has been progressively recognized as a priority in recent European energy policies. Consequently, an exponential growth of variable renewable energy sources penetration is occurring in parallel with the extensive electrification of the demand. Conventional centralized energy systems based on fossil fuels are transforming into efficient decentralized systems supported by renewables and stand-alone energy consumers are shifting towards interconnected energy communities of prosumers able to both consume, locally produce and store energy. For maintaining grid stability and for managing grid congestions, increasing flexibility in the energy system becomes necessary.

As buildings are the largest energy consumer in Europe, responsible for approximately 40% of energy consumption and 36% of CO₂ emissions, they play a key role towards energy flexibility target and can contribute through demand-side management strategies to pursue the objectives of improving the renewable energy usage and fostering the energy-use related carbon emissions reduction. In order for energy flexible buildings to be an asset for the future energy networks, there is a need to provide

a common definition of energy flexibility and develop a methodology for the quantification of the energy flexibility that buildings can offer. Additionally, considering the strong relationship among new generation of smart buildings and energy system domain, the investigation of energy flexibility at building cluster scale represents a profitable way to describe the synergy between buildings and energy grid (unlike the single building), without losing the focus on the detailed technological building related aspects (unlike the city scale).

Therefore, the *energy flexible building cluster* topic is chosen to be investigated in this thesis and the main purposes of the research are: (i) provide a theoretical framework for the definition of energy flexible building clusters; (ii) draw up a quantification methodology to evaluate the energy flexibility performance at building cluster scale.

Since the energy flexible building cluster is a new concept and still lacks a uniform understanding, firstly a state-of-the-art analysis is carried out on currently available energy flexibility definitions and reasons to shift from the single building to the cluster scale. Accordingly, a new definition of energy flexibility and of building cluster concept are proposed and used in combination

to shape the definition of energy flexible building clusters. Then, a collection of the existing indicators that can be applied to quantify energy flexibility at the building cluster scale is presented and the current measures to characterize energy flexibility are overviewed with the aim to identify which aspects are still unsolved and worthy of investigation for an application at the building cluster level. From the review it emerges that the metrics for the evaluation of energy flexibility of building clusters are still fragmented and that the currently proposed operative approaches to determine energy flexibility in buildings prove to be incomplete and still ongoing.

The second part of the thesis focuses on the implementation of the IEA EBC Annex 67 characterization methodology to quantify energy flexibility potential of building clusters. Considering maximize use of renewables and minimize CO₂ emissions as energy flexibility objectives, a control strategy is designed and two novel energy flexibility indicators are suggested. With the aim to obtain the energy demand profiles of the building clusters, a cluster-tailored modelling approach is defined selecting Modelica as proper multi-disciplinary modelling language capable to integrate both building technological characteristics and

energy infrastructure features and different simulations are performed for various cluster configurations. The case-study's results show that the smart operation of the building clusters enables an improvement of renewable energy usage and a reduction of energy-related carbon emissions, but it is necessary to pay close attention to the potentially occurring risks of thermal comfort impairment and increase in energy consumption.

Finally, given the important role of end-users in ensuring that strategies for energy flexibility are viable, the last part of the thesis approaches the energy flexible topic from the perspective of building end-users. The results of a large-scale survey conducted in the Province of Bolzano are presented in order to define first steps towards the assessment of office end-user's perception of renewable energy usage and perception and attitude towards smart grid, smart appliances and smart meters in office buildings. The outcomes point out that the case study office occupants are largely aware about renewable energy sources and conversely, poorly familiar with the smart grid concept. Since social acceptance is an important requirement for the successful implementation and adoption of energy flexibility, organizational and communicative

instruments should be strengthened to boost office end-user's awareness towards smart grid concept, both in terms of benefits and technical aspects.

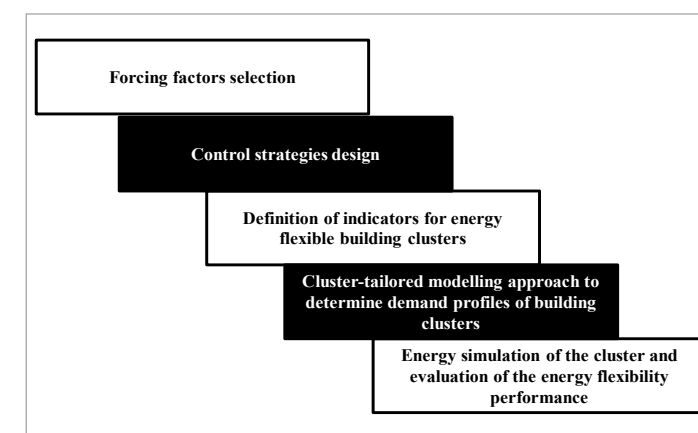


Fig. 1 - Main steps of the methodology for quantifying energy flexibility of building clusters

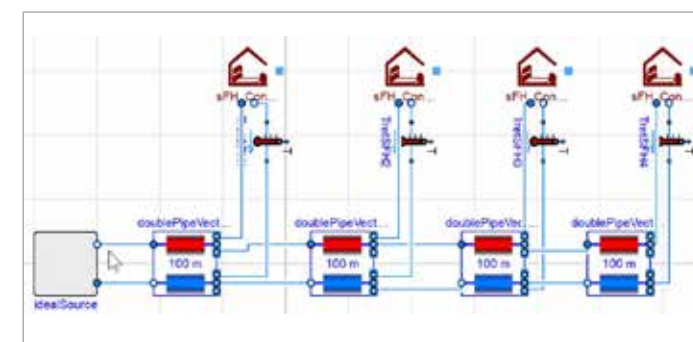


Fig. 2 - Model of the building cluster integrated with the thermal energy grid developed in Modelica language using the IDEAS library's components in Dymola environment