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PhD Yearbook | 2018

Chair:
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DOCTORAL PROGRAM IN ARCHITECTURE, BUILT ENVIRONMENT AND CONSTRUCTION ENGINEERING

Vision

We are a new (2012) *Doctoral Program*, evolution of five other programs, active since the institution of the Italian Dottorato di Ricerca (PhD) in 1988, that merged to create a national reference point for training researchers and experts in *Architecture, Built Environment* and *Construction Engineering*. Our working field includes any critical subject or question related to:

- 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 System* 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.

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The Program pursues the following ten pillars:

1) *Selection* through a full transparent, open process.
2) Candidates as independent, mentored and monitored, *researchers*.
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4) Training activities based on *research practice*.
5) Research practice hinged on the framework of Department activities.
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9) Systematic valorization of PhD holders and their products among stakeholders.
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- plan, attend and pass, with positive evaluation, a complementary series of *Doctoral Courses*, to complete her/his skills as researcher.
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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 Doctoral Programme in ABC 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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DEVELOPMENT OF SUSTAINABLE HIGH PERFORMANCE FIBER-REINFORCED CONCRETES BY USING CALCIUM SULFOALUMINATE CEMENT

Vahid Afroughsabet - Supervisor: Luigi Biolzi

Nowadays, the demand for using high performance fiber-reinforced concrete (HPFRC) with improved qualities is widely increased throughout the world. As it is commonly known, for the production of a high performance concrete (HPC) matrix, a large amount of binder is normally used. The production of ordinary Portland cement (OPC) as the binder of concrete accounts for 7% of CO_2 emission, in which has a notable environmental impacts, and subsequently results in unsustainable concrete. This study is aimed at replacing OPC with innovative cements like calcium sulfoaluminate cement (CSA) and Type K cement to develop more sustainable HPFRC. Hence, twenty four different concrete mixes were developed and their mechanical, physical, durability and microstructural properties have been assessed.

The first objective of this study is to study the influence of CSA cement on the properties of HPC. Additionally, CSA-blended mixes with OPC, and also ternary mix containing slag were produced to investigate the effect of blended binder on the features of HPC. The second objective of this study is to evaluate the effect of different metallic and non-metallic fibers at constant fiber content of 1% on the properties of HPFRC. Also, the effect of fiber hybridization on the engineering properties of HPFRC was studied. The results of this study indicate that the full replacement of OPC with Type K cement had insignificant influence on the mechanical properties of HPC, while the addition of CSA cement led to an increase in the strengths of HPC. Among different cement based concrete developed in this study, the best performing mix was attained by the concrete containing pure CSA cement. The addition of CSA cement results in a reduced shrinkage deformation, improved durability properties, and enhanced bond between cement matrix and fibers. The results of HPFRC indicate that the addition of double hooked-end (DHE) steel fibers significantly increased the engineering properties of concrete. A deflection-hardening behavior was attained in the flexural performance of HPFRC containing at least 0.5% DHE steel fibers. The findings of this study are of great interest to structural engineers and have the potential to significantly contribute toward expanding the use of HPFRC to different structural applications.

Keywords: High performance concrete; Fiber-reinforced concrete; Type K cement; Calcium sulfoaluminate cement; Blended cement mix; Slag; Mechanical properties; Durability properties; Shrinkage deformation; Microstructural properties

DIGITAL TRANSFORMATION OF MULTIDISCIPLINARY DESIGN FIRMS: A SYSTEMATIC, ANALYSIS-BASED APPROACH TO CHANGE MANAGEMENT

Marcella Bonanomi - Supervisor: Prof. Cinzia Talamo

The thesis investigates the important and challenging topic of change management in the context of the digitalization of the construction industry. Digital tools are transforming the way buildings are designed, constructed and operated, leading to significant changes in the way practitioners work and collaborate. Many have recognized that the technological aspects of these changes are the easiest to manage; the more significant challenges relate to the organizational and process-oriented changes required. This is the reason why the research investigates changes in processes and organizational structures in digital transitions. Specifically, the research focuses on digital change in multidisciplinary design firms. To reap the full benefits of digitalization, in fact, more and more multidisciplinary design firms are undergoing digital business transformation, facing a revolution about process and knowledge management.
The essential step to developing successful change management strategies is a solid understanding of changes in context. Although past research on organizational innovation has documented the importance of context and environment in the innovation process, this dimension has largely been ignored in the digital and BIM adoption and implementation literature. Therefore, the research undertakes the significant challenge of trying to better understand how this digital transformation impacts the design processes and organizational structures of multidisciplinary design firms in context. Specifically, it seeks to better understand how to manage change and how to develop change management strategies. Considering these statements, the questions posed are: what changes are occurring in multidisciplinary design firms associated with the digitalization of the construction industry? How to understand, analyze, and manage changes in the design processes and organizational structures? How to draw, calibrate and target change management strategies according to the context of change and the level of digital and BIM implementation?

Given these research questions, the present study is aimed to bring forth a better understanding of what changes occur in the design processes and organizational structures, how they unfold in context, and what change management strategies can be developed to lead a successful digital business transformation. These objectives lead to the development of a systematic, analysis-based approach to which is made up by the following components: 1) a change management framework (Fig. 1); 2) a set of change analysis methods (Fig. 2); and strategic lines and action-based approaches (Fig. 3).

First, the proposed framework identifies two perspectives, namely design process and organizational structure, and four paradigms of change: collaboration, iteration, dynamicity, and network. This is a strength as much of the research in this field focuses only on technology and process, not considering the organizational issues. Second, the set of analysis methods brings together many of the analytical tools providing a methodology for analyzing change in processes and organizational structures in digital transitions. The research is then distilled into strategic lines and action-based approaches.

Fig. 1 - Proposed change management framework

The complexity of the topic has required a multi-method approach. The approach taken includes extensive literature review and expert interviews to define the theoretic framework; a two-case study approach to carry out the experimental research, which meant studying process-oriented and organizational changes in practice.
Mixed-methods of data collection (direct observation, surveys, interviews) were conducted on two main research sites to inform and support the research project. The first site was that of an Italian multidisciplinary design firm located in Milan, Italy. Data collection on this site started in April 2015 and ended in December 2016. The data collected on this site allowed an in-depth investigation of process-oriented changes, in terms of collaboration and iteration. The second site was that of a Canadian multidisciplinary design firm located in Vancouver, British Columbia. Data collection on this site started in June 2017 and ended in October 2017. The data collected on this site allowed a breadth of investigation into organizational changes, in terms of network and dynamicity.
For this research, data from only two case studies were collected and analyzed which we understand is a limitation to the study. Therefore, the research outcomes should be tested further in practice. There is an opportunity for direct and extensive follow up on this research through further study of design practice evolution as digital tools change, and the testing of the proposed approach in a variety of design process and organizational contexts.

Fig. 2 - Proposed set of change analysis methods

STRATEGIC LINE	ACTION-BASED APPROACH	
Advancing standards and practices for knowledge creation and distribution across internal and external organizational boundaries	*Intra-firm Dynamic* Defining standards and procedures for data exchange, deliverables, technology infrastructure, legal framework	*Inter-firm Dynamic* Enhancing a community of practice through participation in digital experts' groups, users' blogs, research labs and conferences
Developing metrics and analytics environments for measurement and optimization and of the design process and the related practices	*Workflow Dimension* Setting up workflows to pull design information from project data towards a performance-based design process	*Workforce Dimension* Customizing business intelligence dashboards for team creation, human resource and project management
Promoting networked structures for organizational models and stakeholder management	*Micro-Level* Formalizing a digital experts' group for support and advice to enable knowledge creation and distribution	*Macro-Level* Fostering partnerships with project stakeholders to support long-term efficiency and innovation

Tab. 1 - Proposed strategic lines and related action-based approaches

FROM CULTURAL HERITAGE TO DEVELOPMENT: THE ROLE OF CREATIVITY

Silvia Cerisola - Supervisor: Prof. Roberta Capello

The role that cultural heritage and creativity can play in regional development has been more and more recognized, underlining the importance of paying critical attention to the peculiarities of the different social, political, technological and cultural models that enable, hinder or displace the creative and cultural economy.
In this sense, the territorial dimension has gained great relevance and the importance of local history and cultural heritage in shaping the features of local systems and in affecting their economic outcomes has been strongly emphasized. The success of a territorial system, indeed, does not depend solely on the material resources with which it is endowed. It also, and crucially, depends on non-material inputs, like the richness of its cognitive elements in terms of human knowledge, intelligence, and creativity. These are fundamental conditions for generating innovation and development.
Cultural heritage is today looked at as an economic asset – even in terms of social cohesion - but also as a basis for sustainable development and quality of life. Creativity is instead considered as a major driver of innovation and, as such, critically important for regional economic performance. Therefore, if cultural heritage and creativity can positively affect regional development, clarifying the channels through which this can occur is extremely relevant in order to design appropriate policies.
The thesis aims indeed at addressing this issue through: i. an investigation of the potential direct link between cultural heritage and economic development; ii. an analysis of the effect of cultural heritage on (different types of) local creativity; iii. an investigation on the role of creativity in regional development; and iv. an overall comprehensive model meant to reconcile the different elements involved and to shed light on the cultural heritage → creativity → development nexus.
In particular, the thesis starts from the idea that one possible *mediator* (*catalyzer*) between cultural heritage and regional economic performance is creativity, expressed according to different patterns. In this sense, the main research question we try to answer is: *Does creativity mediate the effect of cultural heritage on economic development?*
The overall reasoning is graphically shown in Figure 1. Link "A" represents the (potential) direct relation between cultural heritage and economic development which is usually assumed in the existing literature. Link "B" represents instead the relation between cultural heritage and creativity, according to the idea that cultural heritage – through its *aesthetic* and *emotional* values, and thus exerting an *inspirational role* - can contribute to the shaping of the peculiar creativity of a local area. In particular, the focus of the thesis is on the "creative environment", thus on how cultural heritage affects (inspires) the specific creative features of local systems and the way in which these eventually play a role in economic development. Finally, link "C" shows the relation between creativity and economic development; such relation is expected to be positive since creativity is supposed to trigger the generation of new and original ideas and – through this mechanism – to lead to economic development. The overall reasoning is thus based on the mediating role of creativity between cultural heritage and economic development (links "B" + "C" in Figure 1).

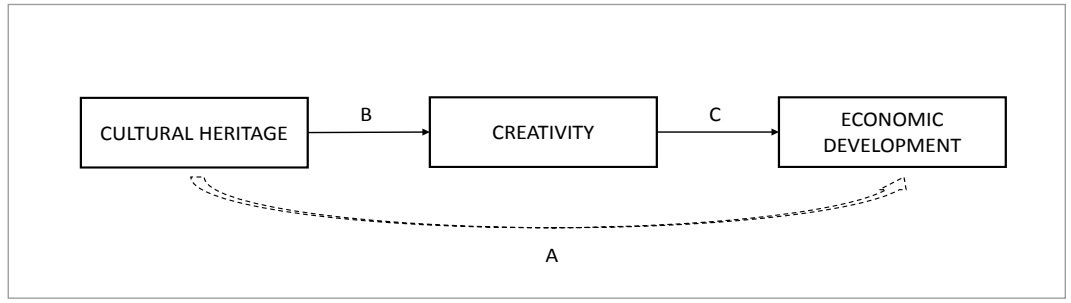

Fig. 1 - Cultural heritage and development: direct and indirect (mediated by creativity) effects

As for cultural heritage, it is defined as *tangible*, being it the physical representation of the history of a given place and people. In this sense, immovable units of heritage also carry with them intangible meanings. Moreover, cultural heritage is considered as a *public good*, thus characterized by non-excludability (no one can be excluded from its consumption) and by a low level of rivalry (consumption by one individual does not preclude consumption by others).
As for creativity, this thesis proposes an innovative conceptual framework that allows to identify and measure different types of creative talents (artistic, scientific, and economic) and all their possible interactions, according to the belief that it is the "mental cross-fertilization" between different creative talents that generates innovative and breakthrough ideas and – through this mechanism – pushes economic development. Creativity is thus defined as *ideation based on talents of different types, i.e. stemming from different domains*.
The potential role of creativity as a *mediator* between cultural heritage and economic development is investigated throughout the whole work, both conceptually and empirically through different econometric applications on Italian provinces. In particular, the potential direct effect of cultural heritage on regional economic development is found to be not significant. Subsequently, the *inspirational role* of cultural heritage on (different types of) creativity is conceptually and econometrically explored, according to the belief that cultural heritage can affect our thoughts and feelings and, through this mechanism, stimulate critical and innovative thinking. Cultural heritage results indeed as a strong determinant of artistic creativity and, to a lesser extent, of scientific creativity. As for the role of (multidimensional) creativity in regional economic development, we conclude that single types of creativity (either artistic, scientific, or economic) do not trigger local economic development; it is instead the interaction between different types of creativity that positively and significantly affect the economic performance.
Finally, the whole reasoning (from cultural heritage to development *through* creativity) is reconstructed through an econometric model that allows to prove the indirect effect of cultural heritage on regional economic development. Being a significant determinant of artistic and scientific creativity, cultural heritage seems to have an indirect impact on economic development through the synergic interaction of these two creative talents and, more generally, through its contribution to other interactions as well.
Hence, the overall work shows how cultural heritage can affect regional economic development through a sophisticated mechanism that sees it as an indirect generator of economic performance through the mediation and catalyzing role played by creativity. This important result has relevant policy implications, that are discussed in the conclusions of the thesis.

PERFORMANCE BASED APPROACH FOR THE SEISMIC ASSESSMENT AND RETROFIT OF MASONRY BUILDINGS

Nicola Giordano - Supervisor: Alberto Franchi

Co-Supervisor: Pietro Crespi

Over the last decades, the technical-scientific community has paid serious attention to the investigation of the seismic response of unreinforced masonry (URM) buildings. As a matter of fact, despite the large diffusion of modern construction techniques such as reinforced concrete and steel, URM structures still represent an important portion of the global building stock. For instance, earthquake prone countries such as Mexico, Pakistan and Peru account more than 70% of URMs over the total building inventory while Italy, Turkey and Iran attest between 45% and 65%. From an historic point of view, masonry is considered one of the oldest construction techniques and was largely used in the past, both in historical town centers and in rural areas. Nowadays it continues to be mainly adopted in the developing countries. In these regions, because of the poor quality of the construction techniques, non-engineered URM structures have revealed a high vulnerability to the earthquakes, causing an enormous number of human losses (to name a few the 2003 Bam Earthquake - Iran with 26 000 fatalities or the 2005 Kashmir Earthquake - Pakistan with 100 000 human losses). Earthquake fatalities, however, are not only connected to emergent nations. Recent studies have pointed out that some developed countries, such as Italy, present important fatality rates for moderate levels of earthquake magnitude. Focusing on the Italian case, the large human losses of the last seismic events (2009 L'Aquila Earthquake, 2016 Amatrice Earthquake) are strongly connected to the structural deficiency and consequent low collapse limit of unreinforced masonry buildings: low quality of the materials, geometrical irregularities, inadequate wall-to-wall and floor-to-wall connections and absence of anti-seismic detailing are just few aspects of masonry constructions weaknesses.

Beside fatalities, direct and indirect economic losses (i.e. physical damages and business interruption) can also be relevant when moderate or severe earthquakes affect areas characterized by a large number of URMs. One interesting case is represented by the city of L'Aquila which is the administrative seat of the Abruzzo region. At the time of the 2009 Earthquake, the historical town center was a governmental, commercial and touristic district. Among 753 buildings located in this part of the city, 81% of these buildings were still condemned in 2010 depriving the city of an important source of income and occupation.

Another aspect that should be considered when dealing with old URM construction is the historic value. Economic studies have pointed out that the preservation of heritage buildings represents significant social and financial benefits for the people. In fact, besides the artistic and the architectural value, heritages attract tourism and investments and contribute in the definition of a "sense of identity for the local community" (G. D. Garrod). However, historic buildings, usually non-engineered, require continuous structural investigations and interventions such as diagnostic tests, monitoring, local repairs and rehabilitation. If these maintenance procedures are not regularly carried out, the effect in case of seismic events can be devastating as observed after the 2009 L'Aquila Earthquake, where 170 over 240 monumental constructions experienced heavy damage or partial failures.

Starting from these considerations, in recent years engineers and researchers have performed the seismic assessment of URM buildings through different numerical modeling approaches such as the continuous finite element method, the discrete element method and the equivalent frame method. Regardless of the modeling methodology, the main goal of these studies is, in general, the evaluation of the capacity of the structure in terms of maximum horizontal load multiplier a_g/g or in terms of force-displacement pushover diagrams. Eventually, the estimation of the building's capacity is correlated with a capacity vs. demand performance assessment, adopting the analytical procedures commonly used for reinforced concrete and steel structures, such as the Capacity Spectrum Method or the N2 Method. With these techniques, the performance of the building is calculated for a specific seismic hazard and is defined in engineering quantities i.e. load vs. resistance factors for internal forces, deformations, displacements, etc.

Without minimizing the importance to express the seismic performance in engineering measures, more recent studies have pointed out the need of a new definition of building performance in which the structural results are translated into more understandable quantities by decision-makers. Particularly, a Performance-Based Earthquake Engineering (PBEE) methodology was developed at the PEER Center (University of California Berkeley, USA). One of the key features of PEER-PBEE methodology is the explicit calculation of system performance measures, such as monetary losses, downtime and casualties, which are expressed in terms of the direct interest of various stakeholders. In recent years the method has been successfully adopted for the design of new buildings and included in American technical standards but its application for the case of existing URM structures is still lacking.

Starting from these concepts, the thesis gives different contributions in the direction of a better understanding of the seismic performance of URM structures.

Firstly, the cross-section behavior of masonry elements is deeply analyzed. Particularly, closed-form equations useful for a preliminary strength and ductility assessment of unreinforced masonry rectangular cross-sections are presented. Expressions for direct calculation of M-N (bending moment - axial load) strength domains and M-χ (moment - curvature) ductility diagrams for different constitutive laws are provided and validated with recent out-of-plane loading experimental tests available in the literature. For a better comprehension of URM members behavior under axial-bending loading condition, 3D M-N-χ diagrams are presented.

Subsequently, in order to critically review the seismic assessment methods currently proposed by the codes, two case study buildings located in L'Aquila (Italy) are investigated. In terms of modeling approach, beam and, more in general, equivalent frame discretization is adopted. In the first application the nonlinear behavior of the stone masonry columns of the *Basilica di Collemaggio* is investigated. In the second example, the focus is the seismic response of the *San Filippo Neri* historical city block. The results of code compliant structural assessment are finally discussed underlining pros and cons of these methodologies.

Finally, the last part of the thesis introduces the concepts of PBEE and extend it to the case of masonry buildings. Particularly, a PEER-PBEE version for URM is outlined in its four steps of analysis: hazard, structural, damage and loss analyses. Expected monetary losses in the form of probabilistic loss curves are then calculated for assessment purpose and for retrofitting design cost-benefit analysis.

APPLICATION OF DEEP MACHINE LEARNING IN MULTI-SCALE BUILDING ENERGY AUDIT

Fazel Khayatian - Supervisor: Prof. Giuliano Dall'O'
Co-Supervisor: Prof. Matteo Matteucci

Introduction

Considering the vast amount of data produced and collected in the context of building energy modelling, resorting to machine learning and data mining tools for processing the information is becoming inevitable. This study is an attempt to benefit from large databases to reduce the gap between building energy prediction and building energy performance. The objectives are met by moving from analytical and numerical based analyses to data-driven models. The process of collecting buildings' energy performance data, has become an integral part of building energy audit research. Therefore, the recent advancements in machine learning merit to be thoroughly studied from building energy auditors' perspective, while their compatibility as well as application should be validated on databases of building energy performance. This research is an attempt to close the gap between the state-of-the-art in deep machine learning and building energy audit, specifically, when dealing with large noisy databases.

Research overview and results

It has been more than a decade since regional and national administrations initiated data collection on buildings' energy performance. This led to large databases of building properties containing information on the geometry, envelope properties, systems characteristics, and occasionally actual patterns of energy consumption. The number of buildings in a single dataset is often in the magnitude of millions, as each category of "*destination of use*" consists of hundreds of thousands of entries. Analyzing such large databases is often associated with reliability assessment as a prerequisite. Considering that these databases are created by manual data collection, they are prone to contain anomalous data that will not be simply separable by resorting to filtering techniques. As a first attempt, this research develops a reliable approximator that can highlight outliers with acceptable confidence, using a blackbox perceptron. It is perceived that even without detailed information on the properties of a building, it is possible to detect anomalies in a dataset by assigning a value of confidence to each entry (Figure 1). The main objective of collecting such vast data on building properties and their corresponding energy performance is to provide decision-makers with viable knowledge. Therefore, the second step of the research extracts useful information from the dataset to support energy efficiency policies. In particular, the second section is aimed at regional scale policies for building energy retrofit, as there are no attempts to explicitly rank buildings based on their non-retrofitable characteristics. Therefore, a pipeline of machine learning tools are developed to create a distinctive ranking system for building energy retrofit potential. The pipeline extracts nonlinear features that faithfully represent the correlation between retrofitable building characteristics and the energy consumption. A new indicator is introduced, dubbed "*Building Energy Retrofit Index*", to replace the conventional energy performance measure for retrofit-based policies. It is observed that the newly introduced index can successfully rank buildings solely based on retrofitable characteristics. Also, the new index contrasts the inapplicability of traditional indicators for policy makers dealing with large scale building energy retrofit (Figure 2).

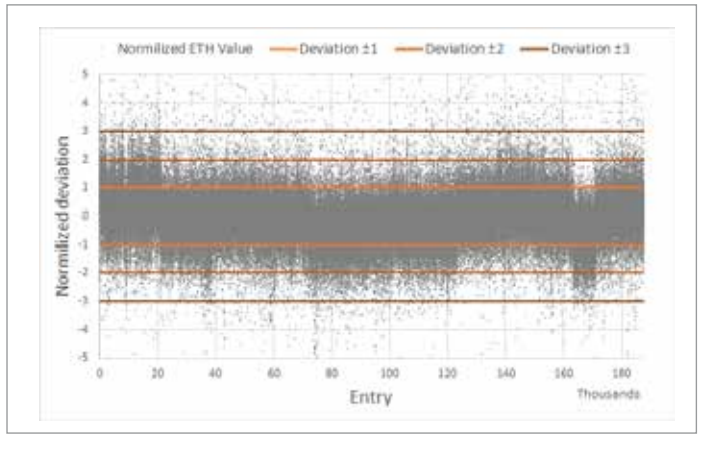

Fig. 1

The final step of the research is focused on obtaining more realistic realizations of the multi-scale building energy model. There are various attempts on addressing the issue of multi-scale building energy calibration, yet, all studies either focus on peak loads, or the cumulative annual energy performance. Consequently, there is a notable research gap in the context of calibrating urban energy models in hourly or sub-hourly intervals. The main barrier of the aforementioned challenge is the computational cost of running energy simulations. This study proposes a surrogate estimator (multi-layer neural network), coupled with Markov Chain Monte Carlo sampling technique (subset-sampling) to overcome this issue. The surrogate model replicates the time intensive calculations of the hourly energy loads, while the sampling engine efficiently generates random inputs from the area of interest by rejecting unwanted outputs. Results show that the newly introduced framework condense the computational cost by 99.6%, reducing the overall time from +500 days to a little more than two days. Such reduction in the computational burden comes at the cost of trivial loss in the estimation accuracy. Validating the calibrated inputs on the energy simulator reveal that the actual calibration accuracy is approximately 1% lower than that of the surrogate model, yet a reasonable tradeoff when considering the magnitude of reduction in the computational cost.

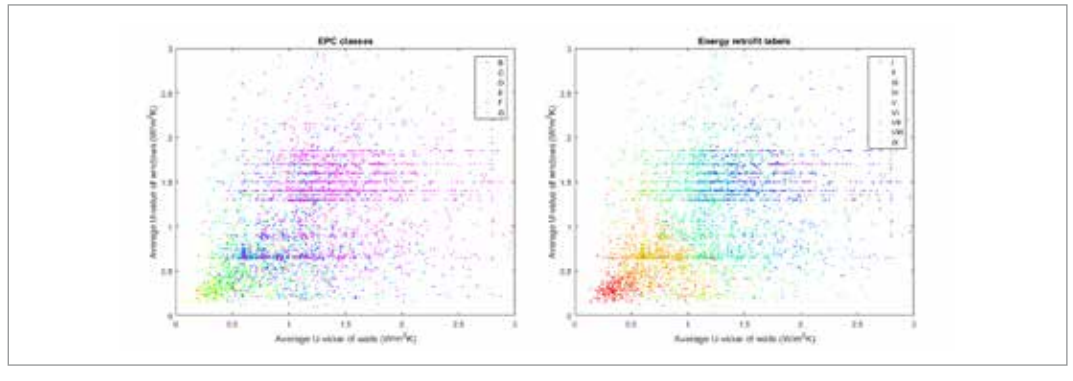

Fig. 2

Conclusion

Since the accumulation of data is inevitable, resorting to data-driven models will become an integral part of research. The common key component that enables the application of deep learning in various fields is the "*magnitude of the collected data*", a factor that started to affect the context of building energy performance just recently. Therefore, plenty of ground is yet to be covered, to fully adapt the state-of-the-art in deep learning to building energy audit. The PhD research "*Application of Deep Machine Learning in Multi-Scale Building Energy Audit*" is a first attempt to explore the territory of deep learning from the perspective of an energy auditor, overcoming the challenge of thoroughly assessing and validating the applicability of various deep networks in building energy audit problems amidst varied data granularities.

FORM AND DESIGN FOR SOCIAL HEALTH FACILITIES IN DEVELOPING COUNTRIES

THE CASE STUDY OF LAURO DE FREITAS, BRAZIL

Monica Moscatelli - Tutor: Prof. Massimo Ferrari - Supervisor: Prof. Domenico Chizzoniti
Co-Supervisor: Prof. Antônio Pedro Alves de Carvalho, Federal University of Bahia, Brazil

Healthcare in developing countries focuses on Primary Health Care (PHC), that has the objective to promote health and offer assistance to the local population, through polyvalent health facilities that provide human development and wellbeing.
At the opposite pole, Emergency Medical Assistance (EMA) refers to disasters or emergency situations: earthquakes, floods, migrations, tsunamis, terrorist attacks, wars, and economic crises.
These two different strategies have often been confused; the links to the context in which they are applied are different, as well as the objectives, the resources used, the social dimensions, and the time perspectives.
Most prefabricated systems are designed through a logic of "closed" systems that reduce the project flexibility, getting strictly defined configurations both in terms of typology and technology applied.
A primary health care approach needs a flexible and adaptable method able to acquire the principle of self-sufficiency with "open" systems, thus avoiding any fixed solutions. The search result is primarily to define a flexible, expandable and versatile facility through a construction system and a logical settlement that can be expanded according to site requirements.
A consolidated and generalized procedure is needed to ensure a proper planning to help designers to build appropriate and integrated structures in different developing contexts, especially in remote areas where health care problems are increasing due to the lack of healthcare, water, transport and electricity, in order to identify the possibilities and the problems in the area to solve them rationally.
This work aims to identify a procedure that can define the typological, figurative and constructive aspects of the architectural structure of a social-health prototype for the marginal areas of the developing countries.
A special consideration is given to the compositional aspects that define the architectural space of the prototype arising from the study of the socio-cultural aspects, the needs of the communities and the analysis of the colonial era architectures of the Northeast of Brazil through the study of disaggregation of the space of the architect Peter Eisenman.
Without historical awareness, it is difficult to define an appropriate prototype to the intervention context. An interpretation of the buildings of the historical tradition was possible through the analysis of the projects of two important modern architects: Lina Bo Bardi and Richard Neutra.
Planning a social-health centre requires a multidisciplinary approach in order to organize in an efficient way the building over time. The prototype should be able to respond to the rapid changes and the needs of the medical staff and the population. Thus the requirements of flexibility, modularity, aggregation and reversibility become a key component to respond to the subsequent transformations of the health structure.

Fig. 1 - Research methodology

The methodology is therefore organised into three phases:

- a settlement strategy that aims to implement the primary health services network in the territory through new buildings that can be expanded over time;
-
- the definition of the activities of the social-health facility according to the existing legislation and community needs;
-
- a critical approach defines the architectural structure of the prototype according to the typological, figurative and local construction techniques.

The identified procedure integrates the requirements of the primary health care prototype with economic, social, cultural, institutional conditions; but above all, it seeks into the historical experience of architecture, the features of the social, functional and figurative model.

The rural district of Quingoma of the municipality of Lauro de Freitas, in the Brazilian state of Bahia, has been identified as a real case to develop a methodological approach that can be generalized and applied to other developing countries that need a health and educational facility integrated into the reference context.

The challenge is therefore to create a self-sufficient prototype that, faced with an apparent planimetric and structural simplicity, proposes spaces that can project, ideally, well beyond the limits for a health centre proposal, and provide the basis for a wider research on new settlement models that preserve the tradition, the local customs and habits, such as the school or a cultural centre for the whole community.

Fig. 2 - Map fragment of the Bahia region, Carta das Cortes, 1749

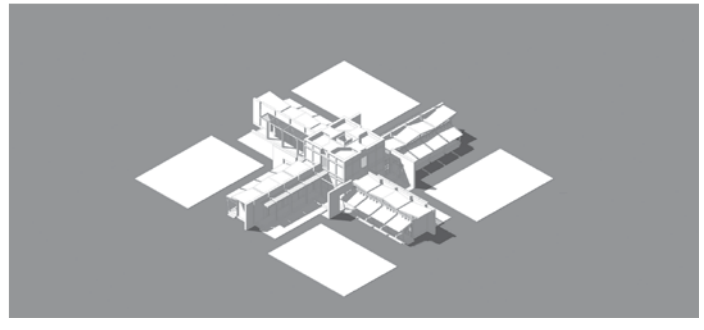

Fig. 3 - 3D view prototype

EMBEDDING MATERIAL AGENCY IN ARCHITECTURE. INTEGRATED COMPUTATIONAL WORKFLOWS FOR DESIGN AND FABRICATION

Dr. Roberto Naboni - Supervisor: Prof. Ingrid Paoletti

Advancements in the field of computation are nowadays offering unseen opportunities in the way we analyze, design and process complex problems. At the same time, an unprecedented pace of innovation in the fields of material science and engineering is leading to the development of novel manufacturing opportunities. Combining advanced materials and advanced design processes, a new approach to architecture is arising based on the underlying logics of computer programming: we can nowadays process an incredible quantity of information, fundamentally extending our capacity to establish relations between bits and atoms, and between the material and the virtual.

Building upon this context, this doctoral research investigates how materials can be actively involved in the design process, exploring the concept of material agency. The research aim is to research a novel design approach based on computational strategies and a technical framework by which to model, simulate and fabricate advanced material behaviors and their organization within architectural systems. The generative use of the so-called *material computation* supports the design of integrated building systems, in which variations in material layout and properties can be informed by functional, productive, structural, and environmental logics.

In order to study opportunities arising from architecture conceived with computationally enhanced materials as a focus, the doctoral research employed multiple methods entwined in a triangulation of approaches, which corresponds to three sections of the thesis.

The first one, the meta-level, is centered on the design of a theoretical framework developed through the method of interdisciplinary literature analysis. This level positions the research in the very specific philosophical context of materialism, which creates the premises for an uncommon approach to design. Principles of material formation are derived from the combined readings of material science, philosophy and developmental biology altogether - where these processes happen in a non-mediated manner. Contextualizing these principles in architecture brought to a historical interpretation of architecture as an evolutionary relationship between materiality and design. Fundamental precedents of material-based practices in architecture are presented and analysed, and concurred to establish a direct relationship between the evolution of materials, means of calculation, and architectural tectonics.

The second part of the thesis, the meso-level, is where the underlying methodological approach for material-driven design and construction is crafted. A method of investigation based on a constructive design research is discussed, in order to support a bottom-up design approach which starts from the analysis of material systems to develop architectural design. Prototypes are used iteratively as tools to test material behaviours, to question useful applications, and to evolve design and fabrication algorithms which embed material behaviours across several scales.

The third part of the thesis, the sub-level, constitutes the core part of the research, where the previously theorized approach is applied to the development of specific research projects, presented as case studies. A range of proto-tectonic systems are developed to challenge the current understanding of design and materialization into a unique integrated process. Computational workflows are conceived to embed material properties and behaviours as generative parameters in the design of architecture, and to coordinate the designer's control on advanced manufacturing tools. Design and fabrication cease to exist as distinct phases in favour of a highly integrative approach.

The four projects are specifically tailored on the base of the different material systems, while contributing to the general framework outlined in the previous sections. The projects include:

- Design and construction of lightweight temporary gridshells with the use of super-thin anisotropic corrugated sheets;
- Employment of non-standard materials and integration of crafting techniques into computational processes;
- Conceptualization and development of a cellular-based functionally graded structures with Additive Manufacturing;
- Exploration of the robotic implementation of fiber composites structures at large scale in applied contexts, through the technique of robotic coreless fiber winding.

From an instrumental point of view, an integrated platform of computational tools (custom scripts, Finite Element Analysis, Particle Spring Systems, bespoke CAD/CAM routines) has been developed specifically for each of the research projects, to enable a higher level of control on the simulation and construction process, which would otherwise be impossible to achieve. Materials are organized, tailored and crafted with the use of individualized fabrication protocols. Emerging from this instrumental development, newly conceived tectonic systems are created with emergent overarching principles. In all of them, matter is articulated to fulfill several functions. Consequently, form is generated in a complex way to satisfy multiple criteria. Multi-functionality, lightness, permeability are spontaneous results when the architectural morphology is expression of the material agency. Complexity does not result in expensiveness, but in sustainable use of the resource.

On a general level, the research has produced supporting theories for the creation of a new design paradigm. Multiple design outcomes provide evidence for novel models of construction, based on integrated technologies, which can be successfully applied in the diversification of our construction repertoire. Beyond the possibilities of mass-production, this research establishes an approach to create innovation in architecture, which takes advantage from newly developed and atypical materials.

Fig. 1 - Final demonstrator of the case study on Anisotropic Cardboard Thin Gridshell

Fig. 2 - Final demonstrator of the research project Weaving Enclosure

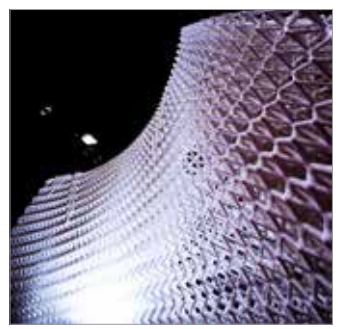

Fig. 3 - Final demonstrator of the of Trabeculae Pavilion: a load-responsive structural skin systems with Additive Manufacturing

REAL-TIME INFORMATION MANAGEMENT FOR ENGAGING END-USERS IN BUILDING OPERATION

ICT-BASED METHODS AND TOOLS FOR ASSESSING BUILDING BEHAVIOURS AND PROVIDING END-USERS WITH CONTROL STRATEGIES

Daniela Pasini - Supervisor: Prof. Bruno Daniotti
Tutor: Prof. Angelo Luigi Camillo Ciribini

Considering the remarkable shift that the digitalisation is nowadays bringing about in the construction sector, the research explores how the massive deployment of intelligent solutions for monitoring buildings and the enhanced practices for managing information are changing the way buildings are not only designed and constructed, but also experienced and operated. Indeed, great amounts of data are collected through several devices during building operational stages. However, barriers still exist for making data available and valuable in real-time to users. The research mainly addresses barriers due to issues on information awareness, information structure, information redundancy and interoperability, information transmission and information fruition.
For overcoming those barriers, the research defines a framework for extracting knowledge from data gathered through ICT devices at different levels of granularity in order to track user behaviours and assess building conditions, considering methodological and technological aspects.
On the methodological side, a critical analysis of information to be collected for specific uses and a focus on users who can benefit of that information allow outlining an enhanced process for managing information, also deriving advantages from the availability of real-time data.
On the technological side, the development of strategies supported by recent processes and paradigms (i.e. BIM (*Building Information Management*) processes and IoT (*Internet of Things*) paradigms) and relying on the use of ICT (*Information and Communication Technologies*) solutions allow an ordered collection, management, sharing, exchange and update of information among actors and devices.
Within that context, the defined framework is built upon methods (digitally-supported practices) and tools (digitally-enabled workflows) based on information management. The goal is the engagement of users in building operation and the definition of control strategies for satisfying the needs of occupants, by establishing a connection between as-designed virtual models and as-delivered physical assets.
Digitally-supported practices are proposed as procedures for keeping users engaged in building operation, relying on a bottom-up approach. Starting from the detection on real case studies of user behaviours affecting building conditions (e.g. energy-hungry behaviours), different scenarios are simulated in order to outline the impact of user behaviours so to propose customised control strategies and promote behavioural changes.
Moreover, for making information available to users in the form of control strategies, digitally-enabled workflows are developed for exchanging and updating information, connecting different data sources, relying on the development of both open and proprietary solutions. Hence, after defining what kind of information needs to be managed for producing a model of as-delivered buildings, solutions are developed for making that information available and valuable to users (i.e. with reference to BIM models, web interfaces and mobile applications).
Hence, by investigating how the integration and sharing of information supported by collaborative environments and recent information technologies enhance the management of the built asset, the research:
1) proposes a framework for delivering buildings as service providers, extracting knowledge from real-time data for tracking user behaviours and designing user interactions with buildings, aligned with user needs and requirements. 2) defines specification for information management in operation, also analysing whether and how the centrality of users is changing the building process. 3) proposes methods (digitally-supported practices) and tools (digitally-enabled workflows) that rely on BIM practices and ICT solutions toward an information-driven asset management.
The results allow: 1) implementing workflows for enriching building information in the operational stage and, consequently, operating buildings with an increased value originated by information. 2) assessing how buildings work in the operational stage, especially taking into consideration the influence of users. 3) defining strategies for engaging different actors in building operations and informing them about the behaviours of both buildings and users. 4) providing control strategies when unexpected behaviours (e.g., energy-hungry behaviours, unusual comfort conditions and failures related to facility management) are registered.
Within that context, the research provide solutions for managing information in order to embed the end-user perspective within a digital environment and, consequently, to improve the dialogue between users and buildings, to enrich user experiences within buildings, also increasing users' understanding of buildings' operational performance.
Outlining procedures for user engagement based on an enhanced use of ICT solutions, the thesis presents solutions for overcoming barriers concerning information awareness. As those procedures rely on an ordered and structured information management for avoiding incomplete processes for exchanging and sharing data and information among actors and tools, the research addresses issues related to information redundancy and interoperability.
Moreover, barriers on information transmission are overcome introducing workflows for managing great amounts of data and information that are dynamic and produced with high sample rates so that data and information are made available and valuable to users through different tools, making possible information fruition.
Through the proposal, application and validation of developed methods and tools, the research provides a breakthrough for the implementation of BIM-based processes in building operation. Indeed, proposed practices and workflows enhance the real-time information management in a BIM environment for assessing building behaviours and providing end-users with control strategies.

THE CREATION OF A CITYWIDE BUILDING INFORMATION SYSTEM: CRITICALITIES AND POTENTIALITIES OF PUBLIC INFORMATION ON BUILDINGS

Alice Pasquinelli - Supervisor: Prof. Franco Guzzetti

Nowadays, the role of geographic information (GI) is more relevant than ever. Spatial data have evolved over time and have transformed from being a technical tool serving highly specialized sectors (e.g., military, engineering, construction) to become a digital service supporting common daily uses. This sector moved from the traditional concept of cartography, where a static draw provided a representation of a given territory at a defined scale, to the modelling of territorial objects: geographic data have become queryable, manipulable, constantly updatable, usable in different application domains. Moreover, geographic data have also become more complex: in fact, it is common to refer to Geographic Information System as a mosaic of spatial information related to a specific territorial region.
This complexity entails increased difficulties for data managers, typically public bodies, in the creation and management of an information system supporting administrative duties, whether from an economic or a technical point of view. Hence, it has become difficult to make full use of the potentialities related to the GI. Moreover, it is due to highlight how a sound and efficient management culture of existing data is currently lacking in Italian public sector, despite technologic and informative progresses that took place in the last decades. The transposition of existing databases on digital format (mainly solicited through regulatory provisions) has not been followed by a change in the traditional, paper-based data management approach, or at least not in a complete and even way nationwide. Consequently, public data are often out of date, replicated, misaligned and devoid of connections with other data sources: these criticalities characterize the current informative public heritage on buildings, with different levels of severity within different administrative contexts.
The objective of the research presented is to adopt an object-oriented approach in the management of public information on buildings, creating an informative system able to connect existing data, with the final aim to implement analysis and services related to the built environment at city scale. The point of view assumed is the one of a public body, having a privileged access to building data and using these data for public, collective purposes.
Initially, a reference framework was outlined for the themes involved in this research. As far as what concerns the theme of building data interoperability and integration, examples of virtuous countries in Europe were investigated: this search reveals how in different foreign contexts (the Netherlands, Germany, Great Britain, Spain) this topic has been considered as a strategic issue to be addressed at national level since the late '90s. Thereafter, the main references in the informative territorial and urban modeling were deepened: particularly, Italian technical specifications released within the Intesa GIS framework were considered, as well as European standards related to the Directive 2007/2/EC "INSPIRE".
Parallelly, a critical observation on existing building information within Italian public archives was carried out, considering the main informative sources available.
For each one of them, a critical analysis aimed to evaluate the following:

- specific informative contents;
- data level of completeness;
- updating rate;
- access modes to the data;
- common information among different databases.

In addition to the Topographic Database (TDB), the official, object-oriented data model for built and natural environment in Italy, informative sources considered include the cadastre, ISTAT census micro-data, SIATEL data on energy consumption, and municipal civil registry.
Starting from this analysis, an harmonization procedure was defined in order to associate each building reported in the TDB with the main key references of building-related information: cadastral identifiers and addresses. In this way, each building mapped within the TDB can be connected with the other external building data sources: the setting of connections among existing building databases aims to create a Building Information System (BIS) implementable at municipal level.
After this analysis was concluded, and a theoretical procedure was defined, the actual implementation of the BIS was tested on a prototype area: Gavardo municipality, member of *Comunità Montana Valle Sabbia*.
This required an intensive work of geometric re-definition of buildings within the TDB to set up logic consistency with cadastral buildings mapped in the land registry cartography, as well as a specific on-site survey to complete and check the association between buildings and addresses. Also, a massive data cleaning on other datasets provided was required. After these preparatory operations, TDB contents were enriched with data coming from the different sources considered. Furthermore, also the modelling of building data according to international standards was tested, in order to evaluate the level of detail with which such models may be populated using public existing data.
Lately, in order to associate the harmonization efforts done to the benefits related to the availability of a BIS, a use case aimed to test its real usability was developed. To this purpose, an energy need assessment for heating at district scale was computed thanks to the support of a multidisciplinary group of engineers and architects expert in building energy efficiency: the obtained estimation outputs were compared with actual consumption data, demonstrating how this gap between estimated and measured values is negligible on urban scale, even if more variable results are achieved at building level. Thus, the availability of a BIS would allow the quick and automatic availability of instruments, useful to evaluate the requalification potential of entire city portions, providing useful data to identify possible retrofit options with related costs and payback periods.

Fig.1 - Building data supporting different application domain

Fig.2 - Building data published in a CityGML compliant city model

INDUSTRIAL STEEL RACK UNDER MONOTONIC AND SEISMIC LOAD AND ISSUES ASSOCIATED WITH BASE SETTLEMENTS

Marco Simoncelli - Supervisor: Prof. Claudio Bernuzzi
Co-Supervisor: Prof. Annamaria Cividini

Description of the research
The research activities of the PhD thesis have been focused on the steel framed structures used for storing goods and products (i.e. pallet racks, cladding racks, drive- racks, shelving racks) under monotonic and seismic load, with attention also to the problem of the influence of the base settlements on the reduction of the frame performance. From a structural point of view, steel storage racks are quite complex systems, because of the key features affecting their behavior. In particular, the presence of regular perforation systems along the uprights and the extensive use of mono-symmetric cross-section members (Fig. 1) hampers the use of theoretical approaches for member design.

Fig. 1 - Typical mono-symmetric cross-sections used for uprigths

The obtained results can be summarized in different points:
Warping influence. Despite the extensive use of mono-symmetric cross-section members (Fig. 1), in steel storage racking, the design rules and the finite element analyses are, nowadays, based on the same rules adopted for by-symmetric cross-section members. The main idea of the thesis is that the structural analysis of these typologies of frames must be executed with advanced finite element formulation, and if *beam* element is considered, the 7th degree of freedom *beam* element must be used. The results of the research show non-negligible differences when one formulation is used instead of the other one (in terms of global displacements and internal forces). Only when the eccentricity of shear center and cross-section centroid is limited the results obtained from the use of the two formulations became similar.
The use of system length in the stability checks. The load carrying capacity under monotonic load condition is evaluated. More than 500 cases have been analyzed and discussed, by varying the cross-section dimension, the rack layout and the joints stiffness. In particular, 4 European and 2 North American approaches are discussed and compared underlining similarities and differences. It has been demonstrated that, the use of the effective length equal to the system length, as recommended by one European approach (the EU-RAM), lead in many cases to an overestimation of the rack performance if not balanced by the definition of suitable local imperfections and/or reduction of the member stiffness (as in the US-NOLM approach). More in detail, differences, in term of SI value, are up to 60% when the EU-RAM approach is compared to the EU-GEM and EU-IRAM approaches (that are always equivalent to each other). With respect to the EU-DAM, it has been observed that in case of 6DOFs analysis differences are up to 40%, but when 7DOFs analysis is performed, these approaches became equivalent. The US-approaches gives practically equal values of SI when frame with rigid beam-to-column joints are considered, while when more flexible frames are considered, differences increase up to 40% for 7DOFs analysis and 60% for 6DOFs one. The SI associated with the US-ELM approach is always great than the one associated with the US-NOLM. Finally, the results associated with the US-ELM approach are compatible with the ones associated with EU-IRAM and EU-GEM approaches, showing, once again, great differences with the EU-RAM one, up to 60%.
Influence of base settlements. The interaction between the skeleton frame and the supporting floor slab is an aspect of relevant importance for the safe use of medium-rise selective pallet racks located inside multi-storey buildings. It has been demonstrated, based on 2304 practical cases, that the influence of the relative deflections of the upright bases can significantly reduce the load carrying capacity and should never be neglected. Furthermore, an equation to predict the reduction of the rack performance with respect to rigid floors, has been proposed. Prediction of the reduction of the rack performance is always on the safe side and no additional calculations are required when compared to those carried out under the assumption of rigid floor slabs.
Seismic design. The most common used approaches in the seismic design of storage rack are the Lateral Force Method (LFM) and the Modal Response Spectrum Analysis (MRSA). Both methods are based on the reduction of the elastic spectrum to the design spectrum via the use of behavior or *q* factor and suffer from many defects. In fact, the degradation of rotational stiffness and flexural resistance of the connections, due to the loading and unloading sequences in the plastic range induced by earthquakes, is totally neglected. Experimentally an unstable behaviour of the cyclic response of beam-to-column joints has been observed, as depicted in Fig. 2, where the typical moment-rotation (M-Φ) joint response under monotonic loading (dashed lines) is plotted together with the cyclic response (solid line). It can be noted that unlike joints for assembled steel buildings, the hysteresis cycles are characterized by a remarkably progressive and regular stiffness and strength degradation.

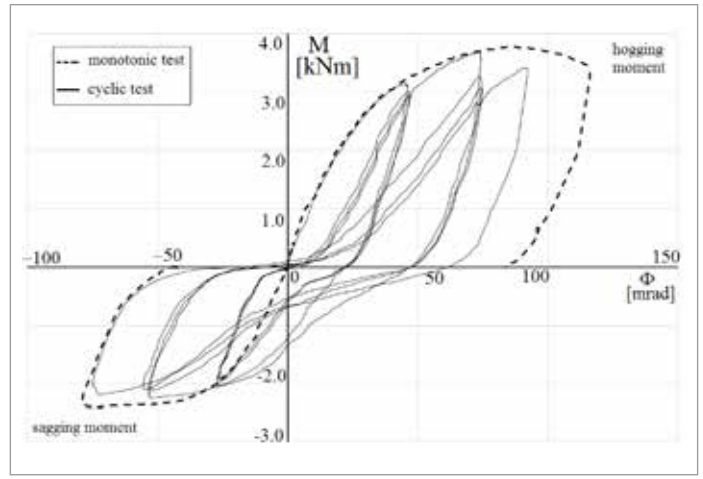

Fig. 2 - Example of behaviour of beam-to-column joints.

The reasonably efficient NLTH-LCF procedure has been proposed and applied for the design of storage pallet racks in seismic zones and combines traditional non-linear time-history (NLTH) analysis with low-cycle fatigue (LCF) theory. 56 design cases have been considered to assess the load carrying capacity of 14 racks, which differ in terms of geometric layout and component performance. It has been underlined the importance of modelling the effective cyclic joint behavior. Furthermore, the monitoring of the damage in joints due to cyclic excursions in the plastic range cannot be neglected for the safe use of the rack during its total service life, especially when severe earthquakes occur. The direct comparison of the performances assessed via the NLTH-LCF and the MRSA approach underlines, once again, the great importance of the *q* value. A great dispersion of *q** has been observed, that is the value of the behavior factor to be adopted in the MRSA approach to obtain the same performance assessed via NLTH-LCF approach. It can be hence concluded that the proposition of a unique *q* value, independently of the geometric layout and component performance, to be used for designing storage racks appears to lead, in many cases, to an unsafe and/or un-optimal design.

SHAPEABLE CEMENT: INNOVATIVE CEMENT AND MULTI-PERFORMANCE COMPONENTS FOR BUILDING SKIN

Andrea Zani - Supervisor: Tiziana Poli

Nowadays, designers and architects can use tools and software to explore new and complex architectural shapes that can bring to the development new envelope components. However, to fully exploit the potential of parametric and computational design, a deeper connection with design process, performance analysis, and manufacturing process is required.
Furthermore, the use, performance, and feature of complex shape panels entail the need to develop new materials and innovative interaction with manufacturing techniques. In the current state of the art, cement-based materials with their uniqueness fit the requirements regarding aesthetics and performance. Nevertheless, optimization and innovation in the production and manufacturing process are necessary in order to overtake the main limitation of this process; the formworks.
The main objective of my Ph.D. research is to develop an innovative building envelope component made from a cement-based material coupled with a stretchable three-dimensional fabric in order to simplify the mold systems for façade applications.
In addition to the simplified manufacturing process, this composite material allows for the development of a tailor-made thin, lightweight, and translucent cement-based panel based on performance. Simultaneously, I will develop a parametric tool to control this material in all the design steps from the idea to the fabrication stage passing through performance analysis.
Shapeable cement is a non-structural composite material made by 3D-warp textile and a specific cement mix for interior or façade applications.
Test, design and optimization processes carried out in this thesis show that with this innovative composite material can reduce the material used by 40% compared to a traditional GFRC element.
With this material, traditional formworks are not necessary even for free-form panels. Furthermore, with its features, it is possible to design and realize high-performance façade applications like shading systems with complex geometry able to improve daylight performance and energy savings.

Keywords: Cement-based material, Fabric Concrete, Complex Shape, Shading Device, Performance Based-Design, Performance Optimization, Parametric Tool.

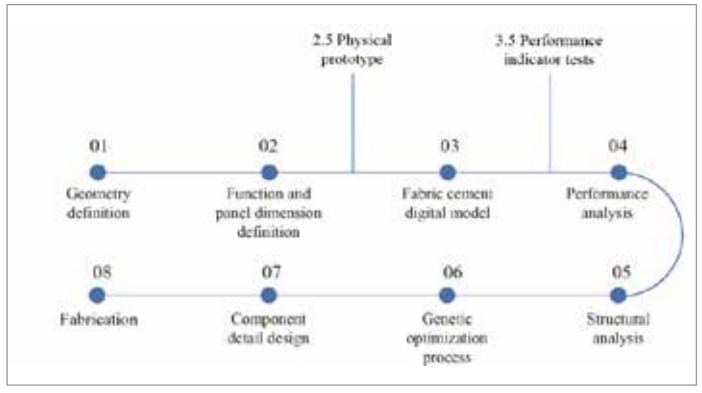

Fig. 1 - Grasshopper tools workflow

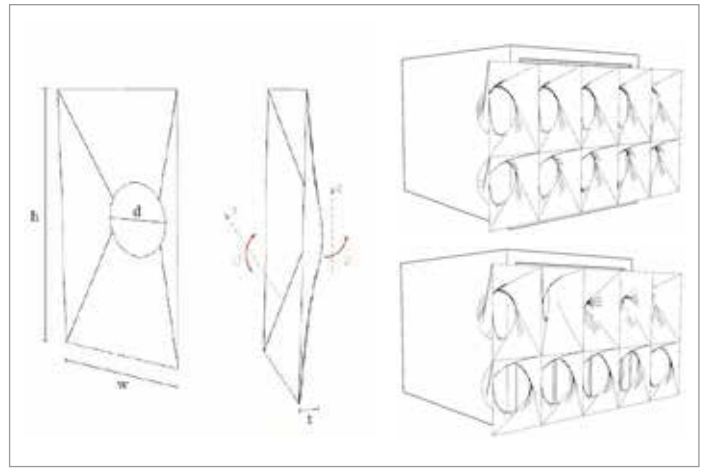

Fig. 2 - ables: Diameter opening, shading depth, opening rotation.
Two examples of funnel shading system

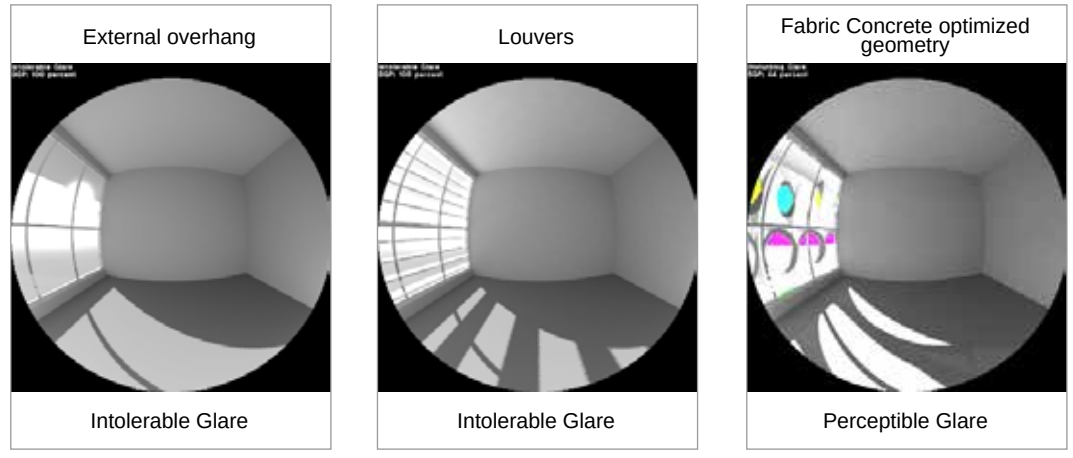

Fig. 3 _ Image-based DGP analysis for three different shading systems