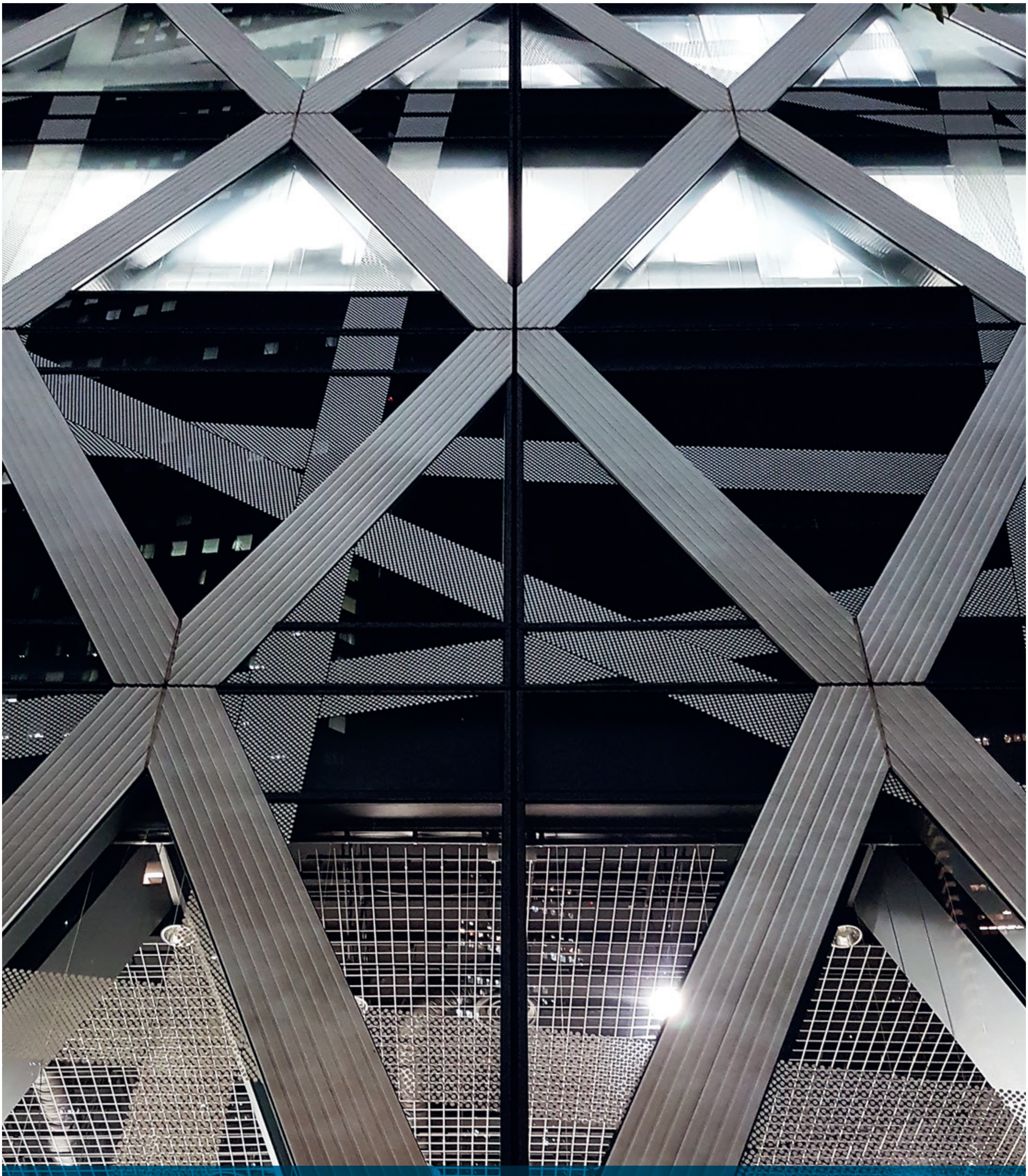

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CONSTRUCTION AND ITS INTERCONNECTIONS

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Cover illustration: Mode Gakuen Cocoon Tower in the Nishi-Shinjuku district (Tokyo, Japan) by Kenzō Tange, external view. © Riccardo Gulli, 2018

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DIGITAL TECHNIQUES TO ENGINEER AND BUILD A LARGE SCULPTURE IN HERITAGE PUBLIC SPACE

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Abstract

Planning and realising a large sculpture in a heritage public space requires succeeding in diverse, sometimes contrasting, multidisciplinary objectives. This paper reports on a research project developed to support the communication, engineering and construction of a permanent sculptural masterpiece within the public historic centre of Rome. While the entire process of creating the art piece is explained, the main emphasis is on the experimental application of various technologies such as Ground Penetrating Radar (GPR), Laser Scanning, Virtual Reality (VR), Parametric Modelling and Numerical Simulations. These technologies were utilised due to the size of the sculpture and the peculiarities of the context. The primary focus of this study is to develop and implement a workflow that can enhance collaboration and efficiency among stakeholders like artists, clients, engineers, urbanists, archaeologists, art foundry fabricators, and public authorities. The project adopted an action research methodology because of its strategic ability to connect experimentation and practice in order to address a realistic cross-disciplinary problem in its actual context.

Keywords

Multidisciplinary collaboration, Virtual reality, CAVE, Art engineering, Digital heritage.

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1. INTRODUCTION

This paper reports on a research-to-practice project to support the communication for visualising, engineering and realising a large sculptural masterpiece in the public historic centre of Rome. The sculpture is permanently installed in Largo Goldoni, on the main axis of the Spanish steps.

While the entire process of creating the art piece is explained, the main emphasis is on describing the experimental application of different technologies such as Ground Penetrating Radar (GPR), Laser Scanning, Virtual Reality (VR), Parametric Modelling, 3D Printing, and Numerical Simulations to solve the non-standard problem regarding the technical feasibility of the artist's concept. The adopted technological pipeline demonstrated the successful completion of the tasks required by the scale of the object and the multiple constraints of the location, overcoming the resource-consuming uncertainty typical of the traditional methodology.

Due to many existing stakeholders and regulations oriented to ensure the safety and preserve the cultural values of the place, the following boundary conditions generally apply in comparable cases:

- seismic requirements;
- foundation in a highly installed underground supply system;
- archaeological constraints in a very significant area;
- restrictions on visual impacts in a preserved landscape;
- distance from surrounding facades/buildings/car lanes;
- distance from lighting wires and clash prevention for *in situ* casting;
- clearance to existing traffic signs and vehicles on adjacent streets;
- tight timeframe due to scheduled unveiling events usually being participated in by authorities.

The field of investigation is to explore how the use of digital tools and virtual reality in modelling, simulating and developing sculptural components for artwork might enhance collaboration and streamline the workflow among artists, clients, designers, architects, engineers, urbanists, archaeologists, art foundry fabricators, and public authorities.

An action-research methodology was adopted for this project, chosen for its strategic ability to connect research and practice in order to solve a practical problem in its real-life context. By means of a complex case of study, a comparison between traditional and enhanced workflow was developed to provide and prove a generalisable methodology for optimised implementation in comparable cases.

2. STATE OF ART AND CHALLENGES FOR IMPLEMENTATION

2.1. STATE OF ART ABOUT DIGITAL TECHNIQUES FOR ART

Over the last decade, there have been significant developments integrating digital technologies into the experimental creation of exhibition artefacts [1–6], although very few of them were designed and tested for permanent installations [7–9]. A brief review in Table 1 shows where the state-of-art has reached with digital tools for designing and tailor-building large artefacts.

In the realm of monumental public art, employing new technology as digital support for designing and manufacturing is a diverse spectrum that can boost creativity, precision, and expedited production, always based on *ad hoc* processes oriented to a new, unique prototype.

In the scientific literature, there is very poor documentation regarding specific descriptions and exploitation of project details for the technical feasibility of large works of art, although many existing masterpieces are standing in museums, gardens and even in urban spaces.

2.2. TECHNICAL CHALLENGE: GENERAL CONSTRAINTS OF EXECUTION PHASES

Going beyond the artistic unicum of each case, including the one presented in this paper, the development of technical design, including the quantitative-qualitative control and evaluation of a large sculpture artwork before its construction, must face, more in general, two main project-dependent categories of complexity: size and context.

2.2.1. SIZE DEPENDANT CONSTRAINTS

The size of the artwork imposes a sophisticated concept and performance evaluation oriented to overcome many different, contrasting, multidisciplinary goals and constraints. To name the most relevant:

- structural system behaviour, including foundations, to ensure static and seismic performance and obtain authorisation from the Local Civil Engineering Department;
- coherence for sub-systems production both, set of components in the foundry laboratory for the above-ground parts and in the installation site for the foundations;
- transport of the sub-systems, including anti-terrorism or local restrictions for long vehicles, and their assembly and finishing in opera.

2.2.2. CONTEXT DEPENDANT CONSTRAINTS

The context of the installation, generally located in historical venues, imposes constraints, mainly oriented to

3D Modelling	*CAD Software*: For making complex 3D models of sculptures, software like 3D Studio, Rhino or SolidWorks are used to allow artists and designers to model and optimize their designs digitally before physical manufacturing [10].
	Parametric Design: Allows artists/designers to create intricate, rule-based geometries (e.g. in Grasshopper). Users can easily modify these geometries by changing the parameters [11].
3D Scanning	*From Existing Models*: Maquettes geometry is captured with 3D scanners to obtain point clouds/meshes capable of including up to fine details if necessary [12].
	Site Analysis: Using various scanning technologies, the site is collected as a reference for placing the virtual artwork into its context to ensure it will merge within any environmental or architectural constraints.
VR/AR (Virtual and Augmented Reality)	*Immersive Design*: Utilising VR and AR technologies, this technique allows the artist to immerse himself into a 1:1 visualization of how their artwork appears in its full context and helps to understand scale, proportion and spatial relations [13].
	Interactive – Mixed/Augmented Design: These technologies enable to modulate design in real time and offer instantaneous feedback, encouraging exploration, collaboration and decision-making during the design process [14].
Digital Fabrication Techniques [15]	*3D Printing*: Is used for prototyping and sometimes as final production. It permits making complex shapes which are difficult or impossible to produce using conventional methods.
	CNC Milling: Use of CNC machines to curve sculptures or parts thereof with accurate detail.
	Laser/Water Cutting and Engraving: It cuts thick depth and can either cut or engrave patterns on materials, allowing for detail work to be added onto the massive sculptures.
Robotics [16]	*Assembly Automation*: Robots/drones can play an important role in automation of the assembly process for large installations containing multiple components.
	Robotic Arms: Consists in attaching of different tools, used for automating the fabrication of massive parts that make up sculptures.
Algorithmic Design and Artificial intelligence	*Algorithmic Design*: is an approach to define and explore broad set of possible solutions considering criteria such as strength usability, structure, aesthetics or material consume [17].
	A.I. integration: AI can enhance, in terms of progressive optimization, designs for material, structure and cost. AI-powered tools can furthermore help to generate new shapes.
Digital Twins and Monitoring [18]	*Digital Twin*: is a model implementation and build of a computable replica of the sculpture for regular monitoring and maintenance. This digital copy can be used to simulate environmental and context impact or progressive degradation over time.
	Sensors and Internet of Things (IoT): Include sensors within the sculpture to give live data about its condition, for example, knowing when actions might be required.

Tab. 1. *Synthesis of digital tools used to support designing and tailor-building large artefacts.*

preserve the stratification of cultural values and ensure the population's safety. To name the most relevant:

- archaeological constraints regarding the digging for the foundation plinth and, eventually, the drilling of micro-piles;
- landscape constraints imposing the main size of the work with the obligation of testing the impact of the sculpture versus the surroundings;
- local urban regulations regarding, e.g. the distance from adjacent facades, buildings, car lanes, traffic signs, etc.;
- interference with the existing lighting wires, distance checks for the body of the sculpture and the crane trucks during the construction phase;
- interference with underground supply service systems (electrical cables, water pipes, gas, telephone, internet fibre, ancient aqueduct, etc.).

Inevitably, using traditional methods, due to the mentioned limitations, is not feasible to achieve a successful realisation according to a preliminary scheduled timing. At present, the realisation of this kind of artwork implies a relevant and unpredictable increase in time and costs in most cases.

The present paper – extending and integrating a previous short memory by the authors [19] – provides further technical details of the implemented digital workflow, a synthesis of post-project interviews, including a case-based critical discussion about the support this typology of non-standard projects/processes provided and, more in general, can provide.

3. CASE OF STUDY GENERAL FRAMEWORK

3.1. PRELIMINARY PHASES

As part of the redevelopment of the Largo Goldoni area, Fendi, a fashion company based in Rome – known for its many involvements in cultural patronage – has promoted a project to install a contemporary work of art donated to the Municipality. It was located in an area previously occupied by a newsstand and downgraded as a kitsch souvenir shop, negatively impacting the historical surroundings.

A mixed selection Committee was established, composed of the General Directorate of Contemporary Art and Architecture, the Capitoline Superintendence of Cultural Heritage, and Fendi, to select the most appropriate work of art. The art curator Massimiliano Gioni proposed a shortlist of project applications made up of internationally renowned artists, which the Committee examined.

For the initial phase of the project, the authorization process was as follows:

- the Committee chose and approved the work of Maestro Giuseppe Penone, conceptual artist and key exponent of the '70 Poor Art movement [20, 21];
- the National Directorate of Fine Arts and Landscape issued a favourable judgement on the project;
- the General Directorate of Contemporary Art and Architecture, the Capitoline Superintendence of Cultural Heritage, and Fendi signed a *memorandum* of understanding for the implementation of the project;
- the Superintendency of Fine Arts and Landscape of the Municipality of Rome issued a preliminary authorisation for the work installation, with numerous requirements and restrictions for the final release;
- the Special Superintendency for the Colosseum and the Central Archaeological area of Rome issued the authorisation to carry out the integrated survey for the archaeological investigation of the site and the geological evaluation of the ground for the foundations of the sculpture.

3.2. THE ARTEFACT ANATOMY

Superintendency of Fine Arts and Landscape of Rome states: «Giuseppe Penone's work, titled *Foglie di Pietra*/Stone leaves, constitutes the most important contemporary artistic intervention in the historic centre of Rome». It consists of the artistic transposition of two real trees, moulded and then cast in bronze, between

Fig. 1. *Real tree (left) to be transferred into the artistic art piece (right) VR-visualization with colour coding.*

whose bare branches a block of sculpted marble is placed, with explicit references to Baroque Rome in the choice of materials. Small bronze elements depicting architectural fragments from the classical and medieval eras are distributed among the thinnest and tallest branches [22, 23].

The artist selected the higher tree (18 m) from the forest near his backyard, and the other one (9 m) already existed as a bronze sculpture, stored in his warehouse from a previous experimentation. The trunk and branches are supported by a stainless-steel core structure, hidden from view, and covered by bronze skin. Most challenging is the integration of a large *Carrara Statuary* marble block, approximately 3.5 m x 1.5 m x 1.5 m, weighing 11.4 tons, with veins, sculpted on the basis of the conceptual principles of Maestro Penone, placing it between the branches on a height of approximately 5 meters above the public pavement (Fig. 1).

The internal structure, composed of tubular elements that vary in diameter, thickness, and length, is covered with a layer of bronze at variable thickness with an internal tolerance for hosting the structural component. Two circular stainless-steel plates as the base for each tree were preassembled and attached in the Foundry workshop to be screwed to the foundation works, realised *in situ*. The heavy marble block is located on 4 solid pins of 120 mm diameter that are fixed to the structure.

The work is completed by the stone leaves, some additional sculpted blocks, distributed among the offshoots of the thinnest branches and placed at higher altitudes, with weights of a maximum of 70 kilograms.

3.3. ARTWORK DEVELOPMENT PIPELINE

The development pipeline can be described as the following phases:

1) artist concept and rationale: recognition of authentic trees;
2) discretisation and cataloguing of finite components;
3) fabrication of moulds and casting of components;
4) acquisition of accurate geometrical and photorealistic information of both the components of the artworks and the installation context;
5) create a digital reconstruction of a three-dimensional model of the final product placed inside the given context;
6) conducting tests and making modifications to the artwork within a fully immersive virtual environment;

7) production of a three-dimensional detail model for architectural and urban representation and assessment;
8) development of a 3D computer-aided engineering (CAE) model for conducting structural analysis.

Phases 1-3 were initially conducted using traditional analogue methods; however, it became evident to all participants that the project could not be completed within the scheduled time due to various limitations and many technical constraints, as discussed in the following sessions.

At that moment, the first author received full responsibility for the technical control of design development, approvals, site supervision, testing and project management. He started interviewing the artist to collect information about the methodology he was used to adopt in his previous works. Unfortunately, the artist had not constructed masterpieces of comparable complexity up to that moment.

Actually, this project has far more intricate boundary conditions than previous projects of similar nature (e.g., "Ideas of Stone"/*Idee di Pietra*). They had a minor scale of loads and dimensions, nor were they intended for a permanent installation in a public space; these conditions introduce more restrictive requirements [24]. After reviewing the typical making-of process, the author realised that the artist was used to optimise the design of the artistic trees directly within the foundry. The individual bronze pieces and necessary interior structural elements were modified according to the artist's direct instructions in the factory at a 1:1 scale – by highly skilled operators. This involved using heavy lifting, welding, and cutting in a laborious and highly resource-consuming manual procedure.

So, at the end of phase 3, the design documentation consisted of a few concept sketches drawn by the artist's hand, identifying the global dimensions of the artefact. However, no detailed geometrical information was available to develop the following mandatory technical control of the work.

Consequently, the paper authors team has been constituted, aware that a specific *ad hoc* digital workflow had to be developed to support the non-standard multidisciplinary process and ensure its successful implementation. The technical necessity of software integration was twofold: firstly, it was required for tasks like structural analysis and part assembly, and secondly, it was essential for optimising and effectively communicating the design among the very different domains involved.

4. THE INTEGRATED DIGITAL MODEL DEVELOPMENT

4.1. REVERSE ENGINEERING OF THE TREE CAST IN BRONZE

An operative strategy for enhancing the level of knowledge about the artefact was urgent at that specific point.

Right after the conclusion of phase 3, the elements to start from – as usual according to traditional methodology – were the following:

- early hand sketches by the conceptual artist (without context references) and a key map showing the casted bronze tree elements;
- *Carrara's Statuary* marble large stone, sculpted in Pietrasanta under the direction of the conceptual artist;
- bronze skin of the other tree, available in the warehouse of the artist near Torino;
- bronze skin of the branches and trunk, obtained by moulding the artist's real tree, discretised in pieces of a maximum of 2 m length and cast by the foundry of art in Pietrasanta (Fig. 2).

Given the overall constraints, a decision was made to switch to a new approach utilising digital tools to facilitate and support further realization, starting from its geometry.

The authors presented a digital strategy encompassing all subsequent stages of the project, from the post-concept early phase up to the installation of the artwork. After initial concerns, the proposal received unanimous acceptance from all participants, who had never experienced the potential of a digital workflow and was subsequently executed by the authors.

During phase 4, a total of 61 distinct bronze cast branches were scanned and digitally assembled in the three-dimensional reconstruction based on the artist's

Fig. 2. *Left: discretization of wood components. Right: samples of cast bronze branches.*

sketch (Fig. 3). Thus, it was possible to later digitally rotate each branch at each connection based on the artist's feedback.

A FARO Focus 3D laser scanner (with a range of 0.6 m to 130 m and a distance precision of 2 mm) was utilised for the scanning process. To provide a full reconstruction of the cylindrical shape, scanning each branch from a minimum of three positions was necessary, providing sufficient overlap. In order to decrease the total duration of the high-resolution scanning session, many branches were fixed onto two boards and simultaneously scanned from 4-5 distinct angles (Fig. 3).

Fig. 3. *Left: Sketch, mapping tree elements. Top right: bronze branches mounted on a board for scanning. Bottom right: identification number and orientation mark in cast.*

Fig. 4. *3D scanning of the 11,4 tons block of marble carved in the workshop of the stonemason.*

FARO "Scene" software was used to align and combine several scans for the digital reconstruction. A surface reconstruction was performed, with an average triangle precision of 2 mm noise.

The hierarchical model of the tree structure was created in 3DS Max using the scanned surface model. Coordinate axes were aligned to the branch's main directions of each branch's lower end so that a rotation around the main axis of each piece would not result in a discontinuity of the overall branch.

This allowed further re-modulation of the digital model, according to the artist's directives, at least by rotating on the defined axis, the branches sub-systems, as better described in the following sections.

Apart from the branches, the principal marble block – nearing completion in the manual carving process – was scanned. Tests conducted with a *Mantis Vision* handheld scanner were unsuccessful, as the marble surface lacked sufficient visual structure to enable the scanning software to track the scanner position accurately.

So scanning with the FARO laser scanner was used again: 11 different positions were sufficient to capture the whole stone except for the positions on which the stone block was placed (Fig. 4).

4.2. CAPTURING THE PLACE AND ITS SURROUNDING

Given that the digital project's main objective was to assist in creating the artwork within its environment, capturing the urban and underground context was necessary. As a starting point, a volumetric model was created using *OpenStreetMap* data. The contours of the blocks and structures were then imported into Autodesk 3DS Max and extruded to an average height.

However, a more realistic and detailed capturing method was needed for the visual representation for the planned CAVE (Cave Automatic Virtual Environment) VR working session. Once again, the aforementioned FARO laser scanner was utilised to conduct a comprehensive scan of the roadway area extending from the Spanish Steps up to Largo Goldoni Square.

A total of 21 scans were conducted. Four nocturnal test scans revealed that the project's spatial impression is more effectively achieved with diurnal scans. Despite the benefits of fewer people and less traffic at night, both for the capturing process and cleaning the scan noises, we opted for conducting 17 scans during the daytime on street level.

Additional scans were conducted from the rooftop of one building at the installation position to properly capture the piazza's surroundings, including protrusions such as balconies.

Nevertheless, the daytime scans, which lasted around 4-5 hours, necessitated extensive manual effort to eliminate pedestrians and vehicles from the 3D point cloud (Fig. 5).

It was crucial to position the foundation of the artwork at a well-defined position, as established by the selection Committee: the structural design solution should

Fig. 5. *Scan sessions at night (less crowded) and during daytime (crowded).*

be compatible with the interference constraints constituted by the numerous underground infrastructure lines existing in the sub-soil.

Because only rare and unreliable information from different sources was available, an additional survey by GPR Georadar was undertaken. It is a non-invasive technique that uses electromagnetic waves propagated in the ground and reflected by any target instrumentation. The HI-MOD field acquisition unit was used: a monostatic multi-frequency MF array for investigations on flat surfaces and a 2-channel DAD radar acquisition unit. The calibrations carried out allowed the time signal to be transformed into depth.

During the processing, as far as possible, a comparison was also carried out with the maps of the underground services provided by the different companies, which made it possible to attribute the nature of the duct found as identified in the plan (electricity, water, telephone, internet, gas, etc.), for which – despite the many signal anomalies detected – the average depth has been indicated.

The processing of the GPR survey also identified many other underground services that were unknown and not present on the public maps. The 3D model of the above-ground surroundings was enhanced by incorporating a mapping of the underground infrastructure. Given the limited amount of information available, the model was simplified to represent only boxes and tubes based on the survey plan data.

4.3. COMBINING ACQUIRED DATA AND VISUALIZATION = VIRTUAL REALITY

After acquiring all relevant data and preparing the digital model with its necessary interaction methods, a full-day workshop was held in the CAVE (CAVE Automatic Virtual Environment) at the High-Performance Computing Centre in Stuttgart (HLRS). Participants were many stakeholders, such as the artist and several involved engineers, such as the structural designer, technical architectural engineer, project manager, client and the company real estate director together with the lawyer.

The CAVE is an immersive Virtual Reality back projection room with approximately 2.75 m x 2.75 m x 2.75 m dimension, where the participants can experience the digital model in groups and on a 1:1 scale.

The focus of the workshop was to finalize the geometry of the artwork, to find the optimal solution with the engineers and to communicate it with the client for approving the design (Fig. 6).

For this interactive workshop, the previously described data was imported into the VR software COVISE/OpenCOVER [25]. A plugin was programmed to interact with the tree and fabricated parts/branches. In order to achieve a higher level of precision in interaction, it was possible - based on the axis predefined in the model - to make numerical adjustments to the rotation and position of sub-branches using sliders and number input fields, which can be controlled on a tablet PC.

Fig. 6. *Workshop in CAVE: optimizing the project. Visible results of GPR underground infrastructure scan.*

As a result, the tree has been interactively sculpted according to the artist's intention. In this session, the entire tree, including its foundation, individual branches, and stone leaves, underwent several iterations to optimise both its aesthetics and functional parameters.

The decision-making process was facilitated and enhanced by using the capabilities of this "digital sculpting". The artist had the opportunity to obtain an initial perspective and make modifications to his artwork directly within the virtual urban setting, looking at his final product from any desired position in the public space.

Simultaneously, all participants in the session were able to conduct their assessments to provide feedback on the feasibility of the artwork. Additionally, they could evaluate the influence of the artwork in relation to the specific limitations and requirements imposed by the context, such as ensuring that the foundations comply with subsurface services (Figs. 7–9).

As the outcome of this workshop, the discrete 3D geometry of the sculpture within the site has been defined, and, in order to have only minor modifications, e.g. due to construction site needs, a 3D printing of the shared solution of the trees has been produced by the authors and approved by the artist: this allowed to immediately start the following detail design phases, for project testing, approval and construction.

4.4. PROJECT IMPLEMENTATION

The *in situ* installation was executed in accordance with the scheduled timeline, including the necessary period for the foundations' castings to mature.

Within one month, the following phases have been completed: conducting the archaeological excavation and digging a foundation plinth (5 m x 6 m x 3 m); placing reinforcing steel bars on the foundation; pouring concrete for the foundation; allowing concrete to harden; Installing pre-made iron bearing piles at depths of 12-15 m; covering and restoring the piazza's pavement; unloading the components of the artwork, which have been sub-divided for transportation; assembly of steel and bronze components; positioning of the marble stone; and concluding finishes.

The highest institutional representative and international press attended the unveiling ceremony. The sculp-

Fig. 7. *Workshop narrative.*

Fig. 8. *Workshop output: digital model and 3D printed model approved by the artist.*

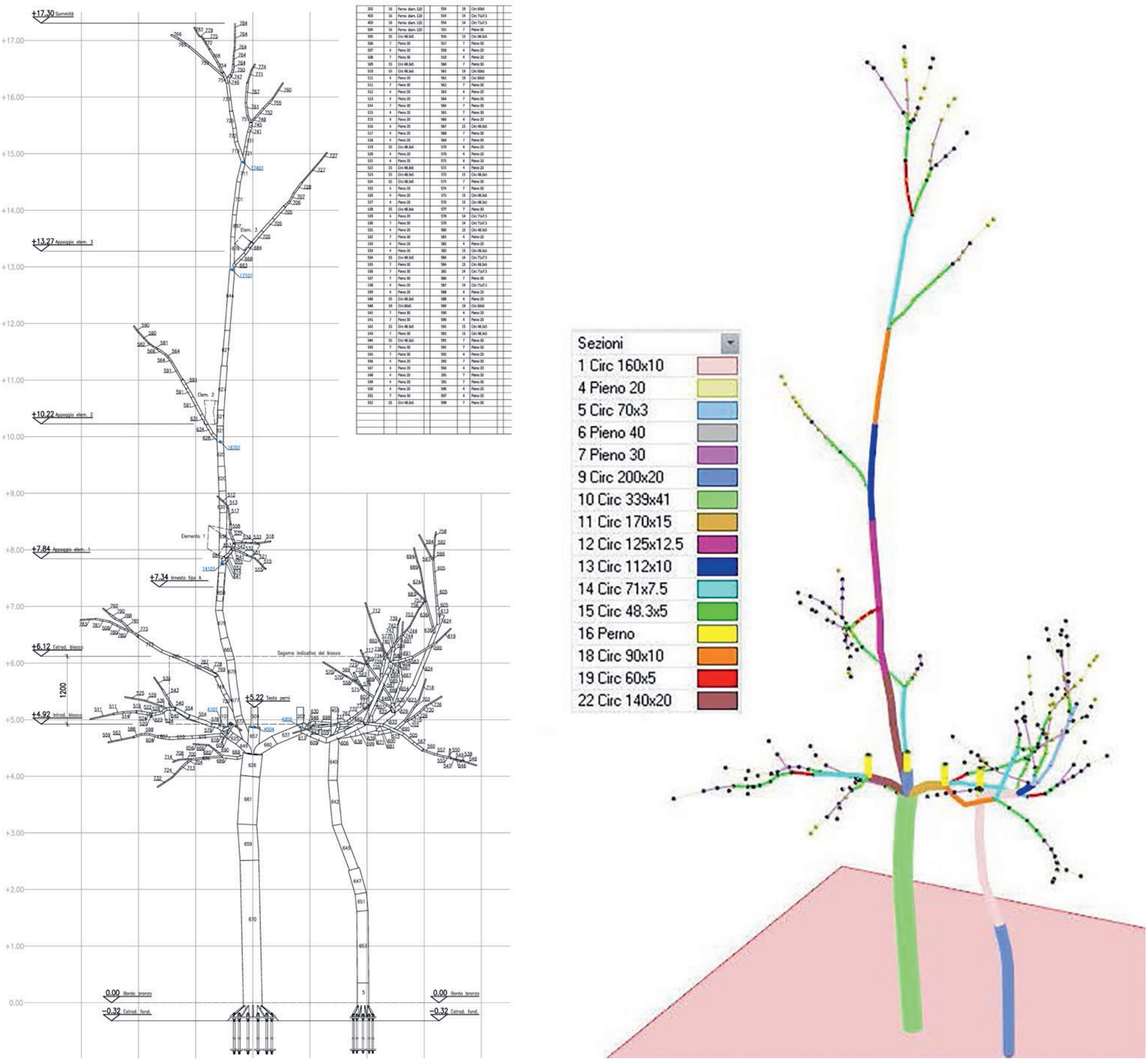

Fig. 9. *Reconstruction of the geometric model of tubular and structural nodes.*

ture in Largo Goldoni's space appears exactly as the simulation experiment depicts.

The 3D rendering and printing results from the Stuttgart workshop, which took place seven months earlier, provided sufficient time for the necessary design and authorizations. As a result, the project implementation adheres to all the current regulations. The physical achievements have confirmed consistency with the simulation, thereby successfully demonstrating the applied research work (Fig. 10).

Fig. 10. *Top: Photo simulation including 3D rendering of the artwork. Bottom: Largo Goldoni today, after the installation of artwork.*

5. DISCUSSION

The workflow adopted in the case of the study demonstrated its general validity beyond this specific artistic unicum: in fact, the goals, constraints and checks mandatory to validate compliance with urban rules, including cultural, usability and safety values (or just a subset of them), concerns all the large sculptures and installations in urban contexts.

Moreover, in order to control works of art characterised by a comparable size and weight, having to operate outside of the standard, the current practice usually resorts to subdivisions into parts manageable at human scale. The methodology proposed here starts right after this critical step to address the optimisation process.

The implementation workflow described in this paper proves that the pre-assembly in the digital setting and the composition of these modules in an immersive environment have guaranteed a strong reduction in timing and facilitated the physical realisation by evaluating both the intrinsic criticalities well before being in the physical workshop and the relationship with the context well before being installed on site.

The demonstration appears evident through the comparison with the currently predominant practices for creating comparable artefacts. The phases mentioned above are tested directly in the workshop with traditional trial-and-error techniques: they have substantially remained almost unchanged over the centuries due to difficulty developing awareness among the artists of the benefits of alternative workflows such as the one presented.

Maestro Penone agreed on the effectiveness of the implemented workflow for engineering the opera, but he still does not consider it as valuable support for the conceptual phase, namely the creative generation of the artistic idea.

With the increasing complexity of simulation models and the continuous growth of information, the visual depiction of data has become a crucial component in the fields of applied science and engineering.

Once the whole geometrical shape has been reconstructed and was available in the CAVE as pivotal information for starting the participant discussion, the immersive visualisations supported efficiently and instinctively the modification, in real-time, of the artefact and the test of a shared solution according to different and many time contrasting specialist domains goals.

Collaboration has been boosted as long as the artist and the client have acknowledged the structural and, in general, engineering problems that had to be faced.

Many potential paths have been explored, recognising patterns in simulation data facilitating communication and comprehension of events well before they could occur in the real world.

For example, one of the two trees, the one stored and scanned in the artist's warehouse, turned out to be about one meter shorter than previously envisioned in the conceptual phase, and thus, it had to be extended in order to have its roots at the correct height. If this operative task were realised in the Foundry instead of in the CAVE, it would have implied at least 3 months of deadline postponing because of the timing for production, delivery and fixing of the stainless-steel solid tube with a diameter of 410 mm and a length of 1.000 mm.

The placement of the heavy stone – hard to prefigure without direct rendering – has been defined during the workshop, deciding to have three cylindrical hinges on the bigger tree and only one on the smaller, identifying the right positions for subtracting to the stone the volume to house them, in order to stabilise the whole system, relying only on the stone's own weight. This solution allowed an invisible joint, also from the pedestrian perspective, standing between the trees, namely under the 11 tons stone, in the public space.

Visualisation of underground supply services guided the structural engineer to avoid the clash with the foundations by lowering the plinth 1,5 m under the pavement level and reaching the surface by means of two concrete columns, in continuity with the out-of-ground iron structure of the trees.

An example of the difficulties faced in the collaborative decision-making process regarded the 3D model scale 1:20, printed at the end of the CAVE session: this object – including documentation to be published – provoked a non-easy discussion about the copyright issues, as seen by the artist and by Fendi lawyer perspectives: they wanted to avoid the divulgation (or potential reproduction) before the construction.

In the end, we realised that this case-specific experience outlined to the stakeholders a vision for pushing the boundaries of the art-making process at the urban scale by using a digital workflow monitoring the concept development – ultimately empowering creativity: artist have experienced a new role; designers achieved an early control of the product, the client won the challenge.

6. CONCLUSIONS

The decision-making process and technical control – from concept to realisation – of art installations in delicate urban contexts requires succeeding in diverse, contrasting, multidisciplinary sub-objectives.

The promising use of *ad hoc* technology in digital support for designing and producing large public sculptures is an open and exciting research field, employing numerous tools to integrate creativity, precision, and efficiency.

Assuming that goals and constraints faced in the "Stone Leaves project" concerns, more in general, all the large sculptures and installations in urban contexts, the discussed results of this one-of-a-kind case-based experimental experience, explain benefits and challenges, applicable beyond the specific case, observed using an ad-hoc methodology as well as provide avenues for further investigation.

A structured interview with the involved actors recognised the effectiveness of the action research in clarifying some of the ambiguity relating to: digital modelling and traditional sculpture technologies for working in tandem; Virtual Reality as a simulation tool for managing complex urban context constraints; strength in the conciliating culture of art and culture of technics.

The technologies and methodologies adopted for the overall project demonstrated their efficacy in speeding up the process and increasing its quality. For example, at least 3 months of deadline postponing has been avoided by understanding in the CAVE, way long before the Foundry worksite construction, that one of the two trees was about one meter shorter than previously envisioned in the conceptual phase. Most branches were rotated and modified according to esthetical issues and clashes with the surroundings. The foundations have been defined. The "leaves of stone" have been revolved and redefined in order to create an axial variation according to global landscape perception. Finally, the 11.4 tons stone positioning – impossible to prefigure without direct rendering – has been identified, converging to a technical solution that ensured the stability of the whole system, also hiding the joints from the pedestrian perspective, safely standing between the trees, under the stone, in the public space.

The digitally simulated model has shown to be consistent with the masterpiece that has been physically achieved, thus compliant with all contextual constraints: this is a successful demonstration of the multidisciplinary applied collaborative work. The accurate knowledge collected about the installation will be precious for its future maintenance.

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Authors contribution

Conceptualization, A.T.; Project Administration, A.T.; Methodology, A.T., J.K., U.W., P.F.; Software Coding, U.W.; Data Curation, A.T., U.W., J.K.; Writing and Validation, A.T., P.F.; Investigation, A.T., U.W., J.K., P.F.; Funding Acquisition, A.T., P.F.

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