Between Drawing and Simulation: a Digital Reconstruction of the Project for the Civic Museums in Padua by Maurizio Sacripanti

Paolo Borin, Cosimo Monteleone, Rachele A. Bernardello, Angelo Gazzetta, Carlo Zanchetta

Abstract

Which is the value of unbuilt heritage? A key point is how configurative and technological meanings enable other structures. This seems interesting to describe and analyze unbuilt heritage, from the documents and drawings, exploiting digital tools which perform historical analysis within simulation environments. From the digital reconstruction of the work, which represents the digital clone of the building as it could be, it is possible to start a series of structural, lighting and fluid dynamics analyses to examine the work according to a process here named "Hypothetical Engineering".
This study deals with the digital reconstruction of the project designed by Maurizio Sacripanti for the Civic Museums in Padua. Each simulation studied the solutions as proposed by Sacripanti, which have been compared with past and coeval construction practices and standards, to demonstrate design originality, made it possible by Sacripanti's geometric skills.

Keywords: BIM, Sacripanti, Civic Museum, simulation, Hypothetical Engineering.

Introduction

"In Padua, I designed a museum by rethinking how museums were born and where artworks used to stand. An image of the Madonna was related to kneeling, to certain gestures […] however the visitor will enjoy it, because instead of seeing one work he can see 27 of them" [Sacripanti 2015, p. 82]

This study deals with the digital reconstruction of the project designed by Maurizio Sacripanti (1916-1996) for the Civic Museums in Padua. Although this project ranked first in the national competition, occurred in 1966, it has never been built because of the critics related to the costs, that such a bold architecture would have required. Since then, the project assumed the aura of a myth and, also for this reason, it has been scarcely explored [Albisinni, De Carlo 2011]. This study proposes a reasoned re-reading of this revolutionary work by means of different interpretations: linguistic, technical and performance [Gazzetta 2016]. The research was carried out through the critical examination of the project drawings, also comparing them with the Sacripanti's general production. In this sense, this study belongs to the Italian tradition in using representation to analyze a building geometrically and functionally [Sgrosso 2000; Docci, Chiavoni 2017]. In a second phase the information was summarized within a BIM model, as a useful tool for organizing knowledge.

In this study the BIM model is not just a database that associates information to geometries, but it embodies the starting point for a set of virtual simulations involving structure, lighting and insulating devices, thermal comfort conditions, to fully understand the actual value of the project.

Independence and Evolution in Sacripanti's Drawing

Many clues suggest that Sacripanti (1916-1996) was firmly convinced that the arts had a single purpose, indeed, he attended the artistic circles of Rome in the post-war period. In the Sixties he actively participated in the neo-avant-garde movement and he was even very attentive to the music experimented in the United States by John Cage (1912-1992). In those years Sacripanti had established friendly relations with the greatest protagonist of the Roman artistic scho-

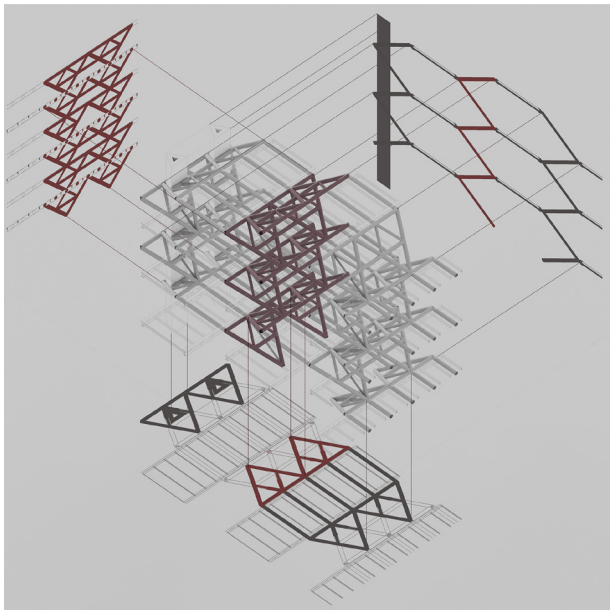
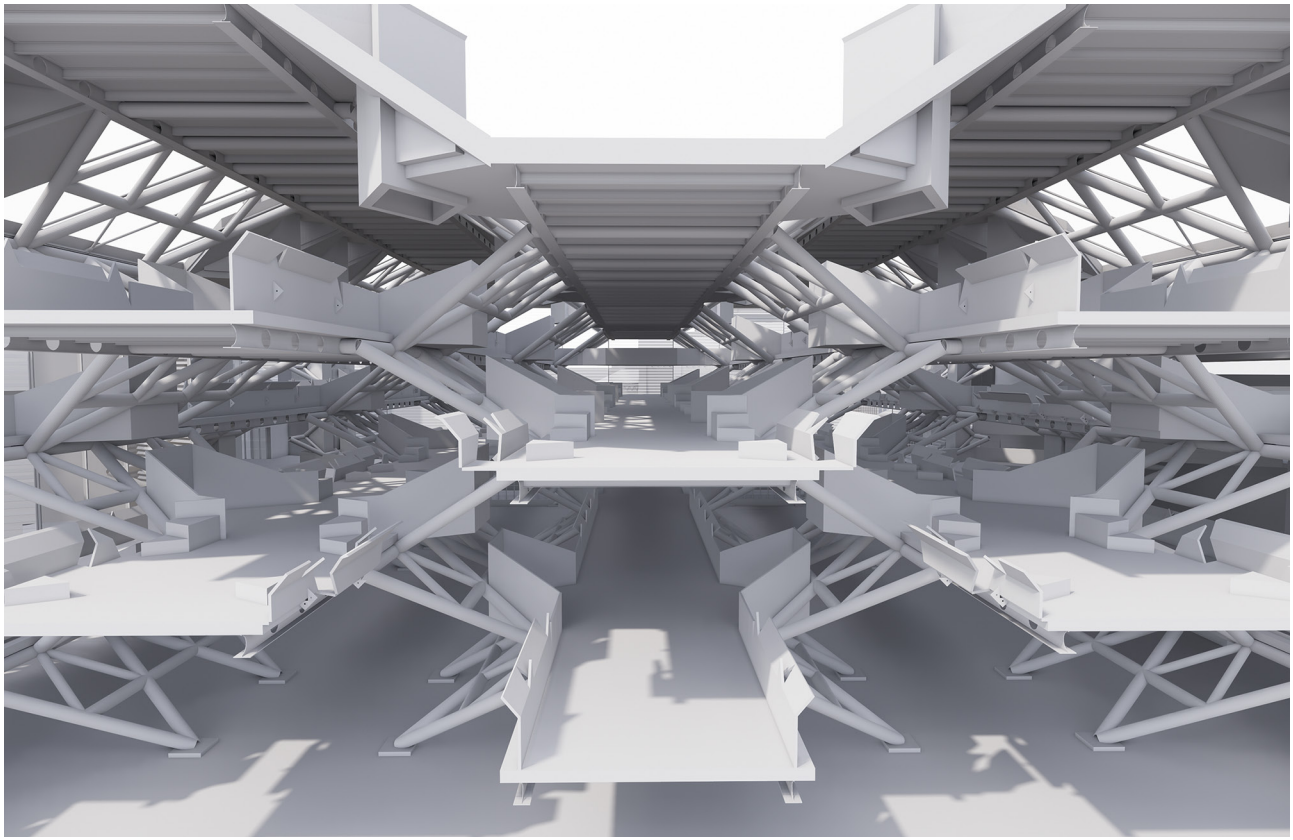


Fig. 1. Structural model: axonometric view of steel sloped abutment (Image by P. Borin).

ol, Mario Mafai (1902-1965), and with some other painters, such as Achille Perilli (1927) and Gastone Novelli (1925-1968). This brief biographical note is necessary to fully understand the primary and independent role that the Roman architect assigned to architectural drawing, intended as a tool to visualize the idea of a project.
In such a fluid and articulated artistic context, like the one that emerged in the capital in the middle of the last century, the drawings for the Eremitani museum in Padua stand out as a descriptive revolution brought into the Italian panorama of the time. The Eremitani museum is an architecture in which rationalist modularity is the basis of an *ars combinatoria* that regulates growth and evolution of the individual elements as well as of the whole. The drawings reveal a compositional procedure that orders the surfaces by repeating a lozenge-shaped module, whose translation generates a specific stratification of the graphic sign. Franco Purini, who in the Sixties began to collaborate with the master, has said Sacripanti's drawings would be interpreted not so much as a "substitute for realization, but as a parallel sphere in which his proposals lived a condition of active suspension, a condition in which they were, so to speak, present in the design culture as models that could be regained and modified" [Purini 2011, p. 36]. Therefore, the principal aim of Sacripanti's drawings for the Eremitani museum in Padua is to express at the same time a visionary attitude and a sense of strong concreteness. Indeed, his way of representing architecture has its own formal autonomy that brings his graphic expression closer to a work of art. The drawings for the Paduan museum express a precise idea, namely that the constructive audacity that the project requires to become reality is entirely possible.
On the role of architectural drawing Sacripanti has left a significant theoretical work entitled *The Pure Drawing and the Drawing of Architecture* that clarifies an aspect of his way of representing a little investigated by the critics, that is the relationship that exists between the evolution of the 'drawing skill' with the thought of architecture [Sacripanti 1953]. Indeed, with pioneering intuition he had understood in the middle of the last century –so long before the digital revolution– that drawing is not only a tool to represent architecture, but also a means of ex-

Fig. 2. Architectural model: cutout view of the exhibition spaces (Image by P. Borin).



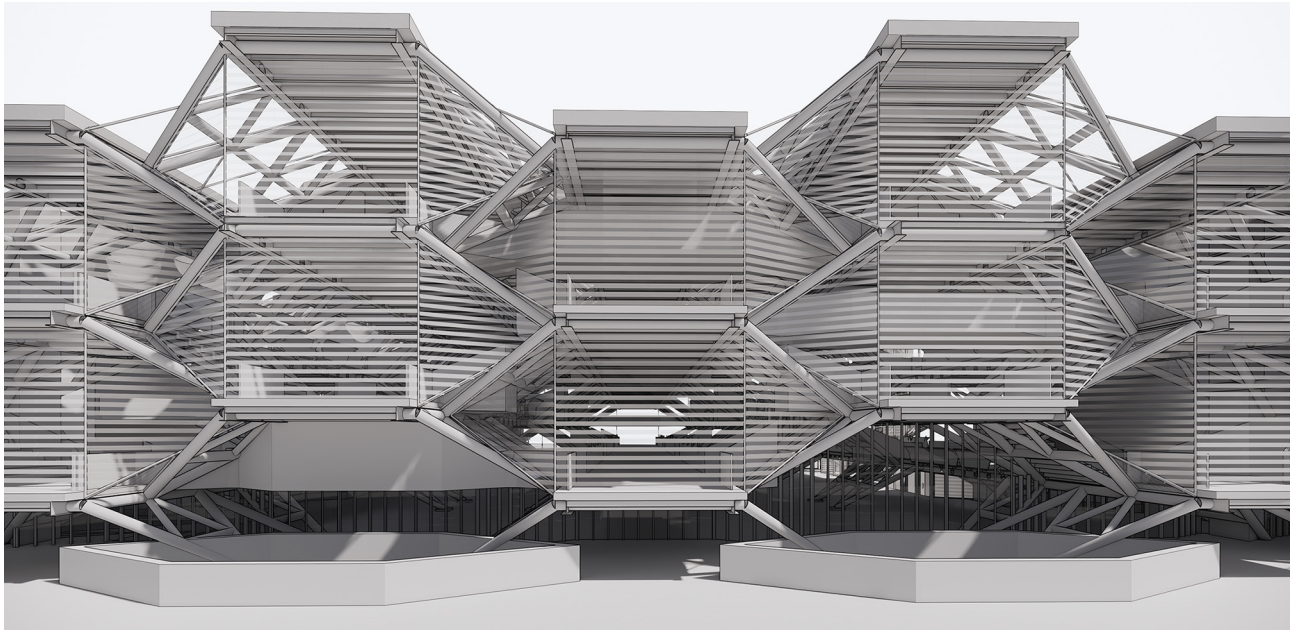


Fig. 3. Architectural model: view of the South façade (Image by P. Borin).

pression that changes over time, following historical evolution of technologies. For the Roman architect every representative technique, conceived in the evolutionary history, constitutes a different tool to represent and introduce new expressive grammars. It is in these terms that the following digital analyses must be interpreted, because the 'evolutionary times' are now mature to investigate a renewed virtual life donated to the project of the museum of the Eremitani of Padua.

BIM modeling of the Civic Museum in Padua

"Parts of elements will be prefabricated in the workshop, according to transport requirements, and assembled on site using bolted flange joints" [1]

The project for the Civic Museum in Padua represents a Sacripanti's general choice of realizing prefabrication-oriented buildings, already expressed in other design experiences. In accordance with this approach, structural BIM modelling aimed at first the definition of the components of the structure, as consecutive portals composed by trapezoidal sloping abutments, and latest the structural simulation (fig. 1). The study concerned the modeling of sub-parts of the abutments, evaluating their feasibility and transportability [Bernstein, Gudgel, Laquidara-Carr 2011]. By digitally constructing the pre-fabrication process, it was possible to define three solutions, different for the dimensions of sub-components to be welded off-site, number of bolted joints, estimating those on sight for aesthetic reasons, trips necessary to transfer prefabricated elements in construction site and auxiliary constructions useful for their assembly. In detail, a multicriterial analysis highlighted the effectiveness of a solution which minimize supporting structures.

Geometrically, the module is composed by five macro-elements: three tripods that form the main support and two V-shape elements necessary to complete the trapezoidal system. This constructive solution would have an obvious impact on the project costs and also it would influence the structural analysis.
For architectural purposes, the aim of this phase was to achieve an in-depth knowledge of the project, specifically in those issues that could have conditioned the building process. Indeed, the architectural model has made possible the study of vertical and inclined closures, floors, vertical connection such as stairs and ramps, the furniture for exhibition purposes (fig. 2). The design of the facades is a series of inclined surfaces, alternately upward and downward, respectively opaque and transparent, in order to avoid the direct solar radiation. The complexity of these elements should not be underestimated: while the façade at the conclusion of the "bridges" is vertical, some parts follow the geometry of the trapezoidal structure, making installation of the surfaces particularly difficult (fig. 3).
A second element of the design analysis was the furnishing system designed by Sacripanti, according to a "parametric" scheme based on folding components. These elements, becoming at the same time railings fulfill the aesthetic function changing the internal spaces, and the exhibition role as support of the art pieces. The case study allowed to construct a BIM library of Sacripanti's objects, as a replica of design drawings, in which seven wooden panels are described with triangular, rectangular or trapezoidal base. They are then assembled in three different configurations, thanks to hinges with triangular section: if the first guarantees the exposure of small objects, possibly becoming a seat, the second and the third are coupled with steel elements for the display of the artworks. Sacripanti completed the exhibition experience by diagrams as "*invasi adatti ai vari tipi di allestimento*". Each diagram consists of a set of the three configurations described above: it is sufficient to assign a quantity take off to each scheme to obtain the overall control of costs. In this sense, the BIM model replicates the computation method described by Sacripanti. Within the drawings for exhibitions setting, the designer specifies a potential ventilation system, choosing to integrate building elements. A steel square section distribution duct is anchored, thanks to steel flanges, to the HE400 longitudinal beams that connect the trapezoidal structure. In this case, the duct is rotated by 45° in order support, geometrically and statically, the triangular hinges of the parametric furniture system (figs 4, 5).

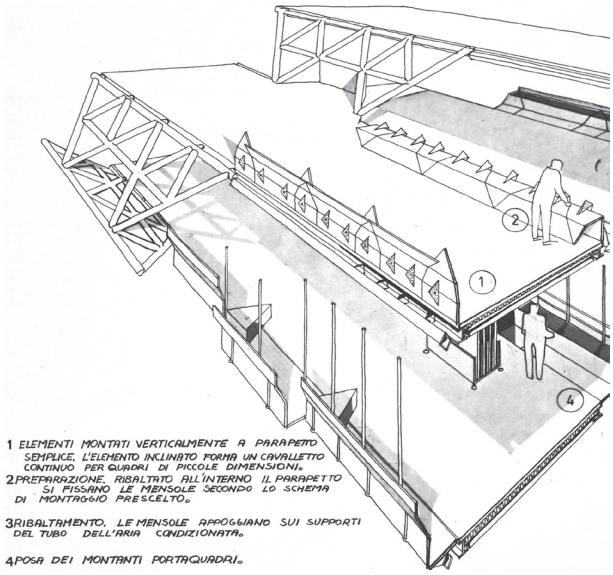


Fig. 4. Assembly of the wooden exhibition systems (Sacripanti 1973).

The evolution value of information modelling in the modular method to the design

The Sacripanti's design language, based on the reiteration of the integrated technological components, finds an ideal actualization, by the technological and methodological point of view, in an interdisciplinary information model translation that have the ability to highlight the technological limits of the propose and the organizational and implementation aspects that this underlines.
The project points a possible develop of a design language based on modular component with mutual

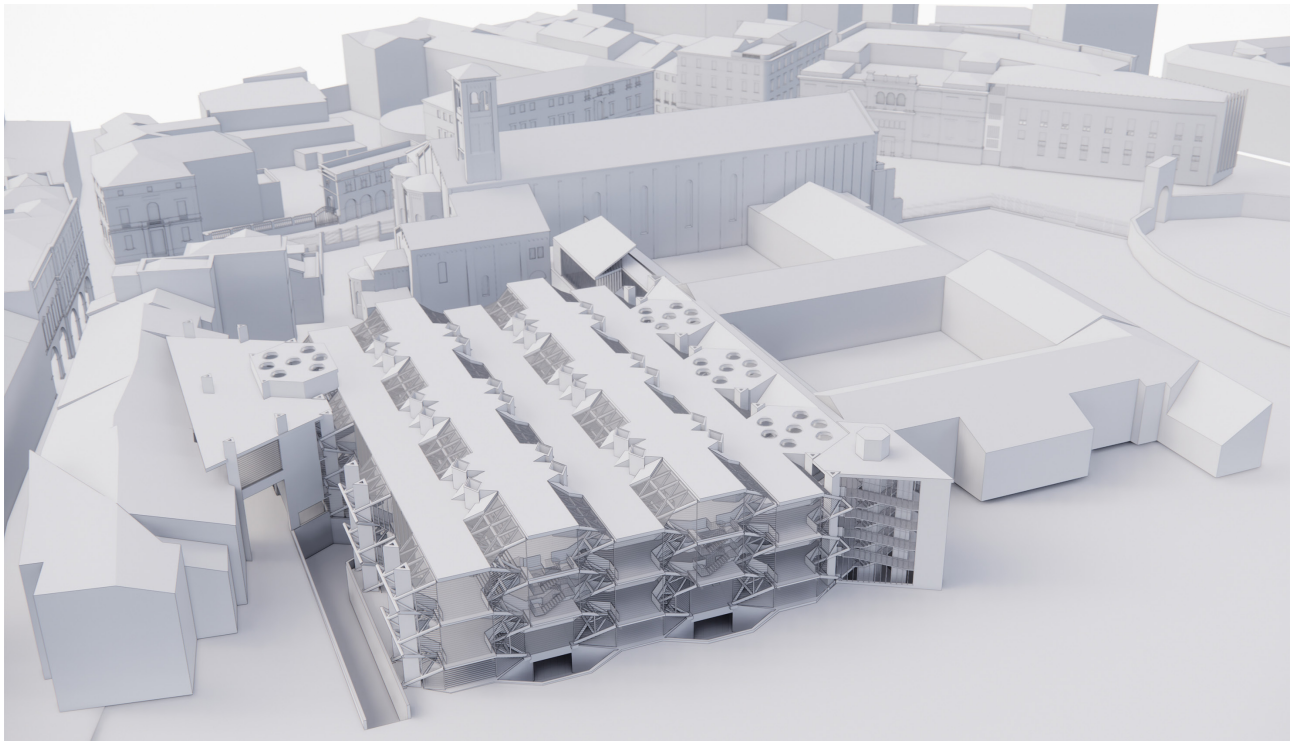


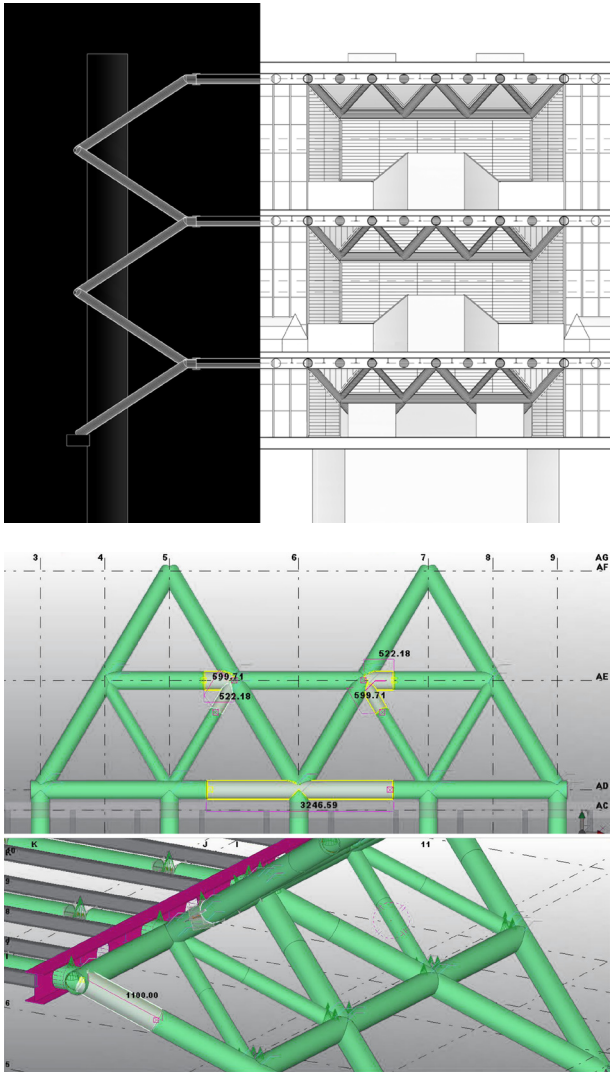
Fig. 5. Bird view of the urban landscape in Padua (Image by P. Borin).

behaviour, which enriches architecture rather than depleting it.
This operation, in addition to having a disciplinary historical value, allows to develop a reflection on the value of the prefabrication and modular design, as well as on the potentiality of the Building Information Modelling as an investigation instrument of the project.
The spread of BIM favoured the diffusion of prefabrication systems in the building process: since the BIM favoured an approach to design oriented directed to the definition of systems and subsystems, objects could easily assembly in prefabricated parts of work [Sacks, et al. 2011]
At the same time this leads the necessity to design in a sustainable way and with LEAN methodologies, adopting procedures to check performance and the quality of the process. Even if the main stakeholders which benefit from the implementation of this method are the building companies, the real purpose of this innovation is the achievement of a sort of custom prefabrication also named mass customization [Thuesen and Jonsson 2009]. This approach sees in the development of variable and variously integrated components the possibility of placing customized products on the market based on industry production, promoting better quality, cost reduction and a consequent greater marginality.
By favouring a design based on parametric models of technical elements, BIM significantly supports an approach of this type. [Nawari 2012] The parametricity of these components makes explicit the rules

that derive from their production [Singh, et al. 2015] allowing for customized modelling, but at the same time oriented towards standardization. [Van Nederveen, et al. 2009]
It is interesting to evaluate, through the informative modelling of Sacripanti's design, how its architectural language makes explicit the potential mentioned, in an era in which assisted design did not yet exist.
From this consideration connected to the methodology and operational instrumentation relating to precast-oriented projects, another more important assumption follows, namely that all the benefits brought by prefabrication can be enjoyed only if this is spread over the entire construction process. Ensuring the transfer of the project and the information system to the implementation phase means thinking through construction processes or implementing what MacLeamy calls Building Assembly Modeling or BAM [Thomas, et al. 2015]. This goal raises questions that address the current limits of interoperability in the construction sector operating on IFC by introducing the theme of the connection between BIM and Product Lifecycle Management (PLM) [Jeong et al. 2009]. Although IFC is a very rich scheme, it is not an appropriate format to transfer specific data related, for example, to the manufacturing sector. Moreover, facing the challenge of the information integration means thinking of information exchange standards between different platforms or, in legal terms, defining an IDM (Information Delivery Manual) that describes the component construction processes, to be able to regulate the integration processes information to the variation of the digital models that represent them.
These are the themes underlying the digitalization exercise of a radical project as Sacripanti's one. The availability of an information model has in fact made it possible to highlight some essential aspects of the architectural project in relation to its conformity and its buildability.
From the point of view of compliance, the availability of an interdisciplinary model allows us to understand how that type of architecture in that historical phase represented sometimes excessive challenges compared to the available knowledge to designers

Fig. 6. Longitudinal section. Assembly of beams and vertical elements highlighted (Image by A. Gazzetta).

Fig. 7. Structural model: hypotethical steel connections in Trimble Tekla (Image by A. Gazzetta).



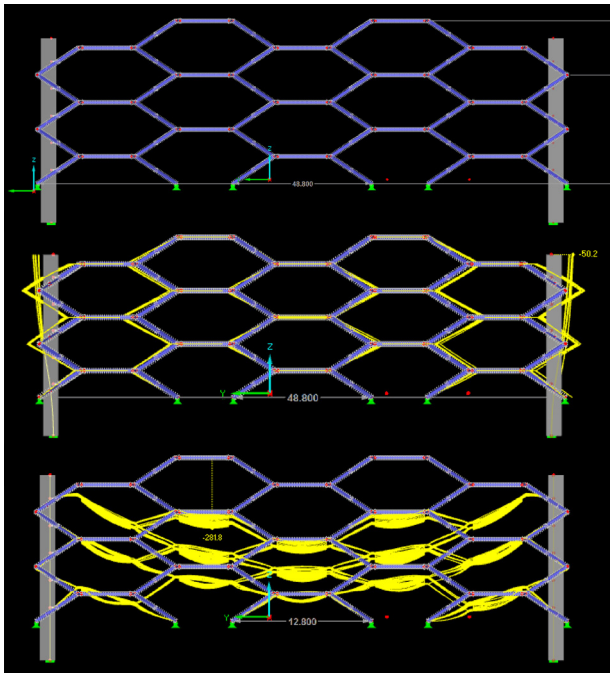


Fig. 8. Structural model: structural analysis model in Dlubal RFEM. Vertical and horizontal displacement (Image by A. Gazzetta).

and installers. In fact, the project exposes, in addition to the lighting and thermo-hygrometric limits highlighted in this article, also a problematic structural approach.
At the same time, in the constructability way, the definition of the assemblies and the respective interfaces determines technological issues that cannot be referred to the manufacturer since, precisely as a function of the definition of the technological interfaces, the design limits highlighted by the analysis are resolved on the compliance of the project.
The structure is thought as a series of identical reticular metal trestles superimposed on staggered modules. Each module unloads the weight, of the afferent deck, on four support points. The first deck is linked to the ground, while the levels above unload, in staggered floors, onto the lower levels. The pattern that is generated is that of a reciprocal structure in which the horizontal forces are gradually compensated by the presence of the underlying decks or by the perimeter buttresses (figs. 6, 7).
The structural analysis show that the proposed solution suffered from two substantial problems:
- the static scheme of the overlapping trestles highlights lability problems if the nodes of the single trestle were not designed to constitute a rigid internal constraint;
- the buttress system was not sufficient to limit the maximum displacement required by law (fig. 8).
Both the problems highlighted are answered in the production processes of the trestles as:
- the division into prefabricated segments allowed to resolve the internal lability by being able to act directly on the welded joints in order to create the node continuity;
- a subdivision into segments that placed a joint in correspondence with the catwalk - impost node would probably have prevented being able to correct the critical points previously highlighted.
Three possible solutions of simple components have been identified, intended as sub-modules that could compose the typical frame module respecting the design parameters (fig. 9):
- type 1: subdivision of the impost into flat segments of beams with horizontal development;
- type 2: subdivision of the trestle into segments which maintain the continuity of the node between the imposts and the deck;
- type 3: subdivision into jointed segments in the connection between the impost and the floor deck.
For the evaluation of the best type of assembly, it has been hypothesized to evaluate qualitatively on a scale from 0 to 3 the main characteristics that influence the design of prefabricated components. In addition, a weighing criterion was adopted that allowed to increase or decrease the constraint level of each parameter. It has been considered to adopt a coefficient 2 for exposed joints and for forecast structures.
A coefficient 1 was maintained for the number of trips, while a coefficient 0.5 was assumed for bolted joints. This type of proposal is taken in a qualitative way to allow for a scale of importance, of course the weighing could be varied according to the needs of the client, the designer or the manufacturer.

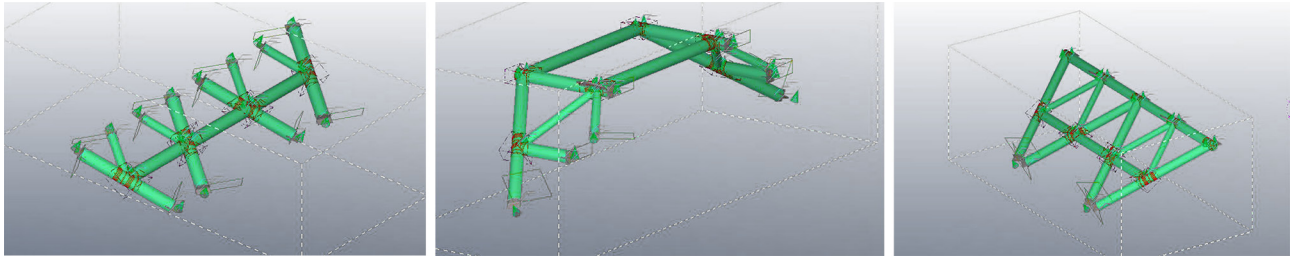


Fig. 9. Construction model: steel assembly hypothesis 1, 2, 3 (Image by A. Gazzetta).

Assembly	Type 1	Type 2	Type 3	Weight Criterion
# bolted joint	0	2	3	0,5
# trips	3	0	1	1
# forecast structures	1	3	0	2
# exposed joints	0	1	3	2
TOTAL weighed	5	9	8,5	

The best proposal for the structure assembling, according to this weighing method, is the second one, because it has the advantage of not needing forecasting works. There are also a few bolted joints to be fixed on site. It should be noted, however, that if in another way of weighing the aspect of the number of trips was considered more binding (especially given the important cost of exceptional transport, compared to the forecast works), the solution 3 would be the best one, but it would have exposed important criticalities in terms of the general static scheme.

MEP performances in the project of the Civic Museum

The design solution of Sacripanti for the project of a museum, raised some doubts regarding its feasibility, especially about the functional and MEP aspects. In the analysis of the project, a part was dedicated to the aspects that even then were critical, adopting the information modelling process that link the architectural, structural and MEP design to the possibility of simulating the performance of the building during its operating phase.
In the project of a museum and an archive it is important to find the balance between the thermal comfort and the energy reduction through the optimization of the HVAC systems, the conservation needs the interior comfort and the conservative standard [Karmann, Schiavon, Bauman 2017]. The implementation of lighting (fig. 10) and fluid-dynamics simulations for the civic museum project, inherent to the internal microclimate conditions, has allowed to increase the awareness of the project, starting also from the few available documents. Furthermore, the BIM project allows to face a second question, centrality today, related to the management of

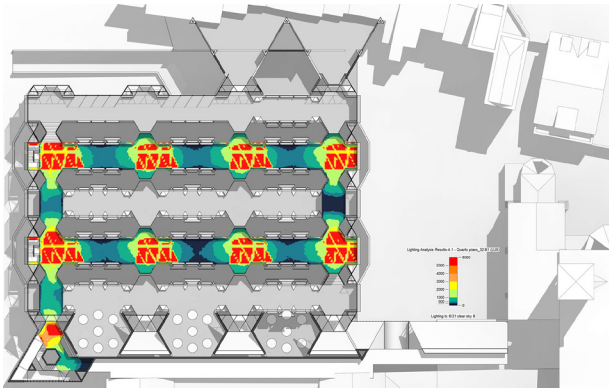


Fig. 10. Architectural model: cumulative illuminance analysis at summer solstice (level 4) (Image by R. A. Bernardello).

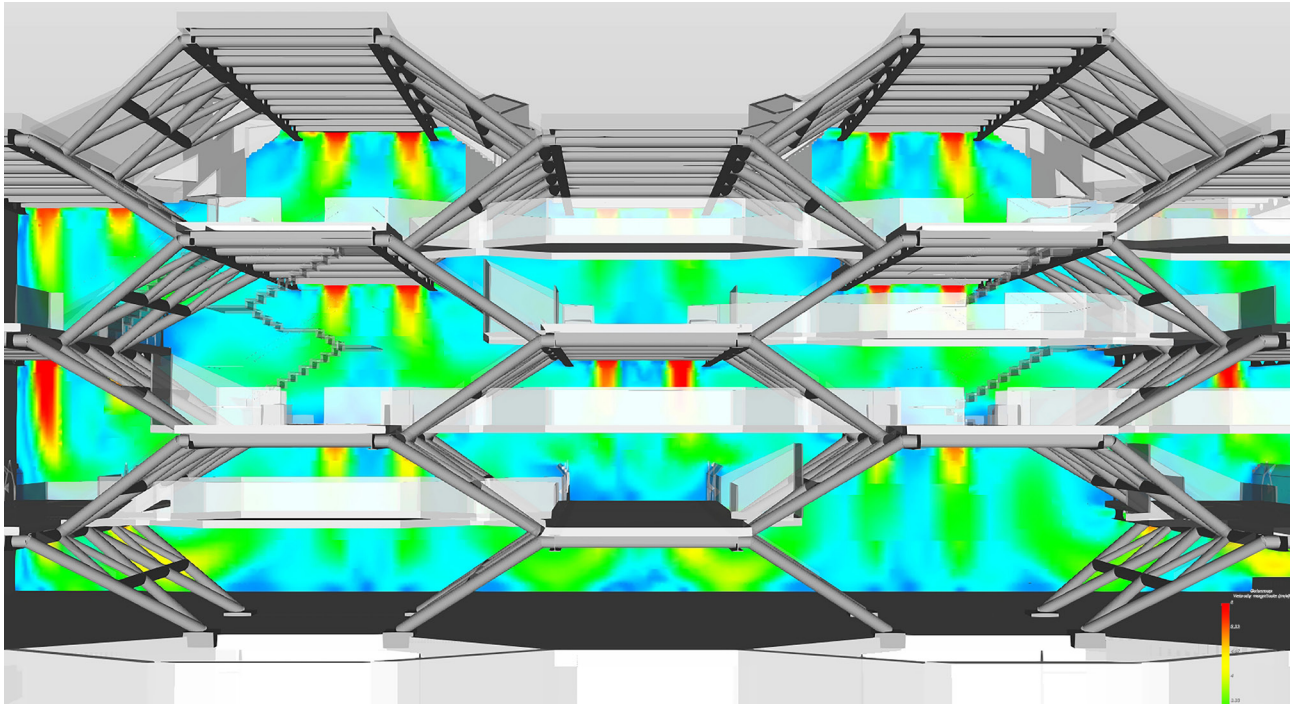


Fig. 11. CFD model (summer): cutout view. Airflow velocity (m/s) (Image by R. A. Bernardello).

the prefabricated MEP systems in the architectural project for complex building, to guarantee the performance described above.
The variation of the external environmental conditions, the age of the buildings, the number of visitors, the lighting are the main external factors that can influence the fast deterioration of the artworks in the museum. The main features of the building are significant to argue the two themes defined above. It is in fact a succession of linear spatial-functional elements, supported by a hexagonal "bridge" structural module, which are placed jointly in a single project environment. The use of large glass surfaces even inside, of which the designer was called to provide more details in a report about the adopted solutions, makes the MEP engineering solution even more critical [2].

The design requirements of an air conditioning and heating system and the use of materials were critically analysed, to make lighting and fluid-dynamics simulations more reliable, in particular for glazed surfaces (translucent double athermic glasses for ceiling skylight, horizontal opaque plastic strips facing upwards and alternating with transparent strips facing downwards, for the vertical walls), within the BIM process it was possible to exchange information between the two types of simulations by implementing the setting of parameters in the CFD analysis with the data obtained from the lighting simulations, in particular relating to the radiation on the ceiling skylights and the floor (figs. 11, 12).
The project of the MEP elements, the clash-detection, the computations of the elements and the preparation of the mechanical model, are some of the

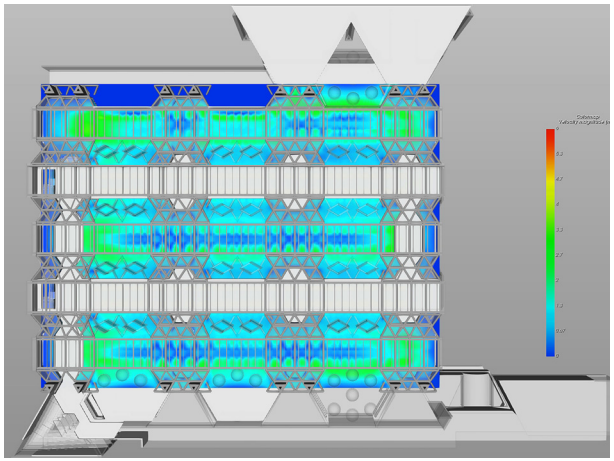


Fig. 12. CFD model (summer): plan (level 3). Airflow velocity (m/s) (Image by R. A. Bernardello).

actions that in a BIM approach would have been tested to guarantee the correct feasibility of the project. The evaluation of interior comfort conditions according to the system designed by Sacripanti, which included an air heating and cooling system, was implemented in the CFD environment. The inserted information and objects represented the starting element of the simulation, but it was useful to work on the project to assure the current standards of regulation and the correct performance of the MEP-system. The case study therefore envisaged the sizing of the operative parameters of the MEP-system, such as the air speed inside the pipes and the height of the rooms that effect the speed of air flow in the rooms.
The BIM model appears to be a useful environment in which the standardization of the MEP elements meets the architectural forms already in the design phase in order not to be a limit, but a tool to guarantee the optimal performance of the building, the interior comfort and the balance between functionality and economic resources' management.

Conclusions

This study is inspired by the "evolutionary theory" of the representation of architecture, formulated by Sacripanti in its theoretical work on drawing and actualizes, although only virtually, the unbuilt project Civic Museum in Padua. It highlighted an easy conversion of the project into BIM modelling, particularly the specification of its structural and spatial components and museum devices. The in-depth study of the first led to a specific design solution. On the other hand, some issues have been highlighted: thermal comfort is difficult to reach in a one-space solution, as well as achieving lighting and acoustic requirements of museum environments.

Credits
The introduction is written by Paolo Borin, the paragraph *Independence and Evolution in Sacripanti's Drawing* by Cosimo Monteleone, *BIM modeling of the Civic Museum in Padua* by Angelo Gazzetta and Paolo Borin, *The evolution value of information modelling in the modular method to the design* by Carlo Zanchetta and Angelo Gazzetta, *MEP performances in the project of the Civic Museum* by Rachele Angela Bernardello.

Notes

[1] AMCPd, Titolo 12, b. 229, *Relazione tecnica di progetto di Maurizio Sacripanti.*

[2] AGCPd, Fondo LL.PP. ex-Mazzonetto, serie 1 Edifici storici, piazze e monumenti, b. 5, Relazione Sacripanti ed allegati. Lettera Aerotecnica Marelli Milano 06/02/1968.

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