

MECHANICAL ENGINEERING | PHYSICS |
PRESERVATION OF THE ARCHITECTURAL
HERITAGE | STRUCTURAL, SEISMIC
AND GEOTECHNICAL ENGINEERING |
URBAN PLANNING, DESIGN AND
POLICY | AEROSPACE ENGINEERING
| ARCHITECTURAL COMPOSITION |
ARCHITECTURE, BUILT ENVIRONMENT
AND CONSTRUCTION ENGINEERING |
ARCHITECTURAL, URBAN AND INTERIOR
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CHEMICAL ENGINEERING | INFORMATION
TECHNOLOGY | MANAGEMENT ENGINEERING
| MATERIALS ENGINEERING | MATHEMATICAL
MODELS AND METHODS IN ENGINEERING



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 centres 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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IoT ADOPTION FOR INNOVATION OF FM PROCESSES. STRATEGIC LINES FOR FM SERVICES OPTIMIZATION AND INNOVATION

Nazly Atta - Supervisor: Cinzia M. L. Talamo

Tutor: Paola Caputo

The several innovations in the field of information management, the establishment of Big Data and Internet of Things (IoT) concepts and the wide development and dissemination of sensing technologies are opening up innovative scenarios for building Facility Management (FM). The IoT - as defined by the International Telecommunication Union (ITU) - is a dynamic global network infrastructure, based on standard and interoperable communication protocols, that enables advanced services by integrating and interconnecting physical and virtual things, giving them unique identities and possibilities of interact through intelligent interfaces.

The application of such a general purpose technology to the specificity of the FM domain may give rise to new opportunities of innovation of traditional practices. Indeed, IoT technology allows nowadays to easily and economically collect data concerning various aspects of the built environment, bringing out new possibilities for a widespread and continuous monitoring. This new availability and accessibility to real-time data and the possibility of integration with different data coming not only from the building itself but also from the urban environment that surrounds it,

opens the door to the development of innovative strategies of services optimization before inconceivable. In particular, these new possibilities offered by these innovative paradigms can trigger innovation in FM, allowing to collect real-time data and information on actual conditions, current operational status and performance of the building and its components through sensors and devices, achieving a greater awareness and a greater understanding of the behavior of the building itself, as well as of the performance of FM services delivered by/to it. This additional information base may represent a strategic asset and a significant driver for the improvement of cognitive and decision-making processes within the FM practice. However, what the technology potentially offers, if not supported by a vision of possible models of application to the building management, risks to generate a redundancy of data, that could become of little use. Indeed, within this very dynamic and complex scenario, the IoT-based FM is rapidly evolving but the basic fundamentals and references are not yet completely consolidated and shared among all the engaged stakeholders and in the meanwhile Clients are increasing their expectations.

Moreover, nowadays FM stakeholders (e.g. Real Estate owners, FM providers, service suppliers, etc.) are increasingly expressing the need of new methodological tools to support them in understanding the nature and the features of this new technological offer in order to become promoters of FM innovation, by exploiting IoT potential when applied to their specific sector. Indeed, FM operators need to outline innovative approaches to handle, in a conscious and aware way, the technological innovations and seize the opportunity to take advantage of their applications. Therefore, the research objective is to propose strategic support lines for FM services optimization and innovation, based on innovative models of IoT application and Big Data management within FM processes, able to support FM operators and companies in:

- orienting, organizing and managing Big Data flows and their sources (sensor, RFID, etc.);
- changing FM services Demand/Offer and related requirements and, consequently, in developing new approaches to Invitations to Tender/Tenders;
- drawing new supply chains based on network approaches;
- outlining new profiles

of competences for FM stakeholders.

Hence, the thesis - as outcome of the research work - provides to FM stakeholders an Analytical-Procedural Framework useful for defining, implementing and requesting IoT-based FM services, made up by:

- an analytical framework for implementing IoT & Big Data technologies within building FM processes;
- a definition of tools and procedures for innovative modalities of FM service provision;
- support lines for the writing of Invitations to Tender (ITTs) for IoT-based FM service provision including required competences.

In particular, the developed analytical-procedural tool for IoT integration in FM processes is able to support FM stakeholders (e.g. Real Estate owners, Facility Managers, FM consulting companies, FM Providers and Suppliers, etc.) in:

- orienting, organizing and managing Big Data flows and sources (sensors, RFID tags, etc.). The Thesis proposes a classification and a normalized taxonomy of detectable FM-related parameters and related IoT sensors and devices to support Clients and FM Providers in expressing the FM information need with respect to IoT requirements, and in rationalize the market offer of Sensing Technologies since nowadays it is still highly variegated and often difficult to understand;

- enhancing the responsiveness of the building and its components as well as defining new condition-based strategies and preventive strategies for improving FM services planning and programming. The Thesis proposes Sensing and Responding (S-R) models for an advance FM information management, as well as a functional model of the multi-layered IoT Architecture (enabling a centralized information management aiming to improve FM decision-making) and innovative organizational and operative models for an integrated management of FM services. Moreover, the Thesis applies innovative condition-based strategies and preventive strategies - enabled by IoT - to the services of Operation & Maintenance, Cleaning, Waste Management, Space Management and Energy Management;
- assessing the IoT-based FM scenario according to the technological and economic feasibility, orienting FM stakeholders in defining new possible business models. The Thesis defines potential business models, analyzing the possibilities, concerns and risks related to the IoT-based FM scenario, focusing on information security, responsibility and ownership within the context of agreements between Client and IT Provider for the provision of IoT-based FM services;
- applying the developed IoT-based strategies for FM processes and services

- innovation, by introducing a methodology - made up by four procedural steps: Explore, Envision, Implement, Support - to design, develop and implement new use-based FM services;
- changing FM services Demand/Offer and related requirements and, consequently, in developing new approaches to Invitations to Tender (ITTs). The Thesis proposes some guidance lines to support Clients in gaining the new awareness and consciousness needed to properly and comprehensively express their requests in ITTs in the context of a tendering process for the provision of IoT-based FM services;
- drawing new supply chains based on network approaches, as well as outlining new required profiles of competences for FM stakeholders. The Thesis defines an innovative model of network-based FM supply chain, as well as a framework of the new required IoT-related profiles of skills and competence for FM stakeholders, articulated into levels of maturity.

Within this dynamic IoT-based FM scenario - currently still at an infantile stage and in need of efforts to harmonize and consolidate the practices - the developed analytical-procedural tool contributes to standardize and systematize the application of IoT to FM processes, supporting in this way FM stakeholders in consciously exploiting the opportunity to create value from the implementation of IoT technologies within their business.

HOLISTIC GENERATIVE MODELING PROCESS FOR HBIM

Fabrizio Banfi - Supervisor: Raffaella Brumana

Tutor: Enrico De Angelis

In a world of exponential growth, the Architecture, Engineering and Construction (AEC) industry is facing a great process re-engineering thanks to the latest developments in technology. Recent studies show significant and beneficial increases through the use of newly advanced methods and digital tools such as Building Information Modelling (BIM) and Terrestrial Laser Scanning (TLS). BIM is an innovative method capable of collecting and analysing a considerable quantity of information (Big data) and improving building management during its lifecycle (BLM). Also, BIM enhances information sharing during the traditional process of new construction, yet it often requires high levels of knowledge management using complex and advanced applications, such as holistic digital models for built heritage (HBIM). In recent years, innovation in the Digital Cultural Heritage (DCH) domain has been supported by the development of modern 3D survey tools able to transmit morphological characteristics of heritage buildings, revealing their uniqueness. Unfortunately, the intricate reality of the built heritage and the growing need to represent the

actual geometry using 3D models collide with the paradigms of complexity and accuracy and opening an operative perspective for preservation, restoration and conservation. The absence of 3D objects corresponding to complex historical elements in BIM libraries requires the creation of three-dimensional objects through a restricted set of modeling commands, requiring a huge manual effort, long processing times and usually leads to a significant information loss during the generative process. Modeling and the creation of HBIM objects have been identified as one of the barriers in BIM application; there are three factors to consider using a holistic point of view: tech solution (i), interoperability /coworking (ii) and cost-effectiveness (iii). Against this backdrop, this thesis proposes a Modeling Management Information System (MMIS) characterised by novel grades of generation (GOG) and accuracy (GOA) oriented to improve the generation of complex elements from point cloud data (Terrestrial laser scanning TLS, Digital Photogrammetry DP), and to face the paradigm of complexity (built heritage and its architectural and structural elements) against

the regularity of BIM libraries (simple geometric shapes for new buildings). Such validation can be extended to the whole model of some specific parts, resulting in a mathematical definition of the geometric accuracy achieved through easy-to-understand indexes behind a complex comparison, but also essential to control the paradigm of simplification where needed. The generative model concept aims to migrate to the modeling concept and HBIM parametrization, thus allowing it to tackle a full interoperability, switching to different environments behind BIM such as design, restoration, Finite Element Analysis (FEA), Construction Site Information Modelling (CoSIM), Facility Management (FM) and Mixed reality (Virtual and augmented reality VR/AR), becoming a useful link in a long chain of interconnected users from specialists, to tourists and ordinary citizens. As has been shown by this study, the recognition of the cultural values of an object depended on its capacity to arouse certain new type of parameters (not just the default parameters in BIM application) that led the society and experts in question to consider it as heritage and

therefore, to a further step in which heritage is no longer defined on the basis of its physical and morphological aspect.

The digital revolution we are witnessing from day to day requires a continuous and constant update on applications, methods of representation, mapping and sharing information. BIM is certainly a phenomenon linked to the incessant progress of IT solutions to support our work and the inclusion of values and information linked to a temporal process stratified over time and in culture. For this reason, the definition of technical requirements cannot lead to tangible advantages. The value of information should be highlighted as much as the accuracy of the model but leaving open a door to future updates and new types of data storage. For this reason, models and methods that simulate the detected reality will become in common use, while the value of built heritage information cannot be contained in a single hub. MMIS bases the generative process of Scan-to-BIM models on the concept of modeling flexibility and free information mapping. Therefore, the centralization of the BIM process cannot require a single information model, but rather the ability to know how to relate in different forms to different types of analyzes and uses. The approach to these methods, software and requirements, therefore, requires specific levels of knowledge and training

paths able to bring out each individual potential. The aim of highlighting some requirements in the modeling has allowed one to highlight how the usefulness of the models produced for each individual research case study have brought important results in different fields of application and analysis, bringing the model from a three-dimensional representation to a management process of the built heritage. The holistic approach to generating accurate and informative models should become a requirement of every BIM expert, avoiding to conceive the BIM as an instrument able to produce a single centralized model. This thesis, in addition to having increased the level of automation of the generative process of information models, has shown that the built heritage requires the knowledge of theories and techniques applicable to different phases of the life cycle of the building. A building is not the serial reproduction of a single prototype, but rather a holistic representation where different subjects contribute and the activities flow into the life cycle. The management of these processes, if left to chance, produces enormous diseconomies. Therefore, the management and multiplicity of these processes, over a period that can not be defined, raises the problem of knowledge management, i.e. the sharing, archiving and restitution of a great deal of data. MMIS has shown how these concepts cannot be expressed in a single model, and the generation of Scan-to-BIM models requires

the ability of experts involved in the process of knowing how to relate to the process of digitizing the built heritage in a conscious and above all sustainable way, improving new levels of information disclosure. Thanks to new modeling requirements and the developed add-in for Revit, MMIS has also made it possible to reduce costs and times of modeling (economic impact), favouring the information-sharing (cultural impact) and the use of models in different types of BIM-based analysis (holistic impact) and maintaining high level of interoperability among different type of application (both open-source or property). The enhancement of information and intrinsic culture in a specific artefact can be improved through the potential of MMIS. The potential of three-dimensional 3D survey techniques opens to various forms of digital modeling and information sharing, extending to the field of built heritage. In this specific context, the importance and the centrality of the user and his knowledge of modeling are the primary sources for the correct management of the process. It is, therefore, necessary an important unifying effort, the definition of general rules that allow us to understand the wealth of tangible and not tangible built heritage values but which, at the same time, do not create a *'straitjacket'* to modeling techniques, the latter considered one of the most important *'driving force'* behind to information sharing in digital era.

COMPREHENSIVE ENERGY SOLUTIONS IN HUMANITARIAN SETTLEMENTS: FROM THE ENERGY-FOOD NEXUS TO A HOLISTIC APPROACH TO ENERGY PLANNING

Jacopo Barbieri - Supervisor: Emanuela Colombo

Tutor: Claudio Del Pero

Energy plays a fundamental role in shaping the human condition: affordable, clean and safe energy is necessary for economic development and eradication of extreme poverty. The Sustainable Development Goal 7 - 'Ensure access to affordable, reliable, sustainable and modern energy for all' - specifically addresses the most relevant challenges of the global energy sector. Despite the relevance of such challenges, this goal is still far to be reached. In particular, humanitarian settings represent the worst case, since energy shortage exacerbates the already extreme living conditions of displaced people, threatening the fulfilment even of the minimum standards defined by the humanitarian system. The research work presented in this doctoral thesis aims at contributing to the specific topic of energy access in humanitarian settings, by (i) improving the understanding of the scientific community on the subject, (ii) exploring the current main criticalities, challenges, and opportunities, and (iii) contributing with a set of actions and tools to promote better energy interventions in such contexts. The work capitalizes the results of a research programme on sustainable energy in

humanitarian settings, including different desk studies and hands-on works in the field. In a first section, fundamentals on energy poverty and energy access are introduced under a global perspective. An analysis of the current status of access to energy focuses on the context of the Global South, looking at both electricity and thermal uses. On a second step, the analysis is centred on energy access in humanitarian settings, evidencing that the lack of sustainable energy provision is one of the major contributors to many challenges of the humanitarian response. In particular, the relevance of the energy-food nexus is underlined in the light of the core elements of the humanitarian system. It is shown that the energy-food nexus can be identified as the essential entry point to energy interventions in situations of displacement, based on the fact that food security and nutrition are among the main pillars of the humanitarian response. In addition, the main overall financial and institutional causes concurring to unsustainable practices that characterize the current situation are depicted, with reference to the humanitarian clusters system. An in-depth review of humanitarian interventions, and

of the relevant scientific and grey literature associated to such interventions, allows to analyse "what have been done so far". The analysis reveals that energy for cooking has been the most addressed topic. This is due to the fact that energy is fundamental for food processing, preparation and preservation, which includes, for example, cooking, refrigeration, and safe water provision. Current cooking technologies and practices in humanitarian settings are analysed, to unveil unsustainable results and negative impacts, and propose possible solutions. The analysis also allows to identify other emerging areas of intervention, including innovative food preservation and sustainable power systems. An exemplificative set of innovative approaches that may improve the success, and widen the areas of energy interventions is proposed in the form of simple case studies. Such innovative approaches include: adoption of technologies used in other contexts; technology adaptation; technology creation with a cooperative approach. The overall analysis brings to the conclusion that best achievements would be reached by shifting from monothematic interventions to a holistic approach considering all energy uses.

Based on such considerations, the next step focuses on "how could we do better". Sustainability of energy interventions in critical settings is tackled by proposing an innovative comprehensive energy solutions planning (CESP) framework. The proposal is based on the awareness that very few studies in the literature deal with this subject with a specific focus on critical contexts, including rural areas of the Global South and humanitarian settings. A clear room is unveiled in this sense, to contributing on the topic in order to support researchers, practitioners and policy makers with the identification of the different phases and actions that characterize the energy planning process. As a first step, the general theory of CESP is introduced through a characterization of the various phases of the planning process, from needs assessment to impact evaluation. More practical indications and specific considerations follow, for the case of humanitarian settings. The CESP framework is applied to a case study in a refugee settlement in north Lebanon, where a hybrid PV-wind micro-grid has been developed to power community refrigerators for food preservation and additional small appliances for basic lighting and communication. The novel CESP framework can be considered as a first step towards the implementation of sustainable energy systems in humanitarian settings. However, the framework itself would lack of effectiveness without a sufficient level of awareness of humanitarian operators on the matter. Consistently, the last part

of the work targets the theme of "transferring knowledge from energy experts to humanitarian professionals". The basic idea is that even the best innovation is pointless if it is not capitalized nor replicated by the humanitarian system. The capacity building programme implemented in the framework of the Sustainable Energy Technologies for Food utilization (SET4Food) project, is introduced as an example of effective action. The programme includes the provision of in-presence and online trainings on energy in humanitarian settings, the development of practical supportive tools, and the creation of an online global community of practice (ENERGYCoP) fostering networking and collaboration among different professionals and stakeholders of the humanitarian sector. The work and the achieved results allowed drawing some policy implications. The most general one is *the necessity to consider energy as a complex matter*. The concept of energy includes thermal energy and electricity, so that both should be considered at the same time. Energy is fundamental for ensuring the fulfilment of many needs, and can be used in different ways. Even in the specific context of humanitarian settings, energy is fundamental not only to ensure food security, which connects to food cooking, water boiling, and food preservation, but also for people security and safety. Moreover, energy utilization influences, and is influenced by, several socio-economic and environmental factors. Simplistic monothematic approaches, are

likely to be scarcely effective, which is the case of many interventions that have been carried out so far. The utilization of holistic planning schemes entails the *need for innovative approaches and solutions*, where the term innovation refers to the adoption, adaptation and creation of new systems or concepts from a local or global perspective. However, this remains difficult as long as *a general framework for energy in humanitarian settings* is not provided. The contribution of the Author to the launch of the Global Plan of Action for Sustainable Energy Solutions in Situations of Displacement (GPA) represents a step on this way.

ARCHITECTURE AND CITIES IN THE PUNJAB REGION

AN INTRODUCTION STUDY OF THE URBAN FEATURE

ARCHITECTURE ACROSS THE MAIN CITIES OF PUNJAB BETWEEN PAKISTAN AND INDIA

Daniele Beacco - Supervisor and Tutor: Adalberto Del Bo

The main objective of this thesis is the identification of architectural principles that characterize the architecture of the cities of Punjab through the analysis of major urban centers and their transformations. The geographical area of study corresponds to the maximum extension of the Punjab region in the last century. This homogeneous cultural area has been reduced in its administrative boundary and divided between the Pakistan of today and India in 1947. The research focuses on the spatial and morphological logic that determine the urban areas of this region, in light of the interaction between geographical, political, social, religious and economical aspects. The restitution of urban and architectural specificities was implemented starting with the discussion of the limited and limiting definition of an "Islamic City". This critical analysis of the characterization became a useful pretext for the delineation of a type of city that is typical of the so-called "city of Muslims" but also possesses spatial organizational peculiarities inherited from the interaction with previous settlements of Hindu people who occupied the Indo-Gangetic area for millennia.

The criticism towards a monolithic definition is too general as that of an "Islamic City", which in contemporary literature and recent research is often accompanied by regional attributions, which becomes the useful tool to implement an urban comparison between the major cities of Islamic world (*dār al-Islām*) and those placed along its easternmost limit, historically outlined by Islamic expansion in the Indian subcontinent. Consequently, the results highlight the need to reformulate the definition of an "Islamic City", which is often not exhaustive for its reference to a mere series of religious and social aspects. A criteria that delineates an urban character starting from cultural, social to religious contributions within regional and territorial borders would be preferred. A specific reflection on the term "Islamic City" and its interpretation in the last two centuries must be carried out in this thesis taking into consideration the main research led by the early European Orientalists and contemporary researchers in the cities of the Middle East and North Africa. In this thesis, the studies concerning the urban analysis of the Islamic city in the Middle East have been joined by the less known

ones conducted in the Indian Subcontinent mainly sponsored by the British government and by contemporary international scholars. The results of these comparative studies have clarified the presence of two main blocks of researchers and theorists: the German and French orientalist and on the other hand the British orientalist. The first group of researchers were prevalent in the early development of Middle Eastern urban literature and are represented by William and George Marçais, Jean Sauvaget, Roger Le Turneau and Robert Brunschvig. The listed authors have outlined the main characteristics of cities inhabited by Muslims. Subsequently, a second generation of researchers developed a profound revision of the description of the cities across the Muslim world. They focused on reducing the numerous general characterizations that defined an urban shape. The second generation of researchers were represented by Albert Hourani, Ira Marwin Lapidus, Richard Eaton, Eugen Wirth. Finally, the third generation of theorists such, Nazar Asayyad, André Raymond and above all the Italian school with Paolo Cuneo, Ludovico Micara,

Stefano Bianca, Attilio Petruccioli (to quote the most important researchers), have carried out a profound re-elaboration of previous urban analysis, intercepting the regional and territorial varieties of *dār al-Islām* undermining the monolithic definition of "Islamic City. Their research along with the recent studies and urban projects promoted by the Aga Khan Trust for Culture in India and in Pakistan aim to achieve a greater degree of knowledge of these regions, bringing the wealth of the urban literature of the Subcontinent to that of the Middle East developed in the last two centuries. In most cases the typical Muslim city was generally influenced and characterized by Islamic law (*Sharia*-understood as a set of behavioral and settlement rules of the Muslim community). However, in this thesis, emphasis are on the fact that such regulatory framework is partly being replaced by the phenomena of necessary syncretism for the

coexistence of two cohabiting communities in the same urban area, the Hindus and Muslims of Punjab. The two groups have different religious beliefs and two distinct political social organizations. On a larger scale the comparative urban analysis concerns the general character of all major cities of *dār al-Islām*, while on a regional scale with reference to the Punjab region, is enlighten the typical spatial organization, analyzing the primary element along with their relations into the urban space up to the organization of the urban block and the residence. Defining the morphological-type principles of the architecture of the cities of Punjab, the research focuses on two case studies for which the need for a definition of composition is evidently more complex than the one indicated in the general definition of an "Islamic City".

The first concerns the historical city of Multan and the second one is the recent construction of the capital of Pakistan; Islamabad as an example of a contemporary city including traditional urban features, so far underrated by architectural and urban research.



Fig. 1 - Multan Walled city center, with the mosque of Nawad Ali Wali that shares the city core with Hindu temple (one is visible behind the mosque) Source Author's photo (2017).



Fig. 2 - Multan Walled City, one of the houses typology named *makan*. Source: author's photo (2017)

DIGITALISATION OF TENDERING AND AWARDING PROCESSES: A BUILDING INFORMATION MODELLING (BIM) – BASED APPROACH TO PUBLIC PROCUREMENT ROUTES

Marzia Bolpagni - Supervisor and Tutor: Angelo L. C. Ciribini

Co-Supervisor: David Philp

In several countries the construction sector is moving from an analogue to a digital approach promoting an efficient and technologically advanced construction industry. More and more, public clients start to implement new strategies, embracing digitally driven approaches. Thus, clients assume an important role as drivers of a digital procurement approach, creating the right digital landscape to set contents and constraints for a computable process. Moreover, within the procurement process, tendering plays a key role for the success of a project; however, the management of a fully computable process is still a difficult task. For the client it is not simple to establish and check requirements over the contractual time. The aim in this dissertation is to investigate and improve the digital tendering and awarding processes in the construction sector by setting consistent and unambiguous information requirements. To achieve this, the grounded theory has been used as methodology to (a) identify how clients are currently implementing digital tendering and awarding processes; (b) identify the legal implications of using BIM in tendering and awarding processes; (c) define different client types

and investigate when Building Information Modelling (BIM) can be more beneficial (d) identify the relations between BIM diffusion at macro level and the BIM implementation at organisation level; (e) illustrate and compare different client requirements related to Information Modelling and Management; (f) identify and test a framework for Information Modelling Requirements; (g) identify how client requirements can be defined and managed in a consistent and unambiguous way to allow automated or semiautomatic compliance checking. First, data is collected through interviews, surveys, literature review and observation in order to understand limits and possibilities of a digital approach and the role of different parties involved in the process. Second, long-term research cooperation with two advanced clients, the Massachusetts Port Authority in USA and the Ministry of Justice in the UK, is established in order to outline the problem and the current situation in detail. The findings show a gap in the industry in defining consistent and unambiguous computable requirements. The outcome of the research allows clients to set digital tendering and awarding processes using a framework that

can be linked to smart contracts. The main limitation of the research deals with the validation of the framework that has been applied only on a single case study and it refers to technical implementations that can rapidly evolve. Future work should be done to test the framework in different projects and in different client organisations. In addition, the link between the framework and smart contracts should be further investigated in order to check requirements during the entire lifecycle.

CONSERVATION AND MANAGEMENT OF BUILT CULTURAL HERITAGE: THE CASE OF PUBLIC COMPLEX PROPERTIES

Cristina Boniotti - Supervisor: Stefano Della Torre

Tutor: Gianandrea Ciaramella - Co-Supervisor: Caroline Cheong

Cultural heritage bears the potential to beget some sound economic value that, by the way, does not at all conflict with its aesthetic worth and can be measured by means of numerical indicators both from a tangible and intangible perspective. Boasting an economic value that is subject to most commonly accepted rules of production, exchange, pricing, and cost-benefit analysis, cultural heritage is likely to strongly influence a country's overall outlook, which implies that a lot of direct and indirect benefits can be achieved for the benefit of communities.

Public properties are a significant cultural heritage and a wide range of real estate, characterized by an important strategic value as well as a degree of social and economic potential, which is required to be adequately conserved and valorized.

In light of the difficulties the Italian Government typically faces in conserving and managing its rich public cultural heritage, which often lingers in a condition of neglect, our research's objective is to identify a set of additional tools capable of providing adequate financial resources as well as skills. The study aims at fostering a preliminary reflection on possible sector-specific models

for public built cultural heritage management that have not been well defined yet, especially so in reference to one of the institutional options, namely the adoption of public-private agreements. The thesis develops a first broad theoretical examination, illustrated in the first section of the text and based on the analysis of secondary documents, as well as an applicable/on field verification, reported in the second part and based on the analysis of primary documents (interviews, financial data, tenders and contract documents).

The general research methodology adopted was of a qualitative rather than quantitative nature. In fact, the resulting considerations mainly follow the examination of the different management models a public entity may adopt and the description of the case studies we collected through interviews. This method allowed for transcending the merely quantitative-formal representation of processes, as all procedures consist in a number of complex interrelations amongst people, enterprises, and public entities. Besides, an adequate sample of public-private partnership (P3) initiatives, though useful in collecting quantitative data, does not exist yet due to

these initiatives' limited number and their being mostly in progress as we write.

The proposal is aimed at proving that the adoption of an up-to-date approach capable of projecting the definition of cultural heritage beyond its traditional boundaries could pose new opportunities. It foresees the converging of investments from different sectors into cultural heritage by means of negotiation dialogues fostering the use of non-heritage funding originating from other domains such as the labor market, regional development, and creative industries, to achieve heritage and non heritage-related goals. This alternative model of cultural heritage enhancement implies that a trade-off be pursued between different parties and the subsequent introduction of the concept of trading zone, which is a form of dialogue and cooperation at once, despite the divergences existing amongst various sectors. This collaboration makes resources become available for conservation and valorization activities, thus boosting the exchange of good practices and abilities, and creating new networks. Although well-established opinions state that the conservation of cultural heritage as common

goods basically pertains to the purview of the public sector, the participation of private resources may pose an opportunity for the public administration to intercept new funding channels. During a workshop organized by the Directorate-General for Research and Innovation of the European Commission, even the Horizon 2020 Expert Group on Cultural Heritage highlighted that the public sector should refocus its own approach by incentivizing and encouraging the private sector to get involved and invest in cultural heritage through new financial instruments such as tax breaks, differentiated VAT brackets, well-designed grants, loan programs, and public-private partnership schemes.

Consistent with the previously illustrated models, P3 is an organizational issue that implies some degree of cooperation between different partners. The interest towards partnership schemes is consistent with the multiplicity of interactions they create and the variety of operational instruments whereby they are implemented. Since P3 has already been adopted in the past and in diverse contexts, as for instance in infrastructure development, our research does not focus on innovating this

alternative way of funding, but rather on describing and analyzing this emerging phenomenon of transaction between public and private organizations in the cultural heritage field, as it has not been widely adopted.

In addition to strong ties between political institutions and the business sector, some strong involvement of society as a whole is advised to foster the implementation of projects and expedite the solution of shared problems. At a local level, for example, private stakeholders participation must be built with special attention to the latter's cultural closeness to the territory involved. Therefore, we also ought to stress that a public-private-people partnership (P4) model is the approach of choice in certain contexts.

For future reference, the effort to involve actors not usually interested in such endeavors will have to be consolidated by conveying the importance of culture in the local economy and promoting collaboration among actors commonly not used to cooperating with other entities. The exchange of ideas and know-how stemming from various fields and disciplines might well lend some precious contribution to local economies

and foster the development of more strategic networks aimed at yet novel and more ambitious goals. New governance models will have to take into account private actors as decision makers and participants in the management of common goods together with public entities. Considering the budget constraints harrowing most European Governments, the P3 and P4 approaches may well ensure private funding and know-how in all-inclusive and long-term projects and further provide some useful guidance in informing future initiatives.

The research is aimed at fostering understanding and awareness of the full potential of cultural heritage. The spread of these approaches might set the stage for implementing European projects aimed at developing effective policies for heritage throughout the territory. These might in turn represent these theories' practical application in an economic context, and subsequently disseminate new management strategies, strengthen the relationship between the public and private sectors, and involve novel market-based partners and stakeholders.

SUSTAINABLE COMPOSITE STEEL-CONCRETE CONSTRUCTION

Giovanni Brambilla - Supervisor and Tutor: Carlo Andrea Castiglioni

The current policies in Europe and in the world are promoting a transition towards a circular economy with the aim of responding to the urgent environmental demands. One of the main sectors of the economy with the greatest business potential within the circular economy is the building sector due to its massive impact on the resource consumption, waste generation and environmental emissions. In this scenario, a more sustainable construction can be achieved by demountable structural systems enabling the disassembly and the reuse of the structural elements at the deconstruction time. This work focuses on composite steel-concrete flooring system which represents the most efficient structural solution for buildings and bridges, as the composite action combines and optimizes the structural properties of the two most used and impactful building materials, i.e. steel and concrete. These systems are currently designed, produced and erected with a shear connection system which makes the disassembly of the structural elements almost impossible. Demountable shear connection systems for composite steel concrete beams were proposed by previous research studies, showing the high potential

of these technical solutions compared to the welded headed studs. However, none of these systems has been introduced in the construction practices and regulated by design codes due to a series of shortcomings. This work focuses on the demountable steel-concrete beams made of precast concrete slabs and steel beams connected by pretensioned high strength friction-grip bolts. In fact, this technical solution investigated in few previous studies provides the highest reuse potential due to the full disassembly of all the elements, as well as the dry and modularity properties guaranteed by precast concrete planks instead of cast in-situ concrete slabs. An unusual and comprehensive interdisciplinary study was performed on the investigated system with a transversal approach capable of breaking down the barriers between different disciplines. Initially, a solution similar to the ones proposed in the previous studies

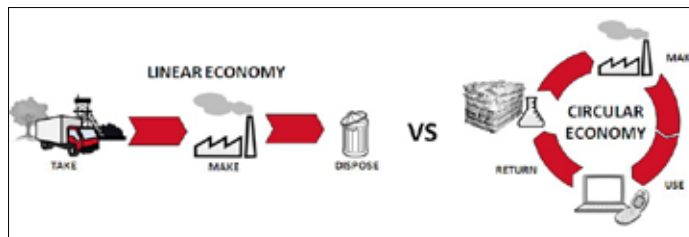


Fig. 1 - Closing the loop for a circular economy.

was examined to validate the behaviour of the structural system by means of a combined experimental and numerical approach. This stage of the research allowed to gain an extensive knowledge of the system in order to develop an optimized and novel solution able to address all the requirements of the different life-cycle phases of the structure, i.e. the production, the assembly, the use, the disassembly and the reuse phases. The feasibility of the novel coupling system was proved by means of experimental push-out tests that showed the significant improvement of the structural performance in terms of both strength and ductility (ultimate limit state), as well as stiffness at early stage of loading (serviceability limit state), compared with the conventional welded studs. At this stage, a design worked example of a multi-storey building was performed, comparing

the proposed novel solution to the most diffused ones. The quantities of the building materials were used as input data in the environmental and economic assessments. The environmental benefits of the reuse compared to the conventional recycling scenario were quantified through a Life Cycle Assessment, considering all the life cycle phases of the building and including the peculiar end-of-life scenarios. Finally, a global cost analysis was developed in order to

evaluate the economic viability of the proposed novel system. Based on the obtained outcomes, this interdisciplinary study demonstrated that the proposed novel coupling system ensures an optimal structural performance, facilitates the manufacturing and the assembly/disassembly of all the structural elements, significantly reduces the environmental impacts of the construction through the reuse of the elements and finally also

provides a business opportunity that can be profitably addressed within the growing circular economy.



Fig. 2 - Specimen for push out tests (a), test layout in Material Testing Laboratory (LPM) of Politecnico di Milano (b), and failure of test specimen (c).

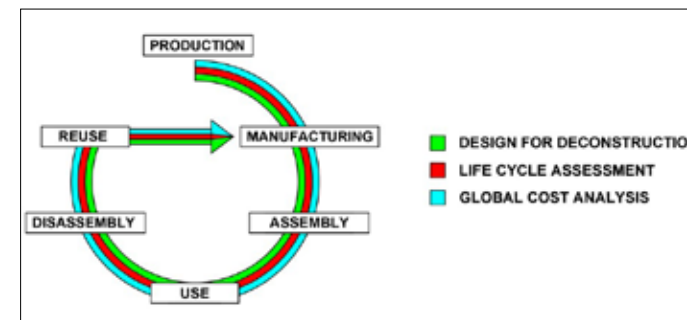


Fig. 3 - Life cycles stages addressed by an interdisciplinary approach.

THE CONSTRUCTION OF A MONUMENT. PALAZZO TE IN MANTUA

Ludovica Cappelletti - Supervisor and Tutor: Mariacristina Loi

Co-Supervisor: Federico Bucci

This research is centred upon the subject of the construction of the monument and addresses two main issues, that shape the study as open enquiries: the *idea* of monument, the concept attributed to it that today intertwines with the problem of valorisation of cultural and architectural heritage; and secondly, its *construction*, as both an architectural and critical process. Within this reference system, this work explores the history of one specific architecture, Palazzo Te in Mantua.

Starting from the Sixteenth century, Palazzo Te develops through subsequent designs; a first hypothesis supposes an architectural construction already present on the island of Te before 1525; the nucleus of Palazzo Te then develops *over* and around this first building, according to a design by Giulio Romano, and it is built approximately between 1525 and 1535.

From the construction of the villa based on Giulio Romano's design, and until today, Palazzo Te has been the object of numerous restorations and interventions dedicated to preserving its architecture and ornamental apparatus; in the Twentieth century, this process has been accompanied by the conversion of the entire palace into an

exhibition centre for modern art and international centre for art and culture, *Galleria di Arte Moderna* and *Centro Internazionale d'Arte e Cultura*. The projects of valorisation, conservation and restoration, the last of which was completed in 2017, have in fact confirmed the acknowledgement of the architectural and cultural value of Palazzo Te.

However the sequence of events of the palace cannot be retraced to one unique moment of construction in which the subsequent and contemporary works could be considered as grafting or additions. Each era offers a unique and recognizable contribution to the conformation of Palazzo Te. The building process continues, changes, and each design offers ever evolving interpretation keys to the same architecture, and to the pictorial and decorative apparatuses that compose it.

Along with the architectural construction, from the Eighteenth century it is possible to systematically retrace the path of a *critical construction* regarding Palazzo Te: the palace is visited and described by architects and travellers, but also surveyed and analysed, and its state of conservation thoroughly documented. In the Twentieth

century, monographic studies are realised, among which the well-known texts by Ernst Gombrich, John Shearman, Manfredo Tafuri and Egon Verheyen, that add an in-depth knowledge of its architecture and art, of the constructive systems employed and the protagonists who have taken part to its realisation, of the original design and its critical fortune.

The architectural interventions and the cultural practice of valorisation of the palace appear to have *built the monument* according to one predominant image: the palace by Giulio Romano, both architect and painter; an image that has constantly strengthened in the collective memory. In 1921 Palazzo Te becomes a museum as monument to architecture and art, *together*.

From Seventeenth century onwards, the relationship with the building is a direct one, it passes through the design of architecture, in an operative approach that necessarily implies an interpretation of the existing structure. Each architect who works at Palazzo Te in various eras observes a different building, one that shows the passing of time; but most of all, one that is *defined* by the passing of time in the shape of architectural

designs realised in the villa. Each one interprets Giulio Romano's design aiming to perpetuate its image; these interventions lead to a continuous re-reading of Giulio Romano's work, that has contributed to the conservation of the palace, but has especially defined a specific relationship with the palace: Palazzo Te thus reveals the stratification of works in its architecture, and thus the monument is *built*. It becomes a *monument* in its idea, according to a process that starts immediately after its construction, being shaped by each executed design and settling in the Eighteenth century, when the palace is already the renowned monument by Giulio Romano. The influence of this interpretation on the perception of Palazzo Te has reached contemporary times, as demonstrated by the frequent interventions on the villa, and poses still unresolved issues regarding the building history of the palace. Today, Palazzo Te shows evident traces of the interventions that have followed Giulio Romano's construction, and that have changed, revised or restored its formal structures and design aspects, shaping the place as known today: a *monument*. This dissertation explores one of the possible interpretations of the system of Palazzo Te and its architecture: the construction of the monument as the result of stratifications of designs that have succeeded one another through time, aiming to bring the history of this civil building back to its intrinsic discontinuity, and to the relationship between each design and the architect

who drew it and the era that generated it. The palace is seen not as one architecture, but as a multifaceted work in its coherence, untied to any authorial research that may identify it as the product of just one architect, but acknowledged as the product of different interventions, pertaining to diverse times and testifying a continuous research in architecture. Therefore, it is not a single architect, nor a single work, that defines the architecture of the palace, but the sequence of designers and interventions, the alternation of these works across the time of the monument, as a collective work. This multiplicity is one of the most modern characters of the villa: the relationship between construction and design depicts a process of continuous construction. This research work proposes to consider Palazzo Te not as the work of *one* architect, but as an architecture that crosses time and is defined by it. Its building history does not conform to a sequence of punctual events, but is shaped as a system that is modified through time, extending through different eras, languages and conditions, and therefore referring to different *times*, rather than simply different authors: this aspect does not characterise only Palazzo Te, but has been observed and studied in many other architectures in history, architectures that find their peculiarity in this feature. This analysis aims to refer to a unique system, from which Palazzo Te seems to emerge as a product of the long progression of time as an architect. The aim is indeed to

rebuild this system, tracing this evolving process as a continuously growing heritage, and considering such aspect as one to be valorised, as suggested by the peculiarity of the city of Mantua within the UNESCO program, thus providing operating instruments for its built heritage.

Finally, this dissertation questions itself regarding the possibility to contribute to a research method able to analyse the numerous situations analogous to Palazzo Te, other architectures where the true architect of the overall monument cannot be identified with one single professional, or one era, but with the long process of transformation itself, a process that history of architecture has consistently investigated in its progression as a fundamental element, and that has recently been approached, in other studies, with an analytical method founded upon the idea of the building as stratified in history. Therefore, this doctoral research, too, aims to move beyond the singularity of Palazzo Te, to acknowledge the value of this and other architectures *beyond* the single architect, towards their construction through time.

CHARACTERIZATION OF COLD FORMED PROFILES AND STRUCTURAL DETAILS OF PALLET RACKING SYSTEMS: APPLICATION OF ARTIFICIAL INTELLIGENCE

Gian Paolo Chiarelli - Supervisor and Tutor: Carlo Andrea Castiglioni

In recent years, an increasing number of pallet racking producers referred to the material testing laboratory (Laboratorio Prove Materiali - LPM) of Politecnico di Milano (POLIMI) for the execution of the experimental tests provided in Annex A of EN 15512 necessary to characterize their products and whose test set-ups I contributed to design. As a result of this experimental activity, a significant number of data are available. In order to extrapolate all possible information from the tests carried out, the main idea of this thesis work is to collect the results obtained by the laboratory for the same test typology from the different producers and analyse them through the application of a learning machine algorithm (a specific field of artificial intelligence).

My initial idea was to create for each typology of test provided by EN 15512, a "predictor tool" that processing the collected data can be used to predict the component behaviour. However, the data processing based on the learning machine algorithm was possible to be applied only on the data related to the bending test on beam-to-upright connections. In fact, a "quality analysis" was performed considering the 2 main aspects that affect the quality

of a database: the dimension (number of data contained) and the consistency of the archived data, with careful consideration to the influence of the test set-ups/ test procedure on the test results. From this analysis it turned out that for many types of tests the available consistent data were too few to represent a statistically significant sample. Referring to other data, coming from different labs turned out to be unfeasible because of differences detected in the testing procedures adopted by different labs, although falling within the freedom ranges allowed by the code.

Artificial Neural Network algorithm (ANN), one of the most common machine learning algorithms, was used to process the data related to the bending test on beam-to-upright connector. Preliminary to the data process, the main input and output parameters were identified by means of experimental observations, numerical studies, and considering previous researches. The output parameters are the main results obtained from tests, while the input parameters are the geometrical or material properties of the structural components that affect the output ones. Then, the optimal architecture of the ANN algorithm was identified by means of an interactive procedure. Finally,

the accuracy of the calibrated tool was analysed, and its possible use was discussed.

Indeed, improvements of the testing set-ups proposed by the Standard, in order to increase the quality of the test results, are presented.

The presented work wants to represent a different possible approach for exploitation of available data by laboratories performing the tests. By collecting the data obtained from the test (honouring the non-disclosure agreement between the laboratory and the producers), repeated for many different producers, useful information can be provided to the industry and to the researchers without any additional costs.

Keywords

Application of Neural Network, pallet-racking system, beam to column connection, consistency analyses of collected data, small databases, experimental tests provided in Annex A of EN 15512.

ENVIRONMENT-DRIVEN CHANGE MANAGEMENT IN AEC FIRMS. LIFE CYCLE PERSPECTIVE IN PRACTICE

Anna Dalla Valle - Supervisors: Andrea Campioli

Tutor: Angelo L. C. Ciribini - Co-Supervisor: Monica Lavagna

The growing awareness of sustainability and environmental goals boost the ongoing process of transformation and increasingly complexity of construction sector. As key actors jointly responsible for the built environment, Architectural, Engineering and Construction (AEC) firms are embraced in the change management, shaping step by step their practice and involving both tangible and intangible resources. In this context, the research project aims to understand and depict how AEC practice are equipping and reorganizing themselves in order to address and meet environmental issues. The effort is to identify and map, in relation to the different phases of the design process, the following resources: i) the team of actors involved; ii) the set of tools used; and iii) the collection of data considered to achieve sustainable goals. In addition, since there is no pre-determined relationship between the resources of a firm and its capabilities, the effort is to figure out their relationship, the information flow and their impact within the decision-making process.

Moreover, consistently with the trends currently underway that consider the integration of life cycle approach and the

implementation of the related methodologies as a turning point, the challenge is to orient and streamline the AEC design process in line with environmental targets and life cycle perspective. To support AEC firms in life cycle design, an assessment framework is proposed to implement – firstly – Life Cycle Thinking (LCT) and – secondly – Life Cycle Assessment (LCA) in decision-making and design process. The framework is tailored to suit the peculiarities of the different process phases and it empowers the different actors in making responsible decisions and operations in their own expertise area. To handle the wide range of information required and the plurality of interactions between the actors engaged, Building Information Modelling is selected as the most suitable tool currently spread in practice and able to

embed the proposed framework. The outcome is a well-framed and organized set of data concerning the whole life cycle of the facility and the connected process to orient decision-making process and enforce life cycle design for environmental but also wider (e.g. economic) purpose. The proposed framework is developed and tested by means of real case studies, selected by the portfolio of an international A/E firm, in order to recreate ex-post the design process and identify the resources currently adopted to meet environmental and life cycle issues. Furthermore, to fill the gap between theory and practice, it is envisioned its application ex-ante, starting from the very beginning and onward the process with the aim to truly orient the decision-making process, identifying the necessary key shifting both in

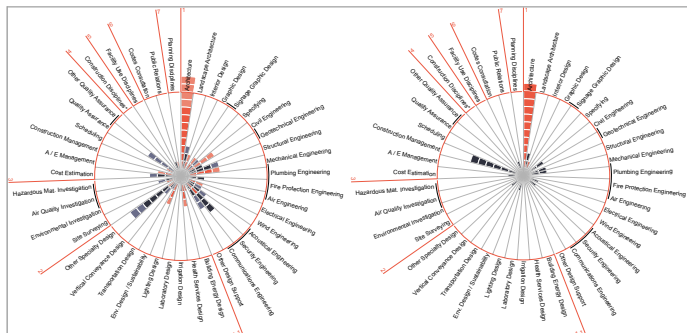


Fig. 1 - Design team comparison of two different case studies.

thinking and in process. The result is the identification of a life cycle AE(C) practice, pointing out the change management necessary to implement LCT into the design process, explicating the progressive set of life cycle information to take into account at each design phase, the connected actors in charge and the resulting information flow demanded, providing different levels of simplification according to the complexity of design projects. In this way, especially when dealing with particularly complex projects, it is suggested the introduction of new competence, recalling the “middleware”, capable of adopting and promoting a systemic vision of the project and process from an environmental and life cycle perspective.

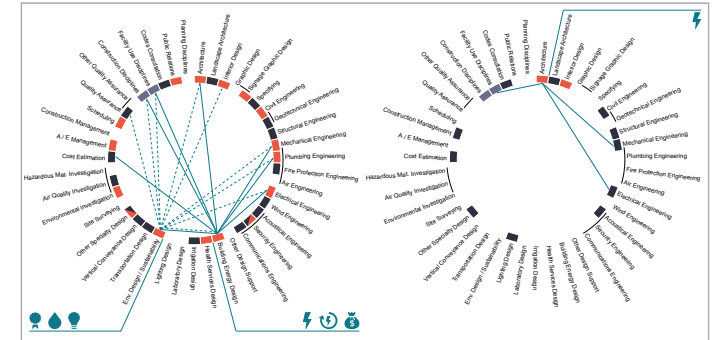


Fig. 2 - Environmental and life cycle information flow comparison of two different case studies of current practice.

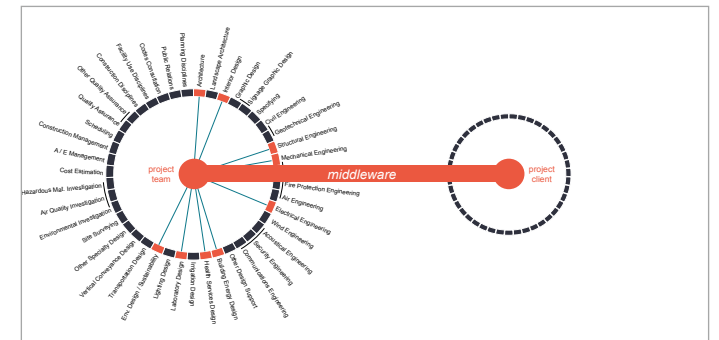


Fig. 3 - Environmental and life cycle information flow of life cycle-oriented practice.

DECISION SUPPORT SYSTEM FOR THE LOCATION OF HEALTHCARE FACILITIES.

SiTHEALTH EVALUATION TOOL

Marta Dell'Ovo - Supervisor: Alessandra Oppio

Tutor: Stefano Capolongo

Site selection for urban facilities is a crucial topic in planning decision processes for the several side effects they produce and the multiple criteria involved, especially for healthcare facilities. Healthcare provision policies generally neglect to address the distribution of healthcare facilities within cities, entrusting every time the choices to different categories of stakeholders (fig.1). Moreover, existing evaluation tool are focused on intrinsic performances of healthcare structures, disregarding the extrinsic characteristics, namely related to the location. Starting from a cross-disciplinary deep literature review across different research fields, the research proposes a multi-methodological approach for addressing decisions about healthcare facilities' location. The proposed evaluation tool can be seen as an innovative approach in the field of decision-making processes regarding hospitals, since it considers simultaneously functional, locational, environmental and economic issues, providing a comprehensive overview about the areas under investigation. Moreover, the topic related to the criteria weight elicitation has been investigated in order

to outline pros and cons of procedures applied. In fact, the evaluation system has been tested to a specific case studies and resulted compared. The research aims to propose an integrated approach supported by Geographic Information System (GIS) and Multi-Criteria Decision Analysis (MCDA) to provide an integrated knowledge about territory and the explicit consideration of the spatial dimension of the decision problems.

The aim of the thesis is to bridge the gap between two different research fields, one concerning aspects related to the health and in particular to the design of healthcare facilities and their location and the other one concerning the Operational Research and in

detail two important domains: the Decision-Making processes and the Multi-Criteria Decision Analysis (MCDA). The need to approach this issue come from the lack of a robust methodology able to solve the decision problem concerning the location of hospitals, but more in detail the lack of guidelines capable to support the Decision Maker (DM) on this specific decision-making process. In fact, since the facility under investigation will impact the society as a whole, as well as the natural environment and the built environment, it becomes important to define a decision support system that can boost strengths related to the Operation Research in order to solve issues generated by the weak awareness about the site selection of complex constructions such as hospitals

		LEVEL OF INTEREST	
		low	high
POWER	low	Stakeholder: Minimal effort Nonprofit Organizations; Non-governmental Organizations	Stakeholder: Keep informed Common people
	high	Stakeholder: Keep Satisfied Health and Urban General Manager, Local Health Unit Director, Experts	Stakeholder: Key players Health and Urban Councilor

Fig. 1 - Stakeholders' matrix Power/Interest related to the location of healthcare facilities

(fig.2).

The real world decisions are characterized by a deep complexity due to several and sometimes conflictual factors. In particular, since the location problems are affected by many issues and then composed by interrelated subsystems and externalities that are uncertain, their solution require a multidisciplinary approach, based on the contribution of different fields of research. These new problems are characteristic of 'complex systems'. These are not necessarily complicated; they involve interrelated subsystems at a variety of scale levels and of a variety of kinds. The location of healthcare facilities is part therefore, of this complex system. It is difficult to predict with certainty all the consequences triggered by the choice of the location and in the same way it is

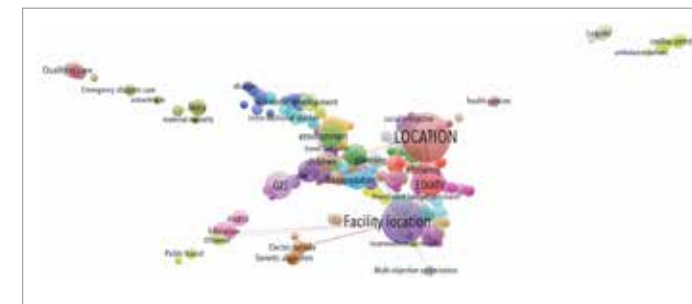


Fig. 2 - Keywords used by the literature reviewed and their relation

arduous to define an adequate set of criteria, able to represent the instances of the stakeholders involved in the process. According to the Theory of Post-Normal Science (PNS) developed by Funtowicz and Ravetz, when the level of complexity increases, a higher effort to solve the decision problem is required (fig.3). After a problem has been recognized as falling within the ambit of PNS, since it has been characterized as having a high level of complexity, it has to be dealt with in a different way. The scientific community will regard then the problem as an object of critical scrutiny, because current knowledge can no longer be used to solve it. Currently, there are no general procedures that have been widely accepted by the community to tackle the issue regarding the location of

healthcare facilities. Considering these premises, the location of healthcare facilities can be considered a typical ill-structured decision problem since it involves issues belonging to different fields of research and there are several and sometimes conflicting stakeholders whose instances should be considered as crucial. It means that, in order to solve it, it is necessary a multidisciplinary approach able to consider all these aspects and to satisfy actors affected by the hospitals' location.

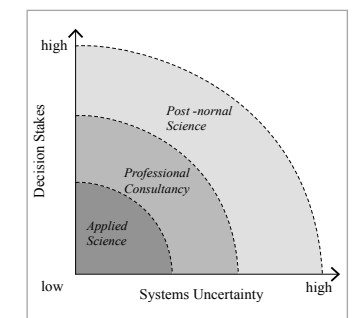


Fig. 3 PNS diagram. Adapted from S.Funtowicz and J. Ravetz

HYBRID MODULAR ARCHITECTURE: A STRATEGIC FRAMEWORK OF BUILDING INNOVATION FOR EMERGING HOUSING BEHAVIORS IN URBAN CONTEXTS

Joseph Di Pasquale - Supervisor: Andrea Tartaglia

Tutor: Elena G. Mussinelli

The research, has been developed in the framework of a Doctoral Research scholarship at the department of architecture, built environment and construction engineering of Politecnico di Milano, in partnership with a co-funding panel of manufacturing companies involved in the construction sector (Gewiss srl, Progress srl, Valsir srl., Simenes Italia spa). The research aims to define a reference scenarios for innovation in building construction, to reduce critical issues of actual production models: global demographic trends to define future housing demand, urban density to reduce sprawl and land consumption, modularization and industrialization to reduce building process footprint. Afterward the research analyze

a series of case studies to seeks the traces of the ongoing urban housing behaviors metamorphosis due to social, economical and technological changes, and of a new type of emerging "house as a service" products. On this premises the thesis proposes a new theoretical framework defined as "hybrid modular" to interpret the dynamic housing behaviors changes, triggering industrialization and footprint reduction of building construction industry. The modular hybrid building is reconceived separating permanent from temporary typological and technological purposes in a building. As a theoretical framework for following experimental phase the thesis hypnotizes a concept project (meta-progetto) in which are conceptually separated the

long lifecycle systems (permanent mother structure) from the short lifecycle systems (plug in/out living modules), allowing the building to change over its lifecycle following the changes of users needs and habits, and to trigger connection standardization and industrial large scale production of living modules units. This basis has then led to the establishment of an experimental step that aims to design a possible application of this principles in a specific prototype building system in cooperation with manufacturing companies to investigate all potential product innovations.

Keywords

hybrid modular architecture, housing behaviors, urban housing.

DISCRETE PHYSICALLY-BASED MODELS IN SOLID MECHANICS

Vito Diana - Supervisor: Siro Casolo

Tutor: Luigi Biolzi

The computational methods commonly used in solid mechanics are based on the spatial discretization of field equations of classical continuum. The governing equations are formulated in terms of partial derivatives of the displacement components which are not valid in the presence of cracks and other material discontinuities. As a consequence, they require special treatment of mathematical singularities and the definition of specific crack growth criteria. Moreover, an internal length parameter usually cannot be defined in these equations.

Discrete approaches and lattice models, instead, avoiding any differential formulation of the elastic problem, result to be particularly suitable for problems involving discontinuities, because cracks are not viewed as a pathology of the displacement field but as a normal solution of the problem itself. Furthermore, microstructural effects can be modeled adopting quite simple strategies.

We implemented in two and three dimensions, a mesh-free lagrangian micropolar lattice model arising from bond-based peridynamics, a new promising non-local theory of

solid mechanics inspired by the atomistic structure of matter and based on integral field equations. The model developed has specific and distinctive features and is based on an original implicit formulation derived analytically. By providing an appropriate mathematical and computational framework, the theoretical aspects of the conceived model and the software implementation strategy are discussed, then innovative applications are proposed. In particular, a quasi-static peridynamic formulation is applied to the study of the transition from local to nonlocal behavior of the stress and displacement fields in the vicinity of a crack front and other sources of stress concentration. Moreover a specific stochastic peridynamic model for glass in which the bond strengths are explicitly related with the size and orientation of the defects in the structural element is proposed. An original generalized micropolar peridynamic formulation is derived starting from the definition of a microelastic energy function which depends on three deformation parameters: the bond stretch, the bond shear deformation accounting for the rotational degree of freedom,

and the particles relative rotation. Hence three different stiffness parameters for each peridynamic bond are defined and calibrated separately, leading to a more general PD model with arbitrary Poisson's ratio and applicable to a wide variety of mechanical problems. Two novel deformation-based failure criteria based on the definition of a bond shearing deformation limit are also introduced.

Finally we developed an original 2D full orthotropic model in the micropolar peridynamic analysis framework which is characterized by four independent peridynamic microelastic moduli. An important and distinctive feature of the model is that the bond properties, i.e. the stiffness constants and critical deformation parameters, are continuous functions of bond orientation in the principal material axes. The introduction of the bond shear stiffness and the definition of a bond shearing deformation measure which accounts for particle's rotations, eliminates the restrictions of the only two independent constants which affects other orthotropic peridynamic formulations and enables the model to predict the mechanical behavior of a wide variety of Cauchy

orthotropic materials undergoing homogeneous and non-homogeneous deformations. Numerical visualizations and examples show the applicability of this discrete formulation in modeling a wide variety of practical engineering problems involving cracks, multiscale modelling, anisotropy and complex nonlinear behavior.

Keywords

Peridynamics, Elasticity, Fracture; Anisotropy; Lattice model.

MEASURES AND LIMITS. CRITICAL ANALYSIS AND DEFINITION OF ENVIRONMENTAL LCA-BASED BENCHMARKS IN THE CONSTRUCTION SECTOR

Sara Ganassali - Supervisor: Monica Lavagna

Tutor: Enrico De Angelis - Co-Supervisor: Andrea Campioli

The thesis "Measures and limits. Critical analysis and definition of environmental LCA-based benchmarks in the construction sector" aims at understanding the potential use of environmental benchmarks based on Life Cycle Assessment (LCA) impact categories in the Italian building sector. The thesis defines a replicable benchmarking approach to set benchmarks for construction materials and residential buildings (technological systems and whole-buildings). Moreover, the study investigates how different construction context requirements can be improved by stakeholders using a benchmarking approach for the definition of LCA-based benchmarks.

The benchmarking process elaborated in the thesis is a replicable process based on the statistical analysis and interpretation of LCA outcomes, which can set LCA-based benchmarks for different building's levels. The study sets benchmarks for (1) seven construction material categories (brick, cement, ceramic tiles, gypsum plasterboard, glasswool panel, stonewool panel and steel), (2) seven building technological systems (exterior walls, interior walls, roofs, windows, interior floors, exterior floors and ground-deck) and (3) whole-buildings.

The benchmarking process is composed of three main steps. The first step is the definition of a reference sample, collecting the technical data of materials/buildings under analysis. The second step is the application of the LCA methodology, pinpointing the life cycle assumptions concerning the system boundaries, the LCA scenario and the environmental data. The third step is the statistical analysis and interpretation of environmental data and the choice of benchmarks. The benchmarking approach provides three different benchmark levels, in order to set a sustainable evaluation scale. The first level is the Best practice value, which corresponds to the best construction practice and the best sustainability level that materials or buildings could reach; the second level is the Reference

value, statistically based on the median value, which corresponds to the construction practice of a specific context; the last level is the Limit value, which corresponds to the lower and acceptable construction standard. The LCA-based benchmarks set in the thesis represent the synthesis of numerical, methodological and contextual assumptions and considerations. The choice of benchmarks is linked to the level of ambition of stakeholders, indeed the "sustainability level" is set from the statistically derived median of the sample, which represents the 'average' material-building. The change of some parameters or factors in the three benchmarking steps, e.g. the definition of new LCA system boundaries or new Life Cycle Inventory (LCI), can affect the process and the final benchmarks. Sensitivity analysis

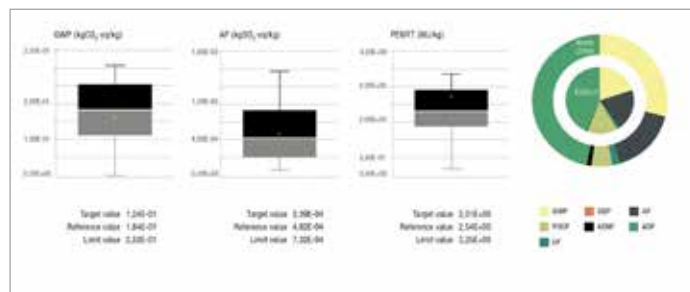


Fig. 1 - Variability of GWP, AP and PENRT impact categories related to brick product category and relative impacts (%) of normalised values through "Eu25+3" and "World(2000)" systems

and comparison between benchmarking approaches (Italian and Danish ones) illustrate how different contexts, modelling aspects and stakeholder requirements can influence the ranges in potential environmental impacts. Moreover, benchmark developers and users have to

deal with benchmarks upgrade process, due to variability parameters that can affect benchmark values if background information are not updated over time. Environmental benchmarks for construction sector must consider the fast change of building industry and

the evolution of technologies, which evolve often too fast for the existing benchmarking tools. Besides background and context data used in the benchmarking, the time period of data is a possible factor that can influence benchmarking outcomes. Indeed, data time period represents the current construction practice and it leads to reference and best practice values based on real technologies.

The environmental benchmarks and the benchmarking approach set in the thesis could be important decision support tools for different stakeholders (e.g. public and private authorities, contractors or practitioners). Final recommendations for benchmark's developers and users are included in the thesis. Indeed, the stakeholders could use the benchmarking process and the values in different construction sector fields, in order to monitor the built environment performances improvement, to deliberate new design strategies for enhancing the environmental sustainability of buildings, to make comparison between performance of different competitors or different design solutions, and to promote Italian green construction market.

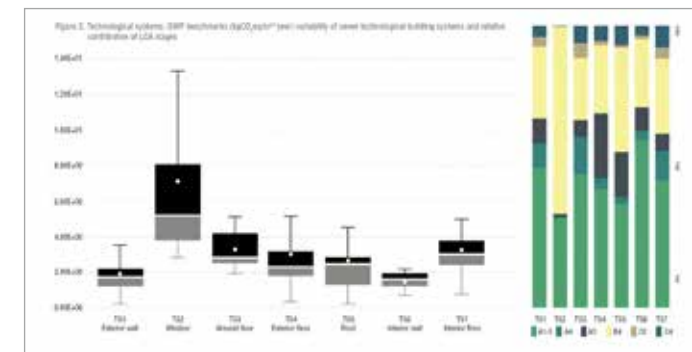


Fig. 2 - Technological systems: GWP benchmarks ($\text{kgCO}_2\text{eq/m}^2\text{ year}$) variability of seven technological building systems and relative contribution of LCA stages

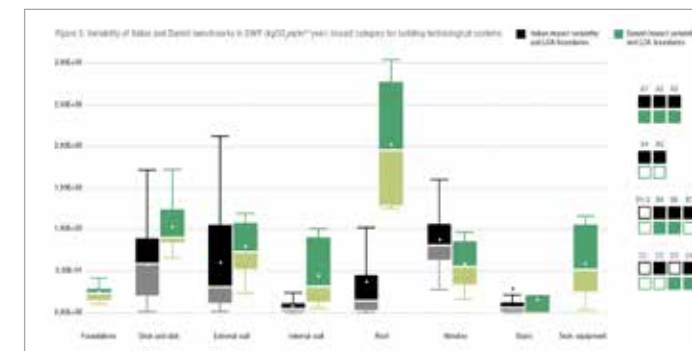


Fig. 3 - Variability of Italian and Danish benchmarks in GWP ($\text{kgCO}_2\text{eq/m}^2\text{ year}$) impact category for building technological systems

EXPERIMENTAL MEASUREMENT AND NUMERICAL MODELING OF THE MECHANICAL BEHAVIOR OF TECHNICAL TEXTILES

Mehdi Ghazimoradi - Supervisor: Valter Carvelli

Tutor: Siro Casolo

The present study aims to numerically predict the mechanical behavior at the Meso-scale of the technical textiles (Glass plain weave composite reinforcement & tetraxial technical textile). Tetraxial textile has warp, weft, and two diagonal yarns oriented at symmetrical angles (typically $\pm 45^\circ$) interlaced in the same weaving process. The flexibility of the manufacturing technique could allow for hybrid distribution of the yarn materials

and, as consequence, a wide range of mechanical behavior. For an accurate modelling, a hyperelastic constitutive model of the fibrous yarns in the textile was considered to account for the peculiar nonlinear behavior of the textile. The modelling of the technical textile representative volume (RV) allowed predicting the mechanical response for uniaxial and biaxial tensile tests. The comparison of FE analyses with the experimental

measurements highlights the accuracy of the numerical model to predict the nonlinear behavior of the technical textiles.

Keywords

Tetraxial technical textile, Meso-scale FEM, Composite reinforcement; Plain weave textile; Glass; Experimental measurements

SUSTAINABLE HIGH QUALITY HEALTHCARE FACILITIES

INDOOR AIR QUALITY AS HEALTH PROMOTER IN HEALING ENVIRONMENTS

Marco Gola - Supervisor and Tutor: Stefano Capolongo

Co-Supervisor: Gaetano Settimo

Introduction

Hospitals are supposed to preserve Public Health, but they are also highly energy-demanding and socially impact on communities and they can determinate negative effects on quality of health of users and performances of environments. Healthcare facilities are able to deal with the definition of Health as the complete well-being and which can fit to the future means constructing sustainable structures. These ones work as a whole, which can be productive only if all its components are healthy. So, speaking about healthcare facilities, sustainability must be analyzed as the major requirement because it must ensure high standards.

Although nowadays there are many evaluation systems that assess building's performance and its sustainability, among the criteria the evaluation of **Indoor Air Quality (IAQ)** is postponed to the regulations into punctual hospital areas.

Starting from the definition that health promotion is also due to environmental factors, the medical activities that are carried out, the design features, the finishing materials and furniture, the maintenance and management activities, etc., the research work has the aim to provide an analysis

on the State of the Art of indoor air in healing environments, in particular related to chemical pollution, highlighting and verifying all the factors that affect the air quality and, supported by an investigation on the current state of inpatient ward, giving rise a tool for healthy inpatient rooms, through the support of *Istituto Superiore di Sanità (ISS)* in Rome.

State of the Art

In recent years, Indoor Air Quality becomes a primary issue that needs more and more to focus because of the increasing number of exposed population due to lifestyles and the permanence in confined environments (about 90% of the day). Even European

Community underlines the priority of energy efficiency strategies, in the same time it recommends to reach healthier indoor environments and the development of a specific European strategy on IAQ. Currently several EU countries have introduced in their legislation rules relating to IAQ; in Italy, there is not any specific reference around the topic. The research project analyses the Scientific Literature, WHO guidelines and also ISO, CEN and UNI standards, norms and guidelines by other European regions and/or other standard values, such as guideline or reference values regarding outdoor and indoor air, for



Fig. 1 - Factors that affect indoor air quality in inpatient room.

better understand the current framework.

Since several years, critical factors due to the exposure to indoor air pollutants have been a matter of concern for national as well as EU legislators, and an increasing numbers of states have been addressing the need for policies regarding health promotion strategies through specific studies. The European Union has often highlighted the importance to investigate and assess indoor air, the relative impacts on health status and possible recommendations regarding future measures.

Although the present criticisms, currently in several countries air quality monitoring are carried out in those professional workplaces in which chemicals are used, but also in some generic indoor spaces for building hygiene assessments. A list of case studies and best practices in terms of design, management and sampling activities has been defined by a systematic review (Figure 1).

Methodology

Starting from these considerations, the research project investigates the current state of the art of many inpatient rooms analyzing volatile organic compounds (VOCs), and the relative influence of microclimatic parameters, ventilation systems and concentration of pollutants, for giving rise to considerations on the design and management for healthier hospital settings. In fact, in the light of the State of the Art, it is considered to be of primary importance to proceed an investigation of selected

VOCs, obtaining indications on concentration levels of pollutants, whose values have not been fully investigated, such as *acetone, benzene, chloroform, dichloromethane, ethyl benzene, o,m,p-xylene, styrene, tetrachlorethylene, trichlorethylene, formaldehyde and acetaldehyde*, as well as carbon monoxide and carbon dioxide.

The definition of methods for pollutants' type, detection and analytical methodologies, instrumentation, etc. has been defined with some expertise on the field considering the specific indoor air standards ISO 16000 and guidelines by ISS.

Results and Discussion

For the development of the research project, some healthcare facilities have been are involved. The analysis last for one year, analyzing winter and summer seasons. The data processing has been carried out by and with ISS; the samples, after extraction with solvent, were subjected to the GC-MS and HPLC analysis. Data have been analyzed with the support of all the useful materials and activity logs, filled out by hospital staff.

The data process permits to obtain a comparative matrix in which is possible to highlight the current criticisms in healing environments into the complexity of all the activities done inside the hospital. In particular Formaldehyde, Benzene and Carbon Dioxide report inadequate values. Starting from the cross-sectional analysis of data, several considerations on the main common aspects around design and management criticisms and

strategies on how to improve the air quality in indoor healing environments, giving rise to:

- a Decalogue of best design and management strategies for healing spaces in inpatient rooms;
- check-lists for a pre-assessment of the performances of the inpatient room, analyzing room features, construction materials, daily procedures and products;
- the definition of a protocol for monitoring if chemical pollution in IAQ in healthcare facilities and for a wide investigation in Italy, for supporting ISS for future guideline values' definition.

Conclusions and outlooks

In the light of the outputs and data analysis, several considerations on the development of knowledge on these topics, how to implement the current research work, and how to expand the research internationally are listed. Although the application on several inpatient rooms obtained adequate results, as WHO suggests, it is advisable to reduce more and more pollution concentrations for guaranteeing healthier environments for users.

Keywords

Indoor Air Quality; Healthcare facilities; Sustainability in healthcare; Chemical pollution; VOCs; Monitoring activity; Air Quality guidelines; Design strategies; Management strategies; Protocol for monitoring activities; Guideline values; Guidelines for inpatient room; Strategies for inpatient room's design.

CROSS LAM ROOF STRUCTURES IN SEISMIC RESTORATION OF HISTORICAL CHURCHES

Nicola Longarini - Supervisor: Alberto Franchi

Tutor: Luigi Biolzi

In the present research, several roof-diaphragm structural solutions for improving the seismic nave transversal response of historical churches are discussed in relation to the effectiveness and the Cultural Heritage Offices requirements. Among the solutions, the cross lam panels (Cross Laminated Timber panels, CLT) one is pointed out, therefore the cross lam mechanical features are described and some different connection types (panel-to-panel, wall-to-panel) are shown as well. The improvements due to the CLT are initially evaluated in terms of damped rocking given by ductile roof-diaphragm, for several church configurations different themselves for number of naves, spans and walls slenderness. The effects of the CLT roof are shown by performing nonlinear analyses on equivalent finite element

models. The equivalent models are also validated by several numerical assessments. Each numerical approach is in-depth analyzed and comparative analyses with the different approaches are also performed.

The nonlinear analyses on equivalent models are useful to fix the thickness of the panels and to preliminary design the steel connections (starting from the in-plane shear evaluation). The connections design is consequently optimized in terms of strength and stiffness by performing linear and nonlinear analyses focused on the dissipative effects evaluation in seismic response. The connections optimization is performed by adjusting the drift (with respect to the masonry walls mechanical features) and the in-plane shear on the CLT panels (is with respect

to the different shear resistance values declared by the producers and the ones obtained by experimental tests). For deepening the CLT's shear resistance and the average shear modulus, experimental tests results performed at University of Udine under the supervision of prof. eng. A. Gubana are considered too. Finally, the several numerical approaches here-in-depth analyzed are applied for the optimization of the cross lam roof structure for a specific case study. Final remarks about the seismic improvements due to the CLT strengthening are pointed out. The remarks are valid for several historical church configurations and for the specific case here discussed.

THE ROLE OF VIRTUAL REALITY IN DIGITALLY-ENABLED DESIGN REVIEW: PROCEDURAL GUIDELINES FOR THE EFFECTIVE IMPLEMENTATION OF IMMERSIVE VIRTUAL ENVIRONMENTS FOR USABILITY-FOCUSED ANALYSIS.

Silvia Mastrolembo Ventura - Supervisor: Angelo L. C. Ciribini

Tutor: Cinzia M. L. Talamo - Co-Supervisors: Elisabetta Oliveri, David Philp

Research and applications related to Virtual Reality (VR) in the Architecture, Engineering, Construction and Facility Management (AEC/FM) industry are steadily increasing in number and scopes. In particular, the implementation of immersive virtual environments (IVE) is experiencing a period of renewed interest since the earlier research efforts of the 2000s. This growing interest in VR systems is closely linked to the ever-increasing adoption of Building Information Modelling (BIM) processes, procedures and technologies that characterises the on-going digital transition of the industry. Communication and review of design proposals are some of the main purposes VR is implemented for in BIM-based design processes. Virtual reality, in fact, represents the visualisation and interaction platform where, through immersion and sense of presence, virtual prototypes of design proposals can be explored and tested at full-scale in an intuitive and engaging manner. Within that context, previous researches show how IVE could support collaboration through improved communication and access to information for all involved stakeholders, regardless of their technical background. Three main

theoretical patterns have been identified in using immersive VR in collaborative and usability-focused analysis: exploration from a user perspective, participation in solution-finding and feedback on a design proposal. The aim is to reduce the gap between design and operations and to deeper understand the implications of design decisions. While research in the application of virtual reality systems in the AEC/FM industry is growing, some obstacles to its effective implementation still exist from both a technological and procedural perspective. Procedural challenges are within the scope of this research. They are primarily illustrated by instances where (1) the lack of a clear VR-aided design review agenda, (2) the unguided navigation of users through the virtual facility prototype, or (3) the unstructured management of the most appropriate level of detail or realism of the VR representation - on the basis of the design phase, the objective of the review and the stakeholders involved in the meeting - can greatly affect the quality of the feedback and the overall effectiveness of the design review meeting. Moreover, motion sickness and previous user experience with VR systems also affect the result

of the design review and should be taken into account. The need for addressing this type of issues in a more systematic way as a guide for the design teams when planning to use VR with other stakeholders is within the scope of this study, which aims to identify the processes, procedures and procedural considerations for implementing immersive virtual reality in design review meetings, especially when client and end-users are involved. A qualitative research strategy has been applied, which is based on building theory from case studies adopting an inductive and comparative grounded theory approach to gather, synthesise, analyse and conceptualise qualitative data. Moreover, multiple data sources were selected according to a flexible data collection strategy based on the emerging theory. As main data sources, two case studies were developed involving a representative panel of design stakeholders (i.e., clients, designers, end-users and an accessibility expert) in the evaluation of immersive virtual reality systems in usability-focused design reviews. In particular, (1) the implementation of semi-immersive multi-user virtual reality was explored in the analysis of

the design proposal for a new public building (i.e., an educational facility with innovative learning and socialising spaces); (2) a fully-immersive VR system (i.e., VR headset) was adopted to navigate the current use scenario in an existing public building (i.e., a hospital pavilion), including the pedestrian simulation developed based on post-occupancy evaluation data. Results from the case studies have been extended and validated adopting other data sources during the development of the project, such as semi-structured interviews with a representative panel of stakeholders. Moreover, talks with VR experts from both the academia and the industry and literature comparison were used as validation methods to sharpen research generalisability and raise the theoretical level of the contribution. The procedural guidelines for the effective implementation of immersive virtual environments in the usability-focused analysis of building projects represent the main contribution of this research. The guidelines are organised in two main sections: (1) a process map representing a session protocol, where the phases and activities of a VR-aided design review meeting are defined; (2) a framework of procedural considerations to guide the users in managing each phase of the session protocol. Filling a gap in the research, the procedural guidelines, as a systematic and comprehensive procedure, aim to maximise the role and the value of immersive virtual reality in design review meetings.

They represent a valuable framework for future researchers, who will use them as a flexible and extensible basis for both qualitative and quantitative research works. Moreover, the guidelines represent a reliable basis to guide practitioners in the implementation of virtual reality systems. They could be either used as they are or adapted based on the specific needs of a building project. Furthermore, as the level of maturity in the use of the tool increases, practitioners can integrate the procedural guidelines with additional activities to be performed as well as observations and further procedural considerations to take into account, including results from their own best practises and other references, such as future technological advancements and process management sources. The growing interest of the construction sector towards virtual reality systems and interactive workspaces requires further research in order to effectively address technology investments and integration of those systems into design processes. In particular, a lack of understanding in relation to the added value, if any, generated by VR adoption exists. Moreover, no guidelines are available to lead users to the selection of the most appropriate VR system based on their needs and expected user performance and interaction with the virtual facility prototype according to VR purposes and related uses. Furthermore, future research works should investigate how cognitive processes in collaborative activities, such as

design review meetings when multiple stakeholders are involved, change because of the adoption of virtual reality systems. Finally, additional research should be related to the contractual aspects of VR adoption in design review meetings; the different types of design processes (e.g., user-centred design, participatory design) should be also taken into account.



Fig. 1 - Navigation within a virtual facility prototype using a semi-immersive virtual reality system

EFFECT OF THE UNCERTAINTY IN OUTDOOR BOUNDARY CONDITIONS ON BUILDING PERFORMANCE SIMULATION

Maryam Meshkin Kiya - Supervisor: Riccardo Paolini

Tutor: Claudio Del Pero

The term of “performance gap” is attributed to the mismatch between actual and estimated building performance. Building simulation tools deal with several inputs which are known as one of the most important sources of the performance gap. Among the uncertain input parameters, assumptions of climatic properties – which are typically implemented through the weather data – are of great importance. Re-scaling the climatic parameters from the mesoscale to the microscale is one of the proposed solutions to reduce the climate-related uncertainty. Among the weather parameters, estimations of incident solar radiation on building facades are associated with uncertainty from two main perspectives, i.e., the accuracy of calculation models as well as the inputs fed into the models. The inadequacy of measurements and lack of interoperability between simulations tools are the main barriers for these kinds of studies. Therefore, there is a necessity for a holistic framework which describes proper quantification, propagation, and post-processing of uncertainties in an urban canyon. In the context of uncertainty quantification, the choice of uncertainty treatment can

significantly affect the final range of variations. Introducing possibilistic and hybrid approaches for uncertainty propagation aside from the conventional probabilistic approach is discussed in this study. It is shown that based on the nature of the uncertainty and availability of data, choosing the correct approach for representing and propagating uncertainty within the model can affect the knowledge for decision support. To simulate building performance in a proper climatic resolution, availability of measured climatic parameter in microscales is necessary. Actual measurements of climatic data often deal with missing values which can come from either instrument error or data maintenance error. Machine learning methods including neural networks are suggested as a reliable tool for predicting missing values. This research study introduces a method to estimate long-term (two weeks) missing values using neural network for parameters of temperature and relative humidity. The method is developed based on measured values from a network of weather stations locating in north of Italy. Re-scaling solar radiation to microclimate by only relying on the measured climatic parameters from network of stations within a

city, is not adequate. Considering that, solar radiation in weather stations is often collected from rooftops and horizontal surfaces, while measurement instruments do not encounter shadowing or reflectance from the surroundings. Meanwhile, building surfaces experience more complex effects from the surroundings. The incident solar radiation on building surfaces is affected by different obstructions including adjacent buildings and vegetations which can add uncertainties to estimations of incident solar radiation. The shadowing effects, reflectance and transparency of trees on the buildings are among the main parameters which embed the uncertainty to estimations of incident solar radiation on building facades. In this study, the complexity of modeling urban canyons as the basic module of cities, is challenged and compared with the current simplifications concerning building surroundings. It is observed that details of urban canyon such as variation in height of adjacent buildings and reflectivity or transparency of surroundings can drastically affect the thermal and visual comfort, as well as lighting energy consumption. It is also shown that the effects of complexity in the

urban canyon are sensitive to the target height and vary on different floors. The annual electricity is the most sensitive parameter among the selected outputs with a variation of $\pm 46\%$. Also, the experience of the indoor comfort for different floors may vary up to $\pm 7\%$ due to the uncertainty in the urban canyon parameters. It is found that the effect of variables with high uncertainty (treated according to the theory of possibility) can be up to 10 times greater than features with lower levels of uncertainty (treated based on the theory of probability). The detailed modeling of the trees was also deeply discussed and the suitable representation of trees for uncertainty analysis was proposed. The model is a balance between the complexity and simplification. The proposed model is a balance between the complexity and simplification. Also, the importance of considering the uncertainty in building surroundings during the design phase of windows are investigated. The results reveals how building surroundings can affect the potential of the glare based on different window to wall ratios. Moreover, the accuracy of solar radiation calculation models are subjected to debate in the

literature, which mainly refer to the uncertainties in sky and solar position information. The accuracy of solar radiation calculation model (Perez sky diffuse model as one of the most popular models in building energy simulation tools) is evaluated by calibrating the model based on actual measurements from Eindhoven, Netherlands. The method uses the subset simulation approach which significantly reduces the computational time. Also, the calibrated Perez is implemented in EnergyPlus. Applying the calibrated Perez model in EnergyPlus revealed how under/over-estimation of incident solar radiation by the default model can affect the reliability of estimations in building energy loads and photovoltaic performance. The 5% difference in estimations of heating energy consumption and 9% difference in PV electricity production are observed by embed the calibrated Perez into EnergyPlus calculations. The proposed method is developed based on measured data from Eindhoven and after that validated based on another location which shows the method is possible to apply on different sky conditions. This PhD study is an attempt to show how re-scaling building's

boundary conditions from meso to micro scale can affect aspects of its performance. It is shown that, the initial requirements of these kind of studies are local measured data and a meta-heuristic attitude towards the inputs of building performance estimations. The main outputs of this study can be used as supporting information for designers and decision makers including architects, building engineers, urban designer/planners and policymakers.

KNOWLEDGE NETWORK FOR INNOVATION OF CONSTRUCTION SECTOR

INCREASING EFFICIENCY THROUGH PROCESS DIGITISATION OF THE ENTIRE CHAIN

Claudio Mirarchi - Supervisor: Alberto Pavan

Tutor: Angelo L. C. Ciribini

The construction industry has long been characterised as a project-based business that delivers one-of-a-kind products. No two buildings are alike, though they may appear similar from the outside. Hence, design and construction choices are made under uncertainty and the role of designers and constructors is consequently burdened with huge responsibilities about the success or failure of the project and its impact on the environment. Design and construction are processes that run in a cycle way through a trial-and-error procedure because it is not possible thought through the entire picture in advance. They can be considered as iterative procedures composed by a creative stage and a mechanical stage where the hypothesis of the former are tested with reference to project requirements. Moreover, the inherent variables of the construction site that can include machine/human failures, adverse weather conditions, and disadvantageous geological conditions brings the site management to face deviations between the as-planned and as-built construction performance, requiring real-time decisions during the construction development.

In this context, decisions usually rely upon the knowledge of experts that act, however, under uncertainty and with access to a limited amount of information. Several studies in the field of psychology demonstrated the difficulties of human brain in evaluating samples, as people's intuition appears to satisfy the law of small numbers. Hence, a possible precaution to the above-mentioned issues is the use of computation intended as the introduction of techniques and technologies able to support the deciders through data driven suggestions. However, the introduction of digital means in the construction sector demonstrated to be all but easy and linear. Thus, the peculiarities

of the construction sector impose the development of social analysis to evaluate possible frameworks able to support the introduction of digital technologies and techniques devoted to improve knowledge management and decision making processes. On the other hand, the need to provide computational analysis in the construction sector impose technological challenges requiring the integration of distributed data generated along the construction chain in a highly fragmented environment. In first instance, this can be interpreted in the need of integrate data, information, and knowledge provided by projects that are not based on a shared rule-set to create the conditions to push the introduction of

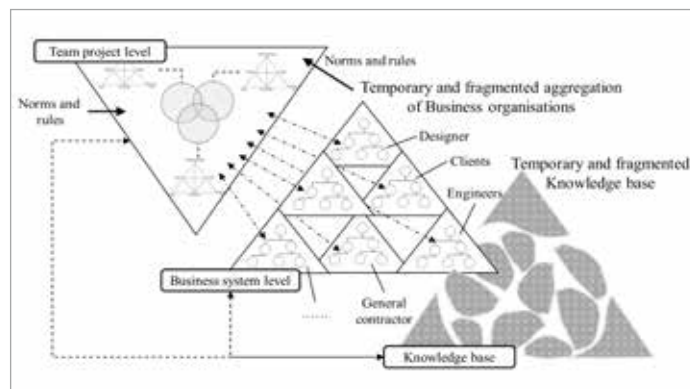


Fig. 1 - An integrated vision of the hypertext organisation schema for the construction sector

computation in the construction sector. Following this focus, the research adopts a multidisciplinary approach including construction, knowledge and management, psychology and social science, and computer science areas. Starting from a theoretical background based on the hypertext organisation schema proposed by Nonaka and Takeuchi, the cultural historical activity theory, and the heuristic decision theory, this research investigate a novel framework for the development of a knowledge management platform for the construction sector. The theoretical analysis results in an integrated schema that extend the hypertext organisation schema to admit its introduction in the construction sector context. This schema forms the basis for the development of the desired framework prospecting a multi-level approach to develop collaborative environments and related platforms in the construction sector.

This framework is supported by the development of dedicated case studies to consolidate the proposed processes. The experimentations are 1) a hybrid classification and clustering approach to organise digital documents from heterogeneous sources and 2) a machine learning image recognition process to verify and semantically enrich building information models. The first case study proposed a novel framework to organise text documents according to a hierarchical structure based on their content. This approach pave the way for the application and development of specialised algorithms of text data analysis that require homogeneous document set starting from the raw documents available in the industry. The second case study demonstrated that specific algorithms such as convolutional neural network are able to recognise peculiar features in images starting from a limited training set allowing the application of image recognition

to building information models. Applying these concepts, the resulting automated process showed the possibility to extract images from an information model, interpret the images and provide a semantic enrichment to the initial model using the information inferred. The evidences collected during the literature review and the results obtained in the development of the framework generated two main implications. On the one hand, the presentation of an evolutionary view on collaborative environments in the construction sector. On the other hand, the analysis of the possible integration between the existing platforms developed at national level and the proposed framework. Moreover, the results of the work defined the basis for the development of a proposal for a European project about the development of digital platforms in the construction sector.

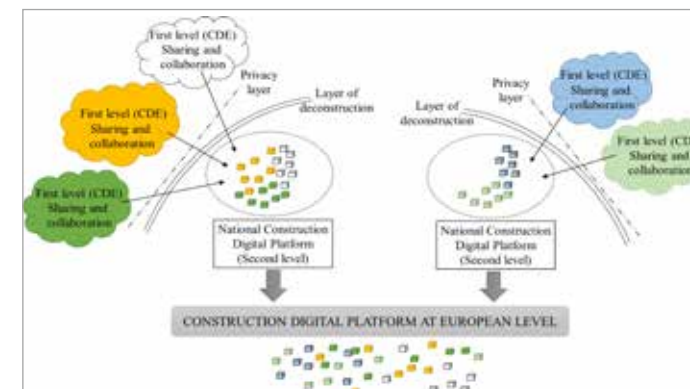


Fig.2 - Architecture of the system including a Digital Platform at European Level

BIM-BASED FACILITY MANAGEMENT EMBEDDED INFORMATION MANAGEMENT FOR MAINTENANCE: BUILDING INFORMATION MODELLING AND DATABASE INTEGRATION FOR THE ITALIAN PUBLIC ADMINISTRATION

Lidia Pinti - Supervisor: Giovanni Utica

Tutor: Gianandrea Ciaramella - Co-Supervisors: Massimiliano Papetti, Mario C. Dejaco

Building Information Modelling (BIM) is a process that allows you to generate, collect and manage all the data about the building throughout its life cycle: design, construction and facility management. Design and construction stages affect only a minor part of the building life in terms of time and cost, compared to the Facility Management (FM). However, the adoption of BIM in the FM stage of a project, with the relative advantages and difficulties, is strikingly less explored in the available literature with respect to the other stages of the project. The main obstacle in the adoption of BIM for the building life cycle is the fear that it does not satisfy the needs of the professional as the traditional method does. Furthermore, a common opinion is that BIM can overturn the way of operating buildings. Finally, the need of training courses is certainly a major hurdle in terms of capacity, money and time to spend. The problems presented are even more obvious when we look at the Public Administration (PA). In fact, in addition to the obstacles described above, the PA must deal with a limited budget and with a large number of professionals with very heterogeneous skills.

The aim of the research work is to underline the possibility of BIM and FM integration in the PA and to highlight the main barriers to BIM for FM adoption, the problems with the current practice, and the most considerable benefits of this merging. The analysis of the discussed problem led the research work to the development of a replicable procedure able to implement innovative tools and methods to manage the variety of processes that characterize the built environment, using simple tools that do not disrupt the procedural process of the conventional method, but with the potential of BIM systems. The focus of the research is the integration of BIM with a dynamic database in order to provide a powerful instrument to control the variables of Maintenance Management (MM). The study is carried out on the school building assets of an Italian PA and deals with the results derived from the analysis of 450 case studies. The Research work is developed into two major steps. At first, the conventional methodology used by the PA is examined and data concerning school building maintenance are gathered. Then, in the second phase, the

research focuses more in detail on database-BIM integration. This research work presents the results of a theoretical and practical study about BIM and MM integration, as the natural evolution of a methodology that needs to follow innovation and to implement new processes and tools. In addition, the research work highlights how BIM can facilitate project team collaboration and reduce errors, time and costs. The research work demonstrates how the PA can combine the main benefits of information storage offered by database applications with the advantages of BIM in terms of visualisation, localisation and immediate awareness in virtual environment.

A DECISION SUPPORT FRAMEWORK FOR TECHNOLOGY RELATED CHOICES IN FAÇADE RETROFIT: RELEVANCE AND IMPACT OF MORPHOLOGICAL FACTORS ON RETROFIT INTERVENTIONS VALUE

Elena Seghezzi - Supervisor: Gabriele Masera

Tutor: Fulvio Re Cecconi

Introduction

Building retrofit is a current issue and a complex task, due to the multiplicity actors and goals involved, in terms of architectural quality, energy performances, comfort of the users, and economic estimation. In this context, technology-related choices represent relevant moments in the decisional process, especially considering the variety of morphologies of existing buildings. Several approaches in terms of support tools and methods have been developed, to help the selection of alternatives in renovation processes. The majority of these tools focus on sustainability, defined in its social, economic and environmental aspects. If, on the one hand, these strategies appear to be well-structured and reflect the complexity of the theme when related to project phase, they disregard aspects related to installation phase, such as morphology and technology. In particular, prefabricated or off-site solutions' use is still based on anecdotal evidence or simple cost-benefit

evaluations. Decisions in building renovation are mainly experience-based and usually lack of a scientific evaluation of alternatives, especially in early stages. The purpose of this research is the development of a decision support framework for technology related choices in façade retrofit, keeping into account sensitivity and uncertainty.

Methodology

Building envelope represents a particularly relevant aspect, as it accounts for the most part of thermal loads and denotes strongly the building and its features. Understanding the real relevance and impact of morphological factors is a suitable strategy to investigate the use of available solutions, as well as to provide a solid basis for their further applications. The proper Decision Process underlying technological choices in the building retrofit of opaque façade has been explored. Morphological and technological parameters have been clearly highlighted, and described by means of information and data, acting as input of the

proposed model.

The formulation of a Utility Function (and its sub-functions) allows to express the value of façade retrofit operations, based on economic aspects. The Utility Function includes data related to building morphology and has been set based on a Life Cycle Cost approach. The output of the UF is therefore the cost of proposed retrofit solutions, including installation, maintenance, and energy costs. Simplifications have been carried out to avoid overburdening of the model. Installation and morphology related aspects are underlined, in terms of transparency, geometrical complexity, materials and cladding, state of conservation, scaffolding area and accessibility.

Sensitivity and uncertainty analyses

The impact of morphology related parameters is tested by means of a sensitivity and uncertainty analysis on input factors. Sensitivity analysis provide an evaluation of how uncertainty in the output of a system can be related to uncertainty in its inputs. Input

parameters chosen for variations are transparency, geometry and insulation. The goal of this analysis is therefore to measure the impact of each input variable on the final output, ranking parameters in order of influence.

LCC is a robust approach to decision support in building interventions; nonetheless, a deterministic calculation does not provide a complete evaluation of data uncertainty, that can be taken into account using probabilistic methodologies.

In this case, uncertainty is related to several factors: macroeconomic aspects, energy needs, maintenance frequency. Monte Carlo simulations are performed, associating probability distribution to each risk factor (maintenance frequency, inflation and interest rate, energy need and energy price).

The result obtained shows that probabilistic LCC is higher than deterministic, confirming how hard it is to provide solid scenarios. For this reason, a model including

uncertainty quantification is a valuable approach that should be implemented in decision-making. A validation of the model is provided through its application on two case study buildings, to verify the robustness and reliability of the proposed methodology.

Conclusions

The proposed model and approach have two categories of outcomes: case specific and general outcomes, related to the model and to the workflow provided. This model allows in fact the designer to evaluate different technological solutions on a Life Cycle Cost basis, including investment and operational costs and can be used both for single buildings and for building assets. Furthermore, this approach provides an evaluation of the effects of morphology on selected options, allowing the decision-maker to compare different solutions keeping trace of their effects.

Considering general outcomes, the application of this methodology does not require complete simulations or complex calculation, avoiding time and cost-consuming procedures. The use of a mathematical and scientific based model helps in keeping traces of relevant information through the entire process, facilitating interactions among the actors of the process and increasing transparency through the process. In addition, this approach provides the decision-maker a quantitative and qualitative evaluation that, applied to each stage of the process, reflects the quality of information and data available at that point.

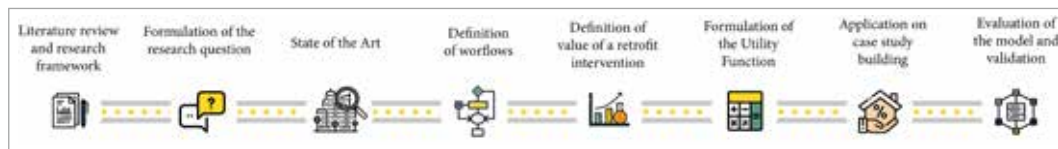


Fig. 1 - Methodological approach

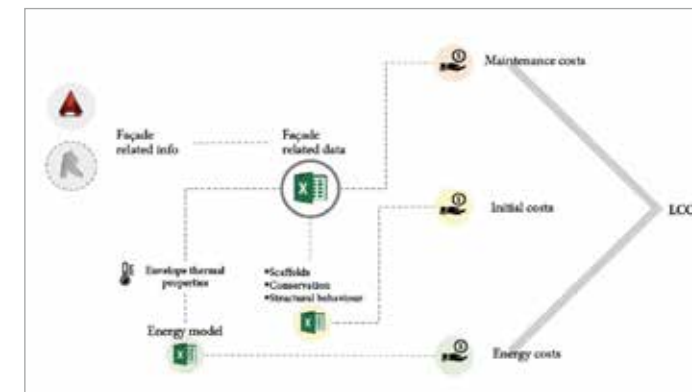


Fig.2 - Model setting

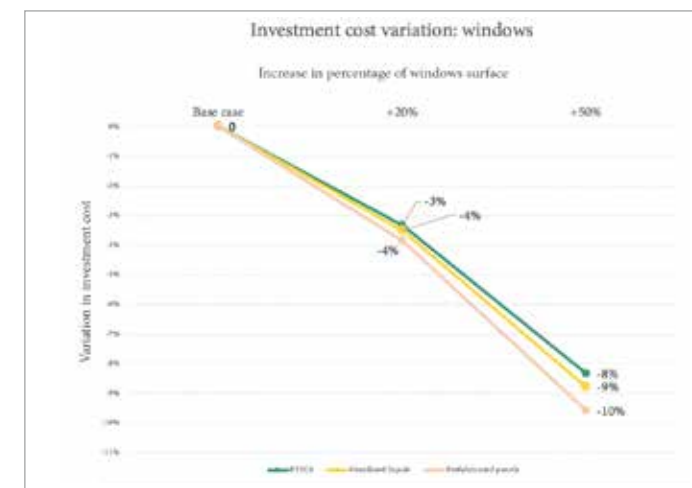


Fig.3 - Example of sensitivity analysis

METHODS OF ANALYSIS & INNOVATIVE STRATEGIES FOR SEISMIC ASSESSMENT & RETROFITTING OF EXISTING MASONRY STRUCTURES

Rafael Shehu - Supervisor: Gabriele Milani

Tutor: Siro Casolo - Co-Supervisor: Marco V. Valente

The majority of existing structures in Italy are built with masonry, especially with clay bricks and lime mortar. Masonry structures exhibit in general very poor mechanical properties, showing a very low resistance to in-plane and particularly to out-of-plane loads. Excessively, the response of masonry structures is characterized by severe damages for a relatively low seismic intensity, highlighting their high vulnerability when subjected to seismic loads. Almost all the cultural and historical heritage assets are related to this typology of construction.

In May 2012, a seismic sequence stroke Emilia Romagna region causing significant losses on the architectural heritage. Different churches and bell towers have experienced relevant damages of their structural and non-structural elements. Consequently, the resisting capacity of these structures is questionable and strengthening interventions are necessary for guaranteeing their safety. The knowledge on the structural response of non-damaged, damaged and strengthened structures is evolving, and investigations with numerical and experimental studies make an essential contribution.

Different case studies with sufficient data for their performance investigation have been available from Curia di Ferrara for this study. Italian technical codes and the current research provide recommendations for different techniques of analyses methods and retrofitting possibilities. Both these approaches have been considered in this dissertation, which treats a comprehensive approach from the vulnerability assessment to the retrofitting solutions, seen from a computational standpoint. At present, the most crucial aspects are the limitations of retrofitting techniques related to their potential invasiveness and irreversibility.

For masonry towers, which include bell towers and industrial chimneys, a relevant enhancement is proposed for what regards their modeling and analysis by means of simplified models. Particular attention is focused on the failure mechanisms that are prone to occur, and enrichment with different kinematic mechanisms is proposed to account for structural and material deficiencies. Practitioners can utilize this approach and make simplified estimations on the expected vulnerability, corresponding

seismic capacity and propose a retrofitting strategy based on the expected risk.

For masonry churches, it is recognized the complexity of their structural response and consequently the derived error and limitations when considering simplified models. A simplified modeling technique is adopted and applicable to any commercial code which provides some minimal requirements related to material models, shell or 3D solid discretization and advanced numerical analysis. The macroscale modeling of the whole structure is quite challenging and reflects many drawbacks.

The dissertation is an endeavor to provide an overview of the current challenges in modeling, analyzing and retrofitting of masonry churches and masonry towers. Dealing with the same specific problems, it was possible to utilize the present tools in order to provide a different perspective on the solution. The results are satisfactory to contribute to the built heritage preservation; however, many challenges that need to be addressed are acknowledged here.

A PLACE FOR THE WORKPLACE TO WORK

A SYSTEM OF PERFORMANCE INDICATORS FOR STRATEGIC DESIGN, MANAGEMENT AND USE OF THE WORKPLACE

Chiara Tagliaro - Supervisor and Tutor: Gianandrea Ciaramella

Co-Supervisor: Ying Hua

New and easily applicable ways to attune the in-use quality of office buildings are needed in order to improve space, business and people performance. This research proposes a framework for key performance indicators (KPIs) to support decision-making processes in the design, management, and use of next-generation workplaces.

Office space has been going through radical changes lately. Recent financial constraints have contributed to modifying corporate real estate strategies and the traditional role of the workplace. Moreover, disruptive advancements in the Information-Communication Technology field have led to three main consequences. (A) New 'smart' ways of working are influencing the traditional office space in both quantitative and qualitative terms. (B) New communication modes and feedback channels empower clients and users of services/facilities. (C) New data are available and suitable to create value, which increases the importance of updated information. These trends converge in the workplace that is expected to evolve according to both organizations' needs and people's preferences. For these reasons, there is growing interest in studying the ongoing changes of

the work environment and how its users perceive it. In fact, various users hold a stake on workplaces, but research to date has not clarified who they are, with respect to their actual roles and responsibilities, and values and needs. Also, several kinds of performances get measured by organizational managers, corporate real estate managers, and facility managers. Though, the related indicators often remain separate in the respective disciplines and at a raw stage of elaboration, thus cannot be exploited to their maximum potential.

How are today's workplaces adapting to the mutable needs of their demanding users? Who are workplace users? How can we better design, manage, and use today's and tomorrow's workplaces? These are the main questions this study aims at answering to. The goal of the research is twofold: first to acknowledge workplace users; second, to select interdisciplinary indicators that all these users deem important in workplace-making, and to systematize these into a manageable list.

The methodology applied to address this double objective

develops throughout subsequent steps of investigation. A triangulation of research strategies is employed. Preliminary review of literature helps set a framework about the changing panorama of the workplace. In a next research phase, the characteristics of workplace users are examined through case studies. In the final phase, KPIs are extracted and elaborated by applying a Delphi technique.

Finally, the research provides a set of key indicators (Table 1) enabling the compound of different workplace users' perspectives into a unified system. This model is suitable to assisting the design, management, and use of next-generation workplaces, while enhancing the relationship between workplaces and their users.

Keywords
Workplace, Users, Key Performance Indicators, Interdisciplinarity.

Category	Class - Impact/Value		
	Financial/organizational	Environmental	Social
Environmental quality		• Indoor air quality and ventilation (2)	• Thermal comfort (12)
Building operation and management	• Cost of corrective intervention (33)	• Indoor air climate (10)	• Acoustics comfort (16)
Space usage		• Light quality, Lighting and daylighting (22)	• Light comfort (natural vs. artificial) (17)
Business effectiveness	• Revenue breakdown (sales or revenue per square foot/ meter, square foot/meter per unit of revenue) (23)	• Acoustic quality, noise and acoustics (24)	• Ergonomics comfort (qualitative) (20)
Costs	• Deadlines met (on time delivery) (31)	• Indoor vs. outdoor environmental quality (lighting, temperature, noise) (25)	
Value/Return/Yield	• Operating costs/person (maintenance, utility, energy) (6)	• Number of FM requests made vs. number or requests met with timing (3)	• Design for All (Accessibility for disabled) (4)
Productivity/Ways of Working	• Return-on-investment/	• Resource consumption (energy, water, materials), Sustainability objectives (waste, energy consumption, etc.), Environmental sustainability of buildings (5)	• Quality of communication strategies to encourage ethics, health and safety practices (11)
User attitude	• economic value added (32)	• Standards of cleaning (21)	• Reliability of the maintenance service (Competence of facility management staff) (27)
Staff characteristics	• Customer retention (30)	• Space utilization (seats at workstations, in meeting rooms, in collaborative spaces; space per employee for filing and archive; each type of space) (8)	
		• Accessibility to ICT networks (1)	• Employee productivity (13)
			• Adequacy of space (survey based data), suitability of premises and functional environment (18)
		• People means of transportation (private vs. public) (19)	• Effectiveness of ICT help desk service, Responsiveness to problems (perceptual) (26)
			• Innovation in spaces and equipment (Δ to benchmark) (28)
			• Engagement, Community satisfaction and participation, Atmosphere of the community (7)
			• Image to outside (9)
			• Effective communication of company culture (29)
			• Psychophysical wellness (14)
			• Multiculturalism (staff composition) (15)

Tab.1 - Final system of KPIs for workplace design, management and use

THE SPATIAL DIMENSION OF A MASS PHENOMENON. ARCHITECTURES FOR GRASSROOTS SPORT

Sara Giulia Troncone - Supervisor: Francesca Bonfante

Tutor: Laura Anna Pezzetti

The thesis studies the evolution of facilities for sport and leisure since the post-war years till today. Although this topic is already studied by historians, sociologists and geographers, the experimentation and construction of buildings for leisure has yet to be fully investigated by architectural research.

In the first phase of the research has been studied the contribution of several disciplines that had introduced new paradigms and themes about the typological and settlement characteristics of the sport spaces.

The study does not focus on facilities specialized for competitions, as many publications on stadia and sport palaces are already edited, but it deals with multifunctional facilities

facing with the urban scale, related with the context in which are located and with a high level of attractiveness. The research focuses on facilities related to this. Since scholars agree about the shift, during the Fifties and Sixties, from a notion of sport as a structured practice (organized and/or agonistic) to the spread of a free behaviour and experience, the so called "grassroots sport". The research aims therefore to investigate the development of what is known as the sport and leisure centre since the Fifties, in its progressive articulation and distinction, through a selection of case-studies which could link the 'politics' of the provision of sports practice and the 'systematic' construction of facilities in two temporal span: architecture

for leisure and welfare policies during the British re-construction of the Post-War period (1960-1979); architecture for grassroots sport and public clients during the democratization process of Catalonia (1975-1992). A comparative analysis is conducted with respect to three key factors: the role of public administration; the protagonists (politicians and architects); settlements and architectural experimentations. The research is organized on the deepening of architectural issues and the structure of the text is used also to structure the apparatus: an atlas of architectures useful for the design of sports facilities in contemporary cities.



Fig. 1 - Gym in the assembly hall, Hazelgrove School, Johns, S Latter and Harward architects, Hatfield, 1955



Fig. 2 - Sports hall, Calton Cavendish comprehensive school, Henry T. Swain, Nottingham, 1971



Fig. 3 - Torroella sports hall, Carlos Ferrater, Jeroni Moner and Arcadi Pla, Torroella de Montgrí, Girona, 1985

BOND OF GFRP BARS AND CONCRETE: FROM LOCAL TO STRUCTURAL MECHANICAL BEHAVIOUR

Ana Veljkovic - Supervisor: Valter Carvelli

Tutor: Siro Casolo

Constructing using newly developed materials presents new wave of modern aspirations in civil engineering society. The material that is extensively used as reinforcement in new concrete structures is certainly the FRP (Fibre Reinforced Polymer). As a reinforcement material, GFRP (Glass Fibre Reinforced Polymer) finds increasing application in reinforced concrete structures due to its good quality/cost ratio. The main advantages of using GFRP reinforcement are: their non-corrosive and non-conductive characteristics and high strength-to-weight ratio, as well as their magnetic transparency and high fatigue endurance. GFRP bars proved their superiority or, at least, great competency in the market as modern building material with many advantages. Since first vanguard applications in last decades of XX century, the FRP reinforcement is nowadays present in many practical design guidelines, endeavouring to take even more share in global use of reinforcement for concrete structures. Still, these guidelines are incomplete or very conservative due to insufficient knowledge concerning certain issues. One of the most important issues in RC

(Reinforced Concrete) design is the bond between concrete and reinforcing bar. It shall provide secure and balanced transfer of forces from reinforcement to surrounding concrete. Although much research effort is spent on proper understanding the characteristics of FRP bar/concrete bond, this area is still treated with great attention, due to many unresolved aspects. Beside bond characteristics under quasi-static loading, focus needs to be put on the durability of bond as well. Having in mind high expectations of FRP RC structures in terms of long life span, it becomes clear that their long-term performance has the leading role in construction and design. Bond durability aspects of interest are its behaviour under sustained load (creep), cyclic load (fatigue), thermo-mechanical load (heating and fire), moisture environment, etc. The bond action is important for RC structural response and it is typically considered in engineering calculations in two ways. First is assuming perfect bond, i.e. no slip occurrence between reinforcing bar and concrete. This approximation is usually overcome by inclusion of tension stiffening effect that is built in some constitutive models

of concrete or bar in tension. Second way is introducing the bond slip effect directly in the calculation, which in turn allows the use of plain concrete and bar constitutive models. Focus of this thesis is put on the second approach that was implemented in this work. This approach also enables the introduction of another mechanism present in FRP RC structures - debonding of the bar from the surrounding concrete. In the experimental part, this thesis is dealing with the static and fatigue bond behaviour between GFRP bars and concrete. The experimental research is based on centric and eccentric pull-out tests. It brings some new clarifications about GFRP bar/concrete debonding process under static loading and the one of few studies on this bond performance under high-cycle fatigue loading. The benefits of using this type of reinforcement with small concrete cover are emphasized for both types of loading. Comparison of the experimental static bond strength with the predictions of available design guidelines showed good match in case of predictions that consider embedded length of the bar. Numerical part of the thesis is dedicated to simulation

of debonding process under static and thermo-mechanical loading. The model based on FEM (Finite Element Method) was created to simulate the pull-out experiments. Subsequently, developed procedure was incorporated into simulation of FRP RC members' behaviour under static loading, using the local bond-slip models obtained from the experiments. This methodology showed better performance comparing to the perfect-bond model and good potential for the use in future.

ESTIMATING THE BUILDINGS HOURLY ENERGY DEMAND FOR SMART ENERGY DISTRICT PLANNING

Federica Zagarella - Supervisor: Simone Ferrari

Tutor: Paola Caputo

For planning smart energy districts in urban contexts, including the integration of the distributed energy supply, district heating networks, possibly integrated with cooling, energy from renewable sources and storages, the assessment of hourly energy demand fluctuations of buildings, even undergone to energy retrofits, is relevant in order to optimise the energy efficiency measures at building level as well as the energy supply system related efficiency and costs. Accordingly, among the commonly adopted tools for urban energy planning, the ones which are more detailed (e.g. EnergyPLAN, Homer, energyPRO, DER-CAM, etc.) base on hourly energy demand profiles. However, from the surveyed technical literature, it has noted that energy assessments are often based on seasonally or annually buildings energy demands otherwise on measured consumptions, whose spread availability is critical, thus more robust methods are needed in case of data lack. Considering this, in the frame of a doctoral research, it has been defined a method for estimating the buildings hourly thermal and electric energy demand profiles, able to be updated and applied in urban areas over the Italian context.

The method includes a georeferenced procedure, implemented and coded in the open-source QGIS software with the Python platform embedded, which adopts spatial data largely available and uniform over the national territory. In particular, data from the local Topographic Database have been used to define the volumetric consistency of the built environment, differently characterized on the basis of defined geometric portions of buildings with reference to the main boundary conditions (namely, "typical thermal zones"). Besides, data from the General Census of Population and Houses (Istat) have been used to characterize the building stock with reference to

the main periods of construction (from old with traditional buildings to recent with buildings complying with energy saving requirements) and the most widespread use categories (residential and common tertiary-office). For determining the hourly energy profiles, a set of dynamic energy simulations is foreseen. In particular, a set of Building Energy Models, considering different envelopes representative of typical solutions in Italy across historical periods, has been defined for both residential and common tertiary-office use categories. Such Building Energy Models have been assessed as simplified building models (namely, "Building Concepts"), and the energy behaviour for space heating

and cooling needs of the typical thermal zones, representative of the different boundary conditions options composing any building geometry, has been determined. Along by this, the profiles of electricity consumption of electric appliances and artificial lighting for each thermal zone have been determined. Then, the derived hourly energy density profiles [W/m^3] can be associated to the characterized

building stock volume calculated in GIS, in order to carry out the assessed urban/district building stock hourly thermal and electric energy demand profiles. Furthermore, based on the data about the installed thermal systems in buildings from the under implementation local databases, it could be possible associating typical heating and cooling systems efficiencies, so that obtaining the urban/district

energy consumption profiles. Remarkably, the determined urban energy consumption profiles represent useful input data to be adopted within mentioned energy planning tools. Moreover, once calibrated the Building Energy Models' properties, through the comparison of simulated energy profiles with measured consumptions, they can be modified, by assigning the new physical envelope and systems properties, for considering the effects of foreseen energy efficiency measures. Hence, by rerunning the whole procedure, it could be possible obtaining the updated energy consumption profile.

As a case study, the defined method has been also tested to the city of Milan, for which the urban annual thermal and electric energy consumptions due to the residential buildings have been validated with the ones from the local energy balance. As result, a deep description of the method and the coded procedure have been provided, therefore the method can be implemented in other Italian cities, for which the used spatial data are available. Hence, the presented method could represent a valid supporting tool to the widespread planning of urban smart energy districts.

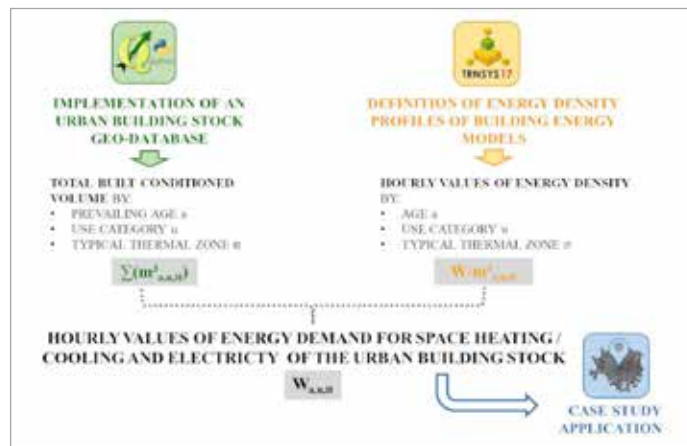


Fig. 1 - Diagram of the defined methodology.

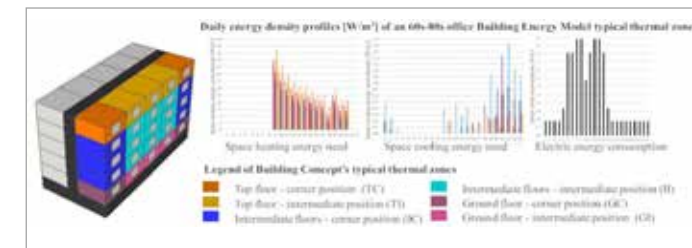


Fig.2 - Building Concept composition in typical thermal zones and example of energy density profiles [W/m^3].

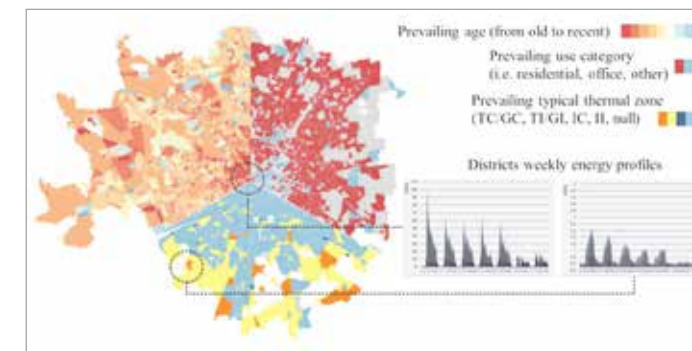


Fig.3 - Case study application: map of characterized building stock and example of districts energy profiles.

SEISMIC ANALYSIS OF UNDERGROUND WORKS AND PRACTICE: THE CASE OF METROLIMA

Marco Zucca - Supervisor: Alberto Franchi

Tutor: Maria Adelaide V. Parisi

The evaluation of the seismic behavior of underground structures represents one of the most actual seismic geotechnical and structural engineering research topics.

In the last decades, different types of simplified and numerical approaches have been developed for the correct analysis of the seismic vulnerability of these important infrastructures and a series of laboratory tests for the seismic behavior characterization of the soils (e.g. resonant column test, etc.) and of the coupled soil-structure system (e.g. centrifuge test, etc.) have been conducted, especially after the recent strong earthquakes where the underground structures have been subjected to significant damages. In the same way, in the last few years, the Technical Codes are beginning to pay attention to the seismic design of these structures.

Despite the significant development of knowledge, described above, still remain open several uncertainties of the correct reproduction of the underground structures behavior under seismic load.

The goal of this research project is to further improve the knowledge of the underground structures behavior under seismic load,

with the application of different simplified approaches, numerical models and laboratory tests, taking as case study the new Lima Metro line 2.

In the first chapter, a short description of the underground structures behavior under seismic action is presented. Particular attention is devoted to the description of the underground structure seismic response during the most important recent earthquake events.

Following the introduction, the second chapter reports a detailed description of the actual techniques for the evaluation of the seismic response of the underground structures, taking into special consideration the evolution of the numerical approaches of the coupled soil-structure interaction system and the definition of the non-linear behavior of the soil.

In the third chapter, the attention is focused on the comparison between numerical methods and simplified approaches through the execution of sensitivity analysis considering the variation of the soil mechanical properties (in particular of the shear modulus) remaining within the category type B according to the limit, in terms of shear waves velocity, defined by

Eurocode 8. The results, obtained by the application of the different type of approaches, are discussed from a critical point of view.

The fourth chapter reports a detailed description of the case study: the project of the new Lima Metro line 2. Otherwise the structural characteristics of the metro stations, particular attention is devoted to the hydrogeological, geological and geotechnical characterization of the project area. A series of laboratory and in situ tests have been carried out in order to obtain the mechanical properties of the soils. In particular, the attention is focused on the Mercado Santa Anita metro station that is the first metro station built. For the evaluation of the seismic behavior of this station simplified decoupled approaches and numerical analysis are performed.

In the fifth chapter, the final considerations of the results obtained by the execution of the different types of analysis are discussed, also considering as observed by the case study described in the fourth chapter.