Ebb & Flow: Uncovering Costantino Nivola's Olivetti Sandcast through 3D Fabrication and Virtual Exploration

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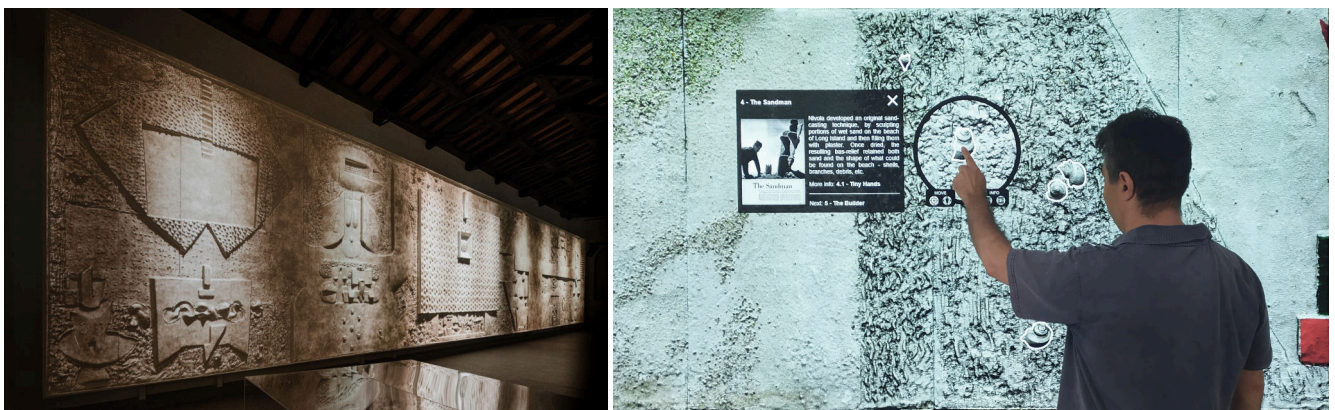

Figure 1: *Physical and virtual reproduction. Left: the physical replica of the Olivetti sandcast as placed in the exhibition (photo by Cédric Dasesson courtesy of Museo Nivola). Right: virtual exploration of the annotated digital model using an interactive visualization lens.*

Abstract

We report on the outcomes of a large multi-disciplinary project targeting the physical reproduction and virtual documentation and exploration of the Olivetti sandcast, a monumental (over $100m^2$) semi-abstract frieze by the Italian sculptor Costantino Nivola. After summarizing the goal and motivation of the project, we provide details on the acquisition and processing steps that led to the creation of a 3D digital model. We then discuss the technical details and the challenges that we have faced for the physical fabrication process of a massive physical replica, which was the centerpiece of a recent exhibition. We finally discuss the design and application of an interactive web-based tool for the exploration of an annotated virtual replica. The main components of the tool will be released as open source.

CCS Concepts

• Computing methodologies → Shape modeling; Computer graphics; Graphics systems and interfaces; • Applied computing → Arts and humanities;

1. Introduction

In 1954 the Olivetti Showroom opened on the 5th Avenue in Manhattan, designed by Studio BBPR with a monumental semi-abstract frieze by the Italian sculptor Costantino Nivola (1911 - 1988), made using a sand-casting technique of his invention (Fig. 2 left). Measuring approximately 23 meters long and 5 high, the bas-relief created

a sensation in its times: a symbol of Italian ingenuity and a novel approach to business communication.

Dismantled in 1969, it was moved to the Harvard University Science Center in 1972 (Fig. 2 right), preserved but almost forgotten. Since the 2000s, a new tide of studies has started to reassess Mid-century Modernism and its protagonists, leading to a rediscovery of Nivola and the Olivetti sandcast, now regarded as a cornerstone of postwar Italian art [AC22].

The artwork is now the focus of a multi-institutional digital humanities project. For a 2022 exhibition at Museo Nivola in Italy, the

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artwork was 3D acquired, a full scale physical replica was fabricated and integrated in the exhibition, and innovative tools and techniques have been explored for supporting its virtual exploration. The main components of these tools will be released as open source.

In this paper, we provide a general overview of the project. After discussing related work (Sec. 2), we summarize the characteristics of the artwork, the motivation for using a physical and virtual replica, and the general ideas that drove our exhibit design (Sec. 3). We then discuss the technical implementation of the acquisition process (Sec. 4) and of the processing steps adopted for creating 3D models (Sec. 5). The physical fabrication process, and the challenges that we have faced to reproduce a very large-scale (wall-sized) sandcast, are described in Sec. 6. Virtual exploration design is, instead, discussed in Sec. 7, focusing primarily on the interactive visualization of an annotated model on multiple platforms. The paper concludes with an assessment of the results obtained and a view of future work (Sec. 8)

Figure 2: *The original artwork. Left: at the original location in the Olivetti Showroom on the 5th Avenue in Manhattan (photo by Hans Namuth courtesy of Museo Nivola). Right: at the current location in the Science Center of Harvard University (photo courtesy of Museo Nivola)*

2. Related work

The project required the combination and extension of a variety of solutions targeting the physical and digital reproduction of large artworks and their use in museum settings. A complete review of the literature is out of the scope of this paper. We discuss here only the approaches most closely related to ours.

2.1. Physical replication for museum installations

Installing accurate replicas of artworks has a long tradition. In particular, moulds and gypsum copies used to be typically produced using the *calco* approach (moulding). However, this approach has now been banned in several countries and for many classes of objects, since it can severely affect the conservation status of the original artwork. For instance, while removing the rubber mould, the patina may also be peeled, damaging fragile parts of the artwork. This situation, and other strong motivations supporting non-contact processes, opened up a wide application space for digital fabrication in CH [SCP*17], since it is the only technical solution to produce high-quality copies keeping the artwork safe.

While (almost) standardized processes, based on off-the-shelf software and hardware solutions, are available for common classes of objects, significant challenges are still posed by those artworks that are more complex in terms of needed level of detail, surface appearance, or just sheer size. In the literature, there are various examples of digitization and physical reproduction for museum installation, from the high detail reproduction of single artworks for one-shot exhibitions, like the Pompeii Graffiti [BCF*04] or Jackson Pollock painting [CPP*15], to more complex architectural elements or environments [Bah01, Ahm04, Art20], up to permanent museum installations of large scale environments, like the 1:1 scale reproduction of the Lascaux cave [BD84] carried out multiple times, following the evolution of the technologies. Our work follows this trend, proposing and documenting a process targeting the capture and replication of a very large artifact (over 100 m^2) at millimetric detail.

2.2. Virtual presentation

The physical presentation of the artwork is complemented with a virtual exploration of a digital replica enriched with annotations that link regions of the model to some related information not present in the object itself [PCDS20]. This requires mechanisms to explore shape and color at multiple scales, as well as ways to present the additional data in the annotations in a comprehensible way. We tackle both problems by constructing our viewer around the exploration of a relightable 2D representation with a visualization lens [TGK*17].

While generic interactive viewers displaying fully-3D virtual replicas [PCD*15, Ske19] have been proposed, the restriction of camera motion to panning and zooming is very appropriate to a large 2.5D sandcast relief and removes one of the main difficulties of 3D exploration applications, reducing learning curves [JH13]. Through a relighting interface, as popularized by RTI viewers [CHI19, P*19, GCD*18, JAP*21], we can still provide a good perception of the 3D shape starting from a normal+BRDF representation of the model [PDC*19].

Through a combined camera and lens controller, recently introduced by Bettio et al. [BAMG21], we map user actions to the joint adjustments in camera and lens parameters that ensure a good placement and sizing of the lens within the view, thus further simplifying interaction, as the user only has to move and scale the lens, which represents the focus of the exploration to also move the camera.

We also enrich the lens with controllers for annotation exploration. In the literature, many ways have been proposed to mark the annotation region [CCDL*20], including labels [BNC*03, SCS05, JSI*10], hot-spots [CLDS13, PCD*15, PCDS20, Aio19], or visual overlays [JAP*21, BAMG21]. Independently from the marker type, presenting all annotations at a time would cause clutter and cognitive overload [ED07]. Considerable research efforts have been dedicated in recent years to the problem of presenting annotations, with solutions ranging from fully static approaches based on authored pre-computed videos that navigate from one annotation to the next [WSA*18], to fully adaptive techniques that activate only one annotation at a time [BAMG15, BAMG21, AMPG22]. In this work, we opted to organize annotations sequentially and at multiple levels of detail, and to enrich the lens with controllers for navigating into this linked representation. This makes it possible to implement a user-directed storytelling approach with details on demand [TRB*18].

3. Project overview and design decisions

The Olivetti Showroom, which opened in 1954 in Manhattan, was dubbed by the American press as "the most beautiful store on Fifth Avenue", marking a crucial step in the history of advertising and the affirmation of Made in Italy in the United States [AC22]. In the engaging and expressive environment designed by BBPR architects, the typewriters of the Ivrea-based company, with their captivating and functional design, represented the best of Italian innovation and creativity. Mythical past and technological future met in the huge sandcast relief created by Costantino Nivola. It is the work that launched the Italian artist in America. The monumental relief embraces the full range of Nivola's creative imagination, the sand of the surface evoking the Sardinian sea, the Mediterranean shore, and the coast of Long Island where the sculptor moved with his family in the early 1950s. It was on these beaches that Nivola began experimenting with making casts using sculpted sand as formwork. In the Olivetti relief, we find shells, marine plants, pebbles and small objects, the hands of the artist, his wife Ruth Guggenheim and their children Pietro and Claire. It is children's play on the beach rising to an art form. The relief is populated by great fantastic figures, male and female. They are the pagan gods who rule nature, divinities that Nivola found in the ancient history of Sardinia, pre-Nuragic idols who had abandoned the shores of the Mediterranean to move, like so many Italian emigrants of the 1930s, to the American metropolis, passing from *nuraghi* to skyscrapers. These great guardian deities are joined by a myriad of smaller figures, scattered throughout the relief. They are nymphs and satyrs, devils and goblins, but they are also women and men similar to their divinities, only smaller, busier and more dynamic. Nivola also brings to the relief his facility with graphic design and art direction acquired in the Olivetti Advertising Office in Milan in the 1930s. Lines and patterns, plays of shape and infinite variations of rhythm and composition animate the surface. In the sketches of the relief exhibited in the permanent collection of the Nivola Museum and in American museums, color plays an important role. As realized for the showroom, however, it was decided that the natural appearance of the sand alone would provide the surface variation. Later, in 1972 when the relief was relocated to Harvard, Nivola would apply color reminiscent to the earlier studies. The original remains at the Science Center of Harvard University.

Preserved by the administration and cherished by students and faculty, the artwork is, nonetheless, placed out of a museum context, in a narrow passageway overlooking a mezzanine. Moreover, the artwork's dimension and collocation severely limit its fruition and appreciation among scholars and the general public (Fig. 2 right).

The idea of replicating the artwork, both physically and digitally, arose with the exhibition *Nivola & New York. From the Olivetti Showroom to the Unbelievable City*, which opened at Museo Nivola, Orani, Italy, in the late spring of 2022. The exhibition aimed to highlight Nivola's connections and experiences in New York City, providing a novel perspective on his public art projects. Furthermore, beyond the limits of the exhibition, the museum intended to acquire a digital model of the artwork for study and dissemination purposes. Conservation was also a significant concern: a 3D scan of the work would allow for a more accurate restoration, should any damage occur.

For all these reasons, it was decided to start a multi-disciplinary project, involving experts from humanities, computer vision and graphics, and fabrication. The project started in the difficult pandemic period, and with strict budgets and deadlines dictated by the planned exhibition date. The team had about six months to go from project start to exhibit opening. The pandemic period also impacted on many decisions and action lines, including the need to limit travel and in-presence meetings to the very minimum, due to complexity and high risks of cancellations.

We set as a goal to first obtain a digitally acquired model capturing the overall shape of the massive artwork, at a resolution sufficient to reproduce the various textures and identify the finest details. Upon inspection, this required a millimetric to sub-millimetric resolution. Color capture was not considered of primary importance, as the artwork was originally presented with the natural appearance of the sand alone. The resulting model had to be produced as fast as possible, due to the exhibit timing constraints, but at a quality sufficient for multipurpose uses (archiving, fabrication, digital exploration, and further research). We discuss our decisions and the resulting process in Sec. 4 and Sec. 5.

As the artwork was designed as a wall-sized piece of art, we considered it of primary importance to include in the exhibition a physical replica as close as possible to the original scale, to let viewers perceive the massive size of the work in relation to their scale, as originally intended. This proved very challenging, since it required the planning and execution of a very large scale fabrication and installation project, whose details are described in Sec. 5 and Sec. 6.

Finally, the intertwined semantic and visual complexity of the work also led us to the decision to go beyond a simple replication, be it physical or virtual, accompanied by a standard side documentation. We decided, instead, to use the artwork as a starting point for a journey in understanding the complexity of Nivola's art, experimenting with ways to explore the connection between visual and semantic information through digital tools. As we are both interested in local museum exhibitions and wide dissemination, we decided to use web-based tools that could also be used in a variety of setups. While the tools were designed for this particular artwork, the needs they answer are more general, and, to the benefit of the community of researchers and practitioners, we plan to release the developed software as open source. We discuss our design decision and initial results in Sec. 7.

4. Acquisition

Digitization was complicated by the COVID epidemic, that prevented a direct involvement of the entire team in the data gathering phase. The project partners had to work through a proxy. Through contacts with the Harvard Visualization Research Lab, the project was referred to a spin-off of the university with adequate equipment and expertise.

The remote team provided two test scans: a rough global view of the artwork and the surrounding areas, captured with a Leica BLK laser scanner for a previous building scanning project, and a detail scan of an area of around one square meter, done with a Peel 3D scanner. The global scan had a good coverage and rigidity, but it would have been difficult to reach the desired resolution with a ToF

scanning device. The detail scan, on the other hand, had a sufficient resolution, but it would have been too time consuming to cover the entire 100+ square meters with such a device. It would also have been difficult to avoid distortions, given the size of the artwork with respect to the scanning area.

So, considering the time, resolution and resources constraints, it was decided to use dense photogrammetry to digitize the artwork. Reconstructing 3D data from photos could give the needed surface detail, simplify the logistics of the on-field digitization and data exchange, and could also generate a usable color mapping.

Using the global 3D model generated from the BLK scanner it was possible to remotely plan a photographic survey, and then instruct the on-site team on how to proceed. The resulting photographic dataset was composed by 1983 photos, taken with a Sony Alpha 7R II, at a resolution of 42 MPixels. The dataset contained some photos that were too angled, or too far away from the surface, or with a lighting severely incoherent with respect to the rest of the dataset. After pruning these images, we obtained 1800 usable photos.

The Agisoft Metashape software was used for the calibration and orientation of the photos, and for the generation of the dense pointcloud. Photographic calibration and orientation took 2.5 hours: no major problems or misalignments were detectable at this stage. The computation of the dense pointcloud (with high quality setting) took almost 7 hours, generating over 800 million points, then reduced to 798 millions after filtering out the external parts and low-confidence points.

All the further processing of the 3D data, and the creation of the 3D models for the reproduction and visualization has been done in MeshLab [CCC*08], the open source visualization and editing tool for digitized 3D models, developed by ISTI-CNR.

Different sections of this dense cloud were then exported, further cleaned, and meshed, to assess the quality of the reconstruction with respect to the needs of the project. A sub-sampled version of the dense cloud was used to generate a global triangulated model (30 million triangles).

Since 3D reconstructions obtained from dense photogrammetry are generated at an arbitrary scale, metric information has to be derived, after the reconstruction, from real-world measurement. The global low-res mesh was used to obtain the correct scaling factor using as a reference both the global Time-of-Flight and handheld scanner test models.

The next step was to establish a reference space suitable for the project. The 3D model was oriented by fitting a plane over the external frame of the artwork, orienting the X and Y axes along the horizontal and vertical edges of the frame; the origin was set to the bottom-left corner.

5. Processing for building replicas

Using the global triangulated model, it was possible to precisely estimate the dimensions of the artwork (23.27×4.57 m) and establish a viable workflow for the reproduction.

The Nivola Museum identified a hall in which to place the repro-

Figure 3: *3D model details*. *The 3D model captures the different surface textures, derived from the various sculpting techniques used by Nivola. Some traces of the sculpting process are visible using the virtual grazing light.*

duction and planned the overall exhibit design around this centerpiece. In order to comply with the museum's safety requirements, dictating the access to the technical systems on the wall in the rear of the relief, it was necessary to apply a 0.96 scale to the reproduction, obtaining a final size of 22.48×4.42 m. This slight change in scale was considered acceptable by the curators, given the close point of observation and the overall proportion of the space.

The available blank pieces for the carving were 1x2 meters, that matched the maximum working area of the robot (Sec. 6). To minimize the amount of pieces to be machined, the most practical subdivision was to subdivide the artwork horizontally, in 23 slices 0.98 m wide, with each slice divided vertically into three blocks: two 1.98 m and one 0.46 m (Fig. 4). In this way, a single blank piece could be used to carve one of the large chunks or four of the smaller ones.

Generating a single triangulated surface from the whole cloud of 798 million points points could be indeed possible, but it would have been impractical to handle, especially considering that, in the end, the fabrication process would need individual 3D models for each block (Sec. 6). So, also the data processing worked in sections. The processing extracted 23 vertical slices from the cloud, each one larger than the required 1m-wide block to guarantee surface continuity across the slices. Each slice was then meshed using the Screened Poisson merging, obtaining a resolution of around 0.7mm (22-25 million triangles per slice, for a total of 533 million triangles). Each vertical slice was then precisely trimmed and cut into the three needed blocks. The 3D model for each block was then exported as an STL file and transferred to the FabLab.
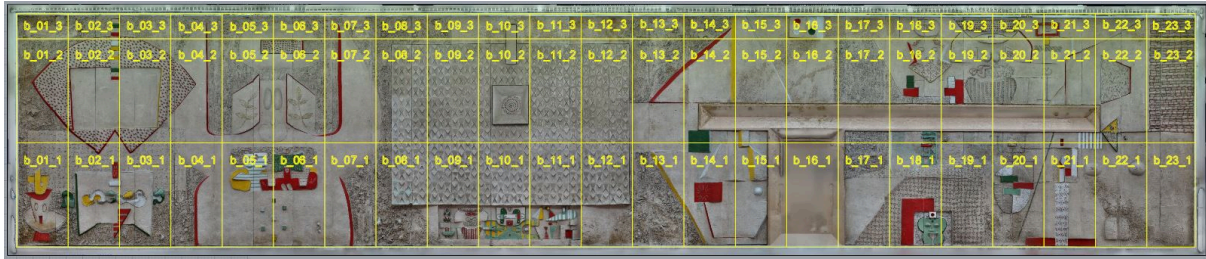
Figure 4: *Subdivision for fabrication. The model was decomposed horizontally into 23 slices, each slice was divided into 3 blocks.*

6. Fabrication and exhibit setup

For the manufacturing of the panels, we used a KUKA robot KR210 R2700 extra, a 6-axis jointed-arm kinematic system set up by ESA SpA (Fig. 5 left). The material of choice was EPS (expanded polystyrene): a rigid and durable thermoplastic material with a density of 30 kg/m^3, which provides excellent surface detail quality while still being lightweight, a crucial requirement for the installation.

As described in Sec. 5, the working area of the robot and the dimensions of the available blank pieces determined a split of the artwork into 69 blocks. The input STL files of the blocks were first prepared using Rhinoceros v.5 (McNeel); the primed blocks were used to calculate the toolpath in Sum3D (CIMsystem); finally, the path was converted to be used in the RoboMove, the built-in software used to control KUKA robots. As a whole, these processing steps took 300 hours.

In Rhinoceros, the blocks were placed in the local reference space of the robot, and vertically aligned into the robot working space to guarantee a coherent assembling, later. An additional processing was necessary to correct or fill the areas that were (on purpose) not properly digitized: the external frame and the featureless inner panels (which were not part of Nivola's work). These areas were re-modeled as flat panels and inserted in the models.
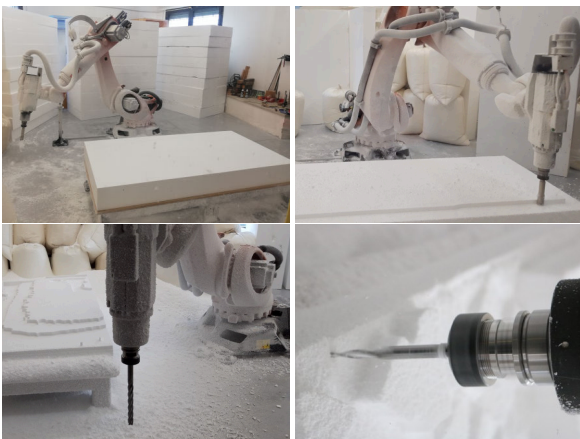

Figure 5: *Fabrication. Top row: the KUKA KR210 R2700 6-axis robot used for fabrication; the roughing pass. Bottom row: the side-trimming pass; the finishing pass.*

The next step, done in Sum3D, was to calculate the toolpath, i.e., defining the trajectory and speed of the drill head that will carve out

the material from the blank piece. The generation of the toolpath considered three carving passes, each with a specific aim and using a different carving head (Fig. 5):

- Roughing of the raw blocks upper surface with a cylindrical flat drill bit of 40mm diameter (vertical transit of 25mm, concentric work with 40% increase).
- Side trimming with a cylindrical flat drill bit of 20mm for cutting lateral plane surfaces to be assembled (vertical transit of 30mm, concentric work with 40% increase).
- Finishing trims with a conical-spherical drill bit of 3mm diameter (vertical transit of 1mm).

After the calculation process, the toolpath was post-processed for adapting it to the specific robot, then used in the RoboMove software used to control the robot. The average processing time was of 60-80 minutes for upper roughing, 10-15 minutes for side trimming, and 2.0-2.5 hours for finishing trims. The actual manufacturing of each of the larger blocks (0.98×1.98 m) required 20-25 hours, whereas the smaller ones (0.98×0.46 m) required 6-7 hours. In total, the carving process took 1300 robot hours, without considering the bonding and cleaning processes.

Figure 6: *Assembly. The individual panels were mounted on a wooden frame before external coating and painting.*

The individual panels were then moved to the museum and assembled in-place. Thanks to the EPS fabrication, the entire artwork replica weights less than 500kg. This made it possible to use a light wooden frame as supporting structure. The frame has a wooden base at the bottom, on which the artwork rests, and each panel is attached by a reversible screw and crosspiece system to the structure.

A special adhesive of a medium grain size was hand painted providing external coating and a coherent representation of the original

sandy surface. For practical purposes, each individual panel was coated and painted prior to mounting. A seamless look was nonetheless achieved by closing all gaps through a slight compression of the panels.

Figure 7: *Projection mapping on the fabricated relief. Creative interpretation of the relief's possible color schemes, based on the many Nivola's preliminary studies. Photo by Cédric Dasesson courtesy of Museo Nivola.*
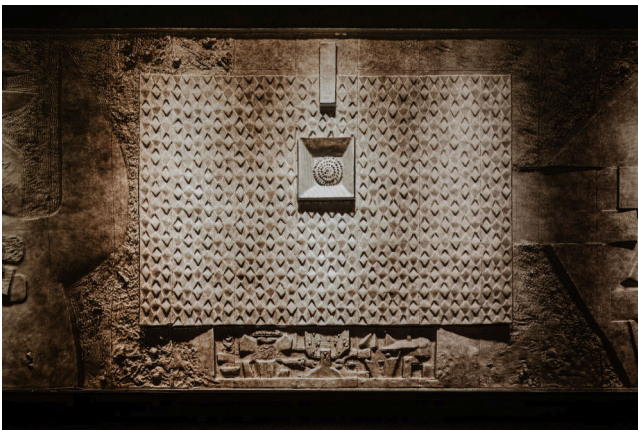

Figure 8: *Central portion of the fabricated relief. The artwork is photographed as presented in the exhibition room. Photo by Cédric Dasesson courtesy of Museo Nivola.*

The final fabricated and assembled replica, as installed in the museum, is presented in Fig. 1 (left) and Fig. 8, with the illumination that was designed for the exhibit with the purpose of emphasizing the relief shapes.

The neutral, uniform, and light finishing of the replica made it possible to explore additional presentation settings. In particular, a projection mapping of the entire artwork was added to the exhibit with multiple purposes: it enhanced the shadows and allowed for experiencing the relief under different light conditions; it gave a creative interpretation of the relief's possible color schemes, based on the many Nivola's preliminary studies, and it underlined the textures, the patterns, and the iconography, providing non-verbal guidance to the narrative and formal structures of the relief. Taking into account the budget constraints of the exhibition, the projection map was achieved by blending the images generated by four 5000

lumen short-throw UXGA projectors. This setup was capable of projecting 4mm-sized details, well perceivable in the rather dark exhibition environment. A representative image of the projection-mapped relief is presented in Fig. 7.

7. Virtual exploration

The physical integration of the model in the exhibition is planned to be complemented with an interactive virtual presentation. The goal is to provide a deeper understanding of the model through a close multi-faceted inspection of its content, forms and style, combined with structured annotations exploited to guide the user in a journey through the model.

In the presentation of cultural heritage items, be it in museums or online, the visitor experience could be easily frustrated if the proposed interaction paradigm does not lead to immediate exploration of the content, through a natural user interface with an extremely short learning curve. Our first decision, also motivated by the 2.5D nature of the sandcast model, was to design the virtual experience around the exploration a 2D planar projection (a view orthogonal to the wall). Through the reduction in degrees of freedom and the use of standard device mappings for pan/zoom actions, this approach avoids the complexity of full 3D motion control.

We further simplify user interaction by using a single virtual object (a visualization lens) as a target for user manipulation. By moving or scaling the lens, the system jointly controls both a focus area and the camera of the surrounding view. Moreover, the lens has an attached dashboard to trigger all interactively controlled actions, in particular for the navigation through annotations. The area for displaying the annotation description is also attached to the lens. This strong focus+context design simplifies the support for large touch screens, where users close to the screen for manipulation purposes naturally focus on a small moving display area, using the rest of the display as an immersive context.

To avoid clutter (Fig. 9) and propose annotations in a sensible order, we exploit an authored sequential and multilevel organization of the annotations, and present one annotation at a time following user actions, also using the lens and its attached interactive tools for navigation control.

Framework The interactive virtual presenter has been designed by heavily customizing the tools provided by the *OpenLime* framework [Ope22], a new open source initiative focused at the web-based presentation of stratigraphic relightable models. The tool uses JavaScript, HTML5 and WebGL to interactively display high-resolution layered 2D models and can be easily tailored to the needs of a specific project on a variety of setups and displays. The framework natively supports normal+BRDF and RTI datasets, and can be easily extended for other multi-channel raster datasets, such as hyper spectral imaging. It builds upon a data-flow design, in which data from arbitrary-size input sources is adaptively streamed to screen-size buffers, that can be mixed and matched through customizable combiners implemented with WebGL shaders. For this project, the framework was used to display a relightable 2.5D model of the sandcast relief with two different BRDF layers, and has been extended to use a visualization lens to navigate through multi-level sequences
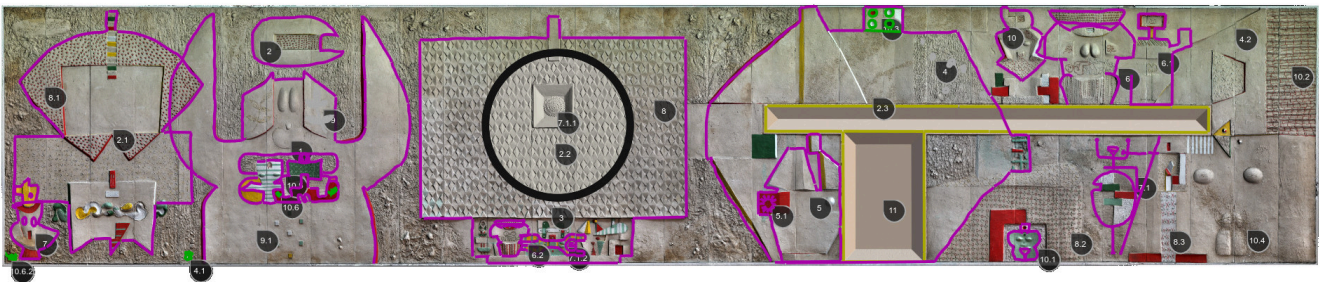
Figure 9: *Annotation overlays. Overlay drawings and pins are associated with each annotation. Displaying all of them, or even all the pins, would create a large amount of clutter. In our tool, we select an annotation at a time using a multilevel storytelling approach.*

of annotations. Thanks to a portable abstraction layer built on top of PointerEvents [W3C19], we unify events generated by input devices in order to handle interaction with both single-touch (mouse or pen) and multi-touch systems.

Multi-layered model preparation The 3D model has been rasterized to a series of registered 45695×14953 (over 650Mpixels) maps by exporting an orthographic rendering of the mural using *meshlab*. We used the same models prepared for fabrication, exploiting the vertical striping subdivision to produce the image incrementally by vertical stripes, reducing memory burden. The maps sample the mural at $\approx$2pixel/mm, i.e., approximately corresponding to original capture size. Shaders were written to export normal, depth, and two BRDF maps: a monochrome one, to show the model without color, and a colored one, to show the current state. Given the characteristics of the artwork, we produced a Lambertian BRDF from the captured color stored in the point cloud, and estimated the monochrome version as the average color of the unpainted areas. The maps were then completed in the not reconstructed and not fabricated areas (the door section, now a concrete slab), by filling them with the appropriate constant values. The images were then converted with *vips* [VIP22] to the multiresolution *deepzoom* format [Mic08], using a tile size of 256×256 in JPEG format (quality 95) with no overlap. The directory tree containing all the tiles is then sequentially concatenated into a single file in tar format, augmented with an index that contains the start offset of each tile (and thus implicitly also its size). Having a single data file makes it possible to move the entire representation quickly among different machines and file systems, and supports very efficiently the extraction of individual tiles with simple range queries on a locally stored file (through *mmap*) or remotely (through any modern HTTP server).
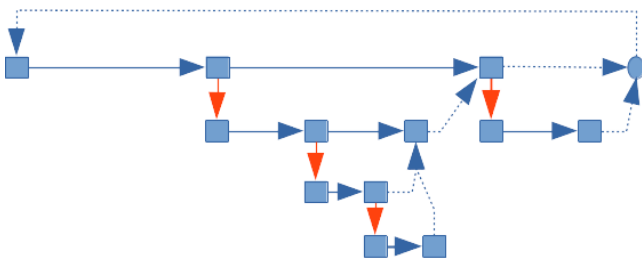

Figure 10: *Multilevel annotations. Blue arrows indicate movement at the same abstraction level, while red arrows provide details on demand. The dotted arrows are not authored, but implicitly added.*
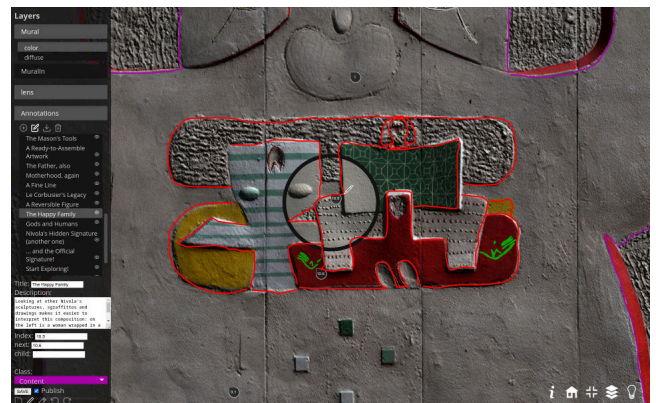

Figure 11: *Annotation authoring. The tool, based on the viewer, allows users to draw over the model, place pins, and control all rendering, viewing, and lens positioning settings associated to the annotation. Moreover, annotation description and hierarchical annotation ordering are also defined.*

Annotation database The layered model is enriched with annotations that provide information attached to model areas. Similarly to other recent works [BAMG21, AMPG22], we associate to each annotation a *visual overlay*, in the form of an SVG markup, and an *external annotation description*, in the form of a short rich text and an optional audio clip, together with the parameters that should be used for an effective lens-based exploration of the annotated area. These parameters contain a lens and camera position and scale, and all the rendering parameters that generate the image (active layers and active shader configurations). Annotations are also arranged in a specific hierarchical order, by adding to them a link that points to the next annotation at the same level and a link that points to the first annotation at a more detailed level (see Fig. 10). This makes it possible, at authoring time, to specify a sequential order for the visit of the annotation tree at multiple levels of detail.

Annotation content and authoring We annotated our models with a simple authoring tool based on the viewer itself (Fig. 11), controlling the lens, light, and camera using the same methods used in presentation mode to identify the interesting areas, to store the lens and camera configuration, as well as the rendering parameters, together with the annotation. The overlays were generated with a built-in graphical editor for the simplest cases (e.g., outlining of compositions) and with an external vector editor for the most complex

ones (we have used *inkscape* and *krita*). In the latter case, editing is done by drawing over the image of the interest area exported by the viewer, exporting the drawing in SVG, and pasting it back into the annotation database. All the data is assembled by the authoring tool in a single JSON file that is loaded by the viewer at startup. The visiting structure (i.e., the "next" and "down" pointers) is created by selecting the relevant nodes at annotation time using a drop-down menu. For the sandcast dataset, the domain experts co-authoring this work defined the scope, i.e., to inform and engage the viewer; the target, focusing on school audience and casual museum-goers; the content, adapting the quantity and the quality of information accordingly. The annotations were classified thematically in *History*, *Content*, *Technique and style*, and *Trivia*. In addition, they were divided according to their relevance, creating three possible depths of exploration to accommodate the viewer's available time and level of interest. The language tried as much as possible to avoid jargon, although retaining the accuracy, the richness and the significance of the information; the style was informal, focused on story-telling and light gamification, encouraging interaction and further explorations. A typical annotation text is in Fig. 12, while the location of the annotations and of their overlays is depicted in Fig. 9. We considered the possibility of a further layer of dataset aimed at scholars and art professionals to be implemented at a later stage.
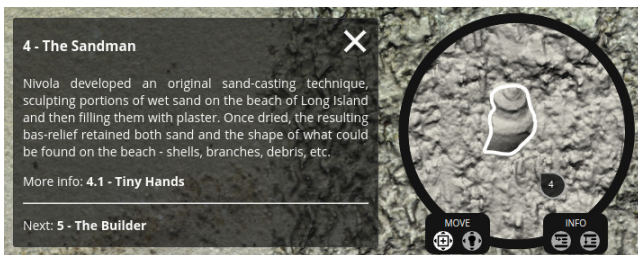

Figure 12: *The interactive lens. The lens is the central interactive object. By moving and scaling it, the view is also automatically controlled. Buttons that decorate the border give access to lighting and annotation navigation control. The information area describes the current annotation, following the lens. Interactive and decoration areas are only visible when the lens is steady.*

Interactive and guided visit with a visualization lens At application start, the user is presented with a full-screen rendering of the sandcast. An interactive visualization lens (Fig. 12) is initially placed at the screen center. The lens is a movable and scalable tool that provides an alternative visual representations for its selected region of interest of the display. It has a circular shape, and shows the monochrome model inside, and the colored model outside, with the idea of using the lens to discover the model as it was originally placed in the Olivetti showroom, under the color layer added during the 2002 renovation. When the lens is moved, the technique of Bettio et al. [BAMG21] is used to also update the camera parameters to always maintain the lens in a good focus-and-context situation. This is achieved by appropriately scaling and panning the view so that the lens radius is maintained between 10% and 20% of the smallest viewport dimension, and the lens is never closer than half its radius from the viewport boundary. In contrast to previous work, direct camera motion is blocked, in order to further simplify the interface. When the lens is steady, the lens border is decorated with additional user interface controls that show the possible exploration

and navigation actions, currently limited to toggling between lens motion and directional light control, and moving in the annotation database through buttons that request the next annotation at the same level (following the blue arrows in Fig. 10) or requesting details on demand (following the red arrows in Fig. 10). The latter button is only visible if details are present. The visual overlay of the current annotation, and its text and image description are also presented. Under the description, if present, a menu showing the available details is also included. The overlay of the current annotation is always visible, while the description appears only when the lens is steady and inactive, and is presented in a box adaptively placed near, but outside, the lens, in the direction with the largest available. Placing all the action buttons and the annotation description around the lens avoids cluttering the visible focus area. At the same time, putting the controls and the description near the focus is of primary importance, especially for large displays, where a typical layout with a fixed annotation display area to the side of the graphics display would lie and the peripheral region of the field of view and would require large gaze changes. The interactive setup is complemented with an automatic playback mode (guided tour), where annotations are sequentially presented one after the other in a timed loop. For this version, we currently simply offer two options: a long tour that visits all the annotations, and a short one that shows only the topmost level of the annotation tree.

Setup and device mapping Our user interface requires minimal user input and has been implemented on for a variety of setups and display sizes. The main target is a multi-touch display (Fig. 1), in which moving the lens and camera is achieved by a one-finger pan gesture, while pinch-to-zoom is used for joint lens and camera scaling. The touch interface gives the possibility to navigate the model using the interaction paradigms used for tablets and smartphones, and the web-based implementation supports both the interaction on those devices (through the web of the museum, directly inside a web-browser), and exploration on large touch screen setups, such as the one shown in Fig. 1 and demonstrated in the accompanying video (selected frames presented in Fig. 13). The same interface can also be operated with a mouse, using the left button for panning and the mouse wheel or a up/down right button drag for scaling, which is useful for data preparation and for remote access through regular PCs.

8. Conclusions

We reported on the current outcomes of an ongoing multi-disciplinary project targeting the physical reproduction and virtual documentation and exploration of the monumental Nivola's Olivetti sandcast relief.

The idea of replicating the artwork, both physically and digitally, arose during the planning for the exhibition *Nivola & New York. From the Olivetti Showroom to the Unbelievable City*, which opened at Museo Nivola, Orani, Italy, in the late spring of 2022.

The exhibition, however, served only as starting motivation and offered a playground for a larger multidisciplinary project that involved groups from humanities, computer vision and graphics, and fabrication, and channelled results from past and ongoing parallel research efforts, funded through internal or collaborative projects.
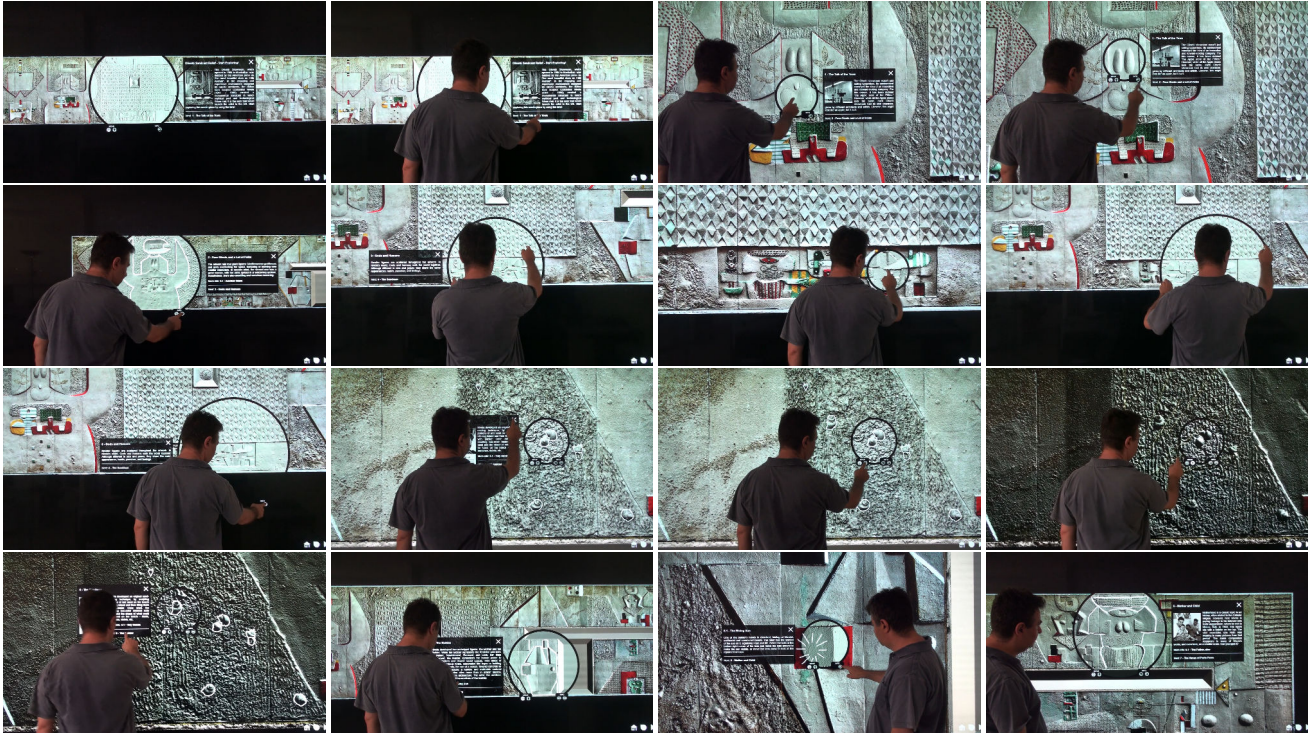
Figure 13: *Navigation example. Frames from the accompanying video showing an interactive navigation sequence.*

The subjects that have been targeted involve both very practical issues, i.e., how to best use state-of-the-art, and mostly open-source solutions to create large models of very massive art works using tight budgets and at a quality sufficient for multipurpose uses (archiving, fabrication, digital exploration, and further research). We also illustrated how such a large replica can be effectively fabricated, assembled, and used in a real exhibit. We finally discussed the design of a tool, whose main components are planned to be released as open source, for the interaction with visual and semantic information.

The information provided here is meant to be useful both to practitioners, willing to embark in similar projects, and to researchers in computer graphics and digital humanities, willing to expand on our results to further improve the state-of-the-art in capture, replication, and documentation of artworks.

Besides refining the current implementation, our current work is focusing on further enhancing the exploration experience, by complementing the fully controlled exploration of the annotation graph with more elaborate discovery options that automatically present context-based application. To do that, we would need to expand recent work on annotation discovery [BAMG21, AMPG22] to more strongly take into account the authored narrative flow.

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