This paper reports on a research project oriented to support the communication for, and realization of a sculptural masterpiece within an urban context in the historic centre of Rome. The sculpture has been installed just a few months before the 2017 eCAADe, thus enabling conference participants to explore the final output in situ. While the whole process of creation of the art piece is outlined, our focus is on the description of implementing various technologies like laser scanning, Virtual Reality (VR) and Numerical Simulations that have been used to accomplish the relevant tasks. The general field of investigation is how digital tools and a VR approach to modelling, simulating and developing sculptural components of an artwork could facilitate the workflow between artist, client, designers, engineers, urbanists, archaeologists, art foundry fabricators and public authorities. Methodologically, an action research approach was adopted for this project, primarily for its ability to link between research and practice in order to solve a realistic multidisciplinary problem in its actual setting.

**Keywords:** Cross-disciplinary Collaboration; Virtual Reality; Integrated Design; CAVE; Digital Support for Art

**INTRODUCTION**

This paper reports on a research project oriented to support the communication for, and realization of a sculptural masterpiece within an urban context in the historic centre of Rome. In respect of the scheduled workplan, the sculpture has been installed at the end of May, just few months before the 2017 eCAADe, enabling conference participants to explore the final output in situ. While the whole process of creation of the art piece is outlined, our focus is on the description of implementing various technologies like laser scanning, Virtual Reality (VR) and Numerical Simulations that have been used to accomplish the relevant tasks.
The general field of investigation is how digital tools and a VR approach to modelling, simulating and developing sculptural components of an artwork could facilitate the workflow between artist, client, designers, engineers, urbanists, archaeologists, art foundry fabricators and public authorities. Methodologically, an action research approach was adopted for this project, primarily for its ability to link between research and practice in order to solve a realistic problem in its actual setting.

SCULPTURE AND PROJECT PHASES
The artist, Giuseppe Penone, key exponent of ’70 Poor Art movement, has been called by “Fendi”, a fashion company, to produce a work of art for donating it to the City of Rome, to be installed in an urban public heritage space, “Largo Carlo Goldoni” square, close to the Spanish Steps. The work consists of the artistic transposition of two real trees, whose maximum height “above ground” amounts to 17.53 m, and their total weight to 8 tons. They support a large
block of stone approximately 3.5 x 1.5 x 1.5 m, weighing 11.4 tons. (see Figure 1)

The development pipeline can be summarised in the following phases:

1. Artist idea and rationale: Identification of real trees;
2. Finite components discretization and cataloguing;
3. Construction of the mold and casting of components;
4. Digital survey of both, the artworks’ components and the installation context;
5. Digital reconstruction of three-dimensional model in the context;
6. Testing and remodelling of the artwork in an immersive virtual environment;
7. Manufacturing of a three-dimensional model for architectural/urban representation and evaluation;
8. Realization of a three dimensional CAE model for structural analysis.

While phases 1-3 were carried out in a conventional, analogue way, it turned out that due to numerous constraints the project could not be realized within the given time frame without a supportive digital workflow. It was both needed technically (e.g. for the structural analysis and for the assembly of parts) as well as for optimization and communication of the design.
REVERSE ENGINEERING OF THE TREE CAST IN BRONZE

In similar projects, the artist optimized the design of the artistic trees directly in the foundry. The single cast bronze pieces as well as necessary interior static structure elements were adjusted to the artist’s directions in the foundry at scale 1:1 by heavy lifting, welding and cutting in a cumbersome manual process. Compared to these projects, the boundary conditions of the discussed project are much more complex, just to name some constraints:

- seismic requirements in Rome
- distance from surrounding facades/buildings/car lane
- distance from lighting cables
- restrictions on visual impacts (max 80 m)
- foundation in a highly installed ground of archaeological importance
- tight timeframe
- branches have to maintain a clearance of 5 m to existing public lighting wires, traffic signs and two floor buses passing very frequently on the adjacent street.

As it turned out, a realization with the conventional approach was not possible within the given constraints. After phase 3 it was decided to switch to a different approach with digital tools supporting further realization. The authors proposed a digital workflow, which covered all following project phases up to the final installation of the art piece. The proposal was accepted by all participants and then carried out by the authors.

In phase 4, 61 different bronze cast branches had to be scanned, identified and re-assembled in 3D. Whereas it would have been much easier to scan the whole tree or at least main parts of it, the late decision to implement the digital method required us to reverse engineer the tree. An overview over the marked elements as well as a reference line on some cast elements helped to a certain degree but the procedure still caused substantially more work. (see Figures 2 and 3)

For the scanning process a FARO Focus 3D laser scanner (range: 0.6 m - 130 m, distance accuracy 2 mm) was used. Each branch needs to be scanned from at least 3 positions in order to have enough overlap for a seamless reconstruction of the cylindrical shape. In order to reduce the overall scan time (a high-resolution scan takes more than 5 minutes), several branches were mounted on two boards and scanned together from 4-5 different positions. The complete scanning procedure took about 12 hours. Each scan captures a spherical 360° area around the scanner, just excluding a 15° cone at the base. (see Figure 4)
For the next step, FARO “SCENE” was used to register the different scans to each other and crop out the area of the point cloud which contains the branches. A surface reconstruction was also carried out within Scene with a typical triangle size of 20 mm. At a branch diameter of 50 mm, these results in a surface approximation of 2 mm, which matches the distance resolution of the scanner. A higher resolution would not be more accurate but would only capture more noise.

The surface models were imported into Autodesk 3DS Max, where a hierarchical model was created which resembles the structure of the tree as it was sketched by the artist (not as grown). The coordinate axes were aligned to the branch directions of the lower end of each branch so that a rotation around the main axes of each piece would not result in a discontinuity of the overall branch.

In addition to the branches, the main marble block which was in the final stage of being carved by hand had to be scanned too. Tests with a Mantis Vision hand held scanner did not work out at all. Apparently, the marble surface did not provide enough visual structure to allow the scanning software to track the scanners position.

Thus, the same method - scanning with the Faro laser scanner - was used again. 11 different positions were chosen - from below and from above - to capture the whole stone except for the positions that the stone block was placed on. (see Figure 5)

CAPTURING THE SQUARE AND ITS SURROUNDING
As the focus of the project is set on supporting the realization within the surrounding context, it had to be captured both above and below ground.

A first a volumetric model was generated from OpenStreetMap data, the outlines of the blocks and buildings were imported in Autodesk 3DS Max and extruded to an average height. However, for the visual representation for the planned CAVE (Cave Automatic Virtual Environment) VR working session, a more realistic and far more detailed capturing method was needed. Again, the previously mentioned FARO laser scanner was used to scan the street,
space from the Spanish Steps to the Largo Goldoni Square.

This was 4 blocks along Via dei Condotti as well as the buildings surrounding the square. All together 21 scans were made. Four night-time test scans showed, that the spatial impression for the project is better done with daytime scans. And though the advantage of less people and traffic around night-time and thus in the scans, we decided to do 17 daytime scans, one at every street crossing and multiple scans on Largo Goldoni Square to compensate for shadowing by pedestrians and vehicles.

Further scans from the roof of a building at Largo Carlo Goldoni were taken to complete the square surrounding and having protrusions like balconies fully captured and not only from street level. However, the daytime scans (approx. 4-5 hours of scanning) required a lot of manual work to remove people and cars from the 3D point cloud. (see Figure 6)

The foundations of the artwork, namely the roots of the two shafts, can find a place only and exclusively in a position such as to be compatible with the interference constraints constituted by the numerous underground infrastructure lines which exist in the subsoil.

Because only rare and unreliable information is available, a survey by GPR Georadar instrumentation was undertaken. So the 3D model was further enriched with this mapping of the underground infrastructure. Due to the limited information density, it was only modelled as boxes and tubes in the 3D model based on the survey plan. (see Figure 7)

**COMBINING ACQUIRED DATA AND VISUALIZATION = VIRTUAL REALITY**

After having acquired all relevant data, a full day workshop was held in the CAVE at High Performance Computing Center Stuttgart (HLRS). Participants were the artist, several involved engineers as well as the client. The focus of the workshop was to finalize the geometry of the artwork, find the optimal solution with the engineers and communicate it with the client to approve the design. (see Figure 8)

For this interactive workshop, the static point clouds of the surrounding as well as further geome-
try like underground piping were imported into the VR software COVISE/OpenCOVER[1][2]. A plugin was programmed to interact with the tree and with the fabricated tree parts/branches. The branches could be picked and freely moved with a 3D mouse.

To interact more precisely, rotation and position sub branches could also be changed numerically with sliders and number input fields on a tablet PC. The CAVE model was updated instantly. The whole tree, its foundation, individual branches, and also the stone leaves were moved through multiple iterations and therefore optimized for aesthetics and also functional parameters.

The decision-making process was facilitated and strengthened by means of a conceptual session of “digital sculpturing”. The artist was able to get a preliminary view and also edit his work right in the virtual urban environment. At the same time, all
other participants in the session could carry out their assessments in real time and thus could give feedback on the constructability of the artwork. They could also evaluate the impact of the artwork against the context-dependent constraints, including compliance of the foundations with underground services. (see Figures 9, 10 and 11)

**PROJECT IMPLEMENTATION**

The installation working site for “Leaves of stone”, which included the maturation time of the foundations’ castings, took place coherently with the planned schedule.

In less than a month the following phases have been respected: Archaeological excavation and digging of foundation (5x6x3m); Siting of plinth reinforcing steel bars; Plinth concrete casting; Hardening of concrete; Insertion of prefabricated iron bearing piles (depths of 12-15m); Covering and restoration of the paving; Unloading of the work of art components, discretized for transportation; Installation of steel and bronze pieces; Placing of the marble stone; Final finishes.

For the inauguration of the work of art, permanently installed in the public space, a ceremony was held on May 22nd 2017 with the presence of the highest institutional representative and international press: the image of the sculpture, its three-dimensional shape in Largo Goldoni’s space, after the unveiling, looks identical to the one prefigured by the simulation experiment.

3D rendering and printing output of the Stuttgart workshop, which was held seven months earlier, allowed the right procedural time for the authorisations by the competent authorities. As a result, the project implementation is compliant with all the existing regulations. The simulation has shown to be consistent with what has been physically achieved:
Figure 12
Photo-simulation including 3D rendering of the artwork

Figure 13
Largo Goldoni today, after the installation of artwork.
this is a successful demonstration of this applied research work (see Figures 12 and 13).

**CONCLUSIONS**

The discussed results explain the benefits and challenges observed using this method as well as provide avenues for further investigation.

For the overall project, these technologies and methodologies showed their effectiveness in speeding up the process and increasing its quality. For example, one of the two trees turned out to be about one meter shorter than previously envisioned in the conceptual phase and thus one of the trees had to be cut shorter 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. Most of the branches were rotated and modified according esthetical issues and clashes with the stones and surrounding buildings. The “leaves of stone” have been revolved and redefined in order to create an axial variation according to global perception. Finally, the foundations have been defined.

Digital simulation 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 research work.

By means of structured interviews to the involved actors, an original contribution is that the research helps in clarifying some of the ambiguity relating to: digital modelling and traditional sculpture technologies working in tandem; Virtual Reality as simulation tool for managing complex urban context constraints; culture of art versus culture of technics. The result of structured interviews of all participants are currently ongoing and will be presented in next future.

**REFERENCES**


[1] https://github.com/hlrs-vis/covise

[2] https://www.hlrs.de/covise/