From Knowledge to Wisdom

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Preface

DACC Research 2012-2018: Reconnecting Culture and Competences

Antonella Cecchi

Director of the Department of Architecture Construction Conservation (2015-2018), Iuav University of Venice (Italy)

The most marked characteristic of a department dedicated to Architecture in the sense of Construction and Conservation is that it places Architecture as a constructed reality at the center of its teaching and research; or better, the indissoluble connection between a knowledge of form and a knowledge of construction. A connection that constitutes a category of awareness of architecture as designed in the past and a category of operational practices running across the entire process of projection from the analytical phase of the first moment of planning, to the identification of the materials and systems of construction to be used; a connection that overrides and informs the activity of construction on the building-site and which reveals it's quality when tested over time.

Traditionally, in Italian schools of architecture, the body of knowledge of Composition has been seen as separate from that of Construction, to the extent that it was believed that the stages of projection bound to Science and the techniques of construction, the technology of materials, the design and installation of plant, quantity surveying etc. – are merely instrumental in that they confront practical problems which can be resolved by technical-engineers according to the formula that the architectural project is essentially engineering work.

The framework that has governed the scientific-cultural program of the Department of Architecture Construction Conservation DACC is the awareness that these bodies of knowledge are not merely instrumental, but on the contrary they all participate in the significance itself of architectural work. And this framework is very different from the flattening out of the cultural program into a series of practices deprived of any cultural awareness in line with old professional canons which are by now entirely uncertain. It is a framework which, on the contrary, requires as a cultural necessity that we look again at the contents of the disciplines that contribute to the project, whether they are technical-scientific or compositional, within a particular logic - the project of architecture confronting the developments of the present realities of the world.

Looking at the present situation, one notices that the essential problem is not so much the practical interaction between the artistic-humanistic disciplines and the technical-scientific disciplines, etc., but rather a course of teaching still based on disciplines which have been artificially circumscribed. The new developments in the world (and that of the project) make it necessary to overcome the conventional confines of these disciplines in order to develop a body of knowledge appropriate to Architecture [1]. As we all know, "there is an ever wider, deeper and more serious mismatch between our areas of knowledge - which have become separated, fractured, and subdivided into separate [conventional] disciplines - and problems of reality that are ever more multidisciplinary, transverse and multidimensional"[1] [2].

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[1] Edgar Morin proposes a reform of the modes of thought and teaching which can be achieved through a reorganisation of "paradigmatic" bodies of expertise concerning our general attitudes towards organizing knowledge. In particular the failings of our areas of expertise (which have been separated and fractured into separate disciplines) with regards to reality and to the problems which emerge as more and more as poly-disciplinary and global - the separation of the disciplines that makes us unable to understand that which is all connected, that is, the complexity of these same bodies of expertise, the uncontrolled expansion of knowledge which escapes human control.

The Department of Architecture, Construction and Conservation (DACC) of Iuav University of Venice has in its six years of activity (2012-2018) been heavily engaged in transmitting a knowledge of forms and of the construction of buildings as they continuously interact in order to go beyond the subordination of one to the other which still, sometimes, characterizes some taught courses. This has been the main direction of research in DACC as is exemplified by the contributions collected in this Special Issue; the association of the project and construction as a category of enlightened-awareness of works of architecture, without cancelling its methodological, theoretical and technical particularities. The Department DACC, has kept faith – during a change in directors[2] - with the original cultural project which requires us always to remember that the project is, in any case, a tool, or rather, the indispensable instrument with which to reach what is, or should be, the real goal: the creation of new architecture and the transmission of architecture which already exists to future generations.

The revision of the disciplines involved in the notion of “Architecture as a constructed reality” requires concomitant innovations with respect to research. Putting “Architecture as a constructed reality” at the center of attention requires us to take an innovative view of the multiple problems involved in any building - whether one is dealing with new constructions which are about to be built – or whether one is concerned with the architecture of the past which is to conserved.

In connection with teaching-outcomes one can talk of “a technical awareness of the form and an understanding of the functioning project”. A complete understanding can be attained only if the two paths of constructing the new and the maintenance of what exists can be made to converge.

A questioning relationship with reality (i.e. professional practice) is effected by means of competent expertise in contrast to the uninformed media that reduce the project to a formal exercise embodied in computer-generated images (rendering); but also in contrast to an autoreferential culture which reduces the project to a replication of compositional units seen in the repertories of the history of architecture. Once again, the interlocking of composition, construction and conservation emerges as indispensable.

The developments of recent history show that it is entirely wrong to think that in architecture the “new (representations and construction)” consist in the special effects of buildings “off-budget” promoted by the media, since they are susceptible to the sensationalism characteristic of the recent past. The culture of the project cannot be separated from the requirement for Architecture capable of contributing to the promotion of high-quality civil buildings, for Architecture as a responsible response to everyday necessities bearing in mind the future of cities, for sustainable Architecture that expresses a complete awareness of the “limit”.

At the heart of research in DACC are the themes of the project, construction, and of building-techniques understood as an analytical investigation into the ways in which buildings are thought of, constructed, interpreted, preserved, transformed and understood.

The title “Architecture Construction Conservation” indicates precise definitions by which to calibrate and measure the culture of the project across the relevant expertise of the form and building-techniques, surpassing the conventional division between new building and conservation. Holding everything together is the awareness that it is essential to keep alive on on-going dialogue between the moment for action and the moment for reflection, between research and teaching, so too between the project and its realization, between the construction of the new and the conservation of what exists which is the only guarantee of raising levels and making all of us improve.

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[2] 2012-2015: Director prof. R. Dubbini, Professor of History of Architecture 2015-2018: Director, A: Cecchi, Professor of Strength of materials.

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I would like to thank Emanuela Sorbo for editing this special issue, the professors who wrote for this special issue and all the professors who have undertaken the task of characterizing the department. Thanks also to Richard Schofield for having translated my observations and for his long-term friendship.

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The Forth Bridge's Human Cantilever: Engineering, Photography and Representation

Angelo Maggi
Department of Architecture Construction Conservation, Università IUAV di Venezia, Dorsoduro 2206, 30123, Venice, Italy

Abstract: During the Victorian Age, when the results of ambitious engineering radically transformed the principles of construction, photography proved to be a faithful and indispensable witness. This is plainly seen in the magnificent enterprise to build the railway bridge over the Forth River, accurately captured by the lens of the photographer and engineer Evelyn George Carey, whose excellent work to record those events is without equal. His almost daily annotations were free from symbolic meaning and monumental tendencies: it was the bridge itself that held the most important role. In the form of an experiment it was decided to illustrate the principle of the cantilever at the Royal Institution in 1887. It was during that particular circumstance that Carey produced the famous photographic image of the Human Cantilever. Carey presents to the observer an encyclopaedic array of representations and helps to truly visualise engineering.

Key words: Bridge engineering, cantilever technology, photography, nineteenth century architecture.

1. Introduction

The railway bridge that crosses the estuary of the Forth River in Scotland is considered to be one of the masterpieces of nineteenth century engineering, the largest ever built and the first to have a superstructure made of steel: one of its two designers, Benjamin Baker, defined it "a romantic chapter from a fairy tale of science" [1].

During the Victorian Age, the rules of the past for the art of construction were broken by the bold inventions of famous engineers the likes of Joseph Paxton, Isambard Kingdom Brunel, Robert Stephenson, John Fowler, and Gustave Eiffel, although they seemed to be unaware of the consequence of their proposals, nor did they seem to be at all anxious to change the shape of the outside world. Theirs was a light and aerial vision of the structures they built, and with great intuition they chose photography as a faithful witness to this radical transformation. The invention of photography had played an essential role in the field of engineering, suggesting a new way of exploiting the constructed object: the photographic image had become the medium between reality and image, establishing new relations and creating further possibilities for a reading of the structure and for its "scientific" interpretation. As the engineer and architecture historian Sigfried Giedion once said: "Only photographs remain as witness that the overcoming of gravity in apparently floating constructions was achieved in magnificent form during the nineteenth century" [2].

No wonder, then, that all the stages in the building of the Forth Bridge were observed through numerous photographic sessions, which were to become one of the most exciting collections of images in the history of photography.

2. An Engineer Photographer

The official photographer at the Forth Bridge building site was the engineer Evelyn George Carey, who was also an assistant engineer on the project. Only rarely do photographers fully and from a professional point of view understand the buildings they take pictures of, and the aims of their creators the way Carey

Corresponding author: Angelo Maggi, Ph.D., professor, architectural history and theory, history of photography. E-mail: amaggi@iuav.it.

did. Carey's goal was to record as accurately as possible and on glass negatives the progress of construction as the railway bridge rose above the firth of Forth, and to do this with technical know-how and painstaking precision. Despite the considerable efforts required to handle his cumbersome camera equipment as he moved about the caissons and the maze of unfinished steel beams, Carey succeeded in recording the passing of time in a story told through images at an engaging pace, and with a vision that was crystal-clear and perfectly in focus. Plainly expressing through his art what modern industrial civilization was capable of achieving, the photographer did not just reveal the widespread fascination with the new steel technology, but he also chose to photograph the men who laboured at the site, his analysis an intense and original one, which seemed to penetrate the human side of the day-to-day events he witnessed. For Carey's camera lens, the bridge played a dual role: it was both a monument under construction and a workplace. Carey's series of photos for the Forth Bridge (Fig. 1) was one of the first critical and historiographical assessments by an engineer photographer, and it was widely acclaimed; the photos provided an accurate recording of this notable happening, from the inauguration of the site, to the laying of the three large columns; from the first images of the small island of Inchgarvie located in the middle of the river and used as a foundation for one of the imposing cantilevers, to the work carried out to complete the railroad track crossing the bridge. What especially stood out in some of the photos was the metal framework itself, whether it was the large steel tubes riveted and then carefully checked over in the workshop, or the trusses that were employed in the laying of the foundations; still today, the memory of the photo lens conveys an extraordinary message, telling the story about a project based on willpower and commitment, and progress at the height of its creative expression. While the bridge was being built, between 1883 and 1890, there was bitter controversy within the scientific community, resulting from the anxiety that continued to linger long after the collapse of the Tay Bridge. The memory of the 75 victims of the disaster that had taken place in 1879 while the train was crossing the bridge was still a very vivid one. For this reason Fowler and Baker took

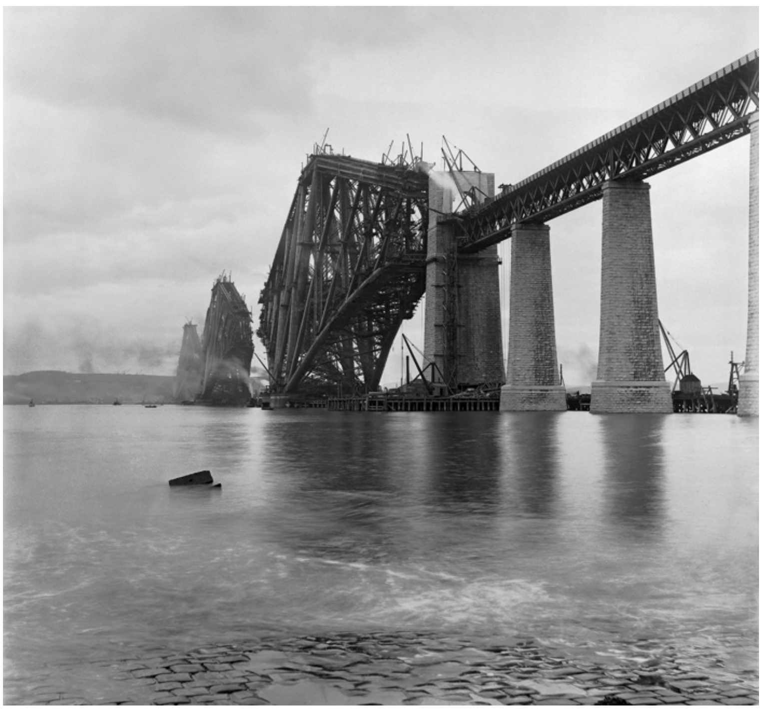

Fig. 1 Evelyn George Carey, Forth Bridge nearly completed from the Hawes Pier on 15 April 1889 (*National Archives Scotland*—Neg.n.323).

numerous precautions, applying rules for safety that were so restrictive that their project appeared to be risk-free. This bridge, assured the engineer Wilhelm Westhofen, supervisor of the project and author of the first important book on Forth Bridge, would "by its freedom from vibration gain the confidence of the public, and enjoy the reputation of being not only the biggest and the strongest, but also the stiffest bridge in the world" [3].

The public watched in amazement as, from 1882, tremendous quantities of materials began to arrive by sea and rail on both shores of the Forth River. The building sites stretched out into the sea-side towns, bringing with them their gigantic masonry pillars to support the railway viaduct, so gigantic that houses and ships and people suddenly appeared to be catapulted into the Lilliputian dimensions narrated by Jonathan Swift. Surprisingly, the bridge was actually built twice: each section of the structure was assembled on land and then dismantled before being moved out to the bridge site for its final assembly.

Carey's photography was particularly extraordinary when combined with Westhofen's book entitled *The Forth Bridge*, published in 1890 on the occasion of the project's completion [4]. The author could still remember the noise of the steel hitting the steel, of hammers, riveters, hydraulic spades and generators; he could recall the men working on the shores, and the makeshift workshops. The book included the vastest and most detailed account of all of the stages in the construction of the bridge, alongside photos that had been taken with great care and printed with what at that time was a new technique in photography, the gelatin-silver process; the book proved to be successful with its readers, particularly when the images were accompanied by Westhofen's narrative.

3. Critics and Engineering Challenges

Never before, in all of the United Kingdom, had there been so much faith in engineering. A whole generation of engineers would learn from the experience of its predecessors, and create a style that would soon claim to offer universal solutions. Fowler and Baker's solutions indeed ended up changing the physiognomy of nearly everything that was going on in engineering during those years: design and era were entwined. Despite this, within a few years, the bridge became the target of critics and experts who vehemently found fault with the idea of accepting "the aesthetics of a work of engineering with the absence of all ornament" [3]. Amongst those who energetically refused the solutions that the construction of the bridge proposed were John Ruskin and William Morris, the latter of whom, during the annual meeting of the National Association for the Advancement of Art and its Application to Industry held in Edinburgh in 1889, indicated the Forth Bridge, at that time nearly complete, as being "that supreme expression of ugliness" [5]. Morris' point of view was, of course, not shared by Underwood and Underwood, the famous international company that published stereoscopic views, and that at the end of the nineteenth century, in one of the most famous 3D views of Scotland, produced the image whose caption read "Scotland's Pride—the great Forth Bridge and the Highland Kilt." This celebration of the national costume alongside a modern symbol for the Scottish landscape ultimately determined the inspiring role played by Fowler and Baker's impressive structure. The Forth Bridge likewise attracted the interest of the art historian Kenneth Clark. In *Civilisation*, published in 1969, the scholar declared that the bridge was the most imposing construction to stem from the skill of two designers who had renewed the Gothic experience in building" [6]. Curiously, a panoramic view from the top of a beam, boldly realized in the sixties by the architecture photographer Eric de Maré, was chosen for the back cover of the book. The artist de Maré's creative research, which was characterized by shots from a strong perspective often interpreting the bridge as a game of geometrical shapes, recalled the dynamics of Carey's own technique.

4. The Human Cantilever

The issue at the heart of nineteenth-century debate, which was a seeking out of new forms of architecture that could form an alliance between scientific progress and art and, as a result, the resources for alternatives to the traditional canons of aesthetics, perceived the poetics of iron as the best opportunity to express a new concept of formal beauty. This way of thinking was perhaps more accurately expressed in the comparative wall diagram drawn by Professor Charles Robert Cockerell for the South Kensington Museum, where the outline of a cantilever from the Forth Bridge was compared with works like the Great Pyramid of Giza, the Pantheon and the Basilica of Saint Peter in Rome, the Leaning Tower of Pisa, Saint Paul's Cathedral in London and the Central Transept at Crystal Palace. Carey's decision to photograph this lecture diagram was seen as something quite unique and it became the object of the curiosity and interest of the halls of academia. A similar study, in the form of an experiment, was conducted by Baker when he decided to illustrate the principle of the cantilever while giving a talk at the Royal Institution in 1887. It was during that particular circumstance that Carey produced the famous photographic image of the Human Cantilever (Fig. 2).

The "Chambers's Journal of Popular Literature, Science and Art" (1 September 1888) published the following description of the living model: "Two men sitting on chairs extend their arms and support the same by grasping sticks which are butted against the chairs. There are thus two complete piers, as represented in the outline drawing above their heads. The centre girder is represented by a stick suspended or slung from the two inner hands of the men, while the anchorage provided

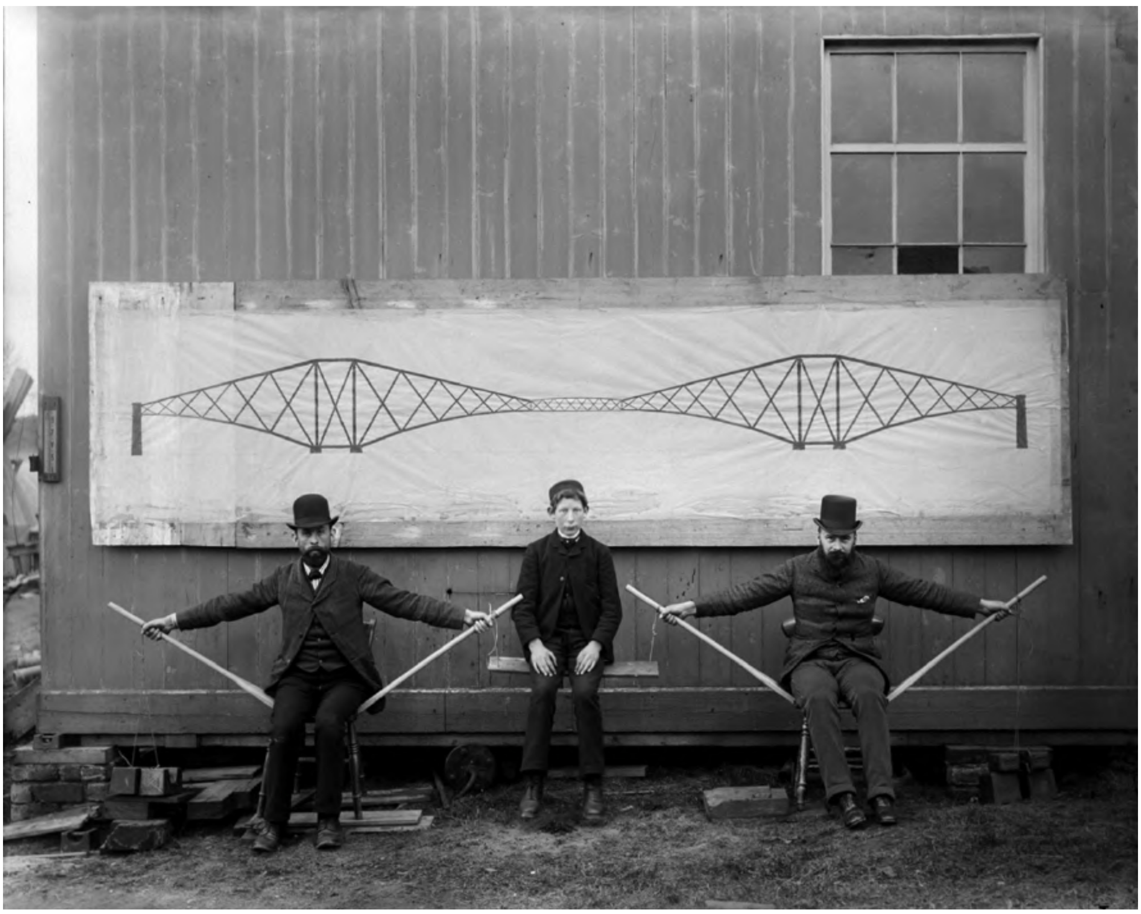

Fig. 2 Evelyn George Carey, Forth Bridge Human Cantilever "Youth on swing between two man"—1887c (*National Archives Scotland*—Neg.n.171).

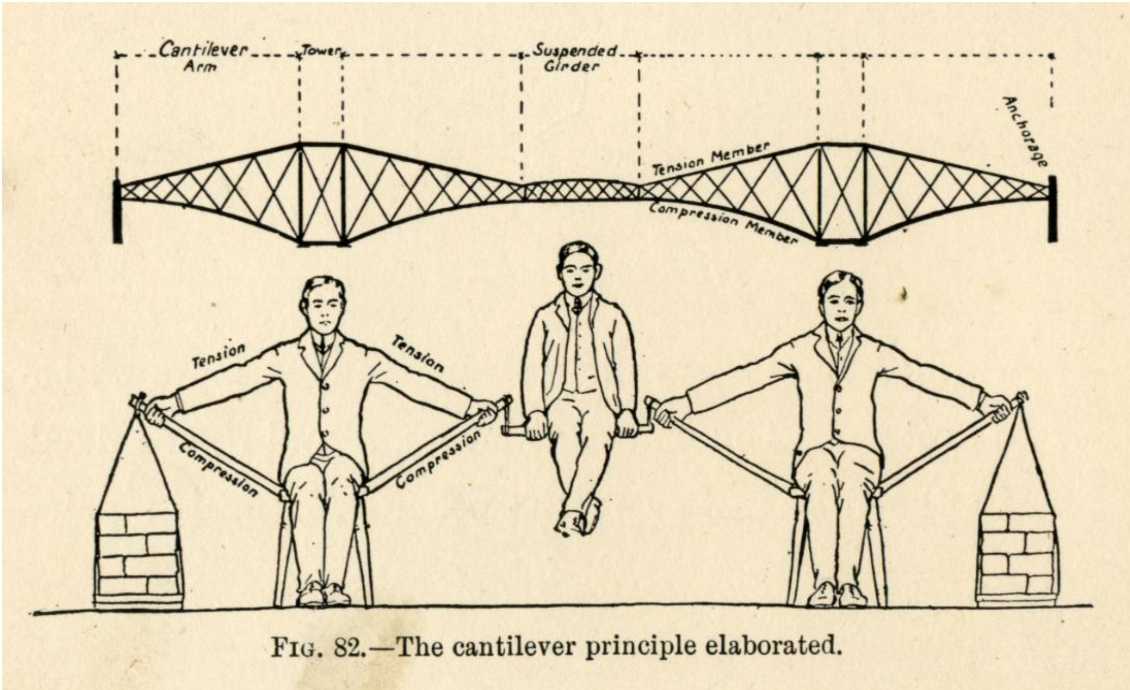

Fig. 3 The cantilever principle elaborated with Watanabe as a living model [7].

by the counterpoise in the cantilever end piers is represented here by a pile of bricks at each end. When a load is put on a central girder by a person sitting on it, the men's arms and the anchorage ropes come into tension, and the men's bodies from the shoulders downwards and the sticks come into compression. The chairs are representative of the circular granite piers. Imagine the chairs one-third of a mile apart and the men's heads as high as the cross of Saint Paul's, their arms represented by huge lattice steel girders and the sticks by tubes 12 feet in diameter at the base, and a very good notion of the structure is obtained" [8].

The other man at the centre of the composition was Kaishi Watanabe (Fig. 3), one of the first generation of Japanese engineers to travel West so that he could ultimately imitate the innovations in technique that had been developed in the Forth Bridge building site. A student of Fowler and Baker, Watanabe was invited to participate in the "living model" of the Human Cantilever to remind audiences of the debt its designers owed to the Far East where the cantilever principle had first been invented and applied.

5. Conclusions

It was this very photograph that revealed just how revolutionary the design for the Forth Bridge really was. The unprecedented dimensions of the linking girder arms, the comparison with Baker's design in the background, and the "tableau vivant" in the foreground, would significantly enrich the spatial perception and vision of the project, contributing to the more practical professional training of future engineers. Of the many photographers who, at the end of the nineteenth century, carefully observed the changes that were the result of the Industrial Revolution, Evelyn George Cary's vision was the most analytic, careful and mindful of the results achieved by science and technology. At the basis of his photographic interpretation of the Human Cantilever was the conviction that the Forth Bridge constituted an icon of the supremacy of humankind. This suggestive and highly spectacular image represented everything that was behind the design for the bridge, one of the most ambitious challenges in engineering and in the culture of that time.

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Non-linear Analysis of Bridge "Guglie" in Venice: Sensitivity to Designed and Realized Shape

Daniele Baraldi, Anna Manzato and Antonella Cecchi

Department of Architecture Construction Conservation; Università IUAV di Venezia, Dorsoduro 2206, 30123, Venice, Italy

Abstract: In this paper, numerical non-linear analyses of the "Guglie" bridge, located in the historical city of Venice (Italy), are proposed. The focus is twofold: on the sensitivity of the realized shape of the bridge by reference to originally designed shape; and on sensitivity to mechanical parameters of constituent materials. The history of this bridge is very interesting, and the bridge actually built is different from the Marchesini's project (1580). In fact, in the original design drawing, the shape of the arch is a perfect circle arch, while the shape of the actually built arch is not perfectly circular. Hence, in the aim to evaluate sensitivity of bridge behaviour to designed and realized shape, non-linear analyses are carried on by means of FEMs (Finite Element Models) under in-plane state hypothesis. Furthermore, parametric tests are also performed for evaluating the influence of masonry mechanical parameters on non-linear bridge behaviour.

Key words: FEM, masonry bridge, pushover analysis, parametric tests, Mohr-Coulomb yield criterion.

1. Introduction

In this research, a study for the evaluation of sensitivity of mechanical behavior of historical bridges to arch shape is proposed. The case study of "Guglie" bridge (Fig. 1) in Venice is adopted for performing numerical tests.

The analysis of masonry arch bridges is an active field of research for the community of Architects and Civil Engineers. Many arch bridges made of masonry were studied both with in situ or laboratory experimentations, together with the numerical simulations of the tests [1-11].

As well known, historical buildings are often subject to different design and construction phases, furthermore structural damage due to settlements and/or external actions require subsequent restorations that may modify the original geometry of the structure and the mechanical characteristics of the materials.

This research aims to evaluate the sensitivity of arch shape in the structural non-linear behavior of bridge. Structural pushover analyses are developed by means of Finite Element code Strand/Straus7 [12]. A numerical 2D model, under plain strain assumption, is proposed both for the designed and the actually realized bridge, also accounting for material parameters.

The non-linear behavior of the different materials of the bridge (masonry, Istrian stone, filling material) is modelled by means of a Mohr-Coulomb yield criterion. In the following, after a brief description of bridge history and its geometric characteristics, a critical analysis of numerical results is presented.

2. Historic Background and Geometric Characteristics of the Bridge

The "Guglie" bridge (Fig. 1), located in the "Sestiere di Cannaregio" is one of the 430 bridges that connect the 121 islands of Venice; it is one of the most important and ancient of the city [13-15]. As typical of historic bridges, it is made of masonry and Istrian stone. The name "Guglie", is due to the presence of a sort of slender stone pyramids with square base placed at the four corners of the bridge [13].

Corresponding author: Daniele Baraldi, Ph.D., Assistant Professor of Structural Mechanics, research interests: mechanics of materials and structures, computational mechanics, masonry structures. E-mail: danielebaraldi@iuav.it.

The Guglie bridge was built in wood in 1285; in 1580, the wooden bridge was replaced by the current arch bridge in masonry and Istrian stone, completed with parapets, on the basis of the project designed by Marchesini, as highlighted by existing inscriptions on the bridge. Important restorations were made in 1641, 1760 and 1777, and consistent interventions were realized in 1823 and 1871, related to the stairs of access. In 1987, an important restoration and static consolidation was carried out [14].

The actually built bridge is different from the Marchesini's projects, as it can be seen by comparing Figs. 2 and 3. In the original design of the bridge, the shape of the arch is a perfect circle, while the shape of the current arch, which was surveyed during the last restorations, is not perfectly circular. Two hypotheses may be proposed to explain this difference; the former may be referred to realization phase and technical problems: i.e. disarmament operations of the rib or possible settlement of the structure over the centuries; the latter may be referred to different choices during the realization phase.

Several materials made the arcade, most of the vault is made in brick, while the two arches of head are made of Istrian stone. The gothic texture is used, the size on average is similar to the gothic brick ($27\times14\times6.5$ (cm^3)).

The bridge presents an angle from one pedestrian bank to the opposite side that measure 79° (degree). The dimensions of bridge are: span equal to 19.68 (m); rise equal to 4.45 (m); thickness in correspondence of the keystone and the crown equal to 0.38 (m); thickness in proximity of the springing equal to about 0.83 (m).

Fig. 1 Picture of "Guglie" bridge.

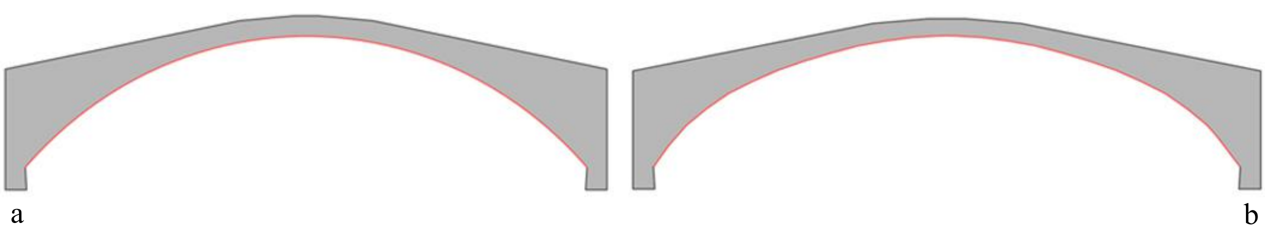


Fig. 2 Transversal section shape of the designed bridge (a) and of the actually built bridge (b).

3. Numerical FE Models

In order to evaluate the sensitivity of the actual bridge shape with respect to the designed one, several numerical tests are performed by focusing on the non-linear behavior of the bridge. For this purpose, an FE Model, under in-plane state hypothesis, already adopted for performing static and modal analysis of the bridge [16], is here extended to the non-linear field. Due to existing numerical tests and thanks to a recent structural dynamic identification of the bridge, elastic mechanical parameters do not need further calibrations, whereas several considerations will be done about non-linear parameters, namely Mohr-Coulomb parameters such as cohesion and friction angle.

3.1 Geometry of the Models and Materials

Standard isoparametric quadrilateral elements are adopted for both models (Figs. 4 and 5). Plane strain conditions are assumed. The model considers a generic longitudinal section of the bridge; hence three different materials are adopted for the FE model, listed in Table 1. For each material, an isotropic elastic-plastic behavior is assumed, with material non-linearity taken into account by means a Mohr-Coulomb yield criterion, that allows to account for tensile and shear failure of the materials, without considering failure in compression.

The first material is the masonry adopted for the load-bearing arch, depicted with color red in Figs. 4 and 5. The actual masonry texture is not taken into account and, as previously stated, an isotropic behavior is assumed for the material, by adopting an elastic modulus equal to 3,000 (MPa) that is typical for masonry made by historical artificial clay bricks. A friction angle equal to 30° is assumed and three cohesion values equal to 0.2, 0.5, and 1 (MPa), are adopted, in order to consider masonry made with historical lime mortar. Then, the second material is the fill placed at the extrados of the masonry arch, depicted with color green in Figs. 4 and 5, and characterized by a smaller elastic modulus and density with respect to the structural arch and two different values of cohesion: 0.1 and 0.2 (MPa), which account for the low quality of the material. Finally, the third material is the Istrian stone placed on top of the fill, depicted with color orange in Figs. 4 and 5. Due to its limited thickness with respect to the other portions of the arch, the non-linear behavior of this material is not taken into account. Each model presents the following restraint conditions: horizontal displacements set equal to zero at the nodes along vertical external edges, vertical and horizontal displacements restrained at the base nodes of the arch. Both models are characterized by similar numbers of FEs, close to 500 and, consequently, degrees of freedom, close to 600. In particular, two FEs are considered along masonry arch thickness. It is worth noting that both models consider also the presence of the weight of parapets, which are made with Istrian stone and are added as nodal non-structural masses along the extrados of each arch shape (Fig. 6).

4. Numerical Experimentations and Discussion

Numerical tests are performed by applying a non-symmetrical increasing point force at the extrados of the arch, in addition to the self-weight of the bridge,

Table 1 Mechanical parameters of the different materials adopted for the FE models.

Material	Elastic modulus E (MPa)	Poisson’s ratio ν (-)	Density ρ (kg/m^3)	Friction angle φ° (degree)	Cohesion c (MPa)
Masonry	3000	0.2	1800	30	0.2-0.5-1.0*
Filling material	1000	0.2	800	30	0.1-0.2*
Istrian stone	10000	0.2	2000	-	-

* parametric tests performed by varying the mechanical parameter.

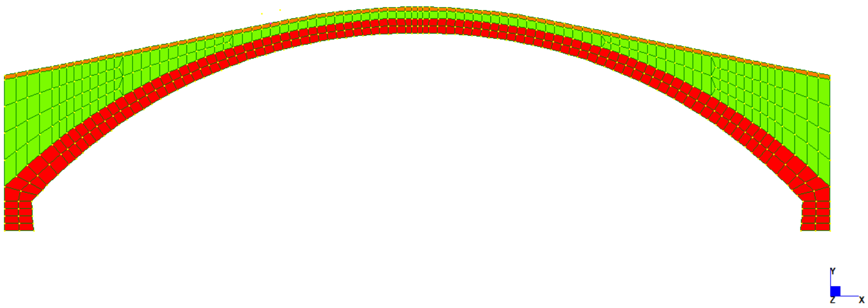


Fig. 3 FEM of the designed bridge.

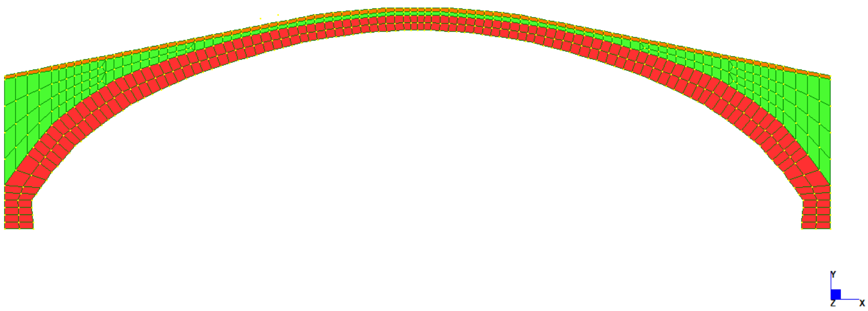


Fig. 4 FEM of the actually built bridge.

Fig. 5 Bridge with non-structural masses representing stone parapets.

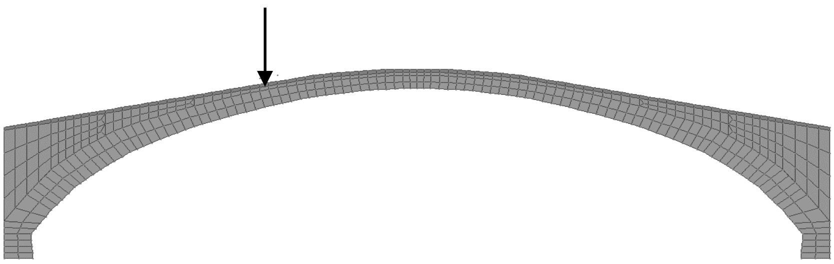


Fig. 6 Bridge subject to a non-symmetric point force.

in order to simulate a possible concentrated eccentric load over the bridge and with the aim to activate a non-symmetric collapse mechanism. Such approach was often adopted for studying masonry bridge behavior and collapse mechanism by means of both laboratory and in-situ experimentations, together with the corresponding numerical simulations [1-11]. In this case, the force is applied at 5.90 (m) from the left edge of the arch (Fig. 7) and the corresponding vertical displacement is measured.

4.1 Pushover Analysis to Compare Designed and Actually Built Bridge Models

The first pushover analysis is performed on both bridge cases, assuming the largest cohesion values for masonry and fill (Table 1), namely c = 1 (MPa) for the masonry and c = 0.2 (MPa) for the fill, for obtaining an upper bound for the following tests. The two bridge types—designed and actually built—turn out to behave similarly (Fig. 11), as showed by the pushover curves. Both analyses are characterized by an initial elastic behavior up to 300 (kN) and a vertical displacement close to 0.01 (m), then the stiffness of the model starts to decrease, with an important force-displacement slope reduction after 600 (kN) corresponding to a vertical displacement close to 0.04 (m). Finally, both bridge types—designed and actually built—are still able to carry an increasing load, but the analyses are stopped close to 1,100 (kN) and a vertical displacement equal to 0.35 (m).

Fig. 8 shows the deformed shape and a map of combined Mohr-Coulomb stresses of the actually built bridge subject to a concentrated force equal to 300 (kN). At this load level, damage starts to appear along the load-bearing arch below the application point of the increasing force. This condition can be simplified as the opening of a first hinge at the intrados of the arch. Then, with 600 (kN) of applied force, Fig. 9 shows the development of a second damaged zone, namely a second hinge, at the extrados of the load-bearing arch, at the left side of the applied force, at almost 2.30 (m) from the left edge of the bridge. Finally, Fig. 10 shows a third damaged zone obtained when the force approaches 1,000 (kN), along the extrados of the arch, at the right side of the applied force, at 10.35 (m) from the left edge of the bridge.

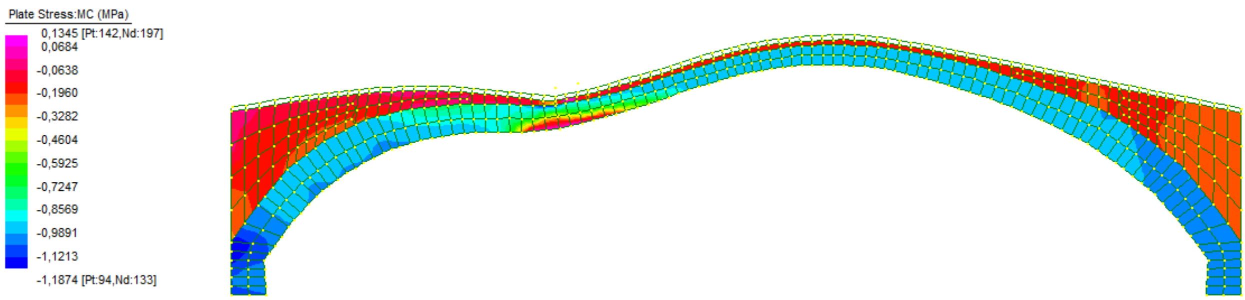


Fig. 7 Deformed shape and Mohr-Coulomb stresses for the actually built bridge with a force equal to 300 (kN).

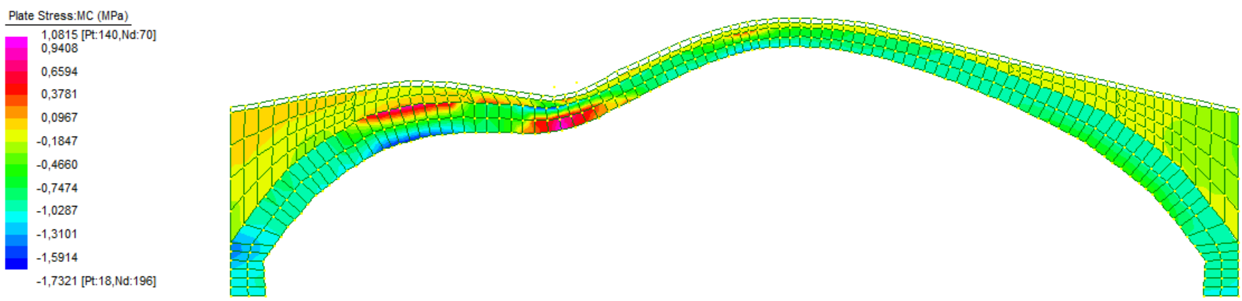


Fig. 8 Deformed shape and Mohr-Coulomb stresses for the actually built bridge with a force equal to 600 (kN).

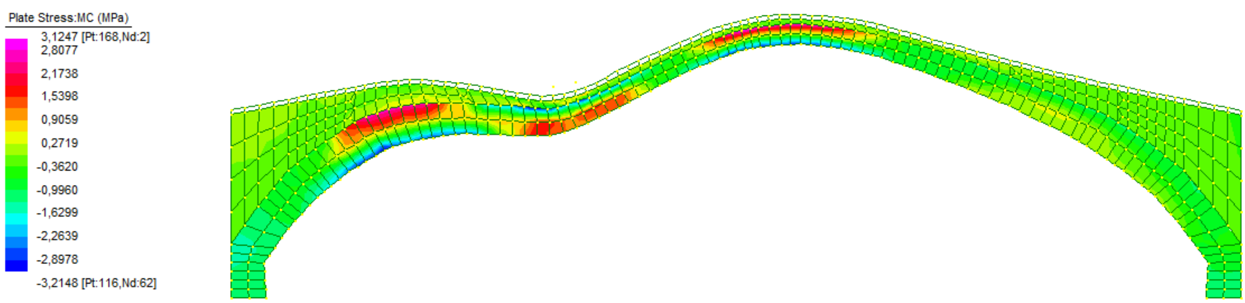


Fig. 9 Deformed shape and Mohr-Coulomb stresses for the actually built bridge with a force equal to 1,000 (kN).

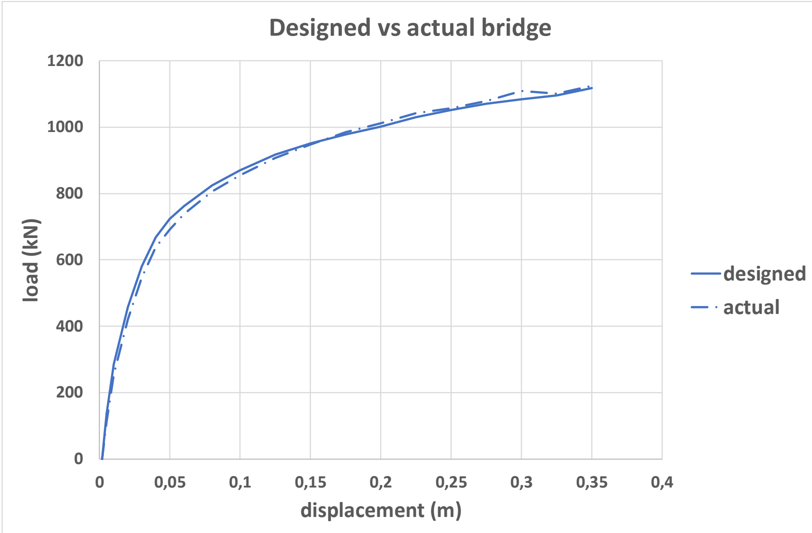


Fig. 10 Pushover analysis of designed and actually built bridges having masonry with *c* = 1.0 (MPa) and fill with *c* = 0.2 (MPa).

Fig. 8 also shows the beginning of further damage at the right side of the intrados of the load-bearing arch, at almost 16.66 (m) from the left edge of the bridge or 3.85 (m) from the right edge. It is worth noting that due to its deformability and thanks to the self-weight, damage into the fill material is not evident and can be neglected. Hence, a mechanism characterized by three or almost four hinges along the bridge span is obtained and the position of the hinges is correctly alternated along intrados and extrados of the load-bearing masonry arch.

Similar positions of damaged areas have been found with the FE model of the designed bridge, hence the difference between the designed bridge and the actually built one does not influence significantly the behavior of the model.

The actually built bridge here studied is taken as reference for the following parametric tests.

4.2 Pushover Analyses Varying Cohesion for Masonry Load-Bearing Arch

Given that the previous analyses showed that both bridge types—designed and actually built—behave similarly, in this section only the actually built bridge is analyzed. Pushover analyses are carried on for first by setting c = 0.2 (MPa) for the fill and varying the cohesion value of the load-bearing masonry arch by adopting c = 0.2 and 0.5 (MPa). Fig. 12 shows the load-displacement curves obtained with varying arch cohesion. It is evident that this parameter for the load-bearing arch is fundamental and influences significantly the load that can be supported by the model. The initial stiffness of the model does not vary significantly, however, the small cohesion values reduce the initial elastic range of the arch, given that with c = 0.5 (MPa) the slope of load-displacement curve decreases for a force close to 400 (kN) and with c = 0.2 (MPa) the non-linear behavior begins with a force close to 200 (kN). This aspect is also evident focusing on the damage along the load-bearing arch. The damaged zones that can be simplified in the formation of hinges are generally obtained with smaller displacements with respect to the previous case. In particular, with c = 0.5 (MPa), the first and second damaged zones appear almost simultaneously with a vertical displacement equal to 0.04 (m) (Fig. 13a) third damaged zone is obtained with a vertical displacement equal to 0.12 (m) and a fourth damaged zone corresponding to the fourth hinge along arch intrados is slightly more evident at the end of the analysis and it is obtained with a force close to 700 (kN) (Fig. 13b). With c = 0.2 (MPa), first and second

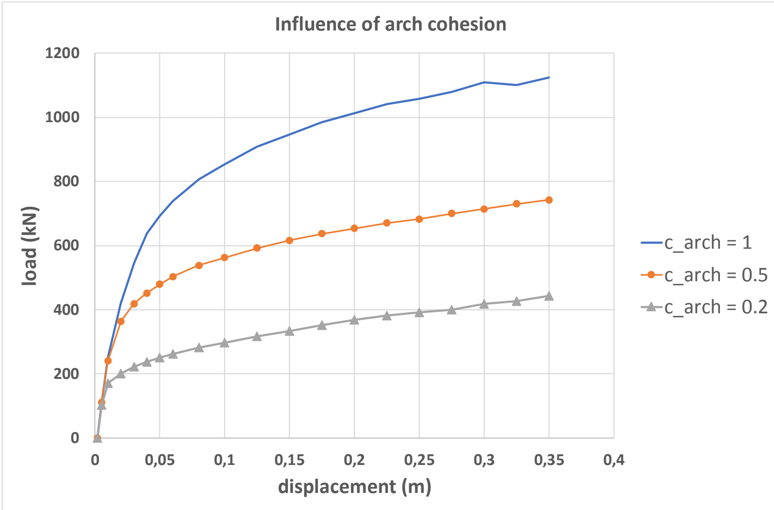
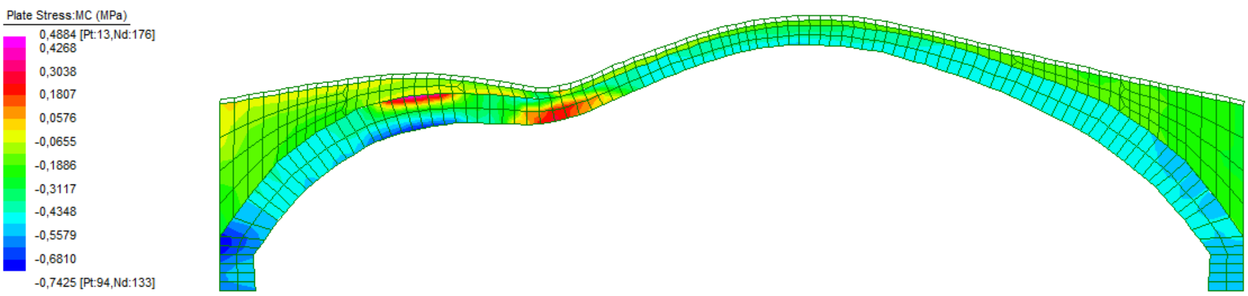
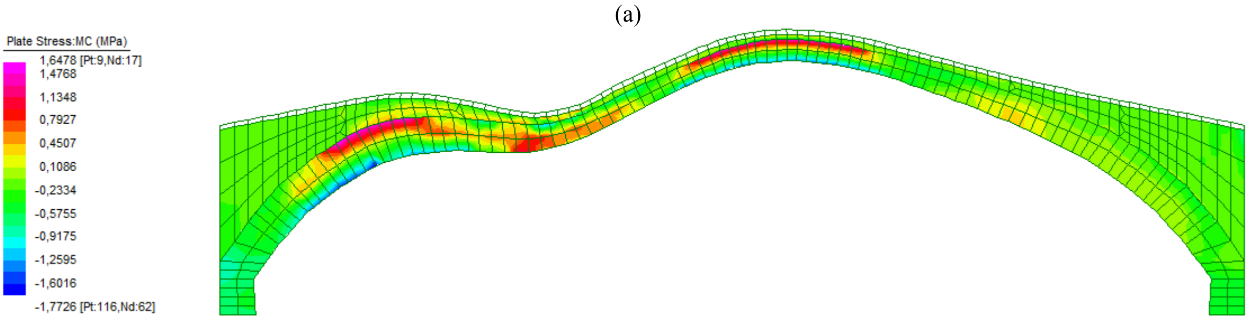


Fig. 11 Pushover analysis of actually built bridges having masonry with varying cohesion and fill material with *c* = 0.2 (MPa).

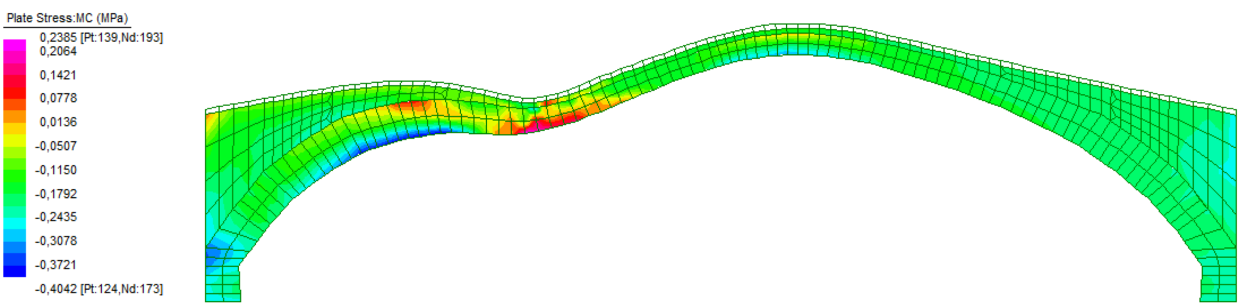


(a)

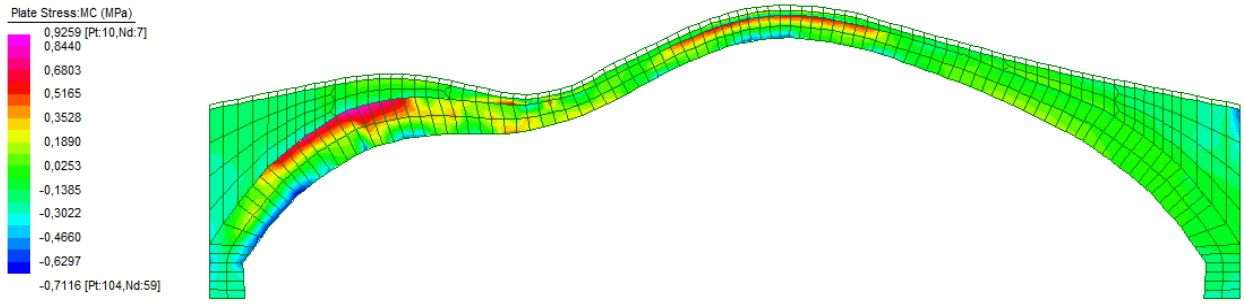


(b)

Fig. 12 Deformed shape and Mohr-Coulomb stresses for the actually built bridge with *c* = 0.5 (MPa) for masonry and a force equal to (a) 450 (kN) and (b) 700 (kN).



(a)



(b)

Fig. 13 Deformed shape and Mohr-Coulomb stresses for the actually built bridge with with *c* = 0.2 (MPa) for masonry and a force equal to (a) 200 (kN) and (b) 400 (kN).

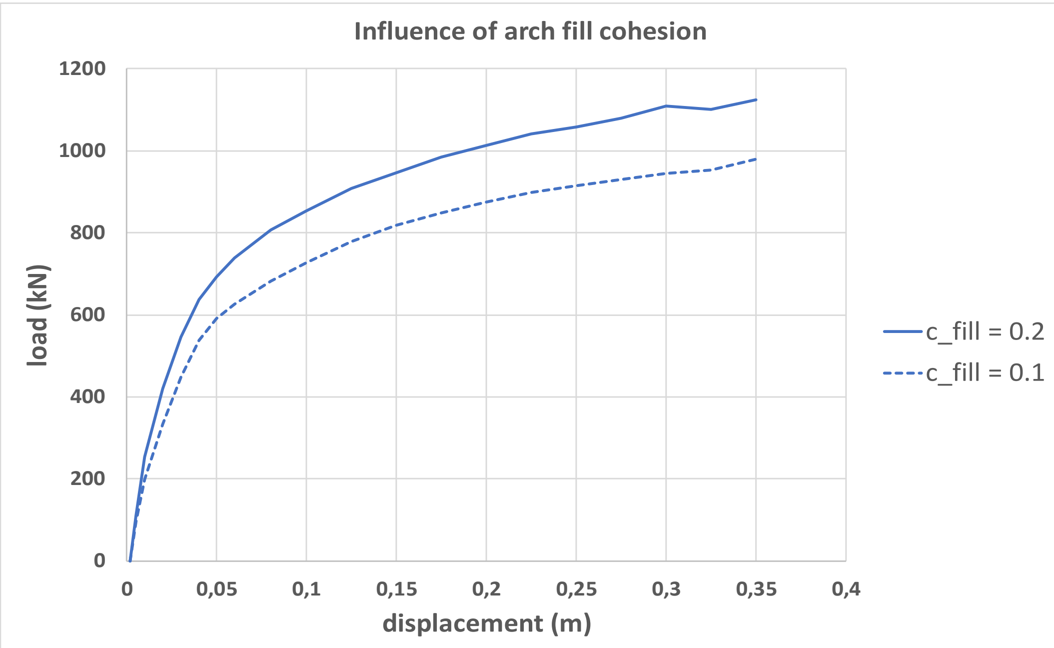


Fig. 14 Pushover analysis of actually built bridges having masonry with *c* = 1 (MPa) and fill material with varying cohesion (MPa).

hinges are obtained with a vertical displacement equal to 0.02 (m) (Fig. 14a) and the third damaged zone is obtained with a vertical displacement equal to 0.08 (m), with a force close to 300 (kN). In this case, the fourth damaged zone in the right half of the arch is not obtained at the end of the analysis but, probably due to the small cohesion value of masonry, the size of second and third damaged zones tend to increase (Fig. 14b) with respect to the reference case considered previously.

4.3 Pushover Analyses Varying Cohesion of Arch Filling Material

The sensitivity of the filling material to behavior of the model of the actually built bridge is evaluated by assuming a smaller cohesion value *c* = 0.1 (MPa). Fig. 15 shows the corresponding load-displacement curve compared with that obtained in section 4.1. The smaller cohesion of the fill material influences and reduces on one hand the initial stiffness and stiffness decay of the model, on the other hand it reduces also the load supported by the model of the arch bridge, that is generally the 87% of the load obtained with fill cohesion equal to 0.2 (MPa); in particular, a concentrated force close to 1,000 (kN) is obtained with a vertical displacement equal to 0.35 (m). Damaged zones of the arch and deformed shapes, however, turn out to be not influenced by the smaller

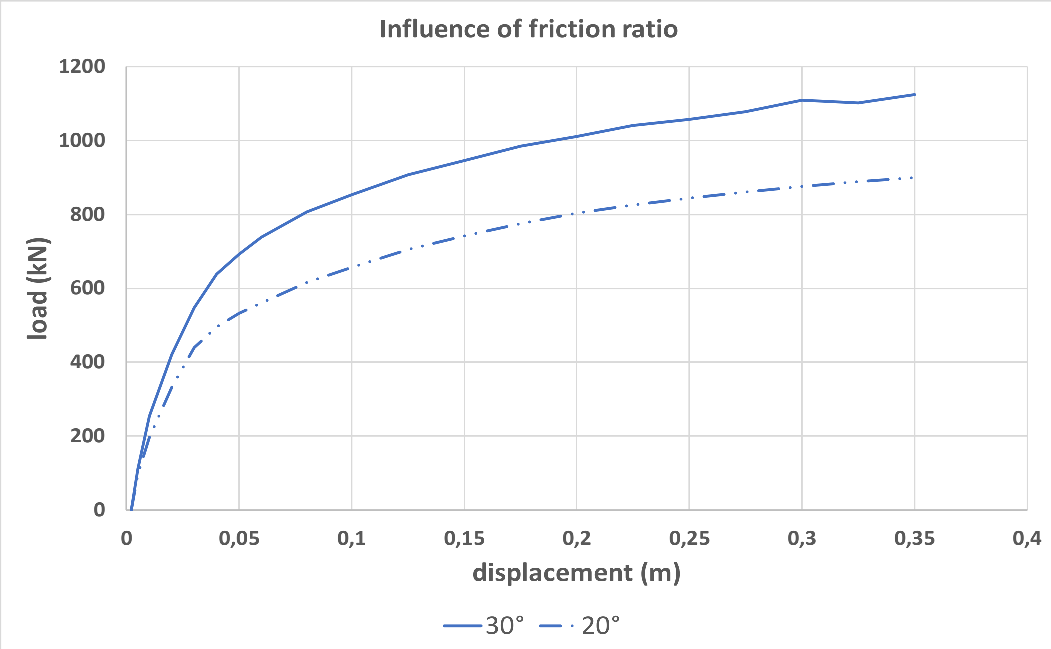


Fig. 15 Pushover analysis of actually built bridges having different values of friction angle.

cohesion of the filling material.

4.4 Pushover Analyses Varying Friction Angle of Masonry and Filling Material

A final comparison with respect to the first pushover analysis on the actually built bridge is performed by evaluating the sensitivity of friction angle, that is reduced to 20° for both masonry and fill materials, whereas cohesion values are kept equal to those adopted in section 4.1. Similarly to the previous comparison, the smaller friction angle generally reduces the initial stiffness and the stiffness decay of the model (Fig. 16). In this case, the load supported by the model is generally reduced to the 80% of that obtained in section 4.1; in particular, a concentrated force close to 900 (kN) is obtained with a vertical displacement equal to 0.35 (m). Furthermore, the damaged zones along the masonry load-bearing arch are similar to those obtained with the reference case and three clear hinges and a fourth one partially developed are obtained at the end of the analysis.

5. Final Remarks and Conclusions

In this paper, non-linear pushover analyses of a masonry arch bridge have been performed. The "Guglie" bridge in Venice has been taken as case study, given that geometric characteristics were determined in past research activities, together with a validation of material parameters by means of structural fast and low-cost identification procedures [16]. A particular aspect of this masonry bridge is represented by the difference between the original design with respect to the actually built structure. Hence, two FE models of the bridge types have been developed by considering the longitudinal section of each arch, under in plane strain hypothesis, and by taking into account three different materials into the section, namely masonry load-bearing arch, filling material and Istrian stone. Material non-linearity has been evaluated by means of a Mohr-Coulomb yield criterion and material parameters such as cohesion and friction angle have been varied in order to account for their influence on non-linear behavior. Pushover analyses have been performed by applying an increasing non-symmetrical point force in the left portion of the bridge, together with its self-weight. The first set of analyses showed that the difference between the designed and the actually built bridge does not influence significantly the non-linear behavior of the structure, since very small differences have been found in the pushover curves, in the deformed shapes, and in the maps of damage. The collapse of the bridge has been generally characterized by the formation of several damaged zones, which can be considered as hinges along intrados or extrados of the load-bearing part of the bridge. In particular, three clear hinges have been found, causing an evident decay of the stiffness of the structure, whereas a fourth hinge has been found almost at the end of the first set of analysis. Then, the parametric tests showed that the cohesion of the masonry of the load-bearing part of the bridge plays an important role in the overall capacity of the structure, whereas the cohesion of the filling material and the friction angles slightly reduce the stiffness and the strength of the structure.

Further developments of this work will focus on the three-dimensional behavior of the bridge by performing for first a further structural identification of the three-dimensional dynamic behavior of the structure, together with the evaluation of the linear and non-linear behavior of the structure subject to dead and live loads.

Other possible developments of this work will regard the comparison of the FE model proposed here with other analytic models commonly used for arches, vaults and domes [17], and with other numerical models, with particular attention to the DEM (discrete element method) [18, 19].

Acknowledgments

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Prolegomena for a Living Architecture

Armando Dal Fabbro

Department of Architecture Construction Conservation, Università IUAV di Venezia, Dorsoduro 2206, 30123, Venice, Italy

Abstract: Rational and intuitive can be considered as two sides of the same coin? If they coexist in the design process, what do they refer to and what do they stand out for? What kind of relationship can be established between the act of prefiguring the work and of putting it into operation, according to procedures and techniques that are coherent and necessary for its construction? The value of an architectural project is shown by its being a continuous search for expression of art, even if, as we know, architecture also has a social function and plays a civil role. The universal meanings and the cultural reference context, which have always been the heritage of the architectural project, are increasingly taking on a secondary value. Issues and concepts such as: tradition, memory, modernity, invention and location seem to have lost any research prerogative at the expense of the meaning and use attributed to the architectural and urban composition in the overall design process.

Key words: Architectural composition, rational architecture, expression of art, the universal meanings.

1. Introduction

"Rational Architecture is not an aesthetic or moral vision, a way of living, but the only systematic response to the problems posed by reality"[1] [1].

The problems posed by the reality Rossi spoke of, with reference to rational architecture, include those of a pragmatic order that mainly lie in the sphere of the functional and technical. It is no coincidence that the quotation is from the introduction to a 1974 work by Hans Schmidt (regarded by many as the theorist of Socialist architecture) and that it comprises the political and social sense that these themes had, and how much ideological value was attributed to technique and technological innovation in the fields of architecture and urban planning.

Today, technique reigns supreme in the teaching of architecture and scientific research seems to have become entrenched in increasingly specialized horizons which undermine the universal meanings and cultural contexts of reference that have always been the heritage of architectural design. Themes and concepts such as: tradition, memory, modernity, and invention seem to have lost any research prerogative to the detriment of the meaning and use attributed to architectural composition in the overall design process.

In presenting the book *Invention of Tradition. The Experience of Architecture*, Carlo Magnani highlighted certain stages of these aspects. For example, he stated that the invention of tradition is a critical exercise that is anything but consolatory, capable of interpreting reality, and reminded us that "(…) the comparison with modernity (…) is unavoidable for a discipline like architecture which has so often made the conception of modern a paradigm of collocation of sense, at times slipping into that of style"[2] [2].

If we look at the contemporary work of Frank O. Gehry, for example, I do not believe that it is only the fruit of an arbitrary or intuitive process, or, worse, a gamble of a gestural character (Jean-Louis Cohen, who is editing a complete edition of his works, said that to study the projects he had looked at several thousand drawings, between sketches done by hand, detailed drawings, solutions and constructional details, etc.). A fact that disputes the recurring idea, the cliché,

Corresponding author: Armando Dal Fabbro, architect, full professor; research fields: architectural composition and urban planning. E-mail: adf@iuav.it.

[1] A. Rossi 1974, p. 11.

[2] C. Magnani 2017, p. 13.

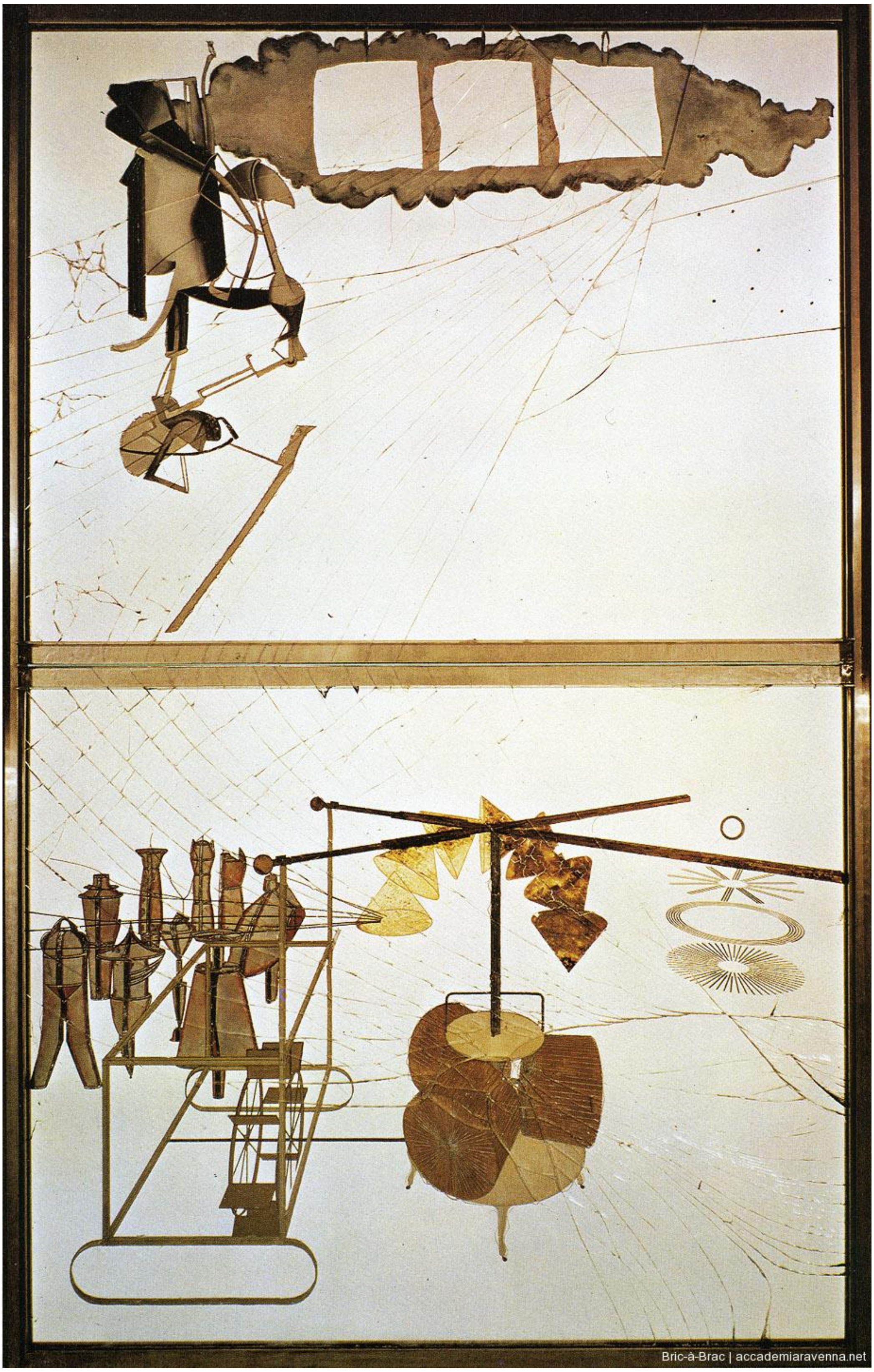

Fig. 1 Marcel Duchamp, big glass, 1915-1923.

Fig. 2 Jackson Pollock at the work.

of Gehry's architecture being one without rules. Just as I believe that even in a highly rational work like the *Casa del Fascio* in Como by G. Terragni (the manifesto of Italian rationalist architecture) if we study it carefully and measure it with the eye of the architect, we can discover imperfections, transgressions, insights, certain oversights that undermine its superior rationality and creative rigour—without in any way decrying its value as a work of art, however. The examples could continue with Le Corbusier's *Villa Savoye* of 1929 or Mies van der Rohe's Barcelona pavilion again from 1929, but also with the works of great artists from Marcel Duchamp with his *Bride Stripped Bare by Her Bachelors* (1915-23), to Jackson Pollock with his *All-over* paintings from the Fifties, etc.

2. Prefiguration, Idea, Design

Consequently, the question of the rational and intuitive in architecture should be placed on a different plane. We should shift onto another level of investigation, which has nothing to do with aesthetic, linguistic or stylistic aspects, as indeed Aldo Rossi and Carlo Magnani have reminded us. On the plane of real conception, architectural design tries to provide concrete answers to civilian needs and, starting precisely from this preliminary basis, expresses the rational dimension of human existence.

Instead, there are those who maintain that the themes and meanings of tradition have to do with the empathetic, personal dimension of the individual, and that therefore artistic invention can be the result of an *ancestral* process, in some cases even unintentionally. For example, Luciano Semerani maintains that in artistic research, especially from the historical avant-garde onwards, the same forms may have the capacity to manifest "regardless of the artist's intentions." Semerani continues by reaffirming that "(…) in time, the achievements of the 20th-century avant-garde (…) were given two different interpretations by the artists themselves. The first being metaphysical, i.e. spiritual, the second physiological, born with the study of perceptual phenomena. I favour a synthesis of the two. It is most likely the continuous flow of the relationships between the archaic and evolved areas of the brain, within languages that do not have signs similar to those of the alphabet, arranged into words and organized with grammar and syntax, that constitute the specific nature of the various arts"[3] [3].

3. Science or Art

"Science decomposes space into place and time; art reassembles place and time into space"[4] [4]. For those who deem architecture a continuity of the historical process, the proceeding within the discipline coincides to a return: "The original legitimates and confirms the new (...) the origin is never crystallized in a text, does not form a binding language: to resonate, it tackles the times, is transformed, offering resistance only to

[3] L. Semerani 2017, pp. 47-48.
[4] F. Carnelutti 1955, p. 9.

unfounded news"[5] [5]. "We all know that in art there is no progress (in reality, progress is only in the individual…)" [6] [6]. This concept was certainly adopted by Max Weber's thesis contained in his book "Intellectual Work as a Profession" published in 1919, in which it is stated that "Scientific activity is inserted during progress. And, vice versa, no progress—in this sense—is implemented in the field of art. (…) A work of art that is truly 'complete' is never surpassed, never ages; the individual can personally assign a meaning of a different value; but nobody will ever be able to say of a work that is really 'complete' in an artistic sense that it has been "surpassed" by another, even though it too is complete"[7] [7]. The same concept is to be found in Thomas S. Eliot when he said that "[the poet] must be quite aware of the obvious fact that art never improves, but that the material of art is never quite the same"[8] [8]. However, the comparison that concerns us is another and is based on architecture's ability to build a process of synthesis between the moment of conception and its realization: between the rational and the empathetic. "It is in the impetus of synthesis that the miracle of art is celebrated"[9] [4]. In other words "To be translated into practice the design needs ideas that solve problems in the light of the project; in turn, the ideas that they resolve need ideas that are acquainted with and organize knowledge into concepts, into abstract categories. The aim of the project is to unify the particularity of the elements that compose it into a vision of the whole"[10] [9].

It is worth lingering for a moment more on two concepts that arouse my curiosity in the fact of not being complementary: that of Prefiguration and Idea. Eugenio Battisti preceded the moment of the idea with "prefiguration" and proposed a clear distinction. "There is," said Battisti, "in treatises, especially Renaissance ones, a clear distinction between architectural prefiguration and idea." He identified two opposing moments: prefiguration "born from stresses whether internal or external, memorized, plays on spontaneous or free or unusual associations, gives rise to a wide range of the possible". These are solicitations of an intuitive kind. The idea, on the other hand, is "a moment of censorship, of counting, coordination, made according to rational categories or ones deemed as such, whose ultimate goal is the normalization of the result." In short, according to Battisti, "great architecture realizes, despite the difficulties, the informal of prefiguration, while construction works exclusively on typology, constrained by economic facts, by the alleged generalized requests of the users, by rules of every kind, but especially by a paralysing form of censorship, (...), by cursory geometrization"[11] [10].

The substantial criticism of the theorization of the city is evident, seen as it is merely as a concentrated "geometry and market"—suffice to think, for example, of our urbanized territories, regulated by laws that belong to the worlds of academic performance and production, rather than being an expression of design prefigurations capable of recognizing and dominating the contradictions and conflicts—that have mistaken the meaning and nature of the city itself, polluting it definitively[12] [11].

Anyway, as Battisti further suggested: "opposition between prefiguration and idea can be mediated in various ways, both by natural impressions and cultural experiences. The ancients related that painting was born from an attempt to reproduce the shadow of a living person, from an almost spontaneous series of signs, subsequently enriched with colours and chiaroscuro, and constructed in accordance with modules, proportions, and perspective. This can also be seen in one of the strictest constructors of forms, namely, Piero della Francesca, who, however, fitted it halfway between geometric rigour and an almost

[5] M. Tafuri 1985, p. 22.
[6] F. Carena 1955, pp. 21-22.
[7] M. Weber 1948, pp. 17-18.
[8] T. S. Eliot 1921.
[9] F. Carnelutti 1955, p. 8.
[10] G. Zagrebelsky 2014, p. 100.
[11] E. Battisti 2009, pp. 165-166.
[12] M. Cacciari 2004.

Flemish emotional sensuality and naturalistic reference"[13] [10].

It becomes important, as well as necessary, to reconsider the reality of our deeds—where everything is governed by deductive logical thought, a product of rules, principles and geometry—in the light of how designs were born and carried out, which on the contrary, contain aspects of unexpected or intuitive invention—Paul Valéry would say "introducing the unexpected and undetermined into the drama of creation"—demolishing its rules, which are the basis of every deep and genuine creative experience[14] [12].

4. The Sense of the City as a Work of Art

In an essay of many years ago, G. C. Argan likened the sense of the city in the unconscious experience of every inhabitant to the paintings of Jackson Pollock from the 1950s.

In an essay entitled "The Visual Space of the City" Argan spoke paradoxically of Pollock's painting and action painting as an unplanned action in a society where everything is planned. For Argan, Pollock's paintings corresponded to "(…) an immense map formed of lines and coloured dots, an impossible snarl of signs, apparently arbitrary traces, tortuous tangled filaments that intersect a thousand times, stop, begin again, and after strange twists and turns return to their starting point. (…) In his agitated tangles of signs he manages to imprison everything which in reality is in motion: the vibration of the light, the iridescence of waterfalls, (...) the waves of the sea, even the confused, eager, unnecessary travels of the people within the labyrinth of the city." "(…) if we re-examine it," continues Argan, "with attention we discover that there is nothing gratuitous or purely random: the tangle of signs, carefully observed, will reveal a certain order, a recurrence of rhythm, a measure of distances, a dominant colouring, a space, ultimately." Like the space of Pollock's painting, the space of the inner city has a background rhythm that is constant but infinitely varied (...)[15] [13].

The image of the "vast unknown", with which the poet Walt Whitman elicited the American landscape, recurs overwhelmingly in Pollock's paintings. The experience of Pollock's *All-over* paintings was greeted (in the Fifties) as the most striking innovation of pictorial space after the Analytical Cubism paintings of Picasso and Braque from the first decade of the 20th century. Today, comparing these paintings with an Ordnance Survey map or a photogrammetric plan of an urban area, they evoke our urbanized territory very well, a territory that is contradictory and standardized, a landscape that seems increasingly *constructed* and progressively less *designed.*

5. The *secundum artem* Road of Architecture

From what has been said so far, it is obvious that there is a single concept of the architectural art which responds *in toto* either to the canons of the rational or to the experience of intuition, while neither of the two choices, taken individually, can ensure predictable outcomes. These are phenomena that belong to the world of creativity, of invention, of the sublime and desire: they are capable of becoming "alchemical blends"[16] that transform a work into a work of art [3]. They are born from experience, attitudes, ways and practices which, once employed, will not contradict one another, but penetrate deeply and affect the artistic action and therefore the work and the creator.

"So, it is not only from a glut of anger, fear, or sexual desire that a work is born. Nor from the very elegance of the game. It is the whole mind that lets the work find itself. But at the same time, it is a great comfort to understand that only with the formal revolutions of the 20th century has there been the opportunity to discover the necessity to found *innovation* on the terrain of our *ancestral traditions*. And also to discover, in the experience of others, and

[13] E. Battisti 2009, p. 168.
[14] P. Valéry 1985, p. 188.
[15] G. C. Argan 1971, pp. 168-170.
[16] L. Semerani 2017, p. 48.

also in our own if we happen to be *creators*, that the magic of successful work, *invention*, and also *innovation*, those real and profound ones, initially insuperable, were *accidental*"[17] [3].

At this point, were we to indicate examples explaining what I have been saying and, interested as I am in the projects of Italian rationalism between the two world wars, I believe that this "poetic" aspect can be found above all in the last works by Giuseppe Terragni.

I am referring to two projects in particular, that of the Unione Vetraria Italiana (The UVI Pavilion of 1939), supplied for the E42, the universal expo that was supposed to take place in Rome in 1942, and a project for a cathedral (1943), the final work conceived by Terragni before his sudden death. I believe that in these two projects, of which only some sketches remain—graphic fragments of a thought that increasingly fled the ideological barriers of traditional and ideological rationalism—it is possible to glimpse those prefigurations mentioned by Battisti that asserted expressiveness, sensitivity, and compositional freedom.

If the drawings for the UVI Pavilion express a geometric-figurative research geared to rediscover the unity of the architectural work in a single gesture—the most effective image to describe this procedure can be found in the book by Mario Labò on Terragni in which we read: "The evolution of Terragni was originally triggered by the *esprit de géométrie*, proceeded from a rigid symmetry to a rigorous lack of symmetry, from static quadratism to a clastic and dynamic rectangulism; a yearning for those *profondes combinaisons du régulier et de l'irrégulier* (...)"[18] [14]—and, vice versa, the totality of the architectonic body, expressed in the disassembly and recomposition of figures within the labile spatial limits between an interior and exterior, in the volumetric rhythms—virtually devoid of depth—of the full and the empty, in an extreme attempt to combine the semantic value of the work with ideas of transparency, abstraction, and purely figurative art.

An architecture of poetry, as the last project that Terragni began to devise a few days before his death would become, but so much more intense and lyrical. The Cathedral project, from the few sketches that have come done to us, is a further plastic transfiguration of abstract rationalism. A dramatically and paradoxically unattainable project, but where, already in those few sketches, everything is complete.

"In his last project, Terragni summarized a large part of the iconographic patterns he used in previous years"[19] [15]. A project that is presented in its bareness of matter and form, summarizing all the forms of architecture. Deliberately detached from the more mannerist forms of "standard" rational architecture, we can glimpse the horizon of a new vision (with more futuristic than rationalist traits, Sant'Elia-style). In my opinion, this is a revolutionary project, the anticipator of research that would develop in the post-war period, especially in the field of reinforced concrete structures, and the architecture of ribs and thin vaults (thinking of the works of P. L. Nervi, G. Michelucci, G. Pizzetti, S. Musmeci, and so on).

"Several elements make Terragni's last project up to date and many elements today make us lament lyrical rationalism and this is not simply because of the formal results, but because of the strong desire behind it. (…) The last cathedral is a work of poetry. Today, in a national architecture that lives off prosaic works, respectable maybe, but still prosaic, this last project of Terragni reiterates with calm pride the necessity for works of poetry: works devoid of contents, but since they are poetic, capable of embracing many, while always remaining free from them"[20] [15].

These two projects have much in common; they are

[17] L. Semerani 2017, p. 50.
[18] M. Labò 1947, p. 24.
[19] V. P. Mosco 2015, p. 32.
[20] V. P. Mosco, 2015, p. 79.

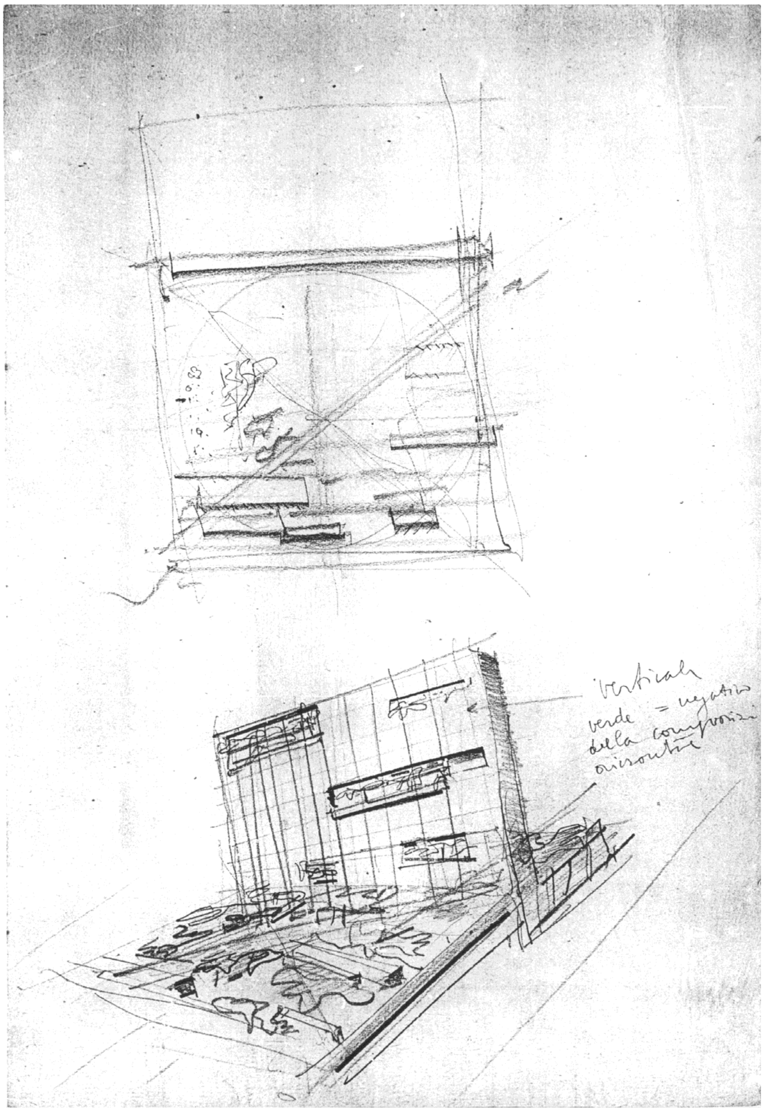

Fig. 3 Giuseppe Terragni, sketch for the UVI project, 1938.

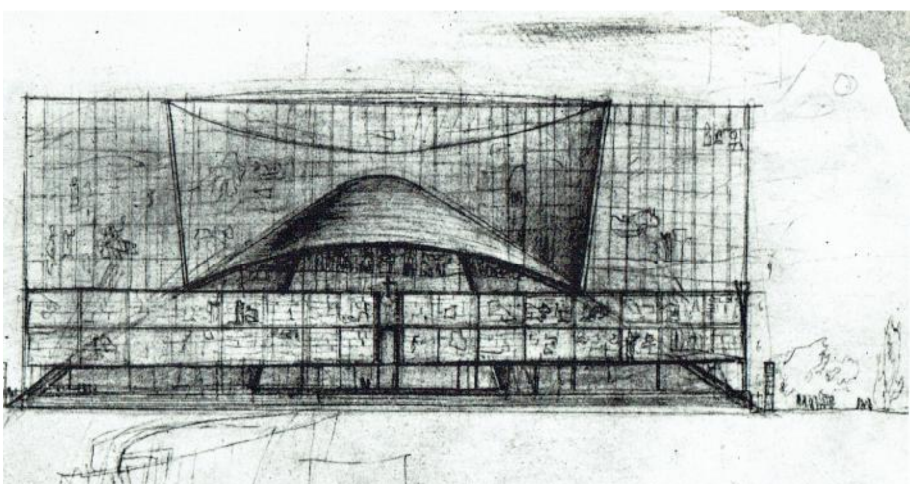

Fig. 4 Giuseppe Terragni, sketch for the design of Cathedral, 1943.

the sign of a promise and a hope for a future architecture that does not wish to shake itself free from the past but pursues it in the images of the architect's vexed mind, unfortunately close to the end at this point.

From the drawings of the cathedral we can infer certain clear references. The sketch of the large gesture of the front wall, which is the prelude to an idea of outstanding support for a large pictorial composition, brings forth the great wall-screen of the project for the Palazzo del Littorio, Solution A, as well as the incredibly fragile space frame, which, in the single geometric design that has come down to us, dominates the entire composition of the façade—and, for me, this is not a superstructure resting on top of the entrance building, where some scholars have assumed its positioning[21] [15], but looming in the background to the composition—as a conclusion of the great paraboloid, a sort of awning with shades, which incorporates the transparencies and figurative resonance of the first sketches for the UVI Pavilion from 1939. Abstract rigour and an anguished sentiment[22] express the longing of a thought that is not inward-looking, but the prolegomena for a living architecture [16].

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[21] V. P. Mosco 2015, Terragni 1996.
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Analysis as a Project

Esther Giani

Department of Architecture Construction Conservation, Università IUAV di Venezia, Dorsoduro 2206, 30123 Venice, Italy

Abstract: This article is driven by the research carried out in the last five years at the Department of Architecture Construction Conservation (Iuav of Venice) about the industrial district of Porto Marghera near Venice. While not addressing the area itself, this paper is about the analyses carried out during the research, inevitably a part of the project process. This research is based on a rigorous knowledge of the location, taking into consideration all the protagonists in the various transformations that Porto Marghera has undergone and continues to undergo. The main goal of the research is to provide those involved with objective analysis with which to operate. Objective analysis that reflects the researcher, who is a designer, namely who may use these findings, traces, abacus and matrixes for *designing* (sustainable) scenarios. The research methodology is *inductive* [1] and employs mapping, sorting and cataloguing, in order to deconstruct the different significations of the problem. Mapping the Venetian district has allowed a greater awareness of the areas of complexity and difficulty. We are in the field of project analysis: the inductive procedures put in place, re-propose a source (an arché) that can be different from the object investigated. A derivative. The more rational and prudent the development of the analysis, the lower the risks displacement. The work on Porto Marghera, collected as an atlas, as a catalogue (but that would also like to be an handbook) is not therefore necessary to design a masterplan, which sooner or later will surely have to be drawn up. The Atlas proposes the site's procedural, albeit highly interpretive, reading and aspires to activate analogue suggestions giving rise to "retentissement", that is phenomena of identification of formal principles, of figures participating to the culture of each protagonist [2]. The ultimate goal of this research is to explore the potentials of various mechanisms for territorial recuperation, or rather to show that the question of land reclamation is just a prerequisite. The forms of recuperation are an integral part of the architectural project without limiting it or depriving it of its usual characteristics such as function, creativity, quality, and even beauty.

Key words: Analyses, architecture and urban project, atlas, mapping and sorting, design project.

1. Introduction

Forms' analysis for a project can follow different paths and methods: addressing a semiological/structuralist approach; elaborating analogy-based links; or diagramming separate overlapping layers of observation. In a more complex manner, the analysis can also consider the network of possible references. These may include traces and methods whose end should be an autonomous opportunity to design, when (and if) the observer succeeds in using those analyses as a moment of poetic reinterpretation.

1.1 A Working Hypothesis

Should the set of projects examined present obviously similar characters and similar morphologies even if not immediately linkable to evident models, in other words, if the observed projects clearly belong to a recognizable figurative area of interest, it will then be quite useful to be equipped with a sort of atlas[1] of morphemes that will help match similar styles. Likewise, in order to reach a more objective, indisputable and evident identification, a simplification of the "recurring" will have to be achieved. So far, again borrowing from other disciplines, the best, easiest and most practical way to sort and simplify seems to be through formal and geometric matrices.

This extraction (and abstraction) process calls for an act of force, which necessarily exposes the researcher to the risk of misinterpretations, that is, of personal

Corresponding author: Esther Giani, arch. M.A. PhD, prof. Research field: architecture and industrial landscape. E-mail: giani@iuav.it.

[1] This text comes from the *Introduction* [2] of a book that collects the research tackled by the author in the years 2012-2018 at the Architecture Construction Conservation Department of the Iuav University of Venice.

interpretations (especially in terms of forms), which might create great distance to the originals. We are in the field of project analysis: the inductive procedures put in place, re-propose a source (an *arché*) that can be different from the object investigated. A derivative.[2]

The more rational and prudent the development of the analysis, the lower the risks displacement.

These risks will always exist, but it will also always be possible to identify the phases during which the researcher produces an interpretative deviation. It is necessary, however, to support the investigation equipment through graphic devices (diagrams, mapping, etc.): these drawings, these families of forms will enable an understanding of the different phases (of analyses, of observations, of approaching to the project).

As an experimental (or instrumental) hypothesis—an interesting procedure would compare a work's different elaborations, independently of the scale and type of design used (hence treating in the same way plans, details, sections etc.), searching for recurring morphemes.

The task is certainly complex, because it assumes such a "geometry spirit" to permit to detect and separate signs systems that can be assimilated to each other in the project's complexity. This approach can bring real surprises: in so doing it could result that the structural scheme has strong similarities with the decorative apparatus of the façade, or that the design of a floor may have a lot in common with the windows, doors, etc.

The critical research tries to retrace the figurative influences, the (pre-textual) references used by the authors under consideration. It tries to rebuild social, historical, economic conditions, policies, etc. We all know that this kind of information does not have a real objective, scientific foundation unless a contemporary work and/or author is studied. Therefore, it appears limiting to consider this methodological step as fundamental.

The work in its physicality, in its representative criteria, is the only reliable element of investigation.

1.2 A Working Pretext

Over the past five years, we[3] have focused our research on Venice's industrial district (Porto Marghera) as an element of investigation; its history, its regulatory framework, and its bibliography have all been depicted in broad strokes [6-8].

Above all, we tried to build a comparison system between elements, which seemed to present similar features and related morphologies. We also worked through charts and matrices to highlight its recurrences. Having fixed limits, such that some characters fall into an abacus and not in another collection, inevitably produced interpretative leftovers that represent the real design potential of these analyses.

2. Porto Marghera of Venice

The Venetian industrial district has been placed under a magnifying glass, using differing levels of contrast and means of observation available to the architect-designer. We've been experimenting an investigation method (by simplifying and adapting it) permitting us to evaluate advantages, weaknesses, opportunities, even threats of the phenomenon observed,

[2] A famous precedent is the French OuLiPo Experience (Ouvroir de Littérature Potentielle, Potential literature lab.). Amongst the members/works we recall: Italo Calvino's *Invisible cities* [3], George Perec's *A User's Manual* [4], or Raymond Queneau's *Exercises in Style* [5].

[3] We are member of the Research Unit coordinated by the author, titled Abandoned Areas and Landscape Renewal. Giancarlo Carnevale established the Unit in the early 2000 as Iuav had a special department devoted only to Research (Dipartimento Unico della Ricerca; director: prof. Luciano Vettoretto). The unit is much like a sponge: it grows (by absorbing researchers, scholars, professors of many disciplines and coming from a variety of universities) depending on the topic, on the funds, etc. The author is amongst the founders; together with Irene Peron and some scholars who contributed to the *ATLAS*, she set PRE.testi a sort of community where pre-texts are taken to do, speak about, and write about architecture.

regardless of the scale.[4]

Various observations were then extracted, summarized, sorted, unified and collected in forms to be subsequently recomposed in collections of related morphemes.

The set is a prospective analysis that is proposed in the form of atlas. The Atlas and the collected set of analyses cannot be considered objective nor the only possible choice. Our aim was to propose a rational method of approaching the Porto Marghera phenomenon showing *possible* interpretation (*projective* analysis, indeed).

It's not just the readings of implicit and hidden formal structures of the Venetian industrial landscape, but rather mappings of real and true "inventions" [lit: recoveries/findings] [5] produced thanks to the instruments (sources, rules, surveys, digital drawings) and to the observer's eye. The Atlasis a kind of pretext search of extrapolated morphemes almost entirely autonomous with respect to the observed phenomenon. The Atlas proposes the site's procedural, albeit highly interpretive, reading and aspires to activate analogue suggestions giving rise to "retentissement",[6] that is phenomena of identification of formal principles, of figures participating to the culture of each protagonist [9]. Images being present in everyone's consciousness may find a correspondence also in the reader, thanks to combinations proposed by Atlas. The *retentissement* sets in motion the reader's *creative* activity, identifying itself with the writer: "All readers who read over a work they love, know that the pages loved affect them" [9].

The material organized in this way results in a collection of clues to formal possibilities, "pretexts, not innocent arché. It will always be the *text*, the project the only one to explain why" [10].

2.1 The Pretext: Porto Marghera of Venice

The research project investigates the issue of industrial areas (abandoned or in the process of abandonment, in decline/contraction) in the urban environment; it finds some of the arguments in macro-economic fields: densification and more sustainable land use through the recovery of brownfield that is recognized as possible development sites for urban centres. Abandoned places meant both as volumes (empty buildings to be re-introduced in a functional cycle) and as de facto available space in the community. An industrial landscape's potentials are at the same time sought out and denied, in a negative spiral that seems to find no plausible solution, especially towards the territory seen as *heritage* to preserve, save and transmit to future generations[7] [11].

The theme of the recovery of industrial areas has been recognized since the Nineties, but the economic crisis and the technological progress that caused a progressive contraction of industry production has

[4] SWOT analysis is a framework used to evaluate a company's competitive position by identifying its strengths, weaknesses, opportunities and threats. Specifically, SWOT analysis is foundational assessments model that measures what an organization can and cannot do, and its potential opportunities and threats. Analysts present a SWOT analysis as a square with each of the four areas making up one quadrant. This visual arrangement provides a quick overview of the company's position. Although all the points under a particular heading may not be of equal importance, there is insight in seeing how the number of opportunities measures up to the number of threats, and so forth. When using SWOT analysis, an organization needs to be realistic about its strong and weak points. The organization needs to keep the analysis specific by leaving out grey areas and analysing in relation to real-life contexts. For example, how do the organization's products and services compare to those of competing firms? SWOT analysis should be short and simple, and should skip complexity and over-analysis because much of the information is subjective. Thus, companies should use it as a guide and not as a prescription.

[5] The author is Italian. The word invention (*invenzione* in Italian) has a Latin root: *invenio*, meaning "finding or discovering of something".

[6] Bachelard published in Paris *La poétique de l'espace* in 1957. In this work he proposes to present a series of "phenomenological observations" on imagined space, which is regarding space as an image *figure*, understood as a place of imaginary qualities [9].

[7] We aim to include this research within those referring to UNESCO "serial heritage" according to which the recognition of historical and cultural interest, usually assigned to a single asset, is extended to typologically and thematically connected objects. "The 'serial' recognition, with prescriptions on recurring values, could in fact be recalled in the individual declarations of cultural interest, thus activating a 'network protection' (Italian Law n. 42/2004)" [11]. See also: *Submission format for serial nominations on the World Heritage List*, UNESCO 2011.

brought the issue back to forefront. The reflection linking industrial areas to the appointee's intentions for the transformation is, therefore, of a primarily economic nature: need to discourage extensive soil consumption and increase infrastructure cost depreciation capacity.

However, our *pretext* is in Venice, the *positive* of Porto Marghera: in other words a safe investment (every day tourists double the residents, and the trend is not letting up).

The abandonment of industrial areas, rethinking of the relationship between downtown and the urban edge, and the "shrinking cities" phenomenon have emphasized empty areas, residual spaces, interstices of the built as strategic places for a more complex and organic vision of the city. The notion of "urban melting pot" starts from pluralism and polycentrism recognition of the new territoriality's features, and identifies an innovative and effective project strategy in spatial interaction [12]. The Zenghelli's "acupuncture" [8] applies itself to the small scale, operating through grafting and minimum technical manipulations, able to stimulate urban metabolism and auto-generate the city and its public spaces. Actions that already proved particularly efficient in suburbs, of which brownfields represent the 3.0 version; areas taken into consideration as "the city centre anaemic decline: in the best case, limbos of lives suspended in an unstable survival or in a constant frustration. (...) The idea that the surgeon is replaced by the pranotherapist or the acupuncturist is a simplified metaphor, but all in all useful to understand paradigm shifts. Sew, cut and tie again become realistic practices highlighting urban biodiversity" [12].

3. Conclusions

Thanks to accrued experience in almost 20 years of studies and projects, combining results of the many urban instruments produced over the years and comparing similar situations, a conclusion was reached; for such complex and compromised territories a general strategy (planning the entire district) is not adaptable with the single areas' peculiarities for which it would risk failure, nor with implementation times for which it would risk to be out-dated even before being completed.[9]

Abortive attempts are attributable to general planning (scale problem) or to planning, albeit punctual, not aimed at recoveries (underestimation of the theme) [13-15].

This work on Porto Marghera is presented as a catalogue (but also interested in being a sort of handbook) It is not therefore a prerequisite for the drafting of a masterplan, which sooner or later will surely have to be drawn up. This research work provides the necessary data to establish the selection parameters for crucial points, to insert a possible (and plausible) re-composition of the Venetian district [16]. In other words, this work reports the objects present in Porto Marghera, whether they are artifacts, infrastructures, or lands; it names, lists, catalogues, describes, orders and selects them according to

[8] We are using Zenghelis words not referring to the author's theory but rather because of the semantic power this formula has. In fact it is a matter of scale. Zenghelis *topographic acupuncture with a big needle*—[is] capable of absorbing the urbanisation of sprawl. Simple monumentalities that make their intention clear by means of their form (or the way their intention is instilled by the form) and their strategic positioning, as logical conclusions of the topographic dynamic and the social geography of the location (or the way the latent intelligence of each place is capitalised upon—and projected into a future evolution). (…) In the meantime, projects engendered by this approach, would not need to invent programmes; conceived as a system of formal acupuncture, they would need to be strategically inserted within the existing urban pond: objects of absolute Architecture, seen as a system of walls and strategic partitions—Architecture's quintessence. In this way only, Architecture can embody the *idea* of the city, since the city is neither "given", nor devised by protocol. It is the by-product—and the resulting form—of conscious, collective conviction; and this is made (and represented) by Architecture. For this reason, not only can our present political system not sustain the city: it dismantles it—and is incapable of designing it. Elia Zenghelis, *The immeuble-cité a strategy for Architecture*, III Architecture Biennale Rotterdam (2007).

[9] We, as a Research Unit dated up to 2000, did many projects, especially on demand (by the Public Administration); we used areas and topic for design studios, for workshop and to be developed by thesis researches. All the steps have been published and/or exhibited and/or shared within symposiums and international occasions.

hierarchies revealed from time to time and that can be carried out according to choice, requirements and curiosity. Collections showing design opportunities that are not infinite, and which all pass through environmental compensation (recoveries) which is the only true *conditio sine qua non* [17-19].

3.1 Analysis as Project

If analysis is *already* a project, its representation is the more so. Remembering that a simplified representation does not mean simplistic and that, on the contrary, a form of interpretation is another one of the pursued objectives. The research of graphic codes and representation procedures, necessary to describe both the processes in their complexity and the continuous changes in direction, both the state of fact and the potentialities, was the training we have undergone to precisely tone up the body of research [20-22].

The work was carried out within a clear framework: the design project between responsibility and potentiality. The paradigm was equally clear: analysis is already a project.

Typological reconnaissance and infrastructural condition data have been reinforced by analyses of functional and environmental impairment. Overlapping data allowed us to recognize areas capable of compensating obstructions and hardship with features that make some areas suitable for the activation of a possible regeneration process.

This research started and was developed within the Academy, that is not an instrumental appendix to the production system, but rather a key place of civil architecture for an advanced socio-economic system. It can return to being a decisive driving force for social change.

This research is the outcome of many persons' work: students, PhD candidates [23, 24], research fellows, researchers, professors but also technicians, administrators, politicians and dreamers [25]. There is not room to thank everybody, nor to retrace more than twenty years of observations, considerations, objections, nevertheless the wish with which we parted (and sometimes found ourselves) remains unchanged: *ad maiora*!

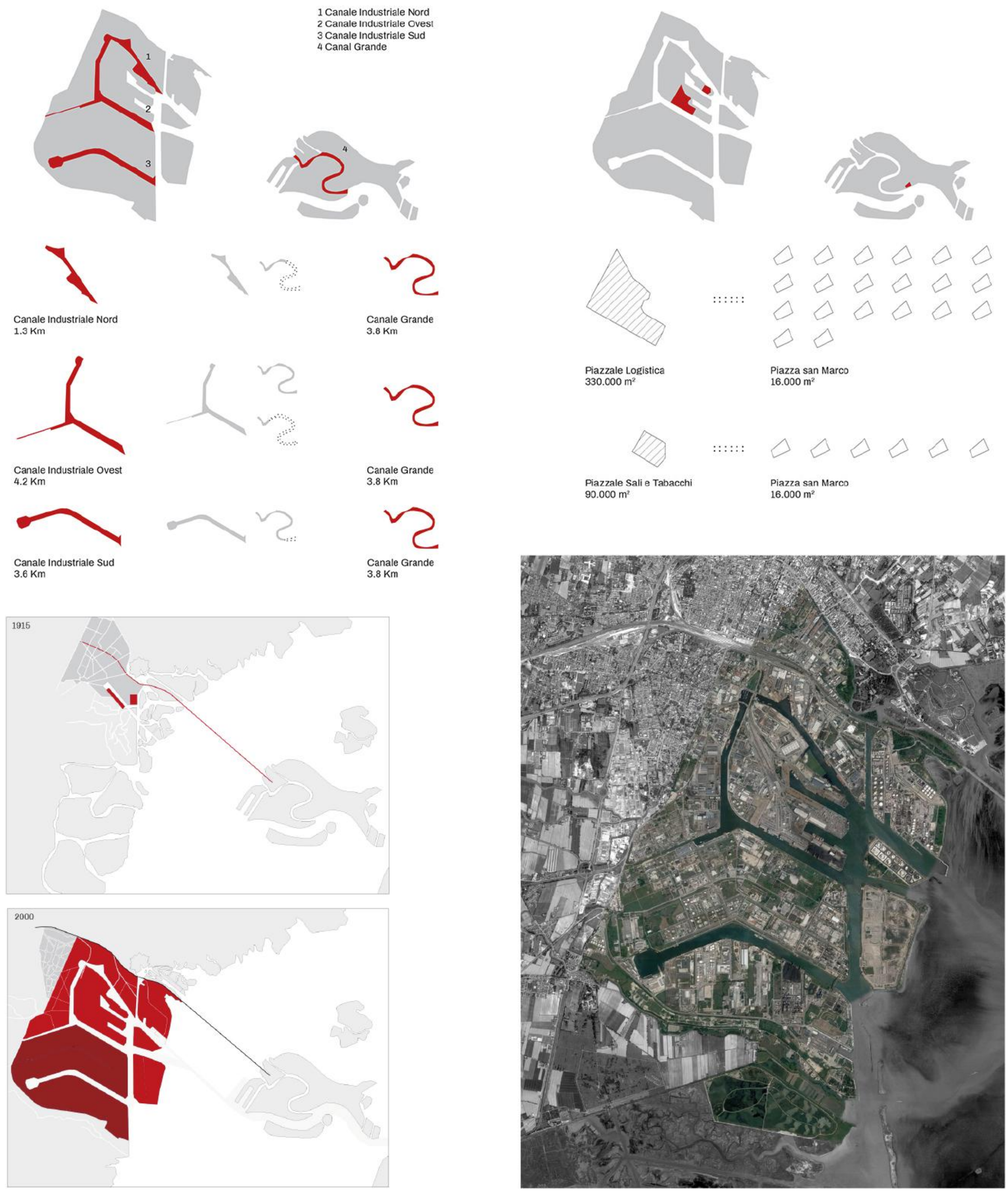

Fig. 1 Porto Marghera: the industrial district of Venice. The site, the dimensions (in terms of canals and surfaces). Porto Marghera is more than twice Venice, use to be mainly a chemical district (oil transformation), use to host thousands of workers, it's the dream of one man (G. Volpi) that became true in 1907. Today the area is in recession: Areas employed only partially coexist with industrial areas that are still productive, settings semi-transformed to commerce and storage, already regenerated areas, derelict land, resulting soil strips between different plants, emerged lands or artificial islands.

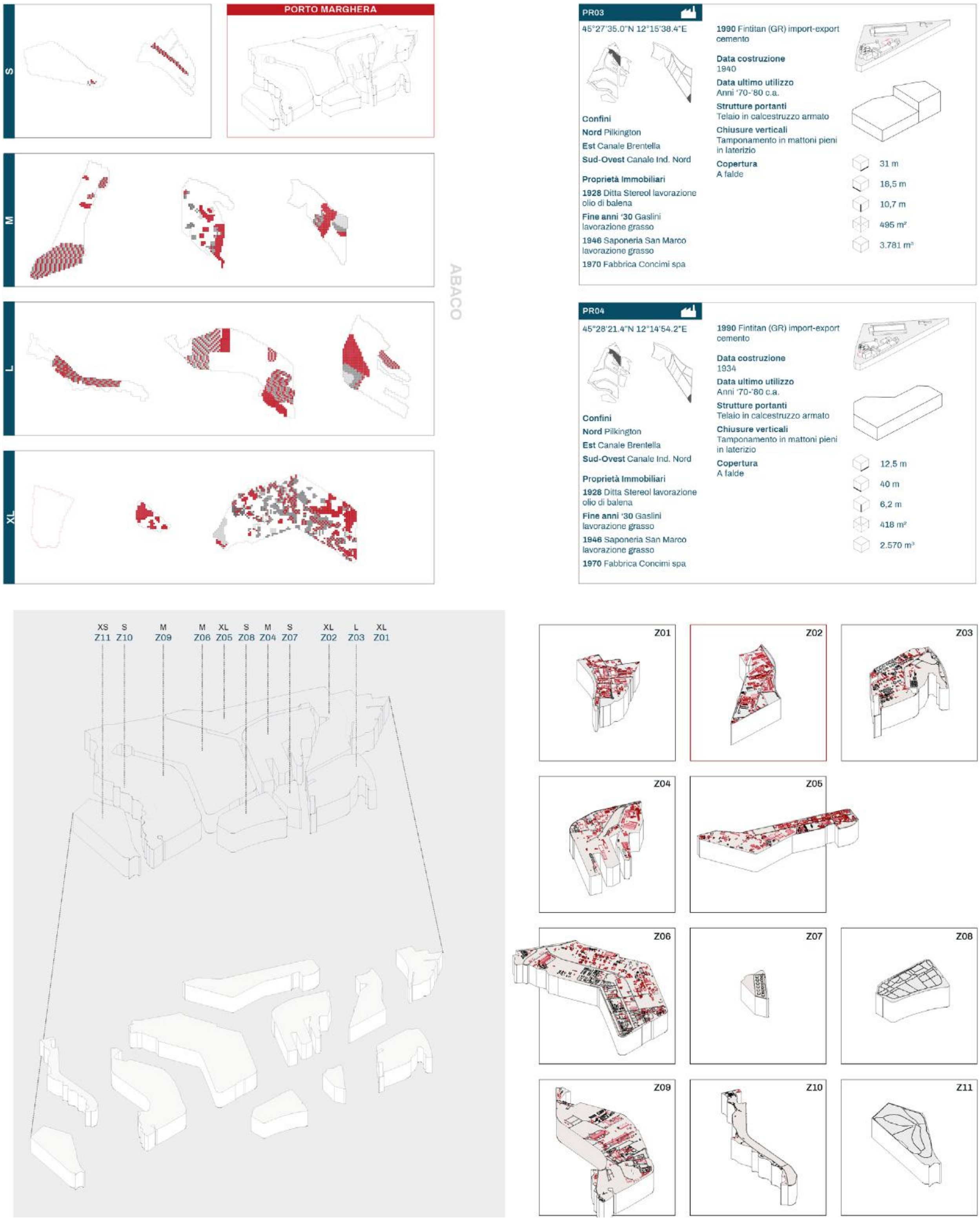

Fig. 2 **Charts from the *Atlas* [2]. Literature and history of the district show us that regeneration failures are due to masterplan strategies that do not consider remediation processes inside the project. The production building is often examined only from an aesthetic point of view, not considering its recovery strategies in relation with the land shaped by remediation. The Atlas focused on the district both in terms of building and areas (pollution).**

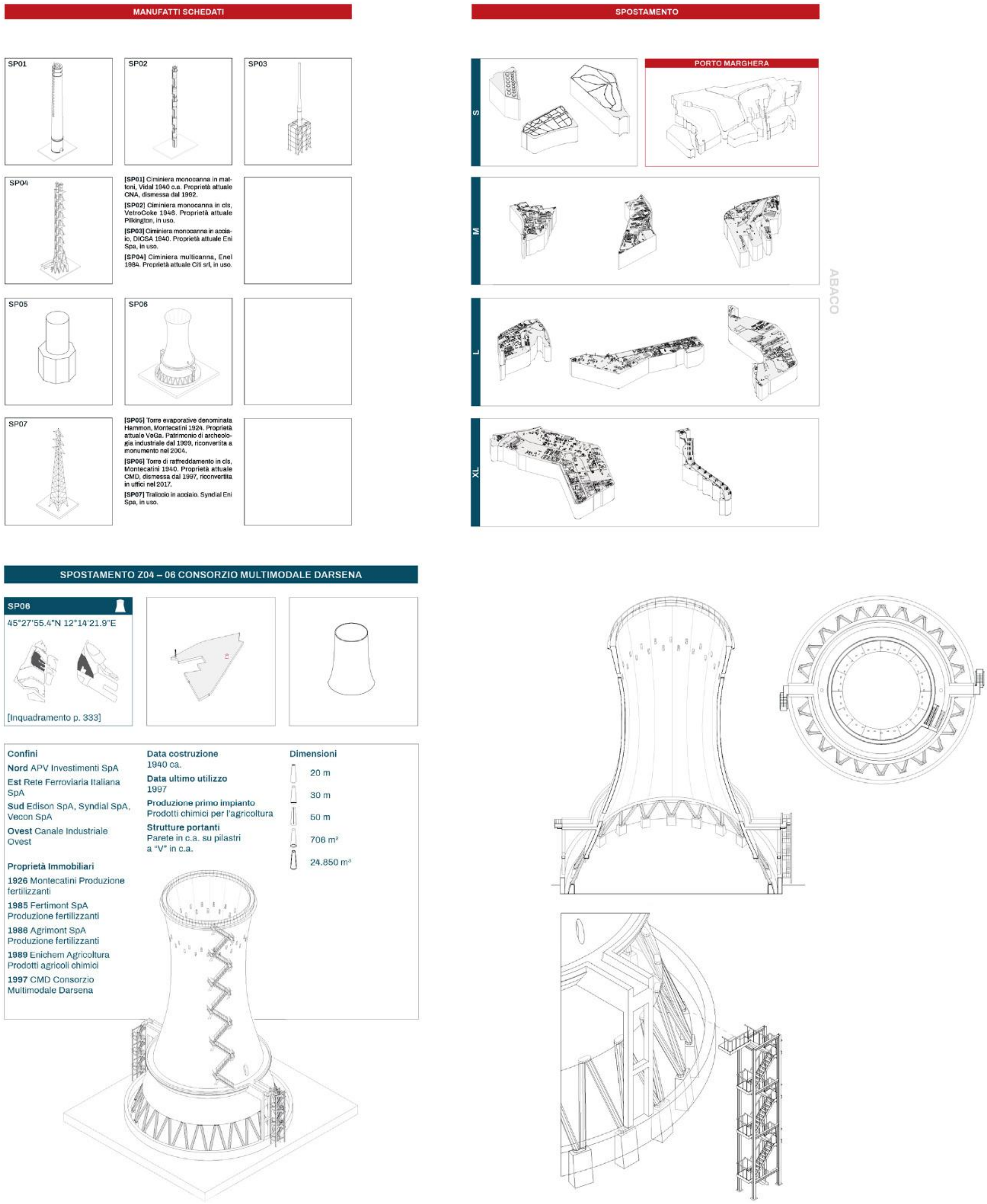

Fig. 3 Charts from the *Atlas* [2].

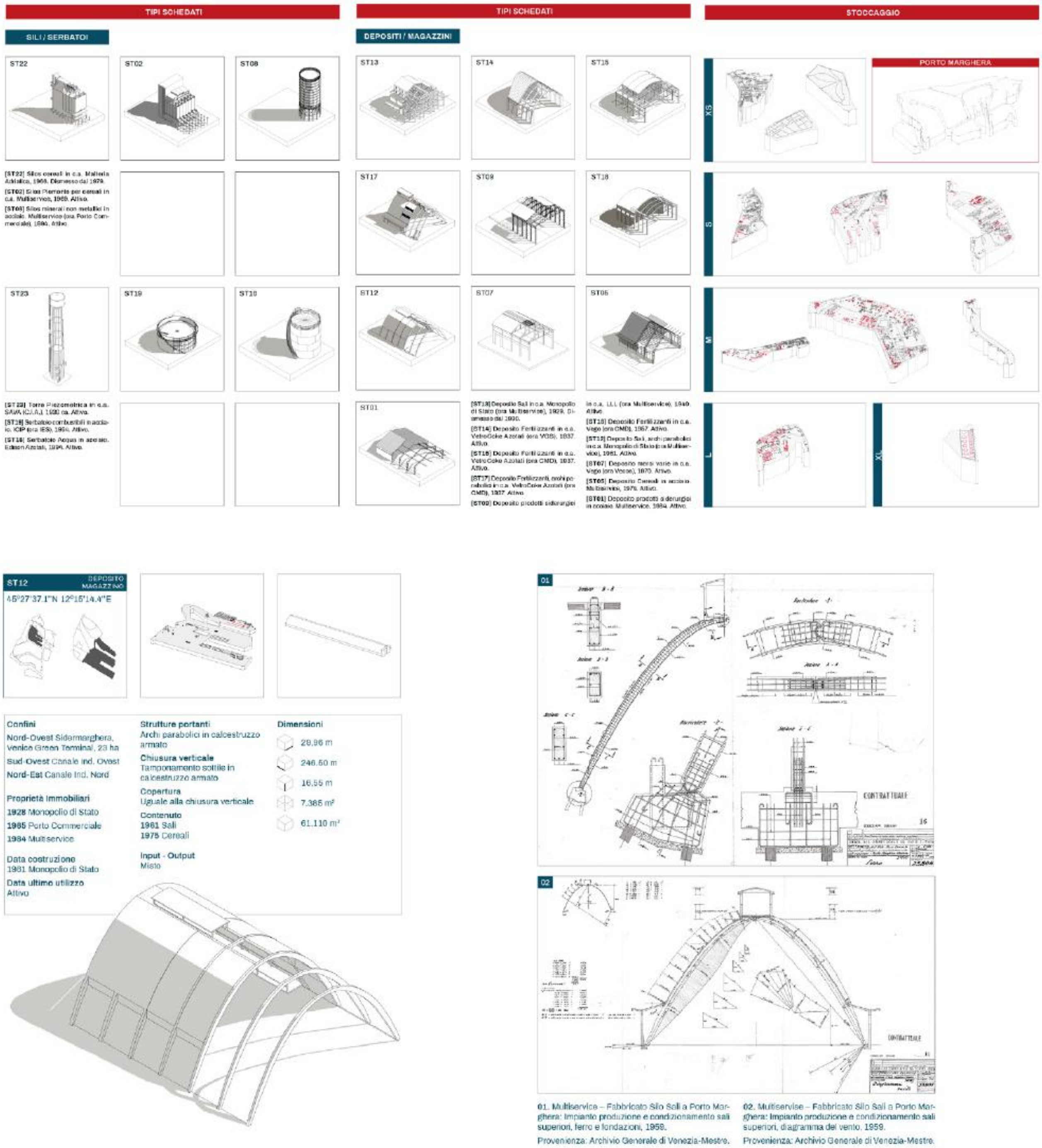

Fig. 4 Charts from the *Atlas* [2].

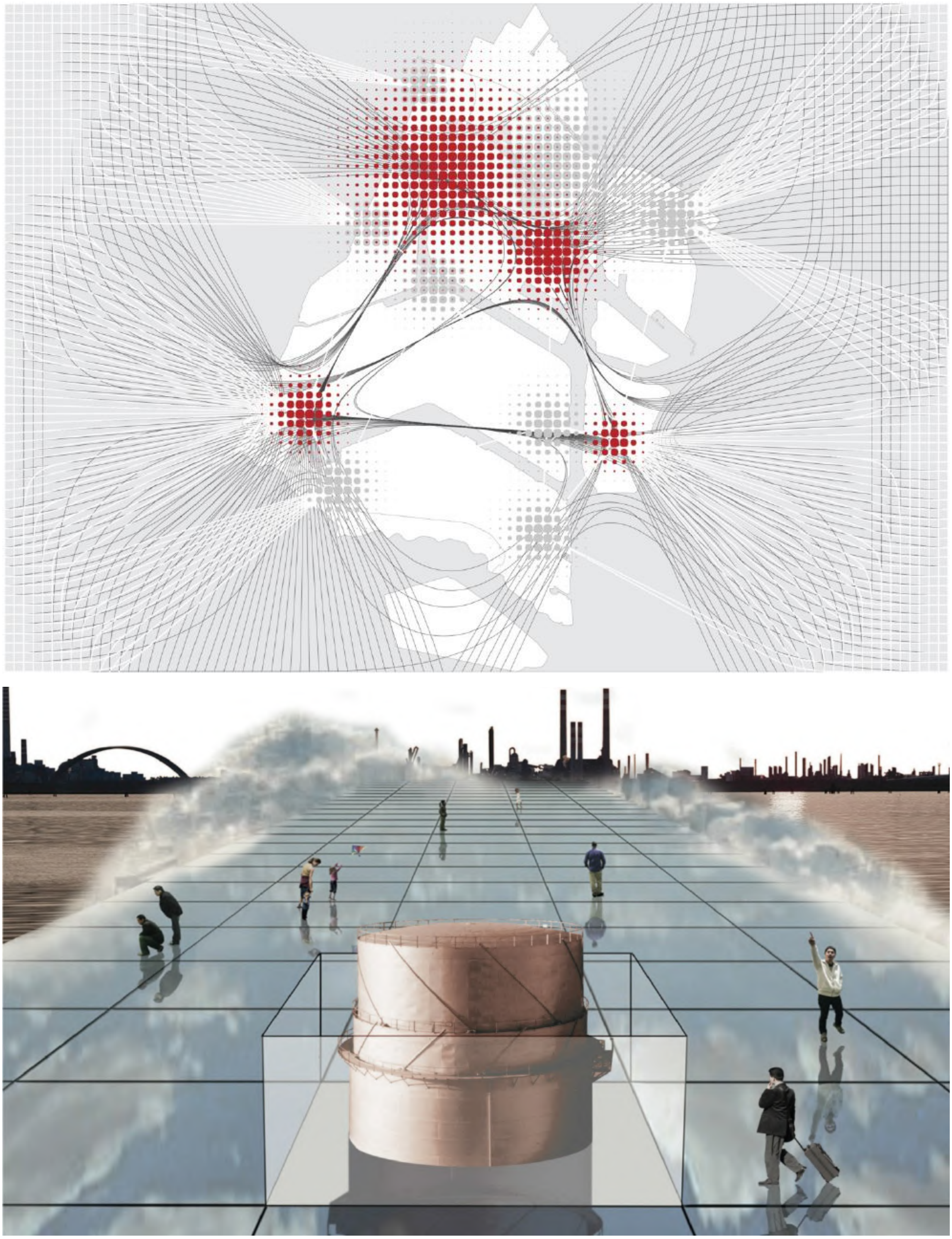

Fig. 5 Above: Project strategy in spatial interaction [12]; the 'acupuncture' strategy: 13 areas to start the regeneration process, [24]. Below: Porto Marghera, radical vision (collage by D. Scomparin). From the *Atlas* [2].

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Measuring the Floor Area of Buildings: Problems of Consistency and a Solution

Dario Trabucco and William Douglas Miranda
Iuav University of Venice, CTBUH Research Office Santa Croce 191, 30135 Venice, Italy

Abstract: Measuring the floor area of a building may seem a straightforward activity, but it is not. What to be included and what to be considered vary in virtually every country, and definitions such as GFA (gross floor area), NRA (net rentable area), etc. are also misleading as they are not consistent. In an era in which international actors contribute for projects in all major cities, having a consistent system to measure the floor area of a building is of the utmost importance. Consistent measurements allow not just for easier and better design, but also for the comparison of buildings, as the floor area is the nominator of all parameters of sustainability, energy consumption, construction cost, occupancy ratios, cleaning fees, etc.

Key words: Floor area measurement, gross area, net area, internal dominant face.

1. Introduction

When building developers and designers are determining the functions and elements that are to be incorporated into a project, an equilibrium must be found between sustainable, innovative design and the tried-and-tested principles that generally dictate a financially successful project. While a glass, box-shaped, multi-story building may be an economical option to construct that maximizes the interior, usable space, this may not be the most desirable option for a tenant or owner [1].

This is especially evident in office buildings, and in the 1990's, the concept of "Sick-Building Syndrome" was recognized, which showed that deep-planned spaces that were artificially lit and conditioned had a negative effect on the health, satisfaction, and well-being of occupants [2]. In order to combat this, and create desirable, high-quality spaces, trends in building design began to incorporate more and more "green" elements, as well as exterior and shared spaces. Building developers can still be hesitant to the incorporation of new amenities to their spaces because they sacrifice the maximum amount of usable, workable space that may be possible on a site and can significantly increase building costs. That being said, the incorporation of these additional building amenities correlates directly with occupant satisfaction and the efficiency of workers in an office building, thus considerably increasing the value of the spaces. It has long been proven that this can be seen as a viable method for return on investment [3].

While these innovative and sustainable building elements are beneficial on a building-by-building or unit-by-unit basis, large governing bodies have also recognized the positives that these types of buildings have on cities as a whole and the general public, so they have seen the need to create regulations to promote good building and construction practices across entire urban realms [4, 5]. In some cities that have recently experienced intense building growth, like Hong Kong and Singapore, adjustments to the regulations on how spaces are measured were made, in order to incentivize the construction of high-quality spaces.

These incentives can lead to cities that are more environmentally sustainable and more enjoyable for the occupants, but can lead to major global discrepancies in the value of property. As most cities

Corresponding author: Dario Trabucco, Ph.D., associate professor. E-mail: trabucco@iuav.it.

and countries have their own unique method for measuring property, a building built in the Americas, Europe, or Asia, which, apart from the building location, may be identical and indistinguishable and can have completely different values for the amount of floor area, as a consequence of the "how" identical buildings are measured differently depending on the jurisdiction. This is especially problematic in a time when international property investment is at an all time high, not to mention the number of designers, engineers, and consultants who operate globally and all rely on the floor area calculations in their respective professions. All disciplines in the building and construction industry rely upon a project's "per-square-meter/foot" calculation as the necessary figure to compare efficiency and value. For example, property value can be measured with dollars-per-square-meter, energy efficiency can be compared with kilojoules-per-square-foot, construction speed can be analyzed by examining the number of square meters built per day, etc.

These calculations rely upon the fact that the primary figure in the analysis—the control of the study—is based off of a precise, unbiased, and unambiguous measurement, but unfortunately, this is not always the case.

2. Problems with Existing Measurement Practices

When measuring floor area, the regulations and practices of the local governing bodies are generally what are relied upon, but this can present major problems when a North American building has an Asian developer and a European architect, which is an example of a situation that is becoming more and more common. To further complicate matters, local floor area measurement practices generally use complicated terminology to define floor area. This includes the commonly-utilized GFA (gross floor area) or GEA (gross external area), but an immeasurable amount of other methods and terms are used including, GIA (gross internal area), NIA (net internal area), GLA (gross leasable area), NRA (net rentable area), Carpet Area, among others. While many different standards often use the same terminology, the definitions of them can be drastically different.

According to a study by JLL (Jones Lang LaSalle), a global property firm, the deviations in floor area measurements can vary up to 24%, depending on the location. This can have significant impacts on the comparative analysis of properties (i.e., when comparing cost per square meter between two properties, a major difference in figures may be attributed to the regulations of the local market and not by the actual value of a space). Another major impact of these discrepancies is in the miscalculation of the maximum occupancy for space. For example, an employer may be looking for an office space that can hold 100 employees, but with a 24% discrepancy, the office space may only be suitable for 76 employees, which would have major impacts on the overall occupant comfort [6].

Furthermore, this can also have significant impacts on all building services. Specialized consultants, such as elevator and mechanical/electrical/plumbing engineers, rely on similar occupancy calculations to determine the load that their systems will have to accommodate. In overpopulated buildings, waiting time for elevators can be longer and maintenance and energy costs can increase on heating, cooling, and plumbing elements that are being overexerted and used inefficiently. Especially with increased waiting times for elevators, this can also be a major safety concern, as effective evacuation strategies in case of an emergency can be delayed. Conversely, in under-populated buildings, MEP elements and elevators can be over-designed, leading to increased costs and spaces that could have been used for working or living are now occupied by mechanical rooms or elevator shafts. These are all elements that could have been resolved with accurate and consistent measurements, but now represent significant deterrents for potential tenants.

3. Differences in Existing Local Standards

In every major property market there are standards that are relied on to measure floor area, but as mentioned, this changes depending on location. The RICS (Royal Institute of Chartered Surveyors) is an international organization involved in the land, real estate, construction, and infrastructure industries, and focuses on promoting and enforcing standards and regulations. With their headquarters in London, they are the primary governing body when it comes to measuring floor area in the UK. Similar to RICS, the BOMA (Building Owners and Managers Association) International, is also recognized globally, but their focus is primarily in North America, as their headquarters are located in Washington DC and their standards for measuring buildings are recognized as the approved methodology for calculating floor area by the ANSI (American National Standards Institute). While these standards are used internationally, the specific standards of a project's respective location are generally the go-to measurement system (e.g., in Hong Kong, the Building (Planning) Regulations produced by the Hong Kong Department of Justice are used; in Australia, the Methods of Measurement produced by the Property Council of Australia are used; in Singapore, the Handbook on Gross Floor Area produced by the Urban Redevelopment Authority is used; etc.).

Within these various standards, often the first, most common—and least controversial—definition is that of GFA or GEA. This measurement is everything on a floor within a building envelope, measured to the external face of the curtain wall of a property, and while this measurement is used to help determine building costs for insurance purposes, it is also used in the early stages of the design process, when submitting building applications and approvals [7]. This represents a significant problem, as the determination of the floor area measurement can influence the design, which is unusual for a calculation that should be impartial.

An example of how local regulations can dictate design can be found when comparing the definitions between the UK and Hong Kong. In the UK, the RICS Code of Measuring Practice (6th Edition) dictates that all external open-sided balconies, canopies, parking areas, and green houses should be excluded from the measurement of GEA [8]. Conversely, in the Building (Planning) Regulations of Hong Kong, it is indicated that the area of each balcony—including the thickness of the external walls and sides of the balconies—should be included in the calculation of GFA, the equivalent measurement strategy to GEA in the UK [9]. Generally, most building regulatory bodies dictate a maximum capacity of total floor area allowable on any given site. As a result, in Hong Kong balconies were being excluded from deigns, as they would take away some of the valuable space that could be internal, workable floor area. In the UK, considering balconies would not affect the overall GEA, the decision to include or exclude them is at the discretion of the architect/developer and the decision is dictated by conventional building project design considerations (e.g., total additional construction cost, needs of the building occupants, aesthetic impact, etc.).

4. Encouraging Good Building Practices and the Impact on Measurement Standards

As mentioned before, there are motivating factors to create sustainable, high-quality buildings and spaces, and governing bodies have recognized the need to incentivize this for developers. Governments have made changes to the regulations for measuring floor area, with the view towards the betterment of the building and construction industry, but this process strives away from the ultimate goal of global consistency in measurement practices.

For example, the previously mentioned Building (Planning) Regulations of Hong Kong derive from the 1st Edition of the Code of Measuring Practice, which was published in 1999. Specifically in Hong Kong, there has been ever-increasing growth in building construction, particularly tall buildings. In 1999, there were under 100 buildings over 150 meters in Hong Kong, but now, less than 20 years later, that number has almost tripled to over 250 buildings [10]. The Hong Kong government recognized this building growth, and while the construction of green and innovative buildings was largely beneficial to the environment and local surroundings, some construction projects were not taking advantage of recycled or green building material and producing large amounts of construction and demolition waste. It was recognized that building construction was largely dictated by costs and value, and without incentives, construction of unsustainable buildings would continue to be built as long as they continued to turn a profit. Thanks to the regulations regarding the total GFA allowed on each site, there was a motivation to simply maximize the internal, usable space in a building. Consequently, in 2011, the BD (Building Department), LandsD (Lands Department), and PlanD (Planning Department) of Hong Kong published Joint Practice Note No. 1 [11] and No. 2 [12], with a view to "protect and improve the built and natural environment (through)… the construction of green and innovative buildings." The objective of the Joint Practice Notes was to "adopt a holistic life cycle approach to planning design, construction and maintenance; maximize the use of natural renewable resources and recycled/green building material; minimize the consumption of energy, in particular those non-renewable types; and reduce construction and demolition waste." As the primary strategy to achieve these objectives, the regulatory bodies indicated that, upon application and review, balconies, podiums, skygardens, and even common corridors and lift lobbies could be excluded from the total GFA measurement if they adequately incorporated green and sustainable elements.

Similar adjustments to standards were made in Singapore, in order to improve the quality of spaces. Unlike the Building (Planning) Regulations of Hong Kong, Private Enclosed Spaces and Private Roof Terraces were already excluded from the total GFA, according the Urban Redevelopment Authority, the governing body in Singapore. As stated by the Urban Redevelopment Authority, "Balconies are important features of tropical architecture. Not only do they allow for natural ventilation and lighting, they promote healthier living and facilitates more greenery in our high-rises" [5]. This was an incentive to developers to create more space open to the sky, which would not count against the total allowable GFA. Unfortunately, it was found that developers were still measuring these spaces, and while they were not including the measurements in the GFA for planning applications, they were including them when selling on a unit-by-unit basis. As these balcony spaces are much cheaper to construct, when compared to interior, conditioned space, disproportionately large balconies—sometimes as large as ⅓ of the area of any given unit—were made and would be advertised and sold to the building tenants. To combat this poor practice, the Urban Redevelopment Authority changed their rules in 2013 to cap these exterior spaces at 10% (i.e., Private Enclosed Space, Roof Terraces, and balconies would not count against the allowed GFA on a site, as long as they remained equal to or less than 10% of the area of the attached unit). To further complicate the matter, developers could further apply for the balcony bonus GFA scheme, with approval subject to the discretion of the Urban Redevelopment.

The new rules made in Hong Kong and Singapore are effective methods to discourage poor building practices and promote and incentivize features that are environmentally sustainable and beneficial to building occupants. That being said, these rules also further complicate the measurement of floor area, especially when comparing the measurements internationally. As mentioned before, it is problematic for a mathematic calculation to effect the design considerations on a building, and now, in certain jurisdictions, this—supposedly unbiased—measurement is now at the discretion of governing bodies and depends on the sustainability of the project.

5. International Standards

In 2013, during a World Bank meeting, the IPMSC (International Property Measurement Standards Coalition) was established to develop and implement international standards for measuring floor area of property. This need for consistency in measuring floor area is recognized internationally and, now, the IPMSC is made up of over 80 professional and not-for-profit organizations from around the world.

As a way to draft and consult on these standards, the IPMSC created a Standard Setting Committee, which is an interdisciplinary group of—currently 18—international experts who are tasked with writing and publishing the standards. The process for creating the standards can be strenuous, as each point must be unanimously agreed upon by the committee, before going through two stages of public consultation. This entire process can take over one year, but allows for insights from experts and shareholders from countries, whose local standards may contradict. Although the IPMSC was only created about five years ago, they have already published the International Property Measurement Standards for Office Buildings (released in 2014) [13], Residential Buildings (released in 2016) [14], Industrial Buildings (released in 2018) [15], and Retail Buildings (currently in the public consultation phase).

One of the first actions adopted by the Standard Setting Committee was to create new and unique terminology, in order to avoid confusion or contradictions with the previously mentions definitions used in local standards (e.g., Gross Floor Area, Net Internal Area, Carpet Area, etc.). The IPMSC defines floor area by a series of generic and instantly recognizable terms: IPMS-1, IPMS-2, and IPMS-3.

IPMS-1 relates closely to how local governing bodies define GFA or GEA: the sum of the area of each floor of a building, measured to the outer perimeter of external construction features. As a way to address the problems and discrepancies that were mentioned before, IPMS-1 specifies that open-air and unconditioned spaces, such as balconies and verandas, must be measured but have to be stated separately, clearly distinguishing the spaces. Broadly, IPMS-2 is similar to IPMS-1, but is measured to the internal dominant face (IDF, which is discussed later), instead of external construction features, and relates closely to definitions for GIA. Also, IPMS-3, which is commonly utilized to measure on a unit-by-unit basis and relates closely to definitions for NIA, excludes shared facilities, common areas, and vertical penetrations (e.g., hallways, mechanical voids, elevators shafts, etc.). In order to create further clarity in exactly the amount of space allocated to each building element, IPMS also defines "component areas", which separately state the amount of area allocated to building features such as vertical penetrations, structural elements, hygiene areas, etc.

Another term developed by IPMS is IDF, which is the defining factor in determining the IPMS-2 measurement and originated by the north-American practioners [16]. The IDF is the inside finished surface, which makes up more than 50% of the internal wall section, ignoring the presence of any columns, measured from the floor to ceiling [14]. The definition of the IDF is particularly divisive because structural columns can occupy significant amounts of valuable floor area and interior layout designs of buildings are often dictated by the placement of columns and it can become difficult to distinguish between columns and walls, especially in tall buildings where it is not uncommon for columns to reach dimensions of 5 meters in any direction. Another reason this measurement can be problematic is when measuring for IPMS-1, columns are recognized when measuring to the perimeter, exterior walls, but when measuring to the interior face for IPMS-2, they are not. Because of this discrepancy, designers may be influenced by the IPMS standards on the placement of their columns on the exterior or interior of a building, but as mentioned previously, this is not ideal for a calculation that is supposed to be unbiased.

Considerations such as this—and also others that inherently arise with the evolution of the building industry—are already being addressed by the Standard Setting Committee. Instead of amending previous versions of standards with clarifications and changes, these with be implemented into a single, all-encompassing document, that will be applicable for any building function, including those already addressed by IPMS (e.g., office, residential, industrial, and retail) and those that have not been considered yet (e.g., hotels, observatories, etc.). As well as expanding and spelling out some definitions, such as IDF in the IPMS-2 definition, the standards will also incorporate an IPMS-4 measurement, which will measure the usable floor space, similar to the definition of carpet area, and will generally be measured on a room-by-room basis.

6. Acceptance of IPMS Standards

The concept of needing an internationally recognized standard has began to gain traction, which has lead to the acceptance of the IPMSC standards in some major building markets, which is quite noteworthy considering the coalition has only existed for about five years. The first governing body to formally recognize IPMS as the official standard for measuring property was the Dubai Land Department. Not only does this incorporate an official governing body into the public consultation process, but considering Dubai is such as significant building market, this has influenced surrounding areas to also adopt IPMS. Ajman, another major city within the United Arab Emirates, has adopted the standards, and the Saudi Arabian government is consulting with shareholders to also use the standards [17].

The Middle East is a largely new tall building market, making the existing conventions and regulations newer, and thus, easier to adapt and accept the IPMS standards. With that said, there has also been a trend of established governing bodies and regulation developers that have started to adopt and accept the IPMS standards. For example, the newest publication for measurement standards by BOMA, the BOMA 2017 for Office Buildings: Standard Methods of Measurement, is now completely compatible with the IPMS Standards for Office Buildings [18].

Also, the previously mentioned Code of Measuring Practice developed by the RICS is no longer in production, and instead, RICS Property Measurement Professional Statements have been developed, with the 1st edition being published in 2016 and the 2nd in 2018. The 1st edition reflected the IPMS Standards for Offices and the 2nd was updated to also include the IPMS Standards for Residential. Furthermore, the statements indicate that they “will be updated over time to comply with other IPMS Standards, as they are published.” This means that now, all jurisdictions governed by RICS must use the IPMS Standards for all building measurements, and, except in special circumstances, if a client requires a different standards, then dual-reporting is necessary [19].

Like RICS, the IPMSC recognized that the regulations for some local jurisdictions are difficult to change and some clients will demand certain regulations be used, so asked that a dual-reporting strategy be employed. This means that property can be measured by utilizing any preferred method of measurement, but should also use IPMS to serve as the “mediator”, in order to compare measurement with other properties and provide a clearly defined and distinct value (i.e., if a client asks for the GFA of a property, there are countless measurement strategies to use, but if they ask for the IPMS-1, there is only one, clear measurement strategy to use). This is the strategy that is suggested by the API (Australian Property Institute). In Australia, while most properties require the PCA (Property Council of Australia) Methods of Measurement, the API recommends a dual-reporting strategy be used with IMPS, as they state that “in time the API expects, with Member support, IPMS will become the primary basis of measurement across markets" [20].

7. Conclusions

The receptiveness of international property markets to accept and integrate IMPS standards represents the necessity for globally-accepted rules when it comes to measuring floor area. There is still progress to be made, both in the development and expansion of the standards themselves and the further acceptance of them across all markets. With the promotion of a dual-reporting strategy, the standards can be easier to encourage the use of new standards. Local regulations can continue to be used by developers, for building applications, and by governing bodies, for a strategy to incentivize good building practices. Alternatively, the IPMS standards can be utilized as an unambiguous, unbiased mathematical calculation that is needed to ensure the success of buildings. Not only will is serve as the appropriate measure for comparing properties across a developers portfolio, but—perhaps more importantly—serve as the necessary figure for the activities of various building consultants (e.g., elevator and MEP engineers can now determine an accurate measurement for the loads on their systems, safety consultants can determine the maximum occupancy of any floor or space).

Any person involved in the building industry, whether a developer, designer, or future occupant, can simply ask for the IPMS 1, 2, 3, or 4 measurements, and clearly know exactly what is and is not being included in the space that they are constructing, designing, or buying. The IPMS Standards represent a method that is not only consistent and clear, but fully repeatable across time and location. This can guarantee confidence for investors and potential tenants in their potential properties, as well as create an area of stability in a property market that is constantly expanding and fluctuating.

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Restoration, Strengthening and Planning in Italian and German Reconstruction after World War II: Essay in Three Steps

Emanuela Sorbo
Department of Architecture Construction Conservation; Università IUAV di Venezia, Dorsoduro 2206, 30123, Venice, Italy

Abstract: Post WWII reconstruction took place at a time of fundamental importance for our understanding of the divide, theoretical and technical, between consolidation, reconstruction and restoration. Indeed, this period represents the moment in which the earliest stages of this rift emerged. In this essay, we shall attempt to provide an account of this phenomenon by citing case studies considered important within the Italian and German context: post-WWII reconstruction work in the Veneto region (at key sites such as the Basilica Palladiana in Vicenza, the Palazzo dei Trecento in Treviso and the Church of the Eremitani in Padua), reconstruction of the Alte Pinakothek in Munich, and reconstruction and work for new use of the hospital, Ospedale Maggiore, in Milan, as a seat for the Università Statale. Considering these instances provides us with an opportunity to reconsider the transition, theoretical and technical, between conservation of ruins and reconstruction of memory.

Key words: Cultural heritage, post-WWII reconstruction, cultural memory and identities, architectural restoration and conservation.

1. Introduction

As a result of the air raids of WWII, the situation for Europe's cultural heritage was one of dire emergency, given the extent of the damage and the symbolic impact on peoples of the loss of certain monuments [1-8].

As a result of the damage to cityscapes, a greater sense of urgency was felt when considering the significance of ruins and, particularly, the symbolic and architectural significance of reconstruction operations [9-15].

The architectonic response to this emergency brought into being a variety of procedures on the operational and design front, united however by an interest, commonly held, in the borderline existing between, on the one hand, the role of history in design work (hence, the role documents, pre-war images, and sources in general) and, on the other, the role of technique (that enabled experimentation, in the realms both of technologies and of languages or idioms of expression). Operationally speaking, the fruits of such reflection underpin our relations with cultural heritage assets today. Introduction of the concept of "materiale moderno" (modern material), such as use of reinforced concrete, meant that design for cultural heritage might be open to a wide range of technical solutions. Theoretically speaking, use of reinforced concrete led to what may be described as the demise of the nineteenth-century Viollet-le-Duc/John Ruskin dichotomy [16]. The introduction of a ductile material endowed with static properties differing from those of traditional works in masonry enabled conservation of fragments of ruined architectural works alongside spaces created using reinforced concrete, enabling in turn, as a design and project aim, the reinvention of ruins [17].

In this process, technology, rather than technique, emerged as the instrument thanks to which the theoretical debate on conservation of ruins and/or

Corresponding author: Emanuela Sorbo, MA Politecnico di Bari [Polytechnic University of Bari], Ph.D. SSAV (School of Advanced Study, Venice), associate professor; research fields: architectural conservation and restoration. E-mail: esorbo@iuav.it.

architectural reconstruction could find a solution. This debate pitted a fracture between structural conservation and consolidation—a clash that persists to this day.

During the period of post WWII reconstruction, this clash was germinal. It is present throughout a phase characterised by a degree of ingenuousness, since the introduction of frame structures in load-bearing constructional systems created a universe of modern structures featuring suspended skeletal (i.e. passive) traditional walls and floors.

Post-WWII reconstruction therefore took place at a time of fundamental importance for our understanding of the divide, theoretical and technical, between consolidation, reconstruction and restoration. Indeed, this period represents the moment in which the earliest stages of this rift emerged.

In this brief essay, we shall attempt to provide an account of this phenomenon by citing case studies considered important within the Italian and German context: post-WWII reconstruction work in the Veneto region (at key sites such as the Basilica Palladiana in Vicenza, the Palazzo dei Trecento in Treviso and the Church of the Eremitani in Padua), reconstruction of the Alte Pinakothek in Munich and reconstruction and work for new uses for the hospital, Ospedale Maggiore, in Milan as a seat for the Università Statale di Milano.

2. "Reconstruction artistique en Italie". Strengthening

An exhibition *La reconstruction artistique en Italie*, was hosted by the Grand Palais in Paris in 1946 [18].

The catalogue opened with a quote from Paul Valéry, from Eupalinos ou l'Architect: "ne faut pas que les Dieux demeurent sans toit, et les âmes sans spectacles" (we must not allow the Gods to become homeless and must not deprive souls of spectacles).

The architectural works selected for the exhibition were, significantly, those of the territory of Veneto, headed during this period by the superintendents, Ferdinando Forlati and Piero Gazzola, who heralded an openness to the possibility of a united Europe, which in the post-WWI period constituted the objective for world peace [19-22].

The exhibition's catalogue shows note examples of a methodology of intervention that would be taken up within the sphere of restoration over the following decades, out of which came a lexicon that has since become consolidated, including terms such as "distinguibilità delle parti" (distinguishability of the parts)—post-war terms leading up to today's "rapporto tra antico e nuovo" (relation between the ancient and the new).

The Church of the Eremitani in Padua, the Palazzo dei Trecento in Treviso and the Basilica Palladiana in Vicenza are iconic case studies of post-war reconstruction works—architectural works that kicked off a season of restoration-work experimentation [5, 12, 13, 16, 23, 24].

The Church of the Eremitani and the Ovetari chapel with Andrea Mantegna's frescos, was bombed on 11 March 1944. The presbytery had collapsed, as had a portion of the facade. The nave was seriously damaged, and the adornments of the interior were all irreparably lost. The masonry surviving the collapse presented off-plumbs ranging from 32 cm to 50 cm. The image of the fragment of the facade would become the icon representing the air raids in Italy [4]. Ferdinando Forlati also dedicated a book to the Church of the Eremitani in 1945, published in the series curated by Gino Chierici, *I monumenti Italiani e la guerra* (Italian monuments and the war), which set itself the task to collect "all that might help, so that they don't perish". The stage consisting in collecting the rubbles began immediately—in order to recover fragments of Mantegna's frescoes, above all. Following the war, the fragments were delivered in 109 cases to the Istituto Centrale del Restauro in Rome, headed at that time by Cesare Brandi. Here, repair work was carried out, with the lacunae integrated by adopting the "tecnica del rigatino" (hatching). During reconstruction, all the elements recovered were placed alongside new elements in stone or brick on which the date of reconstruction was engraved, separated from the surviving parts by a black groove, in order to indicate the limits of the collapse, in terms both of time and the materials. The entire apse portion had been reconstructed already in 1946. The procedure adopted to straighten the walls was tested out here for the first time. It was then adopted for the Palazzo dei Trecento in Treviso. The masonry parts were bound with a framework of lattice beams anchored with iron ties and couplings. When the structures were released from the scarfs the couplings were turned to provide the rotation required to restore them to their original seat. Forlati commented on these operations as follows: "in about thirty minutes, stretches of wall of a width of seven metres and of a height of fifteen were gently relieved of their off-plumb, turning on an axis corresponding to the zone just above the ground" [25, 26].

The Palazzo dei Trecento in Treviso was bombed on 7 April 1944. A bomb landed on the floor of the salone (hall) and completely destroyed the Sala del Consiglio (room of the council) and the portions on the northern and eastern side. The surviving stretches of the facades were 87 cm and 110 cm off-plumb. Given these conditions, the German government ordered that the building be immediately demolished. Ferdinando Forlati, however, prevented demolition and managed to persuade the German commanding officers that consolidation and straightening of the surviving walls was technically possible. The initial stage of collecting the rubbles and constructing the works necessary for safeguarding the building commenced immediately in April 1944. On three dates (12 May 1948, 27 July 1948 and 11 July 1949) the walls were straightened (one of the walls, weighing 574 tonnes, was of a height of 12 metres). In this section, the photographs of the model illustrate the method adopted (based on that already tested on the Church of the Eremitani in Padua as we say before): each surviving portion was secured by two frames, made up of thick boards and beams, linked by metal retention elements. The frame or cage created in this manner was anchored with ties and couplings to the beams placed along the floor. At the bottom and on the sides of the walls, rotation axes were created, within which reinforced concrete spandrel beams ran. Wooden wedges were positioned to fill the gap created by the shifting of the rotated wall. For the eastern wall and for the northern wall, the operations lasted ten hours and a little more than two hours, respectively. The workers turned the couplings on one side while loosening the wedges of the rotation axis on the other, thereby repositioning the two walls, which were sealed by grouting. These operations were followed by repair of the damaged or missing masonry, using the bricks recovered from the rubbles of the collapse of the structures. So that the restoration work could be identified—serving also as an admonition for future generations—, a groove was impressed along the edge of the damaged summits of the masonry, separating the new from the old: a slender line which can still be seen today, tracing the line of the damage caused by the bomb [27].

On 18 March 1945, the salone (hall) of the Palladian Basilica in Vicenza was destroyed during an air raid. The deflagration melted the copper cladding, burned the structure of the wooden 'hull', and extensively damaged the masonry, as well as the statues. On the occasion of the photography exhibition of 1946 hosted by the Metropolitan Museum in New York, the photographs of the unroofed basilica were displayed before the world of culture [28]. Out of the exhibition came the book by Emilio Lavagnino dedicated to fifty war damaged Italian monuments, *Cinquanta Monumenti Italiani danneggiati dalla guerra* (1947), in which the author stresses the urgent need for funding reconstruction work because, in the basilica, he saw "a new way of seeing and understanding the classical ancient world, a new way of understanding it in order to go beyond it and venture into the free spaces of imagination" [4]. In 1946, a call for bids was organised for reconstruction of the Basilica's roof [29]. The roof was reconstructed in 1948 with a reinforced concrete structure constructed with disposable formwork boxes in wood, a structure that can be seen in the site photographs in this section. During reconstruction, attention was paid to re-use of the copper elements recovered after the fire. Importantly, among the conditions set forth by Ferdinando Forlati in the announcement was that, during reconstruction, the deformations of the 'hull' that had taken place over time were to be imitated. Among the interventions carried out, we note construction of a reinforced concrete ring above the open galleries in order to "bolster the general structures of the building, the statics of which were always a source of some concern". Reconstruction also included interventions on the three arches of the western corner, re-flooring, consolidation and restoration of the statues, and a general re-ordering of the square with a lowering of the walkway surface of the three steps "as Palladio had originally intended in his plan". On 1 September 1949, on the occasion of the celebrations for the four hundredth anniversary of the monument, an exhibition (*Mostra del restauro di monumenti e opere d'arte danneggiate dalla guerra nelle Tre Venezie*), dedicated to reconstruction in Italy's northeast, was set up in the restored Salone [30]. The exhibition was a celebration of the social implications of reconstruction and architecture, symbolizing resurrection of the nation against, to use Benedetto Croce's words, the "brutality of destruction" [4].

3. "La grande Lacuna". The "Cà Granda" in Milan. Conservation in Reconstruction

While World War II was looming ahead (1938) the Municipality of Milan acquired *Cà Granda*—the name given to the fifteenth-century "Spedale dè Poveri" (hospital for the poor), commissioned by Francesco Sforza and designed by Antonio Averulino, known as "il Filarete". The debate regarded the prospect of providing a new seat for the university. During 1939, surveying took place and a restoration project was drawn up [31-33]. However, the work was interrupted when war broke out. The Ospedale was repeatedly bombed (1 February and 13-14 August 1943) [34].

Up until shortly before the air raids, Filarete's original planimetry for the hospital had been conserved. This consisted in a rectangular plan with a central courtyard and two laterally positioned spaces providing a cross form made up of four rectangular halls facing a central space that was accordingly known as the "crociera" (or point of intersection). The conjunction of the four arms generated four minor courtyards (variously named over the intervening centuries) per side. This architectural typology became the model for construction of hospitals in Italy from that time onward, up to the modern era [35].

Considerable damage was caused to the part of the Ospedale built in accordance with Filarete's design, including collapsed roofing. The attic storey of the facade looking onto Via Festa del Perdono was seriously damaged. The seventeenth-century loggia at the point of intersection with the Sforza "crociera", was completely destroyed. The facade looking onto via Nazaro was likewise seriously damaged. The frontage in Via Francesco Sforza and the courtyard behind, known as the "Ghiacciaia", were practically completely destroyed. The other Sforza courtyards were seriously damaged. In the central courtyards, the side toward Via Festa del Perdono, the southwestern side and, in part, the side attributed to Giovanni Antonio Amadeo were razed to the ground.

During the following year, the Soprintendenza ai Monumenti di Milano (superintendency of the monuments of Milan) and the Genio Civile Italiano (Italy's civil engineering body) drew up and stipulated a plan for execution of urgently required provisional structures. Between 1946 and 1950, work was carried out on behalf of the Provveditorato alle Opere

Pubbliche (public works superintendency) under the artistic supervision of the said Soprintendenza ai Monumenti di Milano, which assigned the works to Ambrogio Annoni, a Professor at the Politecnico di Milano. A university technical board was then set up, which included Ambrogio Annoni, Piero Portaluppi, Liliana Grassi (Professors at the Politecnico di Milano), Amerigo Belloni and Adalberto Borromeo. Following the deaths of Annoni (1954) and Portaluppi (1967), Liliana Grassi worked on restoration of the *Cà Granda* until her death in 1984.

The air raids on *Cà Granda* left a huge lacuna in the urban fabric. In early 1944, the project started up for the new use of the entire building as the seat of the Università Statale di Milano. These premises, which were opened in 1958, have served this function to this day.

The first interventions undertaken under Annoni's artistic supervision, prior to 1949, were of various kinds. An attempt was made at consolidating the masonry in precarious conditions, by means of brickwork and cement repair work. A number of the more structurally damaged parts were demolished, as was the case with the penthouse floors and external structures added to the building's walls over time, demolition of which had already been planned as part of the pre-war project for the 1940s, again under Ambrogi Annoni. Alongside the structurally necessary work, some tasks were executed as per the 1940s project. We may note the clearing away of the cloisters and arcades, reassembly of the arches in line with the scheme that Annoni believed dated back to the fifteenth century, and removal of the parts considered "aggiunte" (additions). These operations were all part of an attempt to return to the hospital the *facies* as per Filarete's intentions, in line with the consolidated tradition of *Restauro Storico* (historical restoration). The following are just some of the facts and figures of reconstruction of *Cà Granda*: as much as 45,000 cubic metres of rubbles removed; 8,000 square metres of floors reconstructed with structures in reinforced concrete; and approx. 8,500 square metres of natural stonework reassembled (anastylosis) [36-38].

In the zones hardest hit by the raids (such as the "Ghiacciaia" courtyard and the frontage looking onto Via Francesco Sforza), in 1954 (the year of Annoni's death), the gap left by the bomb damage was still visible. Only later, between 1961 and 1966, was restoration work carried out according to the solutions drawn up by Liliana Grassi, with Amerigo Belloni and Piero Portaluppi.

On the basis of a lengthy sampling campaign regarding the masonry work of the remaining left side of the facade looking onto Via Francesco Sforza, in 1962, Liliana Grassi discovered a double-lancet window and a number of mouldings in terracotta and foliage elements in the infill masonry work. The idea of the project was to recover and reassemble the fragments of the double-lancet windows in the portion of the facade to the left, by anastylosis. The lacunae of the discovered pieces were to be made up using fragments found in the rubbles of the part to the right. The remaining wall was conserved with authentic elements (small balcony, two eighteenth-century windows). The other parts were slightly set back, and feature the use of contemporary languages. The facade proceeds with the body of the reading room, set back from the body of the church, and with the seventeenth-century portal. The door "dei morti" (of the dead), linking the hospital to the cemetery was conserved in the "a rudere" (ruin) manner. In the reconstructed part of the courtyard, the facade proceeds slightly set back. The same material, bricks, is used, while the language reflects the modern nature of this work. The spaces given over to university use correspond to simple rectangular apertures, an indication of the un-reconstructed cornice, the indication being provided by means of bricks stood on end to create a series of ventilating apertures. Within the space of this facade, we may identify traces of Filarete's building (reassembled using surviving materials) alongside the contemporary mode (as the seat of university offices), seamlessly blending, with no clash that might be detrimental either to Filarete's solutions or to the modern-mode solutions. The new and the old coexist in the form of a harmonious composition [39-41].

Restoration and arrangements for the "Ghiacciaia" courtyard—which had been consolidated during the 1940s—proceeded between 1958 and 1967, the year of Piero Portaluppi's death. We note the presence in 1958 of the only wall remained (consolidated by Ambrogo Annoni after the end of the war) and the pieces uncovered as a result of the destruction. These items were inventoried. The project took the direction of providing a record of all phases of Filarete's "crociera" plan while providing a record also of the later air raids stage.

As per the project, the wall includes all these traces, with reassembly of the arcades by anastylosis, conservation of Annoni's consolidation work and of the traces of destruction left by the air raids, and completion of a part of the "crociera" with an entirely new university wing project. On the one hand, this portion of the courtyard, in its spatial essence, accommodates the spatial proportions as planned by Filarete. On the other, the use of contemporary languages, not only harks back to but also updates the building tradition expressed by the Ospedale. The design work, too, on mobile features (railings and gates), and the masonry work for a number of surface areas, are instances of a contemporary-style reiteration of the fifteenth century elements. Choice of materials, the matching of brickwork and reinforced concrete masonry works harmonise in the use of colour (as in the consolidated tradition of Le Corbusier), the interplay between full and empty spaces [42]. The contemporary facade represents an *interpretation* of Filarete's facade, bypassing the options both of *imitation* and *revival* [43]. However, this interpretation deploys spatial expedients such as alignment of the floors, underscored by the cornice stringcourses, which evoke the baluster of the arcade, or the marked tripartition of the facade (arcade, first floor and mezzanine floor).

We may therefore conclude that the type of operations adopted for the Ospedale varied very greatly (also due to the size of the building). We may point to the anastylosis work for the courtyards, in which, after the rubbles were cleared, the pieces were classified and reassembled; to a project for adaptive reuse of the late eighteenth-century zone, entailing insertion of new elements; and to a project for the finishing of the ruins for the parts destroyed as a result of the raids, in the Ghiacciaia courtyard and the facade looking onto Via Francesco Sforza. The parts of the building listed all vary in terms of the approach adopted to the relation between old and new, to be interpreted in the light of the varying stages of the ongoing theoretical and operational debate (since these works came about between 1944 and 1986). As we consider the interventions for the Ospedale Maggiore we we may see that they attest to the extent to which *historical-critical interpretation* of an architectural work refers to the "*cifra simbolica e culturale*", or symbolic and cultural 'cipher' or hallmark quality, of the building [44, 45].

The reconstruction project, while integrating and reviving a given function of the building, aims also to conserve this symbolic "cipher", present in the ruined parts.

4. The Alte Pinakothek in Munich "by" Hans Döllgast. Planning Spaces

The 1944-1945 air raids severely damaged the entire city of Munich, partly destroying the Alte Pinakothek [7, 11-15, 46]. The building was commissioned by Prince Ludwig and designed by Leo Von Klenze. Only the perimetric walls of this art gallery remained standing. The facade to the north and the loggia facade to the south have been extensively destroyed. During the early post-war years, it was thought that the building should be demolished entirely. This view was disputed, and work on the site was therefore blocked. The ruins marred the cityscape until 1952 [7].

The Munich gallery debate saw two opposing views. Some favoured demolition and construction of an entirely new building. Others wanted reconstruction of the *facies* of Klenze's work.

Starting on 1952, Hans Döllgast—a professor of drawing, composition and perspective at Munich's Technische Hochschule—worked on a gallery project with the premise that traces of the air raid damage should be conserved, alongside a reinterpretation and transformation of the spaces created by Klenze [47-49].

The project reintegrated the parts that were destroyed, respecting the facades but also leaving the signs of the damage visible, also in constructional terms through the use of recovered bricks and conservation both of the roughness of surfaces and the holes left by the flying fragments, shards etc. These interventions aimed to consolidate memory of the air raids.

Alongside the conservation work, the major transformations and Döllgast's intuitive vision of design practices are revealed in his idea that the entrance be moved to the northern frontage, i.e. one of the two facades that displayed the signs of the damage. He preferred this solution to Klenze's entrance to the east. He also inserted a number of stairways leading to the upper floors into the zone of Klenze's loggia—the facade to the south.

This planimetrical indication enables uninterrupted viewings of the works on display and longitudinal definition of the overall plan indicated by the presence of a two-pitch roof alternating with skylights, with respect to Klenze's cloister ceiling. This made it possible to highlight continuity of the facade for the front view.

Construction of the stairways was at the centre of much debate. Following demolition of one stairway which had detached itself from the wall of the loggia (demolition work that Döllgast opposed), a stairway ramp was built that covers the entire width of the room.

Accompanying construction/rotation of the overall planimetrical arrangement was integration of the frontage entailing inclusion in 1955 of a wall in brick (the bricks are "in sottosquadro", or slightly set back so that they may be recognised). The bricks recovered from the rubbles were assembled with a simplification of Klenze's profiles, thus updating the work in terms of its architectural language, while reinstating, and including in the design, the work's rhythmic character.

Döllgast also intended to obtain bare upper spaces with a smooth barrel vault and no cornices. By way of reply, the directors decided to reconstruct the space as per Klenze's project (i.e. with cornices and cloister ceilings) [50].

The building was inaugurated in 1957.

The facades were reassembled using the recovered bricks and adopting once more the proportions adopted by Klenze accompanied by formal simplification of the elements. Figuring as an element of interpretation of the facade is the intention to underscore the rhythm of the horizontal and vertical elements by accompanying them with cornices in reinforced concrete and brickwork overhangs [49-51].

Each compositional element of the facade not only takes up but also updates extant elements, creating a continuity of matching and unseparated elements, making for a single formal solution. Alongside the use of recovered materials, many parts were designed using modern building work systems (e.g. reinforced concrete). The Atrium, or anteroom, was constructed with reinforced concrete trusses, taking the place of the old vaulted-ceiling storage spaces. The walls of the interior were treated with light whitewash for a harmonious chromatic solution for the work as a whole. The design work for all the installations/systems was carefully executed (radiators, fixtures and fittings), as formal and not just as functional elements [47-50].

Döllgast also undertook other reconstruction projects in Munich, such as the Frederick von Gärtner cemetery (to the south) in 1954 and the church of St Boniface (1971). For each of these projects, insertion of new elements took place in the light of the old, not seen as a starting point to be adhered to philologically but as a bond with tradition and as an opportunity for reflection on project and design work. Thus, we see a blending of tradition and innovation, coming about through the agency of contemporary languages [52].

No "betrayal" or denial of ones identity as a contemporary player; instead, a vision of the extant architecture as a stimulus for, rather than as a limit placed upon, design work.

5. Conclusions

Technique, as defined by Gustavo Giovannoni, is thus the "mezzo utile" (useful means) for carrying out post WWII reconstruction, a material metaphor of a country's ability to "rinascere", starting out from a form of interpretation of the past, that includes political, social and economic points of view. Technological innovation is the symbol of this process: to overcome an idea of the "past" towards an idea of 'modernity', a focus on progress and on the future that characterised the entire twentieth-century and of which monuments become symbolic and material *locus* of experimentation. Reconstruction projects can thus become an opportunity for the community to acquire a new common good through an architectural design process and at the same time rediscover a cultural identity in a new urban image. This dual approach creates a separation between the historical image of the monument and its new constructive identity—thanks to which the monument may be used after bombing. The reconstruction projects, in these case studies, and generally on the plane of theory, enable us to reflect on this link (or separation, we may say) between technique, technology and image, that correspond to the various roles of the conservation choices, between restoration and consolidation.

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Venetian Buildings Are “of” and Not “on” the Lagoon

Paolo Foraboschi

Department of Architecture Construction Conservation; Università IUAV di Venezia, Dorsoduro 2206, 30123, Venice, Italy

Abstract: This paper demonstrates that Venetian architecture was the result of specifically conceived structural mechanics and construction techniques, which allowed structural design to take full advantage of materials. Venice witnessed the creation of “structural art” that drastically reduced the incidences of failure caused by extremely soft soils and aggressive environment, which extended the operating horizons of masonry and timber structural materials to the extent that very bold structures were obtained also before the preeminent materials of modern structures. While normal masonry constructions can be governed by Euclidean geometry, Venetian buildings are far more complex and elusive in form. Venice and its architecture can be interpreted and comprehended only in the remit of structural engineering, which played a central role in enabling the construction of the city. The fundamental determinants of Venetian building morphology—the underlying logic of form in architecture, entailed a tectonic form midway between the masonry construction and the skeletal structure.

Key words: Brackish water, skeletal masonry, soil settlement, space-saving structures, weight-saving structures.

1. Introduction

The concept of style to denote the idea that the art or architecture of a particular period shares a recognizable set of characteristics is relatively recent. It stems from the so-called “father of art history”, the German scholar Johann Joachim Winkelmann (1717-68) who proposed an influential biological conception of style as having a birth, maturity, decline, and eventually disappearance and death. In Winckelmann’s view the mature or classic phase offers the definition of a style.

The concept of style suits fine arts, whose products are to be appreciated only by sight and solely for their esthetic, intellectual or imaginative content, but instead does not suit arts whose products are employable manipulations of matter, form, and light, especially the arts that model in mass to enclose utilitarian space. It follows that style classification does not suit architecture, which is the manipulation of space, materials and components that change the environment in order to obtain utilitarian constructions, and is primarily concerned with creating usable and comfortable interior space as well as inhabitable and durable refined mass. Then again, like all attempts to ground architecture in some absolute determinants, style classification offers a simple route to deal with architectural history.

The view of styles developed during the 20th century emphasizes that the history of architecture is a form of narrative or storytelling. That view makes it possible to develop a simplified didactic approach to architectural history for beginners in the field.

Although the idea that style is a version of a fiction is suited to secondary education and would be too simplistic or misleading for higher education and practitioners, it has however been adopted by universities. The view of styles in architecture that was developed in academia has dominated popular histories of architecture, and the academic attempts to classify past architectural styles have always had a far-reaching impact on the practice of architecture.

However, by divorcing form, appearance and image from structure, function and materials, architectural style classification has challenged central tenets of architecture to such an extent that it has had little capacity to understand and interpret architecture.

Corresponding author: Paolo Foraboschi, engineer–Ph.D., professor; research field: structural engineering. E-mail: paofor@iuav.it.

This paper is the second output of a research program devoted to submitting evidence that structural design is an all-pervading activity of architecture and that reading or interpreting a historical piece of architecture needs structural mechanics.

The first output has proven that the Renaissance was born when Filippo Brunelleschi carried out the structural design for the Santa Maria del Fiore dome in Florence (Italy), whose architectural project (concept) had remained unbuilt for more than 50 years because it was so demanding that it exceeded the expertise of the time [1]. Brunelleschi turned paper architecture into a buildable design and eventually the dome was constructed.

The Florentine dome is a Gothic building that terminated the Gothic period and started a new period, the Renaissance. Hence, the Renaissance—one of the most important revolutions in cultural history, and not just in architecture and not just in Italy—was born not as a new architectural style but instead as a new approach to architecture, based on intellectual theory rather than just craft practice and on the separation of design from construction.

The first research output has also proven that, before the pre-eminent materials of modern structures were made available and affordable (i.e., reinforced concrete and steel), no difference existed between architectural design and structural design. Examples have included a masonry dome that failed because the designer isolated the visible exterior form, without appropriate links established to the real building, which has confirmed that focusing on the image instead of the physical referent was (and is) a recipe for failure.

The separation between the two professions—architect and engineer—was institutionalized in France in 1747, while a growing separation between design and the practical craft of building had already initiated in the 17th century, especially in France. With the invention of Portland cement (patented in 1824) and of the industrial process to turn iron into steel (the Bessemer process, patented in 1856), architecture and engineering initiated a process that has led the former to drift apart from the structural design, and the latter to outgrow safety assessment as the only objective.

By relieving walls of their load-bearing function, reinforced concrete and steel permitted the development of the combination called “skin and bones” architecture, which has progressively led architecture to split the Vitruvian triad (firmness, commodity, delight. An equivalent in modern English would be: robustness, utility, beauty). Critique, education, commentary, architects in academia and historians, keen to associate architecture with other forms of art, have been focusing mainly on “beauty”, while they have been disregarding “robustness” and “utility”. In doing so, they have eventually separated principles that conversely should represent three unifying concepts, which has impacted negatively on the contemporary architecture.

Few debates in architectural theory have been as vexed as those around the interrelationships of the Vitruvian triad. Arguing that “form follows function”, advocates of Functionalism believe that delight—or beauty—derives from firmness—or robustness—and commodity—or utility. Those debates involve structural engineering, which provides robustness and some facets of utility; further, the way that the structural system provides robustness and those facets of utility influences beauty and the other facets of utility.

This paper focuses on the architecture of Venice and proves that the standard mechanics of masonry had to be replaced by a mechanics specifically conceived for the lagoon. In Venice, the fact that “form ever follows function”, is not a belief but the inevitable consequence of paying proper attention to the structural requirements of a building.

This paper also describes the concern of Venetian architecture for place rather than space, to designing and building in the nature of materials and environment.

2. Adverse and Restrictive Environment

Venetian lagoon is characterized by three specific features, which are extreme and radically affected the underlying logic of building form—morphology.

(1) Soft soils;

(2) Brackish water and tidal actions;

(3) Shortage of land.

Coastal lagoons are unstable environmental systems. Throughout centuries, a lagoon tends to turn into either a piece of sea or a piece of land. Venetian lagoon has escaped fate because of the constant and patient work of Venetians, who have always performed competent and skillful activity devoted to protecting and preserving the lagoon. Not only has the equilibrium been maintained although the system is highly unstable, but also the conditions of the lagoon have been improved throughout the centuries.

2.1 Soft Soils of the Venetian Lagoon

The stratigraphy of the lagoon is characterized by a layer of highly over-consolidated oxidized silty clay, near the ground surface, called “caranto”. The caranto begins 4-8 m below the mean sea level (2 m near the mainland, 10 m at Lido). The thickness of this layer is 2-3 m. The layer of caranto is discontinuous and in some areas it does not exist. Its strength and stiffness are very high. Notwithstanding, the layer is quite thin, so the caranto cannot bear high loads.

Strength and stiffness of the soils above the caranto are very low. The average strength and stiffness of the soils below the caranto up to 10-12 m are certainly greater than of the soils above, but only to a moderate extent.

Ultimately, neither the load-bearing capacity nor the compressibility of the soil allowed buildings more than one-two stories to rest on a shallow foundation, and not even on a deep foundation with depth lower than many meters.

2.2 Brackish Water Tidal Actions

Ancient bricks were highly porous, so they created the most favorable conditions for water infiltration.

Water infiltration increases the moisture content of bricks, which causes subflorescence and efflorescence and which significantly reduce compressive strength of bricks [2].

Salinity in the lagoon is substantial-brackish water. The salts contained in the water of the lagoon are the same salts contained inside the bricks. For that reason, the degree to which subflorescence and efflorescence can affect the portions of buildings in the tidal range has always been particularly high.

The above-described phenomena entailed that the brickwork portions of buildings submerged at high tides (high water) and exposed to air at low tides (low water) had to be protected against the infiltration of the lagoon water (the difference between high tide and ebb tide that may surpass 1.70 m).

2.3 Shortage of Land

The land of the lagoon is relatively small and was even smaller than now in the past. Yet despite shortage of land, Venice has always had a large population, which was around 20,000 in the 11th century and has always surpassed 150,000 since the 13th century (apart after plagues and the last decades). During the 14th century, Venice was one of the wealthiest cities in the world, maybe the wealthiest one. As a natural consequence, it was the most populous city in Europe, with 200,000 people who lived in the lagoon (180,000 in 1490 and more than 175.000 in the 19th century).

High population density necessitated exploiting the land to the maximum.

3. Foundation and Base of the Building

Venice posed three problems for builders tasked with constructing in the lagoon—namely, to allow a building: (1) to rest on very soft soil layers; (2) to endure the aggressive environment; and (3) to exploit land.

The third problem could only be solved by adopting multi-story buildings, which however made the first problem more difficult to solve, because the more the stories the greater the contact pressure.

3.1 Soft Soils

Soft soils call for foundations supported by piles driven or drilled into the ground (deep foundations).

Technology for installation of timber piles available prior to the 16th century allowed builders to construct piles up to a maximum depth of just 2-3 m, and after up to 6-7 m. Those piles often reached the caranto, especially after the 17th century, when they could even pass the caranto (75% of the land lay less than 1.5 m above the sea level). However, those piles could not guarantee significant load-carrying capacity and stiffness, not even if they reached or surpassed the caranto.

Given that the piles that could be installed before the 20th century in the natural soils could not provide a foundation with adequate strength and stiffness, Venetians improved the soils. Ground modification technique improved the bearing capacity of the soils by increasing the relative compaction of the materials through densification. The relative density of the soils was increased by adding material, i.e. timber piles. Pile driving had thus, for its object, the consolidation of soils and not the transmission of surface loads to lower levels in the soil mass.

The larger the total cross-sectional area of the piles per square meter, the larger the volume of soil displaced to make room for the piles, and consequently the greater the compaction. The greater the bulk density, the higher the shear strength and the lower the compressibility of the artificially modified soils. Venetians took the mechanism of densification to the extreme. The typical density was 5-10 piles/m^2. The diameter of each pile was 0.10-0.30 m. The density of the piles was 0.3-0.7 the building footprint.

On one hand, ground modification technique by increasing the compaction of the material through densification increased significantly the load-bearing capacity and stiffness of the soils. On the other hand, however, the load-bearing capacity and stiffness remained moderate.

3.2 Aggressive Environment

Builders had to enable the timber piles and the base of constructions to endure the lagoon water.

Two natural phenomena kept the timber intact for over 500-1,000 years. Timber rots only when both air and water are present, so in the oxygen starved environment of the water underneath the buildings, the timber was protected at least until the second phenomenon happened. The water of the lagoon carried an extremely large amount of silt and silty clay, and the timber was being blasted by that sediment for years, so timber adsorbed the sediment and quickly petrified into basically stone.

The base of the building was able to withstand extreme conditions and damage by virtue of the judicious selection of the best materials and techniques (i.e., pile caps, called “madieri”, a special waterproof clay, called “tera da savon”, a vertical layer of Istrian stones, continuous courses of Istrian stones, called “cadene”, hydraulic lime plaster) [2].

That construction technique was a viable means to protect buildings from brackish water and tides up to the first half of the 20th century. Unfortunately, because of the sea-level rise, now the lower parts of the walls are frequently submerged under the lagoon water.

4. Weight- and Space-saving Elements

According to Subsection 3.1, compaction allowed for construction of multi-story buildings provided that they were relatively lightweight. Therefore, buildings had to be composed of weight-saving construction elements.

According to Subsection 2.3, buildings had to make optimal use of both the footprint and volume, with the purpose of saving land and exploiting to the maximum the internal space. Therefore, buildings had to be composed of space-saving construction elements.

A building made of traditional construction materials (i.e., masonry and timber) is composed of weight- and space-saving elements only if the following five criteria are met (Fig. 1).

(1) Masonry walls are thin and perforated.

(2) Brick is preferred to stone.

(3) Columns are employed as opposed to load-bearing walls wherever possible.

(4) Floors and roof are made of timber structures, and not of masonry vaults.

(5) The footprint makes the best use of land, and the distribution of rooms makes the best use of the allotted space.

Builders met those criteria as close as possible. In so doing, buildings implicitly followed a format, which not only drastically influenced the construction technique but also gave a specific morphology and character to buildings (Venetian architectural style).

Fig. 1 Gussoni-Grimani palace (building on the right in the photo). Façade of the palace, which overlooks Canal Grande. This building fulfills all five criteria: (1) External walls are both thin and largely perforated, and internal walls are very thin; (2) Load-bearing walls are made of brick units; (3) Columns are used where possible (façade and lower stories), while load-bearing walls and partitions are made coincident with each other to minimize weight and volume of the inactive materials; (4) The structures of floors and roof are made of timber; (5) No inner space is left unused or wasted. As in many other Venetian buildings, manufactured stone (stone veneer) was used as a protective and decorative covering for the lower part of the façade.

Fig. 2 Typical Venetian building: thin walls pierced with large openings. The number of openings in the external walls is high and the total span of the openings is relatively long. Thinness and high void-solid ratio lent lightness to walls. Masonry lintels do not work over those spans, so the building is pierced by arched windows. In this case the windows are spanned by pointed jack arches, which exert lower lateral thrust (the greater the rise of the arch the lower the springing thrust). The vertical stone elements in the façades are not columns but mullions. The load-bearing walls are made of bricks.

Fig. 3 Venetian load-bearing masonry walls are an assembly of brick units, while the connections between the external walls are frequently made of stone blocks (Istrian stone), which resist soil settlements and movements more than brick units. The columns are often made of stone as well, including the capitals. Columns are often slender, and capitals exhibit very high void-solid ratio, so the stone is necessary to carry the stresses (thin columns and perforated capitals entail high stresses, which bricks could not bear).

4.1 Thin and Perforated Walls

Walls were kept as thin as possible (Figs. 1 and 2). Builders used the minimum number of wythes of masonry units that enabled each wall to bear the load. That was a novel and unique approach to masonry construction, since masonry walls had never been shaped in response to the force at work.

External walls and some internal walls were pierced by large openings (Figs. 1-3). Builders achieved the highest void-solid ratios possible. As a result, Venetian walls were both weight- and space-saving construction elements with respect to typical walls.

Many openings were wide. Since the widths that could be spanned by a masonry lintel or a transom were limited, wide openings were spanned by a masonry arch (jack arch).

Many openings were also tall, besides being wide, which implied that the two vertical portions of wall on the sides of those openings were tall too. Those masonry portions were the abutments of the jack arches that spanned the openings. While the lintel exerted only a vertical force, the masonry jack arch also exerted an outward horizontal (lateral) thrust onto the abutments.

However, the lateral thrust that the abutments of a tall opening could withstand was low (especially the openings at the upper stories). For that reason, builders introduced the pointed arch, which exerted a thrust lower than the semi-circular arch and much lower than the segmental (shallow) arch.

Lots of openings were so large that not even the pointed arch could bring the thrust down to a smaller amount which could the withstood by the abutments. In those cases, builders used windows of two or more lights separated by mullions (ranging from single to quadruple mullions used not decoratively but as columns, dividing the window into from two to five equal/not-equal elements).

The combination of pointed arch and mullioned window allowed the openings to be decidedly wide and tall, so that the void-solid ratio of the walls reached very high values.

In order to further reduce the void-solid ratio of walls, capitals of columns and abutments were often pierced as well (Fig. 3).

4.2 Bricks versus Stones

The unit used by builders for masonry structures was the brick, while the stone was used only for specific structures. There are only two exceptions to that general rule (apart from some walls of the

Prison’s Palace, for obvious reasons).

The first exception occurred in the case of the columns whose shaft was subjected to high stresses, where the stone was preferred to the brick since the latter minimizes the weight but the former the volume, which was the preferred option for columns. The most apparent examples are the columns included in many façades, which are slender. The stone was even more necessary for their capitals, which often were perforated (Fig. 3).

The second exception encountered to the rule was the connection of external walls. Buildings had to accommodate large differential displacements between walls, due to great differential settlements of soil. Only strong connections between the longitudinal and transverse external walls avoided splitting the building into separate walls. Accordingly, the intersections between orthogonal external walls were often made of stone. Stone could not prevent the connection from cracking locally but prevented cracks from propagating along the entire connection (Figs. 2 and 3).

Another kind of exception was the stone used as cladding (stone veneer) of external walls, especially at the lower level of buildings (Fig. 1).

Stone cladding on a brick wall entailed an extra-weight. However, builders dressed brick walls with a very thin revetment of stone, thereby only slightly increasing the total weight. In so doing, bricks were protected from the environment and buildings were generally more aesthetically pleasing. Considering that the brickwork was several times thicker than the stonework, in effect cladding consisted in a non-load-bearing envelop.

Thus, what appear to be stone load-bearing walls are, in reality, brick load-bearing walls with a protective and ornamental facing of stone, excluded from the above general rule.

To put it briefly, brick walls were often finished in thin stone veneers, which bear no relation to the underlying structure, whereas they bear direct relation to the construction, since they protect the buildings from the environment.

Well-known examples showing that stone cladding consisted in pure dressing of raw construction (i.e., permanent wallpaper) are the Doge’s Palace and St Mark’s Basilica. In the former case, the thin stones that compose the upper level of the façade are manifestly not structural as the building put upside down the logic of form. In the latter case, the condition is marked by confessed rivets used to fix thin panels of stones to the walls.

Some bridges included stone, but this was not an exception because bridges usually had not to save weight or space. In those cases, stone was preferred over brick for the durability performance and esthetic. Sometimes, the barrel vault of the bridge was composed of two stone arches at the edges and a brick arch in the middle.

The typical stone was the Istrian stone (Figs. 1-3), which is a limestone with very low porosity (high compactness), thereby extremely durable.

No structures, without any exception, were made of masonry with rubble core (sandwich masonry), since it did not save weight or space (it was only a labor saving and cheap masonry type).

Some utilitarian buildings in poor neighborhoods included walls made of timber, which not only were both weight- and space-saving but were also cheap.

4.3 Columns in Lieu of Walls

Builders used columns in lieu of walls wherever possible, supported by the self-evident proposition that the column is weight-saving and space-saving with respect to the wall (Fig. 4).

Columns were made of either Istrian stone or brick.

A masonry construction composed of many columns as well as of thin and perforated walls is midway between the masonry wall structure and the skeleton, as addressed in Section 6 (Fig. 4).

4.4 Timber Floors and Roofs in Lieu of Vaults and Domes

Almost all the floors and roofs were made of timber (Fig. 5), while masonry vaults were used only in the exceptions hereinafter defined, since a curved masonry system weighs much more and occupies much more space than a timber floor over the same span [4].

More specifically, masonry weighs more than timber. A vault needs the fill on the extrados to obtain a flat floor, which adds weight and subtracts space. Due to the strength asymmetry of masonry material, curved masonry structures crack even under the dead load, and turn into thrusting structures. The thrust—namely, the horizontal force transferred through the springing sections to the abutments—can be resisted only if the masonry abutments are heavy and thick. Ergo, curved masonry structures call for massive abutments to accommodate the outward thrust, save those in succession, which press against each other, and those with the tie-rod, which do not press (but the tie-rod was usually not compatible with occupancy).

Nevertheless, in patrician palaces, builders could build curved ceiling without using curved masonry structures (Fig. 6). The curved floors consisted of members having the appearance of an arch or vault, though not of arch or vault construction (false vaults). Vault-like constructions were made of wattle and daub, and hung from timber curved elements which, in turn, hung down from the timber beams of the floor. The wattle and daub surface was plastered. This system occupied little space, was lightweight, and transmitted no horizontal thrust to the walls.

Fig. 4 Wherever possible, builders used columns as opposed to external and internal walls. The photos show buildings where the skeleton forms not only the bones but also the skin. Venice gave birth to the earliest buildings that abandoned load-bearing walls in favor of a framework of columns and beams (the former made of masonry, the latter of timber), which allowed lightweight buildings to be obtained. As such, those structures were the archetype of the “skin and bones architecture” and of the framed structures.

Fig. 5 Largest room of the Doge’s Palace, called “Sala del Maggior Consiglio” (53.8 m long, 26.2 m wide, and 15.5 high), whose ceiling and roof are supported by larch lattice trusses and purlins. Each timber tie-beam consists of four pieces joined by “Jupiter dart” connections. On the mainland, those rooms were often roofed by masonry vaults.

Fig. 6 False vaults: vault-like construction. The floor is composed of timber flat structures—namely, timber beams and timber boards, the latter nailed to former (single boards or double boards), plus a timber component between wall and floor, called “rema” (but no spandrel fill). In its turn, the ceiling is composed of wattle and daub, and it hangs from curved timber elements, which hang down from the floor. The curved timber elements have no structural role, so the false vault exerts no thrust and thus the system does not require thick abutments. The wattle and daub surface is plastered and, in some cases, painted.

In the case of roofs, especially church roofs, another way to obtain a vault-like construction was to build a wooden curved ceiling resembling the hull of a ship turned upside down. That ceiling was supported by the main timber structure, so it played a marginal structural role. Hence, it was indeed a vault-like construction (Fig. 6).

There were only two exceptions to the above-stated general pattern. Builders made a first exception for rooms containing highly inflammable materials (storages, warehouses, fondaco buildings, some mezzanine floors) or devoted to activities that could start a fire (workplaces, workshops, kitchens, cells and corridors of the Prison’s Palace). In those cases, the masonry vault was sometimes preferred over the timber floor, as safety measure to decrease fire risk and fire effects. However, those rooms were small and the vaults thin, so the structural system was not massive.

Where possible, builders arranged a compartmentalization of specialized rooms, so that those vaults were next to each other. The structure of that enfilade consisted of an arcade, which was highly efficient because the outward thrusts of the successive arches pressed against each other, and needed no buttressing and no thick abutments, except for the first and last ones. Nevertheless, those vaults constituted the lower floor of multi-story buildings, so that the weight of the upper walls and of the floors that rested on those walls helped the first and last abutments in resisting the outward thrust [3, 4].

The second exception was made for some churches. Contrary to the first one, this second exception proves the rule. In order to roof the churches with domes and vaults, builders either adopted shapes different than the basilica, which is characterized by large spans, or reduced the spans of the basilica shape, which led to relatively small churches. According to the former option, which was frequently adopted, the plan tended to be centralized; it was symmetrical about a central point, as is a circular, square or octagonal (polygonal) plan, or also a Greek cross. Those plans were roofed by domes (Fig. 7). The masonry dome exerts a thrust much lower than a masonry vault, as long as the brick pattern is built according to specific construction rules [4]. Builders knew those rules, thereby those masonry domes did not need thick drums.

Likewise, when the basilica shape is characterized by relatively small spans, vaults can be used to roof the nave and sometimes the aisles, and a dome or a vault to roof the apse and the transept.

On the contrary, Venetian churches with basilica shape characterized by large spans were roofed with timber structures and a flat ceiling (bold and expensive timber systems).

4.5 Expansions of Venetian Buildings

Venice has always been a densely populated city

Fig. 7 Internal view of Baldassarre Longhena’s masterpiece, the Church of Santa Maria della Salute, at the entrance of the Canal Grande in Venice (started in 1631; completed in 1687). The drum is thin and consists of segmental windows with mullions. As almost every masonry dome, this dome cracked and is split into arches, which exert a springing thrust. Such a lightweight drum can resist the outward thrust of the cracked dome because every arc of dome whose endpoints are two consecutive meridian cracks subtends a large central angle. That is, the resisting thickness of those arches is great (the greater the resisting thickness of an arch the lower the springing thrust exerted by that arch). The resisting system was the result of the brick pattern (loxodromic curves arranged in a herringbone pattern). Altogether, the weight-to-volume ratio of this dome is relatively low. It is to note that the intrados has a shape different than the extrados of the dome, because there is a timber frame between, which is supported by the former and, in turn, supports the latter, creating a wide gap.

and the lagoon was fast consumed by urban development, so that Venetians soon run out of inhabitable space (Subsection 2.3).

Land exploitation entailed that the perimeter of a building should almost coincide with the boundary of the ground plot that the building was erected onto. Since the ground plots were irregular polygons, the perimeters of many buildings were irregular polygons too. Because of that, the neighboring buildings either were in contact to each other along their boundaries or left very narrow space between for the alleyways.

Courtyard houses were widely adopted throughout the Venetian history, also because the courtyard allowed the staircase to be placed externally (Gothic staircases), whereas an internal stair would have been a nuisance to be accommodated in compliance with the other four criteria.

Venetian building forms also made the best use of inner space, not only because of the space-saving construction elements, but also because of space allotted for large medium and small rooms around the tripartite layout of the main façade. The vast central hall, called the “portego”, connected rooms; that is, rooms were connected to each other via a shared hall or en suite, and not via corridors, so as to save space.

The excess of “form follows function” that characterized Venetian buildings from the flexibility perspective suggests that there was remarkably little latitude for building modifications. Actually, exploitation of land and inner space entailed that no allowance was made for new developments of buildings over time.

The Getto provides a clear example. The strong demographic increase of the Getto in the 16th century entailed growing demands for housing, retail and workspace, as well as the demands of new social needs, which could be satisfied only by creating novel real estate space. Those demands led to construction of new buildings very tall for Venice (up to 7-8-stories). Moreover, since rearrangement of inner space was nearly impossible, those demands also led to the insertion or addition of new stories, obtaining lower interstories or higher buildings. In some buildings in the Getto, the writer found masonry walls or columns close to failure by crushing.

5. Serviceability Limit States

Satisfaction of what in modern terminology is called “serviceability limit states” constituted a serious problem for Venetian builders.

5.1 Double Function of the Venetian Terrazzo

Terrazzo is a form of mosaic flooring made by embedding chips in a matrix and polishing, which was created when Venetian mosaic workers discovered a way to reuse marble remnants. Nevertheless, it was the evolution of works of art attributed to the first Roman age, according to a Greek procedure.

With odd-size chips, Venetian builders began to construct terraces around living quarters. Then, terrazzo went beyond its simple beginnings and evolved into a flooring system for both rich and ordinary buildings, and we find terrazzo in many buildings.

Terrazzo was laid onto the timber boards of the floor, which rested onto the timber beams (boards and beams were nailed together). The thickness of terrazzo was never less than 130 mm and often surpassed 200 mm, even up to 250 mm (sometimes more, especially when the terrazzo was poured onto warped floors).

The unit weight of terrazzo ranged from 3.2 kN/m^2 to 4.5 kN/m^2, sometimes even 6.0 kN/m^2. Namely, not only was terrazzo really heavy, but above all it was drastically heavier than all the other non-load-bearing components of the Venetian building. Thus, terrazzo seems to be in flat contradiction to the weight-saving goal. That contradiction prompted some research, which has proven that terrazzo played a paramount role in the structural behavior of the floor [5].

If the structure had consisted of the timber system only, almost all the floors would have not guaranteed adequate stiffness. But conversely, the terrazzo slab was (and is) not structurally independent from the timber system, since interlocking and friction transmitted shear stresses at the interface between the former and the latter, so that the timber-terrazzo floor is a composite structure. As a result, the stiffness of the whole floor was substantially greater than that of the individual timber system and allowed the floor to satisfy the deflection limit. Still, terrazzo provided the floor with an extra load-carrying capacity greater than its weight.

Also the terrazzo floorings that were first built in Venice are still in existence today—a testament to terrazzo’s durability and strength.

Ultimately, Venetian builders considered terrazzo a load-bearing component, while literature has always included terrazzo in the non-load-bearing components. Altogether, the total weight of the timber elements plus the terrazzo slab is not high, as those elements simultaneously compose the structural floor and the flooring system.

5.2 Soil Settlement and Moisture

Although the Venetian foundation system and the weight-saving elements had substantially decreased soil settlements, differential settlements between vertical structures could not be reduced to such a level that could be accommodated without deep cracking. Builders knew that differential settlements needed specially devised construction methods.

In some buildings, the internal transverse walls (at an angle of 90° to the façade) were deliberately not connected to the longitudinal walls (parallel to the façade, i.e. parallel to the canal faced by the building).

In so doing, gaps were created between orthogonal walls. A gap in a masonry structure consists in a structural joint. In its turn, a joint in a masonry structure consists in a purpose-built crack in lieu of natural cracking; while the latter produces meandering cracks, the former consists in a regular, straight, and even fissure between two unconnected walls. That device provided the best esthetic quality, since it allowed the relative movements to occur opening or closing the gaps, without causing any cracks.

On one hand, cracking is not esthetically pleasing. On the other hand, however, cracking breaks the connection between the walls only to a certain degree, so the walls maintain the restraints (only rarely a crack cuts the connection from the bottom to the top of the building and through the entire thickness of the wall). Thus, that device implied that no connection existed between the walls, so each unconnected edge was a free boundary instead of a restrained boundary.

When the longitudinal walls were particularly slender or wide, metal tie-rods were placed beneath the terrazzo to compensate for the lack of connection between transverse and longitudinal walls. So, the tie-rod prevented the out-of-plane collapse mechanism of the external wall from occurring.

Ultimately, the transverse external walls were firmly connected to the longitudinal external walls, while sometimes the transverse internal walls were not connected to the longitudinal external walls. In that way, buildings could cope with large differential settlements between longitudinal and transverse walls.

Satisfaction of serviceability limit states also included devices for coping with moisture, which damaged not only brickwork but above all timber. The floor-system comprised a timber beam (rema), placed at each edge of the floor, between floor and wall, to protect the floor from the rising damp.

In addition, builders often applied a special plaster onto walls, currently called “polished Venetian plaster”, which concealed surface moisture.

In Venetian buildings, architecture, construction and ornament were inseparable. Ornament was something conceived as integral to design, and must not be seen as a secondary element applied to the design.

6. Tectonic Form

The Venetian building structurally considered does not belong to any common structural type; it properly belongs neither to the masonry wall structure nor to the skeleton, in the normal acceptation of those terms. The Venetian building implies a particular sense of the collocation “masonry construction”, while the generally recognized meaning is unfitting.

6.1 Typical Masonry Construction versus Skeleton

The vertical structures of a masonry construction are composed of masonry walls and may include some masonry columns, while the horizontal structures may be composed of either curved masonry structures or flat timber structures. The vertical structures of a skeleton are composed of columns, while the horizontal structures may be composed of either slabs or beams plus floors.

A masonry-wall structure (i.e., the system of vertical structures) has multiple functions – namely, to support the dead, live, and environmental loads, to form the periphery of the building and the rooms, and to provide insulation. Accordingly, the cross-sections of a masonry-wall structure are dictated by the area of the building and rooms that the vertical structures have to surround and the spaces that they have to divide, enclose, and protect.

A skeletal structure, as opposed to a masonry construction, has one function only—namely, to support the dead, live and environmental loads. Accordingly, the cross-sections of a skeletal structure are dictated by the materials that they are made of and by the loads that they have to bear.

The masonry cross-sections that are necessary to shelter a building and to separate one internal area form another entail compressive stresses drastically lower than the compressive strength (crushing strength) even under severe vertical loads. It follows that failure by crushing is impossible, apart from masonry with rubble core or uncoursed masonry, subjected to earthquakes or high vertical loads.

Even though masonry cross-sections are large, tensile stresses reach the tensile strength even under just barely the dead load or small differential settlements. Hence, cross-sections cannot prevent cracking from happening, so that masonry structures bear the ultimate load in the cracked state. It follows that failure by cracking does not dictate the load-carrying capacity.

Being that masonry cannot fail by crushing and that the ultimate load stems from a cracked resisting system, failure occurs only when the masonry structure becomes an unstable kinematic collapse mechanism composed of blocks joined to one another by pins at (near) the edges of some cross-sections (or friction hinges). Stresses and masonry mechanical properties only marginally influence equilibrium and ultimate behavior. As a result, the kinematic collapse mechanism acts as an assembly of pinned rigid blocks, and the load-carrying capacity of a masonry structure is the load that triggers the weakest rigid block collapse mechanism. That result gives a necessary and sufficient condition. For a masonry structure to be in equilibrium with the applied load there must be a line of thrust contained entirely within the masonry sections (lower bound theorem) [3, 4].

Conversely, the cross-sections of a skeletal structure are designed to exploit the structural materials, and stresses are as high as possible, in order to reduce the dimensions to a minimum. It follows that the failure modes of skeleton structures are dictated by strength of materials. Given that skeletons can fail by crushing, fracture, yielding or softening, and the ultimate behavior depends on stresses and material’s mechanical properties, a failure mode consists in an assembly of rigid blocks joined to one another by plastic hinges. It follows that the necessary and sufficient condition involves not only the geometry but also the ultimate internal actions. For a skeleton to bear the applied load the internal actions of every cross-section must fall within the interaction diagrams of that section (moment, axial force, and shear internal actions).

The lower bound theorem implies that masonry structures can simply be scaled up and down in size. Conversely, the interaction diagrams together with inelasticity imply that the proportions of skeletal structures have to change according to their size and materials (as is the case with animal skeletons).

To conclude, a masonry-wall structure that satisfies the architectural requirements always resists the design vertical loads. On the contrary, masonry buildings often resist only moderate horizontal loads, especially are vulnerable to seismic actions.

Conversely, a skeletal structure resists vertical and horizontal loads owing to its size together with type and amount of materials. Thus, the load-carrying capacity of a skeleton depends on its structural design.

6.2 Venetian Masonry Buildings

Venetian buildings did not include curved masonry vaults or domes, apart from some churches (Section 4.4). According to the Italian code, Venice has a low level of seismic hazard. Those conditions may suggest that Venetian buildings satisfied (and satisfy) every structural requirement.

That statement would have been true if the buildings had been constructed on the mainland, but instead was (and is) wrong for buildings constructed on the Venetian lagoon. Oversizing of masonry walls met an exception: buildings in sites where the soil was soft and the space available for constructing was limited. Venice met both those conditions.

On one hand, knowledge and practice derived from direct observation of constructions allowed builders to make full use of structures without undermining their load-bearing capacity, although being made of thin brick walls, many slender columns, and had high void-solid ratios. On the other hand, however, with their privileging of emptiness and lightness, compressive stresses were not far from the compressive strength of materials (crushing strength).

Although the soil had been compacted, differential soil downwards displacements were large. Those soil movements lessened the effectiveness of the connections between orthogonal walls, and their ability to prevent walls from out-of-plane overturning. Besides impairing the connections, those movements also increased the compressive stress level, because cracking always prevents stress diffusion in masonry walls.

To sum up, saving weight and space entailed that buildings were provided with just a small margin of safety against collapse under gravity loads. Nevertheless, the skill acquired by a long period of practical experience allowed builders to balance between saving both weight and space on one side, and providing structures with adequate capacity on the other side.

However, that balance was true for the past, not for the present. A recent research [2] has demonstrated that moisture and salts cause damage to masonry further than subflorescence and efflorescence—namely, ingression and diffusion of lagoon water into masonry have substantially affected the crushing strength of bricks. Compressive strength of bricks with high moisture and high salt contents can be half the value of dry bricks.

That effect, added to the effects of crystallization, i.e. subflorescence and efflorescence (Subsection 2.2), implies that now compressive masonry strength may be substantially lower than in the past [2].

Not a few Venetian buildings can just barely support the loads that are applied, while they cannot even resist the loads that are called on to support (service load, i.e. superimposed load), let alone the ultimate load prescribed by the Italian structural code.

High stress levels imply that structural safety assessment of Venetian masonry buildings must include stress analysis together with the mechanism analysis. Relating forms and materials to maximum strength and no-tension behavior entails satisfying the requirements of both a masonry construction and a skeletal structure.

6.3 Masonry Skeletal Structure

The morphology of a masonry building that fulfilled the five criteria set out in Section 4 implied that Venetian buildings were, and are, governed by a specific structural mechanics, which overturned masonry mechanics and that needed specially devised construction techniques.

In a normal masonry construction, the load-carrying capacity is dictated by the weakest rigid block collapse mechanism. Consequently, the vast majority of the dead load belongs to the resisting system, so that the load system is only composed of the live load and a minor part of the dead load [1, 4].

In a Venetian masonry building, the load-carrying capacity was dictated by the bearing capacity of the soil (ultimate pressure). Consequently, both the dead and live loads belonged to the load system. In addition, the greater the dead load the greater the amount of space occupied by the structure, while buildings had to save space as well. Accordingly, design and construction of Venetian buildings aimed at minimizing the dead load, which is exactly the opposite of what is done in normal masonry structures. As a result, the structural system of the Venetian building exploited to the maximum masonry strength. Thus, equilibrium was (and is) only a necessary condition for a Venetian building to be safe, but not a sufficient condition.

The eye at once deduces the scheme behind the design of many Venetian buildings, which is closer to a skeleton than to a masonry-wall structure (Fig. 8). Nevertheless, that skeleton provided not only the load-bearing system, but also the cladding and partition systems; skin plus bones architecture, as the skeleton composed not only the latter but also the former.

Conversely, reinforced concrete and steel skeletons provide the load-bearing system only; skin and bones architecture, as the latter is provided by the skeletal system while the former by the cladding and partition systems.

Builders learned from experience that, contrary to mainland masonry constructions, Venetian masonry constructions were not governed only by Euclidean geometry and proportions, but also by the strength of masonry material.

Hence, the Venetian building is a skeletal masonry construction. In the light of the definition of a masonry structure, “skeletal masonry construction”

Fig. 8 Procuratie Vecchie, on the north side of St. Mark's Square in Venice, which were rebuilt after a fire in the 16th century. The façade is formed from three superimposed Renaissance arcades of which the lowest, which is open, has fifty arches, whilst the upper two each have 100, containing windows. The façade, with its concentration of loads into points and lines of support, creates a vivid impression of the play of structural forces. With its vast network of columns and arches, this building exemplifies the idea of tectonic.

seems to be a combination of contradictory and incongruous words, since a skeleton should relieve walls of their load-bearing function, while that skeleton imposed the burden of bearing the loads on the claddings. But conversely, it is a special case within masonry construction, not a contradiction or an incongruity. Then again, that exception was the only way to solve the exceptional structural problems of the lagoon.

While the Venetian building structurally considered is a masonry skeleton, the Venetian building architecturally considered cannot be considered to be a skeleton. Skeletons are characterized by no strict interrelationship between the outer form and inner structure, whereas the exterior of Venetian buildings is not autonomous from the interior. While the skeleton epitomizes the ideal of the free plan, the skeletal masonry construction does not allow the spatial possibility of the free plan.

6.4 Tectonic Form

The analysis presented above stresses how all the parts of a Venetian building reinforced the overall structural idea. The collocation that can be invoked to describe both the structural and architectural facets of the Venetian building is "tectonic form".

The idea of tectonic form signifies an approach based on the rational expression of structure and construction of which the Venetian gothic presented a potent paradigm.

The word tectonic assumes a broader meaning in Venice and tectonic can be invoked to describe the interrelationship between the form and structure. Masonry skeletal structure, with no distinction between structure and cladding, typifies the contemporary understanding of tectonic expression as construction made manifest. Tectonic expression is also seen in the process of suppressing secondary elements, in order to base architectural expression on the essential element of a structure, and to eliminate visual clutter; it is seen in the juxtaposition of timber and brick as well.

The specific mechanics that underpinned the construction of that tectonic form and dictated the architecture blends the structural behavior of a masonry structure and a skeletal structure.

The tectonic superstructure of a skeletal masonry with timber floors enables a fresh synthesis to be produced. A normal masonry structure can be governed by accommodating a possible line of thrust within the geometry. In order to assess the safety of a masonry structure, it is sufficient to prove that at least one thrust line, which is in equilibrium with the external load, lies everywhere within the boundaries of the masonry structure.

On the contrary, a Venetian masonry structure must be governed by accommodating the geometric boundaries far away from the real line of thrust. In order to assess the safety of a Venetian masonry structure, it is necessary to prove that the real thrust line lies everywhere within the interaction diagrams associated with materials and geometry.

Ultimately, the tectonic form of Venetian buildings is midway between the masonry construction and the skeleton.

7. Conclusions

A work of Venetian architecture can be understood as possessing intrinsic laws—of geometry, structure, proportion, choice of materials, relation between its members and so on—that are determined not only by the occupancy (the reason why it is constituted), but also by the natural condition of the lagoon (the specific circumstances of the site). This is analogous to an organism, which responds to both its internal constitution and its external circumstances.

The idea that a work of art is analogous to a natural organism in its interdependence of parts to form a whole goes back to Aristotle's Poetics and gained new momentum in German thought in the 18th and 19th centuries, playing a vital role in the ideas of Kant and Hegel, and preoccupying Göthe.

This paper has proposed two aspects to the formation of Venetian buildings: the law of inner nature, according to which each construction was constituted (intended use), and the law of outer circumstances, by which the Venetian type was modified during the first Venetian age until reaching a type that could cope with the lagoon (environment).

The architecture of early Venice was almost entirely made of timber (as such, very little remains). As the city flourished and at its peak became the most prosperous city in Europe, Venetian masons became a renowned community of practice, and architecture modified towards multi-story (high-rise) masonry buildings. However, that evolution was a trial and error (or success and failure) story for improving buildings.

During the first centuries of the Venetian history, constructions evolved like natural organisms—namely, by natural selection and not by adaptation to their environment. The power of Venetian art of building lay first in discovering, in order to eliminate, what failed in the Venice although it worked on the mainland, then in defining novel techniques that worked in the unique situation of the Venetian lagoon. Hence, Venetian architecture began as a succession of attempts to integrate building and site.

Once found a type that worked, it became a strict format that was followed with few and justified exceptions. In so doing, Venetian buildings could rise above common masonry constructions. Accordingly, Venetian buildings, which are distinct from all other constructions and structural systems present in the world, exhibit the defining property of "teleonomy". This means that they are endowed with a purpose of project which they display in their structure and carry out through their performance.

So, the origin of Venice and the process of evolution are the result of chance, which dictated the buildings that survived, while Venice as we know it is the result of both a functional fitness-for-purpose and underlying morphological rules.

Ultimately, in Venice all forms were a creation of necessity: nature was so powerful in the lagoon that form had to follow function without any exception; i.e., necessity prescribed certain forms for certain qualities. Venetian building's forms were determined entirely by their purpose—which was structural and environmental. Therefore, it is always possible to infer the qualities from the forms, the purpose from the shape.

This paper has analyzed the architecture of Venice in the remit of structural engineering, which offers a unique perspective of comprehension and interpretation. Understanding Venetian architecture as "the art of building" does not derive from the recognition of the status of master masons, but from the fact that the distinction between "architecture" and "building" as well as the reworking of historical styles are misrepresenting. Seeking to ground architecture in the craft employed in its making, this paper contrasts what architectural theory, criticism, and histories of architecture have often written about Venice.

Venetian architecture was a complete building system which bounded all the elements into a structurally expressive esthetic unity: a tectonic form. In plain words, the essence of the Venetian architecture was not the creatress of space but lay in the tectonic assembly of elements of construction.

The contrast between a lightweight superstructure and a water-bound base epitomizes tectonic expression of Venetian architecture, which displays no contradiction between form and function. Essentially, function was the consequence of, not only individual need, but also environmental need, while form was the consequence of establishing a relationship with environment.

Venetian buildings are masonry constructions. But whereas typical masonry constructions—their columns apparently swelling under load—suggest a responsive acceptance of gravity, Venetian buildings soar in defiance of it, dissolving into a profusion of slender shafts and delicate traceries. Buildings were soundly built yet some buildings may look flimsy and precarious. What is called “Venetian Gothic style”, which is emblematic of the city and gives Venice its unique appearance, is actually not an architectural style but the only way to build in the lagoon (Venetian skeletal Gothic style).

It can be argued that, in Venice, Gothic never died out, continuing in the practice of builders, whose primary goal was to minimize the weight and size of structures, which tacitly kept alive the Gothic style.

In each epoch, Venetian architecture was not the will of that epoch “translated into space”, but the response to context. Venetian style could change only when the preeminent materials and techniques of modern structural engineering were made available and affordable, i.e. from the second half of the 19th century onwards.

Every Venetian building was enmeshed in its context, and buildings can only be understood when seen as fully integrated in the lagoon. Venetian buildings are “of” and not “on” the Venetian lagoon.

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The Italian Construction Sector Scenario between Economic Crisis and the Need for More Energy Efficiency

Massimo Rossetti

Department of Architecture Construction Conservation; Università IUAV di Venezia, Dorsoduro 2206, 30123, Venice, Italy

Abstract: The paper presents the main aspects of contemporary Italian scenario of construction sector, underlying the importance of renoval in the next years, especially concerning energy efficiency retrofit. Moreover, the paper includes two important case studies in Italy, housing and schools buildings, which both present great needs of refurbishment.

Key words: Construction sector, refurbishment, energy efficiency, housing, schools.

1. Introduction

The construction sector in Italy is nowadays emerging from a deep economic crisis, which started back in 2007 and only recently seems to get close to the end. The last 10 years, in fact, has been some of the most negative since the end of the World War II, with a percentage of -36.5% as investments. New residential constructions, moreover, between 2007 and 2017, decreased of almost 29%; on the other hand, during the same period, extraordinary maintenance was the only increasing subsector, with a percentage of almost 21%. This is particularly important, since the Italian building stock is, on the average, quite old and with low energy performances. Most of the buildings in Italy were actually built before the first laws concerning energy efficiency; these buildings still represent one of the biggest parts of national energy consumption.

Together with the need of a deep and wide rethinking of the entire construction sector, energy renovation seems to be the "main path" for the forthcoming years; not only thanks to the Energy Efficiency Directive (2012/27/EU), which asks to "establish a long-term strategy for mobilizing investment in the renovation of the national stock of residential and commercial buildings, both public and private" [1], or because recent studies identified in the retrofit of residential sector the largest potential for energy saving, but also because this would mean, especially in Italy, a new start for the construction sector, a great decrease of energy consumption and an increasing of internal comfort.

The paper presents the actual Italian scenario of construction sector, especially concerning the economic situation and the energy consumption, and presents some future trends that could help to step away from the crisis.

2. A Deep Crisis

Like other European countries, the construction sector in Italy during the last decade passed through a period of deep crisis. Historically, construction industry is among the ones that most contribute to the national economy, for example in terms of percentage of GDP (more than 8%) [2], and workforce.

The same construction sector, however, more than 10 years ago entered a tunnel from which it seems going out with great difficulty. Some recent signs of recovery give the impression that construction industry

Corresponding author: Massimo Rossetti, Ph.D., professor in technology of architecture; research fields: technology innovation, building materials, and sustainability. E-mail: rossetti@iuav.it.

is restarting, but it is also important to remember some "endogenous" factors that do not really help this sort of re-beginning.

Firstly, a low level of innovation, both of product and processes; secondly, the role of greatest responsible for national energy consumption, a role that unfortunately is coherent with European data. But what seems more important, this role has not even been abandoned during the years of economic crisis, that strongly slowed down the entire construction sector, but not its contribution to environmental problems.

It is clear that Italian building industry needs a deep rethinking, able to bring it close, if not in a short time, at least in the near future, to more advanced sectors (e.g. car or telecommunication). The direction that must be taken by the sector as a whole, that could help the industry entirely going out from the crisis, comes out clearly by the analysis of data, such as year of construction of buildings, condition of housing stock, lack of maintenance, energy performances, etc.

By the analysis of the industry, however, it appears quite noticeable what European Union already identified: the huge potential in terms of energy savings that the existing building stock represents, that means also more employees, considering the numbers of people working in construction industry and linked ones.

3. State of the Art of Constructions in Italy: Crisis, Trends and Energy Consumption

The crisis in the construction sector started back in 2007, at the beginning of the global economic crisis. Even worse, at that time the construction industry in Italy had the benefit of one of the most positive period of the last decades.

During the same period of time, the situation of people employed in the construction industry was equally dramatic: in fact, data show a decrease of almost 28.8% of people working in the construction industry between 2008 and 2017 (see Table 1) [2].

Data are really severe also concerning total investments in construction, that, between 2007 and 2017, decreased of 36.5%; new residential constructions, moreover, decreased of 64.2%. During the same period of time, on the other hand, extraordinary maintenance in housing was the only increasing subsector, with a percentage of almost 21% (see Table 2) [2].

This is particularly important, since the Italian building stock is, on the average, quite old, with a low energy efficiency; most of the buildings, in fact, (almost 65%) were built before 1976, that means before the first laws concerning energy efficiency. This is one of the reasons why buildings represent one of the biggest part of national energy consumption. Data of 2016 show that the civil sector (residential and non-residential) is the greatest responsible for national energy consumptions (39.4%), followed by transport (32.0%) and industry (21.0%) (Fig. 1) [3]. Even more important is the trend of the last years: observing, in fact, the trend of all sectors between 1990 and 2016, the only two sectors with increasing consumptions are civil (+40.7%) and transport (+14.3%) [3].

Table 1 Workers in construction industry (thousands).

Years	Employees	Free lances	Total	% variations compared to the same period of the previous year		
2008	1,238	714	1,953			
2009	1,197	720	1,917	-3.4	0.8	-1.8
2010	1,169	720	1,889	-2.3	0.1	-1.4
2011	1,098	693	1,791	-6.1	-3.7	-5.2
2012	1,033	667	1,700	-5.9	-3.8	-5.1
2013	919	634	1,553	-11.0	-5.0	-8.6
2014	861	623	1,484	-6.3	-1.8	-4.4
2015	864	605	1,468	0.2	-2.9	-1.1
2016	840	563	1,404	-2.7	-6.9	-4.4
2017 (first 9 months)	852	563	1,416	-0.4	-0.4	0.1

Table 2 Investments in construction. (°) Estimation.

	2016 (°) millions of euro	2014	2015	2016	2017	2018 (°)	2017-2007 (°)
		Quantity variations (%)					
Constructions	122,727	-6.8	-1.0	-0.7	-0.1	2.4	-36.5
Housing	66,090	-7.1	-0.3	-0.3	0.1	1.7	-28.9
- new	19,584	-21.7	-2.1	-3.3	-0.7	2.8	-64.2
- extraordinary Maintenance (°)	46,505	1.5	0.5	1.0	0.5	1.3	20.9
Other	56,637	-6.5	-1.8	-1.0	-0.4	3.2	-43.4
- private	33,171	-7.5	-4.3	1.7	1.5	3.7	-36.8
- public	23,466	-5.1	1.9	-4.7	-3.0	2.5	-50.3

Fig. 1 Final energy consumption by sector in Italy, 2016.

All the previous data leave no space for interpretation. The construction sector is, nowadays, going out from such a deep crisis that seems really hard to return to the previous performances, in terms of profits, employees, etc., especially in a short time. Moreover, together with the need of a wide rethinking of the entire construction sector, energy retrofit seems to be the most important way for the upcoming years, for several reasons:

- The Energy Efficiency Directive (2012/27/EU), as already seen, asks to "establish a long-term strategy for mobilizing investment in the renovation of the national stock of residential and commercial buildings, both public and private";
- Recent studies identified in the retrofit of residential sector the largest potential for energy saving;
- This would mean, particularly in Italy, a restarting of the construction sector, a great decrease of energy consumption and an increasing of internal comfort.

As seen, extraordinary maintenance is the one and only sector that grew in the last ten years as investments (see Table 2). Moreover, at the moment, refurbishment sector represents the greatest part of the entire production value of constructions and it seems to remain the same for years to come.

4. The Refurbishment Sector

According to the study of Chamber of Deputies, Environmental Department and CRESME, dated 2017, the value of production in construction sector in 2016 was 166.2 billions of euro (it was 163.1 in 2015 and 162.0 in 2014). The study subdivides this value into three areas: *new*, *refurbishment* and *renewable plants*, that amount respectively 43.0, 121.6 and 1.6 billions of euro. Moreover, the refurbishment sector is divided into *ordinary maintenance* (36.2 billions) and *extraordinary maintenance* (85.4 billions). The sum of these two subsectors gives the whole of the refurbishment sector in Italy (121.6 billions of euro), equivalent to 73.1% of the total (Fig. 2) [4].

It is also important to underline that in 2006, considering this one as the last year of the growing period of construction sector and the "peak year" during the first years of 2000s, the refurbishment sector was equivalent to only 55%.

According to CRESME, on a previous document concerning the same subject, the importance of refurbishment will remain high for years to come, as a result of certain factors, including:

- The strong decreasing of new constructions leads to an increase of buildings ageing and of the obsolescence of their components;
- The "customization" of the property subject to sale;
- The evolution of the European regulations, even for what concerns the energy performance;
- The renewal of tax deductions [5].

The European Commission showed which direction Europe should take during next years to increase energy savings, especially concerning buildings: "The greatest energy saving potential lies in buildings. The plan focuses on instruments to trigger the renovation process in public and private buildings and to improve the energy performance of the components and appliances used in them. It promotes the exemplary role of the public sector, proposing to accelerate the refurbishment rate of public buildings through a binding target and to introduce energy efficiency criteria in public spending. It also foresees obligations for utilities to enable their customers to cut their energy consumption" [6].

Italy, such as during the last years, continues the energy building refitting policies trough tax deduction also for all 2018 [7]. Among the available measures there are:

- The tax deduction of 65% for thermal insulation of external walls, heat pumps, building automation systems, solar collectors for hot water and hybrid generators;
- The tax deduction of 70% and 75% for condominiums;
- The deduction of 50% for substitution of windows, solar shadings, biomass and condensing boilers;
- Finally, the law extended the 65% deduction for one year, expiring December on 31st, of the costs for actions relating to the adoption of anti-seismic measures.

This is the situation, right now, concerning the Italian construction sector. Having in mind all the previous data, it is quite clear that refurbishment and energy requalification are essential to keep, maybe not healthy, but at least "alive", the building sector.

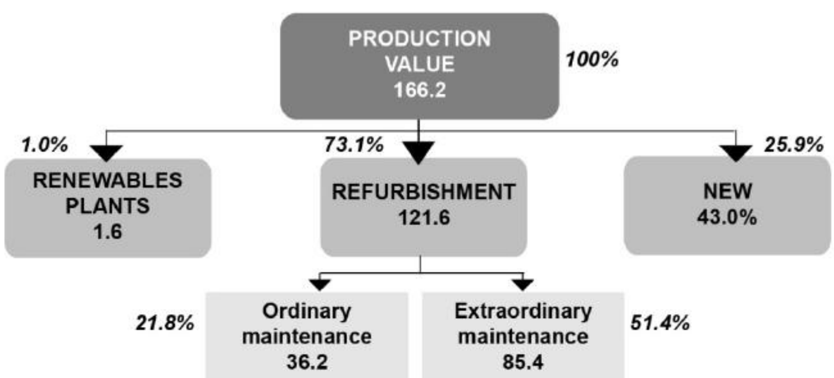

Fig. 2 Production value in construction, 2016 (billions of euro).

This is also the reason why building materials and components producers, in the last few years, showed a strong interested in refitting, implementing the number of building products designed for the refurbishment sector [8].

Many studies, for example, underline the great potential that lies beneath the replacement of windows, at the moment one of the greatest lack in thermal performance of buildings. The replacement of windows, all over Europe, could result in a significant increase of energy performance, such as fuel consumption and emission of greenhouse gases. Based upon these, many producers developed products for the refurbishment market, both new windows and frames to be installed over the old ones. For example, the market offers today PVC frame with reduced section specifically designed to be installed directly over the wood frame of existing windows, a solution that limits the invasiveness of the operation. Similarly, thermal insulator producers developed different products for the improvement of the thermal performance of the building, particularly reducing the thickness of materials. Aerogel is one of these, a material with a nano treatment that can reach very high level of thermal insulation in a few centimeters of thickness (Fig. 3).

5. Two Case Studies: Housing and Schools

The Italian housing stock is a good example of the average state of conservation of buildings, since it represents the great majority of buildings [9-11]. According to the 15th national population and housing census of 2011, buildings and complexes of buildings are 14,515,795 units, grown of 13.1% compared to 2001 census. Among these, residential units are 12,187,698 units, grown of 8.6% compared to 2001. 25% of the entire housing stock was built before 1946; in particular, 1,832,504 buildings (equivalent to 15% of total housing buildings) were built before 1919 [12] (Fig. 4).

Investments in housing, as seen, had a major decrease between 2007 and 2017 (-64.2%, estimated), turning the tide of the previous decade [4] (Fig. 5). On the other side, investments in housing refurbishment were 38% of total, confirming the trend of the previous years [2].

According to CRESME, 49.6 billions of euro in 2016 were related to extraordinary maintenance in the housing sector; again, the same study underlines that extraordinary maintenance increased, during the period between 2006 and 2016, from 38 to almost 50 billions of euro [4]. Based on this, it is possible to assume that

Fig. 3 Spaceloft®, low thickness thermal insulator with Aerogel. Producer: Aspen Aerogels. (Photo: Aktarus Group S.r.l.).

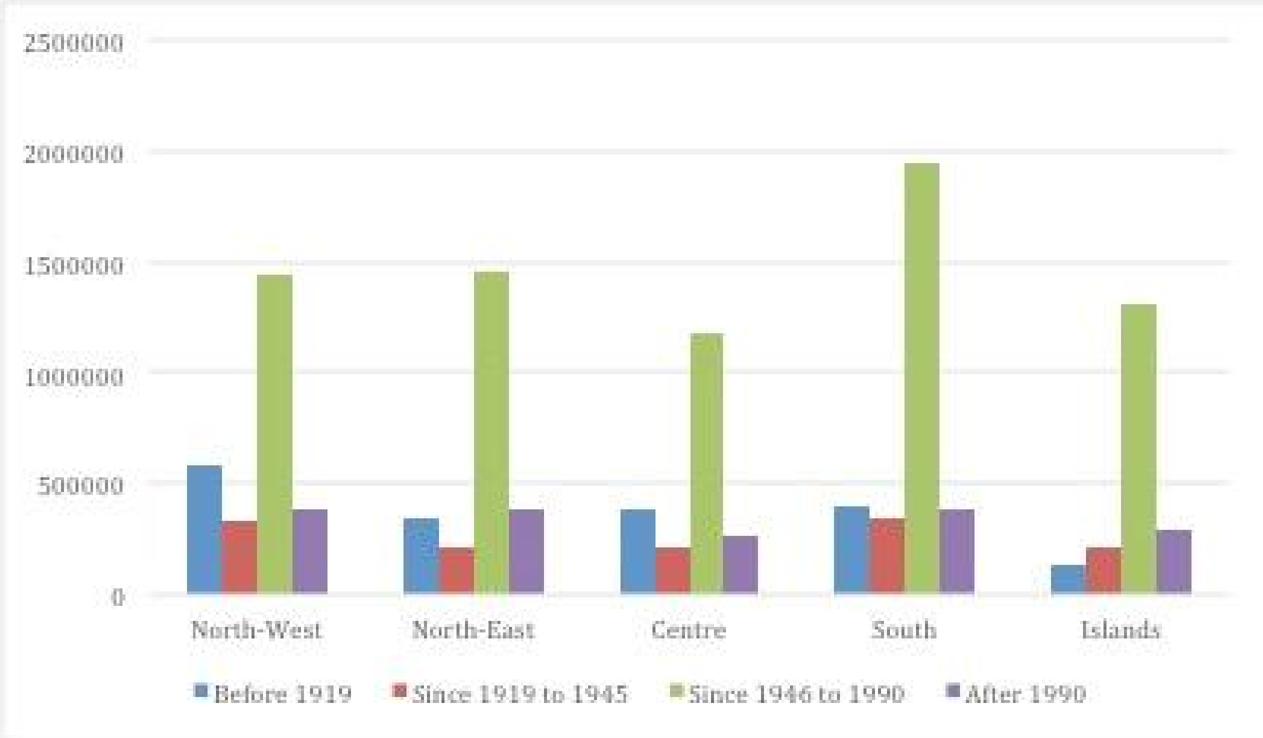

Fig. 4 Italian housing stock, age.

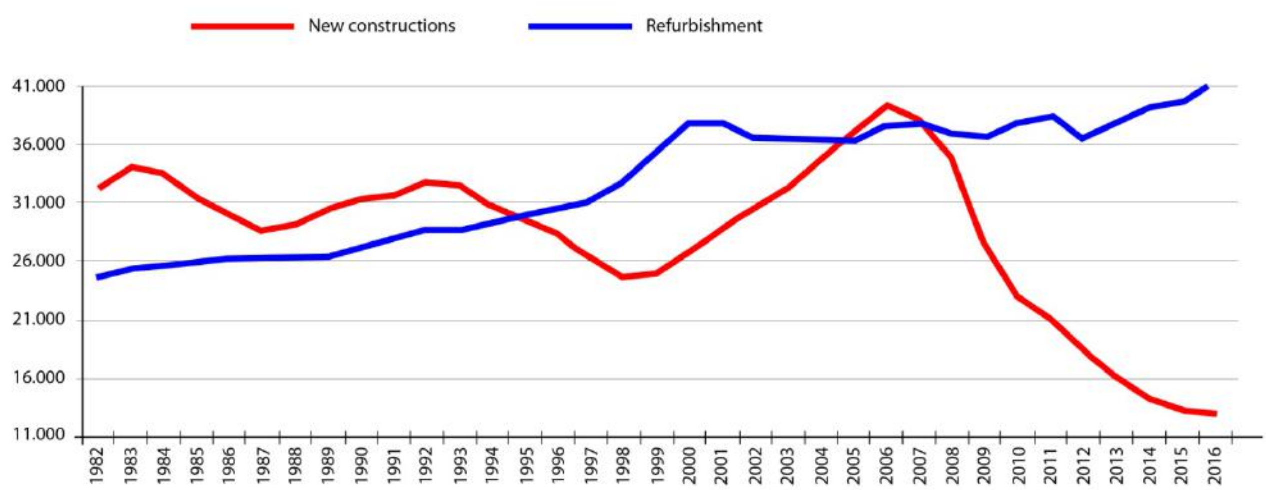

Fig. 5 Investment in housing.

refurbishment and maintenance sectors will continue to be crucial also in the next future [5] (see Table 3).

School buildings are another important sector that needs a major planning for refurbishment and improvement in energy efficiency [13]. The need for a comprehensive program of redevelopment of school buildings comes straight from the Italian Central Government: "The political agenda is built and must been built particularly on a vision and a model of society: in this case, a society where the educational system becomes the most effective leverage for the State and for citizens to achieve more important political targets: a civil growth, an economic development and a social equity. These are three tasks, starting from education, but not exclusively contained in it, that politicians can and should pursue, especially in these times" [14].

Table 3 Housing in buildings more than 40 years old, percentage on the total.

	2011	2021
Metropolitan town	76.2%	85.2%
Capital town	68.7%	79.7%

Table 4 Schools, year of construction.

Construction year	
Before 1800	1%
1800-1899	3%
1900-1920	4%
1921-1945	8%
1946-1960	12%
1961-1975	27%
Since 1976	32%
No data	14%

School buildings in Italy are, on the average, in a poor condition. According to the *Italian Anagrafe dell'Edilizia Scolastica* and some other studies (Legambiente, Tuttoscuola, Cittadinanzattiva), many factors (safety, security, energy efficiency, etc.) are not sufficient to guarantee a sufficient quality condition to users, especially for children. 55% of schools, for example, were built before 1976, which means—such as housing—before the first laws about seismic safety and about reduction of energy consumption (see Table 4).

Other important factors say a lot about the average condition of Italian schools. For example, the presence of static testing certification, which according the Legambiente only 53.7% of schools have [15]; even worse is the situation concerning the seismic safety: according to ANCE/CRESME, schools in seismic areas are 24,073, and those in hydrogeological critical areas are 6,251 [16].

Energy efficiency aspects are particularly important. Even if the use of renewable resources in school buildings is increasingly (from 13.5% in 2012 to 18.2% in 2017), and the percentage of energy obtained from renewables sources is 59.0%, the percentage of school designed using bioclimatic criteria is only 0.9% [15]. This last data is relevant to understand how much still needs to be done for the energy efficiency improvement of school buildings.

6. Conclusion: The Role of Environmental Design

Apparently, there is no need to remark the importance of refurbishment and improvement of energy efficiency in existing building at this historical moment. The deep crisis of construction sector, not yet totally over, the poor condition of building stock, both from aging and energy efficiency point of view, the emblematic examples of housing and schools, are, without any doubt, sufficient reasons and solid enough basis to establish future investment programmes, both from central and local authorities. Also, the academic and research sector could have a leading role in this trend, for example starting course of studies oriented to renovation. Data show clearly that refurbishment and maintenance activities are here to stay during the forthcoming years. Preparing future architects to a specified role—such as experts in housing renovation, or public building, etc.—could be a way to establish a permanent "task force" able to constantly work to improve energy efficiency of buildings. Especially now, when applied research on products and materials—which, as shown, are becoming more and more important in the refurbishment market—is far away from the universities and is pretty exclusive of producers.

Environmental design can surely have a major role in the coming years, especially thinking about its "multilevel" approach, even if the passage from the component (materials and construction products) to the environment must be seen not only from the dimensional point of view. If, as it is, the environmental impact a building process must be considered from a comprehensive point of view, having in mind the entire life cycle. This is even more difficult in renovation activities, where existing buildings were designed in a totally different historical context, probably with a great lack of attention to environmental problems. This can only be done in a proper way considering the building not only as a "single object" to be refurbished "piece by piece" (new windows, external thermal insulation, green roofs, solar systems, etc.), but really as part of a whole environment.

Having in mind this holistic approach, the "refurbishment era", which could be called the one in which we are living now, must be seen as a great opportunity for a radical change, where "quantity" is not only (or not *any more*, preferably) the most important target of construction sector (more GPD, more square and cubic meters, more procurement, etc.). Wide innovation programmes and a real "integrated design management" play a great role to permit better performance of buildings, from a single one (a single part of it) to the entire built environment.

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