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Investigating a Workflow for Obtaining Physical Models from Digital Twins Obtained through Photogrammetry and TLS: New Ways for a Sustainable Dissemination of Heritage

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Abstract: The objective of this article is to generate and validate a workflow that allows us to print physical twins (models) from digital twins obtained from unique buildings of our architectural heritage. These physical twins will guarantee the preservation and diffusion of the cultural asset, and will promote new pedagogical ways to spread the heritage. In addition, these physical cufflinks are an interesting tool to guarantee universal accessibility through low-cost and rapid distribution typological models. We can overcome physical barriers and reach many more users, regardless of their economic, physical, or location conditions. To obtain this workflow, digital twins of architectural elements of high cultural value obtained by photogrammetry or terrestrial laser scanner will be used. The digital twin will be optimized through different platforms, and an optimized exchange file will be generated for its dissemination and printing. A digital platform will be proposed that guarantees the free distribution of these digital twins to any user. Finally, the physical twins will be obtained. For the development of this work, we have chosen to use 3D resin printers with SLA technology (selective laser exposure to light by laser) due to their performance and high quality in the models obtained.

Keywords: physical twins; 3D print; digital heritage; digital survey; 3D data base; photogrammetry; VAT polymerization; SLA

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1. Introduction

This research develops a methodology to facilitate the dissemination, conservation, and universal accessibility of our architectural heritage through physical prototyping from digital twins.

In this research, we have two clearly differentiated stages: the first, which we could define as "from the physical to the virtual", that is, the capture or digitization of reality through new technologies, and the second stage: from the digital to the physical, that is, the physical prototyping from the data obtained or, in other words, the printing using 3D technologies of the captured data (see Figure 1).

- This article establishes the following three objectives: Assess and standardize a workflow that allows us to arrive from a high-resolution «digital twin» (output formats: obj, 3ds, stl, etc.) obtained through photogrammetry [1,2] or TLS [3] to a physical model printed using current technologies [4,5].
- Obtain replicable models of our heritage that serve to bring our monuments closer to the greatest possible number of people through "maker" technologies.
- Promote the "capture" of these "digital models/digital twins" and their free distribution as good practices to guarantee the conservation and dissemination of heritage.
- Try to promote a philosophy of free distribution that brings our heritage closer to as many people as possible through these physical prototypes and their exchange files.

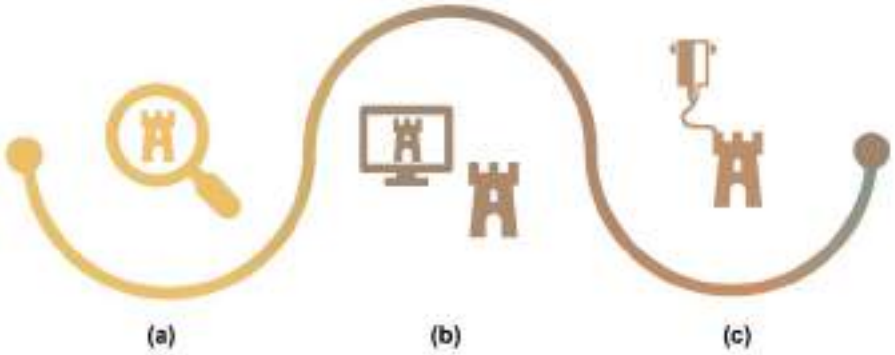

Figure 1. Labor process: "from the physical to the digital and anchor from the digital to the physical": (**a**) Capture of the physical monument using new technology (**b**) Elaboration to generate digital gemelli of our heritage (**c**) Obtain physical gemelli from new technology.

As a three-dimensional working model to test this methodology, we used the digital twin made for the «restoration project for the wall of Cáceres Phase II. Almohad towers of the southwestern wall in Cáceres». This project has been carried out by the architects Isabel Bestué Cardiel (team director), Carmen Cañones Gallardo, Rosario Carmona Campos, Pablo Alejandro Cruz Franco, Adela Rueda Márquez de la Plata, and Javier Chavez Quesada. (See Figure 2).

This restoration project, of which the authors of this document have been a part, has been developed on the Almohad walls of the world heritage city of Cáceres [6,7]. The work area is divided into two sections. The first section, known as the Adarve del Padre Rosalío section, is made up of a section of wall parallel to the Adarve del Padre Rosalío street, an albarrana tower, and a defensive cube. This section has a floor area of 170.79 m^2.

The second section of the wall has an intrasdos with an extension of 16.62 linear metres. The section is on urban land and public space, and has a total floor area of 155 m^2. Through the extrados of this section, a double section of wall can be identified, interrupted by a flanking tower to the southeast. Beneath this stretch of wall, a possible antemural rises from Calle Cornudilla. At the corner of Calle Adarve del Padre Rosalío there is an albarrano wall and an octagonal albarrana tower.

The capture of this digital twin, as we have said, has been carried out using photogrammetry. Work has been carried out by combining point clouds obtained by SfM (with images acquired from UAV, Unnamed Aerial Vehicle) [8,9]. To verify the reliability of the model, the models have been contrasted with the point clouds obtained by means of a digital instrument, a Terrestrial Laser Scanner, TLS [1,10–12], and the result is a three-dimensional model. This is a high quality canvas model [6] of the city, and we can affirm that it has been obtained through a low-cost and precise "intelligent work" flow, having been developed essentially through photogrammetry and verifying the reliability of the model through TLS. All of this digital twin has been processed in cabinet work [13].

When we work with three-dimensional models made up of point clouds and triangulated models, a key point is to validate the geometric quality of our models. As we have said, the model obtained through SfM guarantees a very complete model, thanks to its ability to reach almost all points, especially if we compare it with a model obtained through TLS. On the other hand, this model may contain geometric inaccuracies that must be verified, so the model obtained through TLS helps us to verify the quality of the model through SfM. On the one hand, this model obtained through TLS is less complete due to the physical limitation of access to roofs, which causes phantom zones, but, on the other hand, it is a much more reliable model in terms of precision, since we know the millimeter precision and it helps us to control and validate the results. Ground photogrammetry was more accurate, but has the same limitation as three-dimensional models obtained by TLS. Aerial photogrammetry is less accurate, but reduces the number of ghost zones to almost 0.

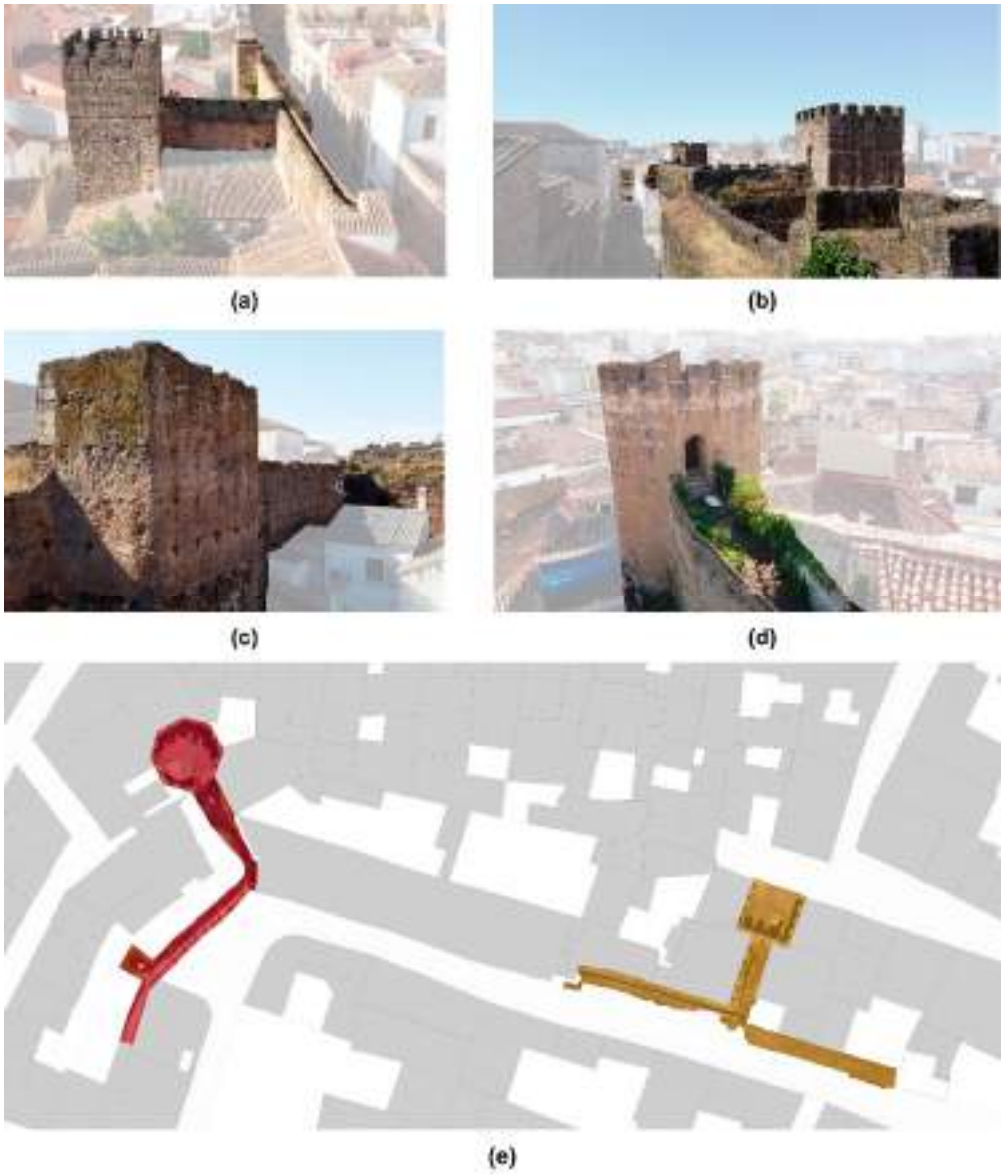

Figure 2. (**a**) Aerial view of the Aver tower, (**b**) view of the fortified complex from the intrados of the canvas. In the foreground tower of the Aver, (**c**) cube of the Aver. Trasdós of the canvas, (**d**) aerial view of the Ochavada tower, (**e**) plan of the study area. Right canvas, colored in red, cube and Ochavada tower. Left canvas, colored in orange, cube and tower of the Aver.

In the geometric validation procedure, we obtain two point clouds. To scale and orient them, we used the RECAP platform to facilitate and guarantee the transition to BIM (Building Information Modeling), in our case, on the REVIT platform, since both belonged to the Autodesk set of tools, where interoperability was guaranteed.

The point cloud obtained using Agisoft Metashape is in a *.psx format. The *.psx format is not compatible with RECAP, so we need a previous step in which we modify the format of our file to a format suitable for RECAP. In the case of the cloud obtained through TLS, there is no problem since we use the cyclone software to process the data obtained through the BLK360 laser, which allows us to export and resample our point clouds in formats compatible with RECAP.

In this way, the cloud of points was obtained in Metashape. To do this, we exported from .psx to .laz. The .laz format, as we have said, is compatible with the RECAP program and allows us to load that cloud, process it, classify the points, etc. Once these accessions have been made, the next step is to link the cloud in REVIT.

The next step will be carried out within the REVIT platform. With the point cloud in RECAP format, we will proceed to link it in REVIT. We will call this cloud of points 1 A. We can have as many as we want, for example, 1 A, 1 B, 1 C, etc. Using homologous points, we will proceed to position these clouds in the model space, making them overlap.

According to what was seen in the article "Protocol Development for Point Clouds, Triangulated Meshes and Parametric Model Acquisition and Integration in an HBIM Workflow for Change Control and Management in a UNESCO's World Heritage Site" [1], we will proceed to make a chromatic differentiation of each of the point clouds to easily visualize geometric differences.

We will proceed to an analysis through sections, elevations, and plans at different levels. This analysis is carried out quickly in REVIT, allowing us to measure and obtain fast and reliable data about the quality of our models, being able to discard entire models or parts of them if necessary. With this system, the level of precision is analyzed correctly.

2. Related Works

2.1. Obtaining the Digital Twin

Obtaining these digital twins is a recurring theme in the scientific literature that deals with the digital survey of heritage. It is important to highlight the DADA Lab of the University of Pavia, directed by Professor Sandro Parrinello, and the LS3D Lab of the University of Florence, directed by Professor Stefano Bertocci, due to their importance, and for being pioneers in this area. Both laboratories are an international benchmark in the field of architectural survey, documentation, and protection of heritage [2,14–21].

To obtain the digital twin [13,22,23] a system is necessary that allows us to carry out different flight missions at different times in order to capture the entire study area [8]. This system has to be versatile, not affect assets, and be low cost. It is cabinet work; this work represents a great advance and innovation in itself, respecting the current state of cultural heritage.

After the study is carried out, it has been decided to use a work methodology, consisting of the creation of a more exhaustive "own" polygonal mesh that allows us to georeference the study area with greater accuracy, facilitating the realization of different flight missions at different times; this work represents a great advance and innovation in itself while respecting the current state of cultural heritage (see Figure 3).

To generate the polygonal mesh, it is necessary to insert some nails (metal spikes) into the pavement that allow us to place the exact targets/targets; once they are located at the points of interest, we proceed to georeferencing with respect to the city simulating topographical nails.

Once we have a flight program and defined the structure of the missions and their objectives, the data will be collected using UAV [8,20,24–26].

For an exact geometric definition, a TLS (Terrestrial Laser Scanning) will be used [27] that will allow us to accurately measure the monument and check the accuracy of the shots made with UAV [2] (see Figure 4).

Thanks to TLS technology we quickly and accurately obtain a three-dimensional model with possible phantom zones, such as the roofs of a building, but by combining these with the models generated from UAV technology, we can obtain complete models of great precision that will allow us to later process the models to generate the physical prototypes [7,27].

This network is susceptible to expansion over time, making it possible to have a series of points that can be used to establish a new network as a result of deterioration, loss, movement of its original position due to inclement weather, vandalism, works, and incidents on the pavement, to link future work models or to carry out different survey campaigns.

In order to interconnect future three-dimensional models or the different flight missions with the use of three nails (points), it is already possible to reference the model, but to work more safely and accurately in this work, more points have been used, thus facilitating

complementary work. Once the three-dimensional model has been obtained, it can be expanded by linking the targets of the previous work with new ones closer to the area on which it is intended to work, and so on, until the entire scope of the project is covered, that is, an extensive project is sectioned into smaller areas for more detailed and precise work. The different models can be linked, obtaining the necessary information by using complementary techniques after the creation of the mesh, such as UAV (Unnamed aerial vehicle) photogrammetry, SLR (Single lens reflex) or the TLS (Terrestrial Laser Scanning) model [28].

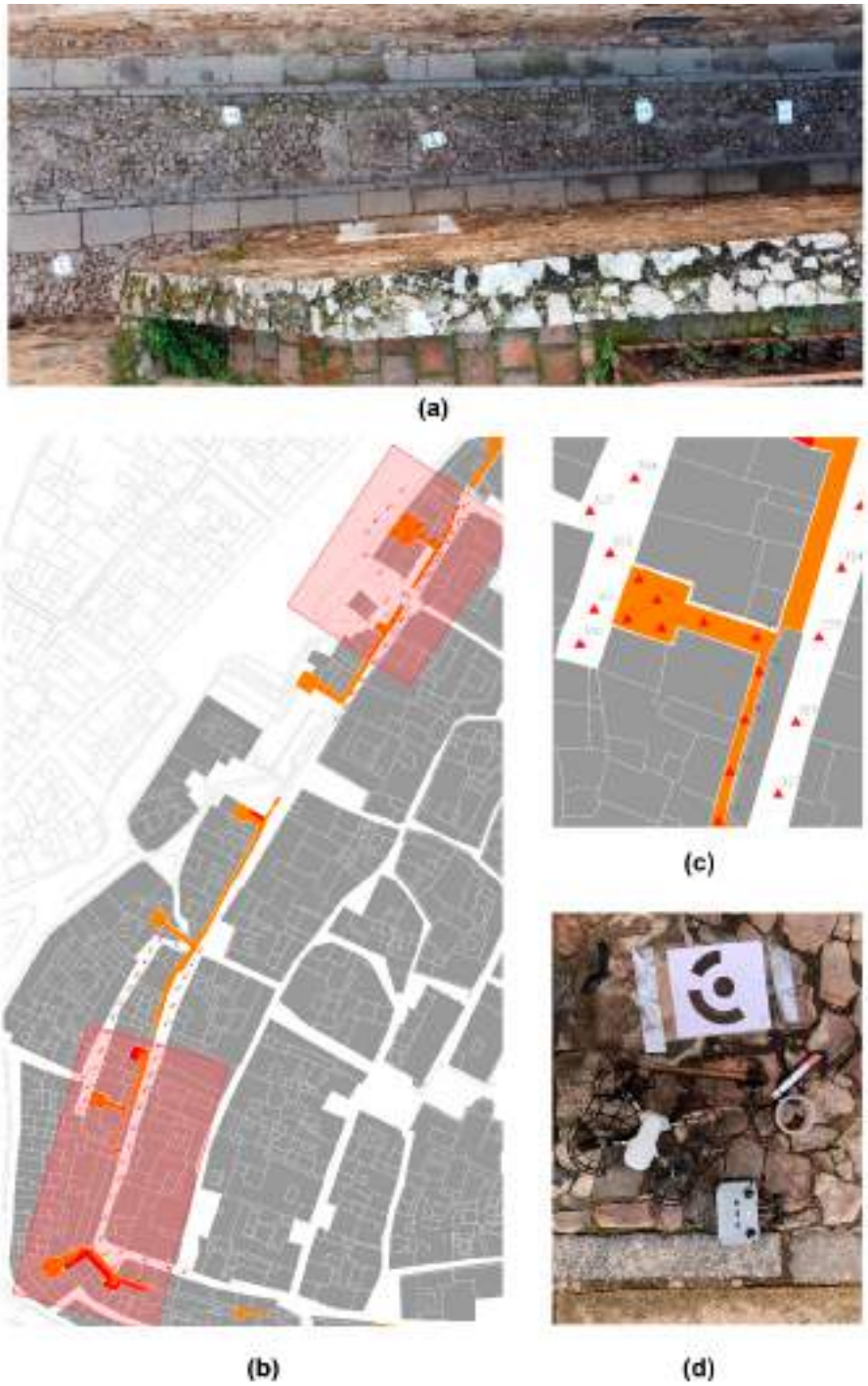

Figure 3. (**a**) Polygonal mesh including the targets, **(b)** work areas and positioning of the different points that make up the mesh. (**c**) Detail of the work area corresponding to the Aver tower (**d**) Work elements.

Figure 4. In the image: (**Left**): the author flying the drone. (**Right**): the author positioning the laser scanner.

2.2. Obtaining the Physical Prototype

Today, the way of understanding reality in our society is constantly evolving given the ease of access to the digital tools that we currently have. In addition, the use of new technologies has been increased, given the situation that COVID-19 has generated, producing a great change when it comes to relating to each other [29–32] and with the heritage that surrounds us [33–36]. The need arises to bring heritage closer to any part of the world in the simplest way possible; therefore, the need for digital twins has become relevant and, going a little further, combining digital twins with the most avant-garde technologies related to 3D printing, we can obtain physical prototypes that allow us to discover the cultural and architectural heritage in a different and cheaper way [11,25,37,38].

We can say that there are three large families of 3D printing technologies. In the first place, we would say that we have the family of addition (additive manufacturing), that is, the one that encompasses all the technologies that replicate reality by adding material, where nothing existed. Based on layers, we can generate our physical twin; in a certain way, we could compare it to the Greek technique of casting with lost wax [26,39]. Secondly, we have subtraction technologies (subtractive manufacturing); these technologies, from blocks of raw material, by means of milling cutters or other elements, remove layers of material and give rise to our physical twin as if it were a classic stone sculpture (normally we will talk about CNC machines here). Lastly, we would talk about cutting technologies (manufacturing by cutting): these technologies, based on sheets of material and cutting templates (DWG, DXF, etc.), will generate pieces that we will assemble; normally, these are laser cutting machines, although we could generate similar parts with CNC printers. In Figure 5, we can see different examples developed by the research team in collaboration with the University of the Americas of Puebla, México.

Figure 5. Different examples of physical models of architecture obtained using different 3D printing and cutting systems. TAD3 Lab. Works in collaboration between the University of the Americas of Puebla and the University of Extremadura. In the figure, we can see models made of wood on both sides that have been executed with a laser printer and CNC cutting machine, and, in the center of the table, we can see white filament models that have been manufactured with a filament extrusion printing printer.

In the case of this research, it has been decided to use an addition technology, more specifically, VAT polymerization, specifically laser SLA (selective exposure to light by laser). A brief summary of the different additive manufacturing technologies has been prepared below:

First of all, if we see Figure 6a, we have the material extrusion technology FDM (fused deposition modelling). This technology stands out for its optimal surface finishes, a wide range of colors and materials, and a low cost. On the contrary, we have low resolution and, in many cases, fragility of the pieces. Secondly, in Figure 6b, we have outlined the operation of the technology known as material jetting (MJ). This procedure allows the creation of objects by combining different materials and colors. It is based on photopolymeric liquid resin that is heated to 30–60 °C, thus obtaining the right viscosity for printing. The print head, which is very similar to that of an inkjet printer, distributes the photopolymer resin on the platform. The curing of this resin is performed with UV light. The projector of this UV light is integrated into the print head and will form different superimposed layers. Like the SLA process that we will see later, this technology is based on the principle of photopolymerization. Among its characteristics is an optimal surface finish, a full range of colors, and a multitude of materials with different physical and mechanical properties, but it has a high cost. Thirdly, in Figure 6c, within the additive printing technologies, we highlight the selective laser sintering (SLS) technology, which is a rapid prototyping technique in which a layer of powder is deposited (a few tenths millimeter) in a vat that has been heated to a temperature slightly below the melting point of the powder.

Next, a high-power laser causes the deposited particles to fuse and solidify. This process is called sintering. With SLS technology, we obtain functional parts with good mechanical properties, and we can make complex geometries. Among its negative characteristics would be that it has long delivery times and a higher cost than FDM technology. In Figure 6d, we see a scheme of the sand or metallic powder printing system, known as 3D binder jetting. This technique consists of the deposition of an adhesive binding agent on thin layers of powder material. Powder materials are metal (e.g., stainless steel) or ceramic (e.g., glass or plaster) based. This technology is low cost, and we can generate functional metal parts. Lastly, in Figure 6e, we have the latest addition printing technology studied: VAT polymerization. This family brings together the technologies that achieve 3D printing through the polymerization of a vat (VAT) filled with photosensitive resin.

Depending on the light source used, we will have different classes: laser SLA (selective exposure to light by laser), DLP-SLA (selective exposure to light by projector), and MSLA (selective exposure to light masked by LCD). All of them will obtain a final item obtained by accumulating layers.

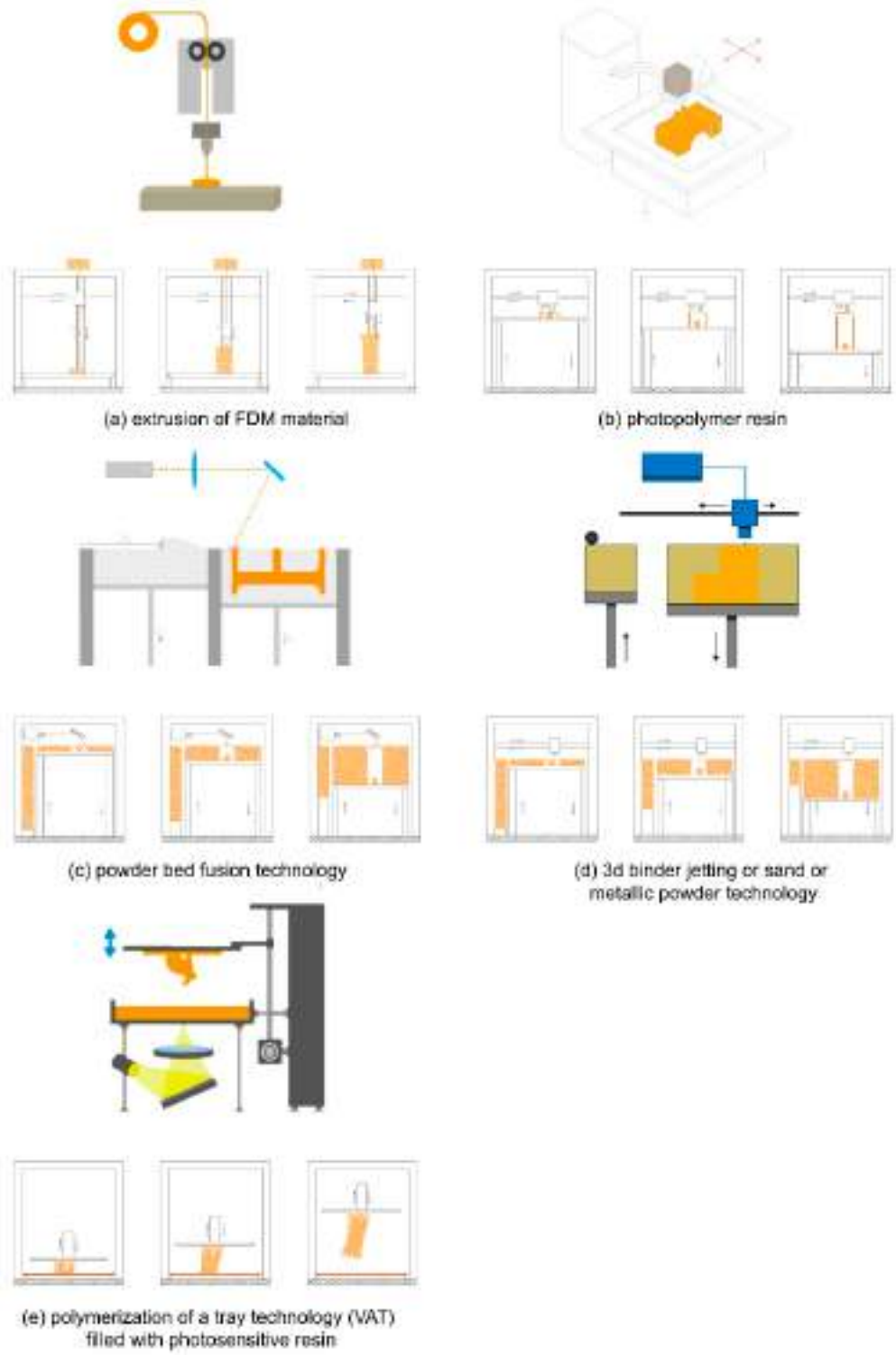

Figure 6. Three-dimensional printing technologies: (**a**) printing through the extrusion of FDM material; (**b**) photopolymer resin (**c**) powder bed fusion technology; (**d**) 3D binder jetting or sand or metallic powder technology; (**e**) polymerization of a tray technology (VAT) filled with photosensitive resin.

2.3. Choice of Printing Technology

As we have indicated, the project is developed in the City of Cáceres, a World Heritage Site, and its physical development will be developed within the FAD LAB: SOL (Smart Open Lab), located in the Polytechnic School of Cáceres at the University of Extremadura.

SOL is an open production space that has supported this project with tools, machines, and knowledge of the community that composes it. SOL's main philosophy is to share knowledge globally and, thus, contribute to development and research.

The printing possibilities within SOL are multiple. Once the resolution of the obtained models and the machines at our disposal were analyzed, it was decided to use the equipment: Form 2. This equipment allows us to obtain physical models using photopolymer resin and SLA laser technology (selective exposure to light by laser). Specifically, the form 2 printer allows us to obtain exceptional resolution and precision in details, specifically between 50 microns and 100 microns.

3. Results: A Standardized Protocol in Five Steps

After carrying out the process, we have managed to generate a standardized protocol with five general steps as detailed in Figure 7.

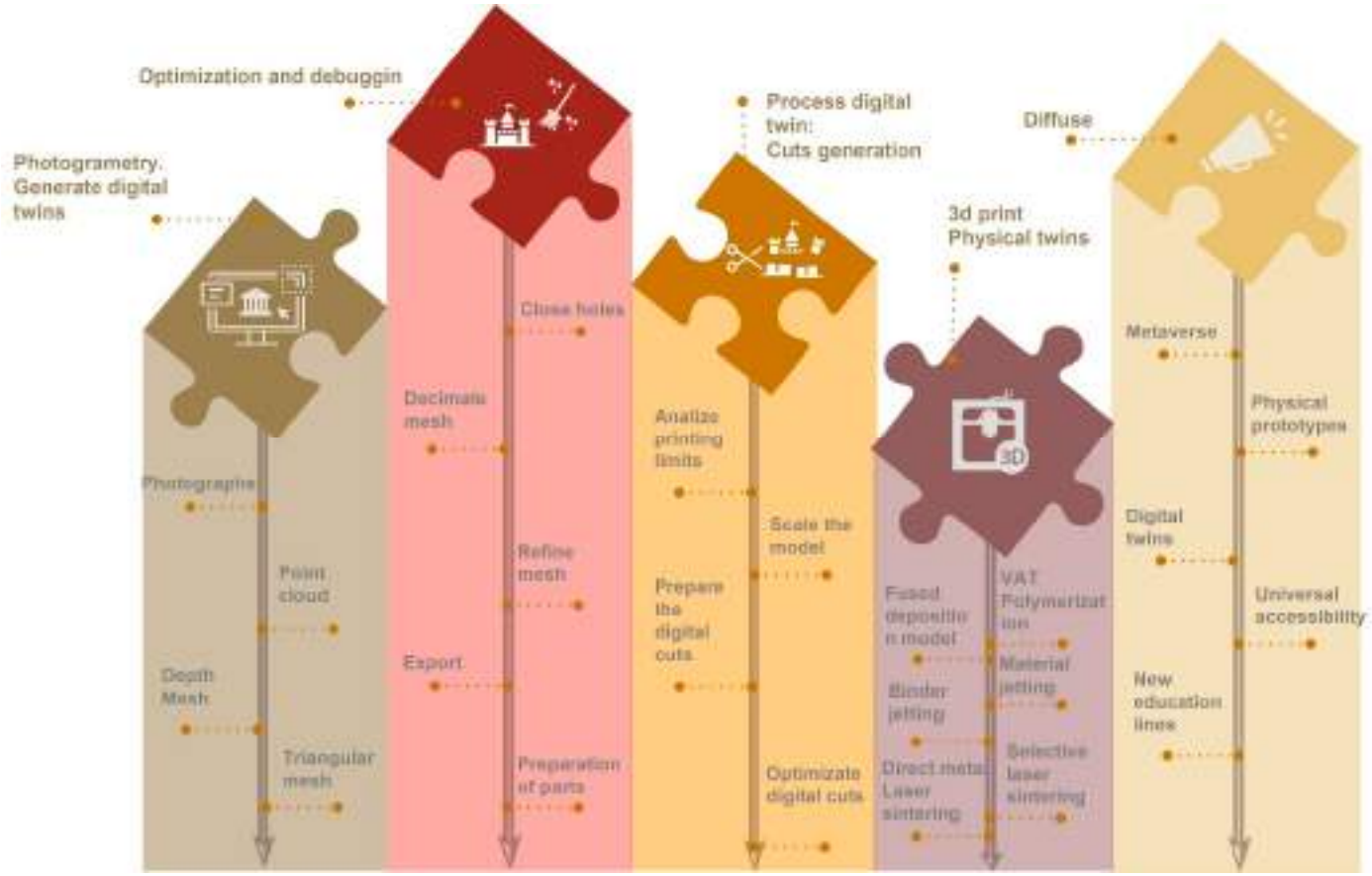

Figure 7. Five steps of the standardized protocol.

3.1. Generation of Digital Twins

As we have indicated, the development of this digital twin has been carried out by combining point clouds obtained by SfM (with images acquired from UAV) and clouds obtained by TLS digital instruments; the result is a 3D digital model [40,41]. It is a high-quality model of the city canvas, and we can say that it has been obtained through a low-cost and precise "smart work" flow [13]. The steps to obtain this physical model are summarized in Figure 8 [1,7,25,42–44]:

- Orientation of photographs: this orientation allows the scattered point cloud to be obtained.
- Generation of dense point cloud and depth maps.
- Dense point cloud optimization by point filtering.
- Generation of the triangulated mesh.
- Generation of the texture from the images taken by the drone.
- This processing gives rise to digital twins made up of huge meshes, which need to be reviewed and refined to obtain three-dimensional models that can be used in metaverses [13,45–48].

Figure 8. Photogrammetric processing of the data obtained by UAV.

In the case of the model obtained with TLS, we obtain a second virtual twin, which will be built from the documentation using TLS. This is cabinet work (see Figure 9).

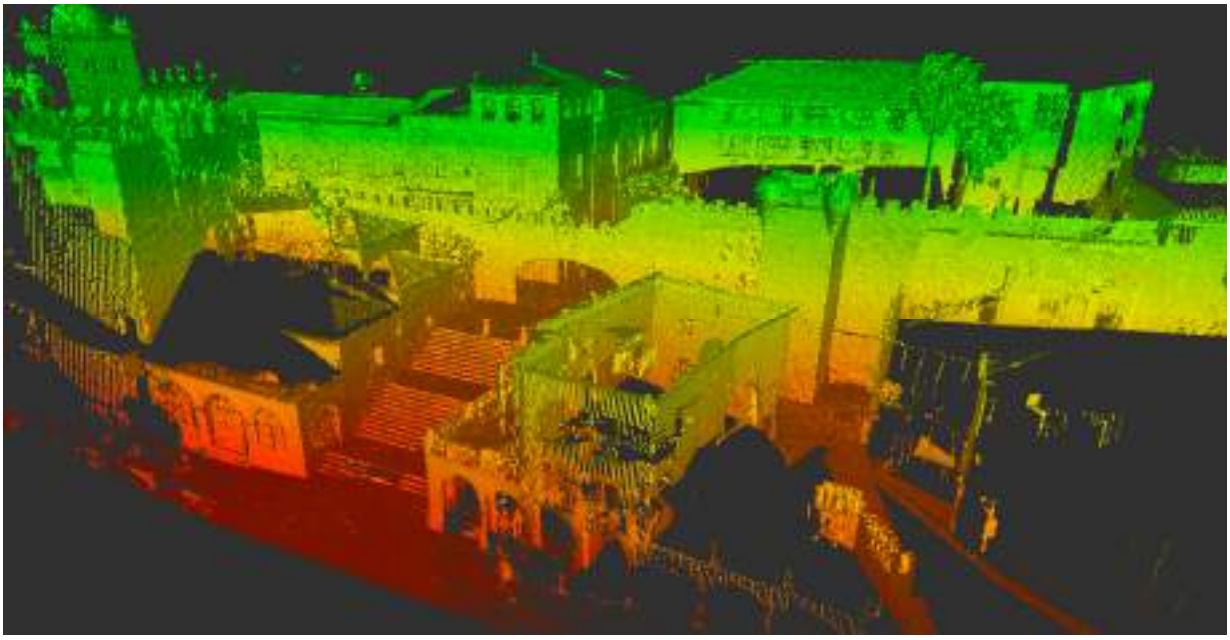

Figure 9. Results of the point cloud obtained with TLS.

After the study is carried out, it has been decided to use the software of the laser scanner Cyclone 360 register, which is software for photogrammetric processing of digital images and generation of 3D spatial data. Its main functions include: automatic alignment of scans, manual alignment of the scans according to the point clouds, allowing the link with other point clouds through the use of targets, and texturing options through the images generated in the scans (see Figure 10):

- Step 1: Importing Scans
- Step 2: Aligning Scans

- Step 3: Model optimization
- Step 4: Detect targets or common and fixed points
- Step 5: 2D planimetry from the point cloud
- Step 6: Export the point cloud for further processing.

Figure 10. TLS processing of the data obtained.

3.2. Optimization and Debugging of the 3D Models Obtained to Obtain Exportable Digital Twins

As we have indicated in the previous section, the three-dimensional model obtained through photogrammetry and TLS [49,50] is a complex and heavy model that requires a lot of computational load [13]. It becomes a priority to optimize it to obtain exportable files in different exchange formats. To debug the model, we use Rhinoceros and Blender interchangeably. With these programs we can repair and reduce the mesh [51].

The first step is to repair the mesh, as it is imperfect, and it is necessary to close holes derived from bad data collection in areas where the point cloud is not dense enough to form a closed mesh from it. The next thing is to reduce the mesh, that is, reduce the number of triangles, until arriving at a simplified mesh that considerably reduces the size of the source file. Then we smooth the mesh. Mesh smoothing consists of approximating straight edges to radii with a given curvature while maintaining mesh density.

At this point, we have mainly used three types of software that have allowed us to study the different models and compare them to search for errors and to suppress ghost zones. Mainly the Rhino software, Blender and the instant meshes application have been used. We have made a retopology of the models and closed holes, as we have commented. We have gone from a triangular mesh to a quadrangular mesh, and we have repositioned the high quality textures in the corrected model using Blender; they are not necessary for the model printed in TLS, but for digital twins uploaded to repositories for AR and VR if necessary.

3.3. Processing of the Digital Twins: Generation of Cuts

This third processing step of this «digital twin» has been carried out again using the Rhinoceros 3D software. We have focused on the environment of the wall, and we have modeled the semi-detached houses in a simplified way. Once this first phase of modeling has been completed, it has been divided into fragments according to the physical limit imposed by the printer model that we have used (form 2), which is 145 × 145 × 175 mm. In total, 24 cuts have been planned, indicated in Figure 11.

In the scheme, we also see a blue area that represents the environment a little further away from buildings. This environment was made using the laser cutter. It was simplified from the parcel of the Historic District.

Below we leave, the Table 1 summarizes the different pieces generated, related to the printing time and the material necessary for its execution. In total, 24 cuts have been planned, indicated in the scheme that we see below. These 24 cuts require 1907.83 mL of white resin (not counting the printing tests), and two resin tank units have also been used. A total of 203 h have been invested in printing alone. These data do not take into account the cleaning and curing time (carried out with the formwash and formcure machines, also from 3dlab, as we will see later) or the time spent on polishing, sanding, etc. (carried out in a traditional carpentry workshop).

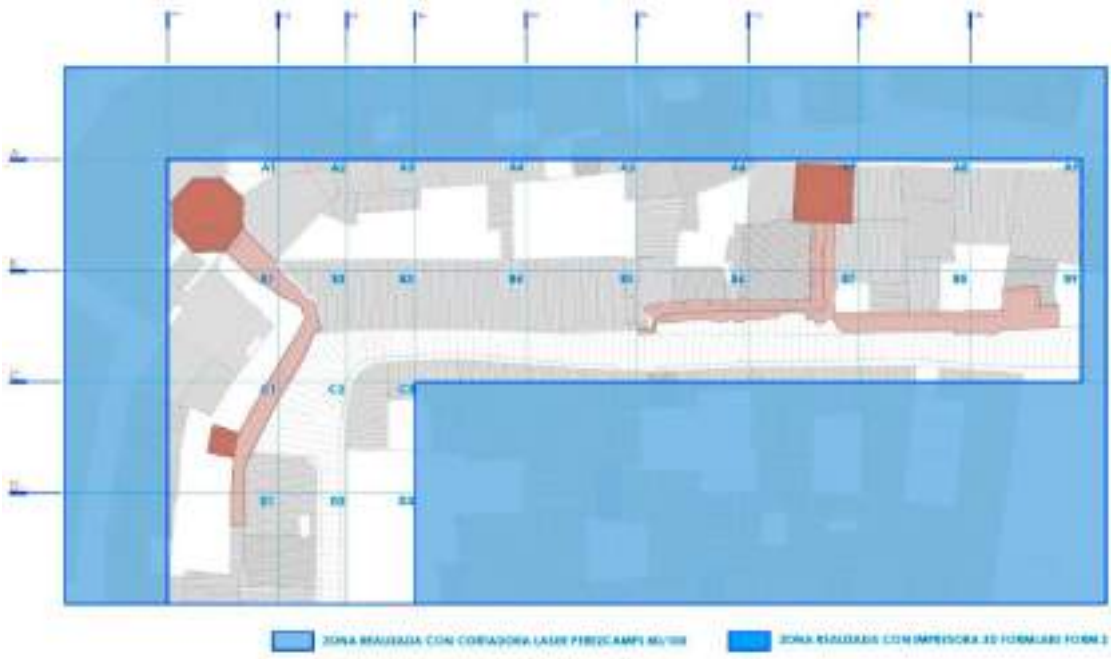

Figure 11. Plan of planning and organization of cuts and work according to the selected printer model.

Table 1. Summary table of physical prototype.

Pieces	Swap File (STL)	Preform	Resin (mL)	Duration (h)
A1	A1_STL	A1_FORM	114.95 mL	10 h
A1	A1_STL	A1_FORM	96.63 mL	10 h 15 min
A2	A2_STL	A2_FORM	77.96 mL	7 h 45 min
A3	A3_STL	A3_FORM	62.31 mL	7 h 15 min
A4	A4_STL	A4_FORM	74.02 mL	8 h 15 min
A5	A5_STL	A5_FORM	68.26 mL	7 h
A6	A6_STL	A6_FORM	92.40 mL	9 h 15 min
A7	A7_STL	A7_FORM	78.64 mL	9 h 45 min
A8	A8_STL	A8_FORM	76.91 mL	7 h 45 min
A9	A9_STL	A9_FORM	70.23 mL	6 h 45 min
B1	B1_STL	B1_FORM	72.46 mL	7 h 30 min
B2	B2_STL	B2_FORM	49.63 mL	6 h 45 min
B3	B3_STL	B3_FORM	50.63 mL	7 h 15 min
B4	B4_STL	B4_FORM	79.17 mL	9 h 30 min
B5	B5_STL	B5_FORM	87.84 mL	10 h 15 min
B6	B6_STL	B6_FORM	280.31 mL	16 h 30 min
B7	B7_STL	B7_FORM	76.31 mL	9 h 30 min
B8	B8_STL	B8_FORM	76.56 mL	9 h 15 min
B9	B9_STL	B9_FORM	79.89 mL	9 h 30 min
C1	C1_STL	C1_FORM	84.07 mL	8 h 45 min
C2	C2_STL	C2_FORM	49.13 mL	6 h 30 min
C3	C3_STL	C3_FORM	51.25 mL	7 h 15 min
D1	D1_STL	D1_FORM	90.15 mL	9 h
D2	D2_STL	D2_FORM	55.26 mL	7 h
D3	D3_STL	D3_FORM	27.81 mL	4 h 30 min

3.4. 3D Print

As we have indicated, this work is carried out within the FAD Lab SOL (Smart Open Lab) and a FORM 2 unit has been selected to make the impressions. A versatile workflow is generated that allows the transfer of the information obtained, thanks to photogrammetry (digital twins) to twins [4] high resolution physics (see Figure 12).

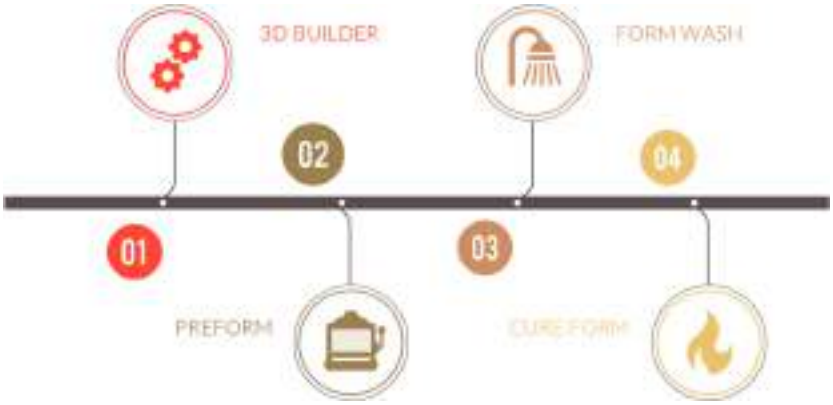

Figure 12. Diagram of the process for 3D printing.

3.4.1. Phase 1. Export of the Photogrammetric Model

Nowadays, there are many ways of exchanging digital files for the different software that we use. In our case, we exported the model with the OBJ extension, since it allows us to keep the textures of our digital twin.

3.4.2. Phase 2. Processed in 3D Builder

To process the digital model, we used the 3D Builder software, free software from the Microsoft Corporation company, that allows users to create, model, and print models in a generalized and free way, being a great help to facilitate the transmission of knowledge in any part (see Figure 13).

Figure 13. Workflow for processing digital twins in 3D Builder.

3.4.3. Phase 3. Preform Processing

Once the digital twin has been processed, it is necessary to continue processing it, this time with Preform, the free software of the Form 2 printer, from the company Form Labs, which uses advanced parameters to generate the supports and optimize the printing of each piece, resulting in a digital model ready for printing (see Figure 14a).

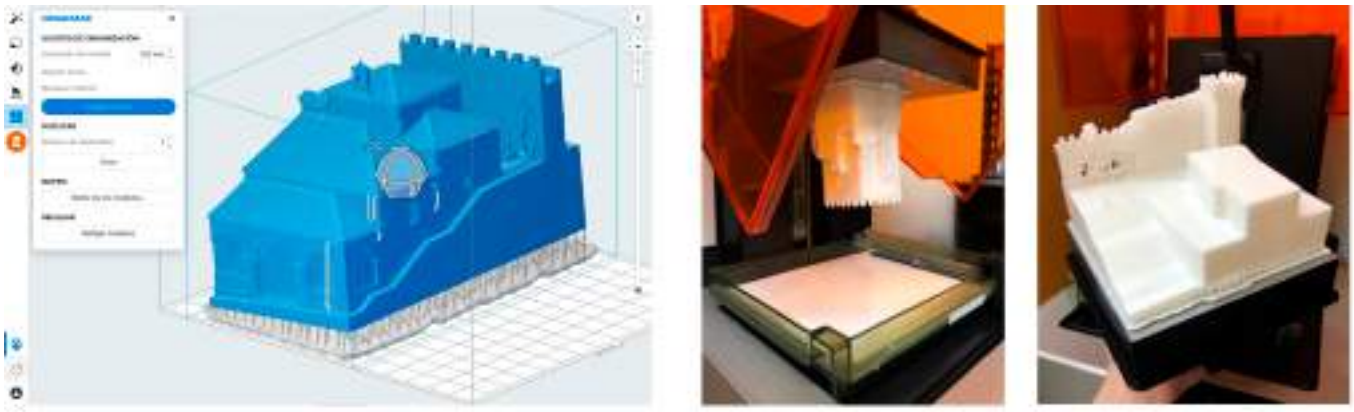

Figure 14. (**a**) digital twin before printing (**b**,**c**) physical prototype on the Form 2 printer.

3.4.4. Phase 4. Printing

To do this, the following equipment has been used within the Smart Open Lab: 3D printer, specifically, the Form 2 model (a stereolithography (SLA) 3D printer), Form Wash, and Cure Form.

FormLabs, Form 2: It works with a resin printer due to the high quality it offers (50–100 microns) (see Figure 14b,c).

Washing in Form Wash: Once the pieces are obtained, it is necessary to wash them to remove the excess resin without the surface curing. This the machine uses isopropyl alcohol, and the sink time will depend on the type of resin that is being used.

Cured in Cure Form: Once the parts have been washed, the supports that have been generated prior to printing are removed. Once the pieces are without supports, they are cured; for this, it is necessary to use the Cure Form. The curing time and temperature will depend on the type of resin that is being used for the prototypes.

3.4.5. Phase 5. Assembly

Once the different pieces of the model have been obtained, both in resin (obtained with the Form 2 printer) and in DM board (obtained with the laser cutter), in specific cases there may be joints that we have had to review. These joints can be treated as wood to improve the assembly, always keeping in mind that these areas are together; they are not the faces of the model obtained by TLS [52] or photogrammetry, in which we have that aforementioned precision of microns and that could not be touched by these methods. In these specific cases, it should be noted that the behavior of the resin used has been very similar to that of wood, in that it can be sanded, cut, drilled, etc., expanding the possibilities of interaction with this material and the possibilities of executing objects. See Figure 15.

3.4.6. Phase 6. Diffusion

This point becomes a labor capital section. We have taken the following path: from the physical to the digital and from the digital to the physical. That is to say, that first moment, in which the material object that is the element of architectural heritage, at the moment in which we have identified that it is a work of art and decided to digitize it for posterity; and

that second moment, in which the digitized work becomes universal, and we fight to reach all corners of the world in that search for universal accessibility.

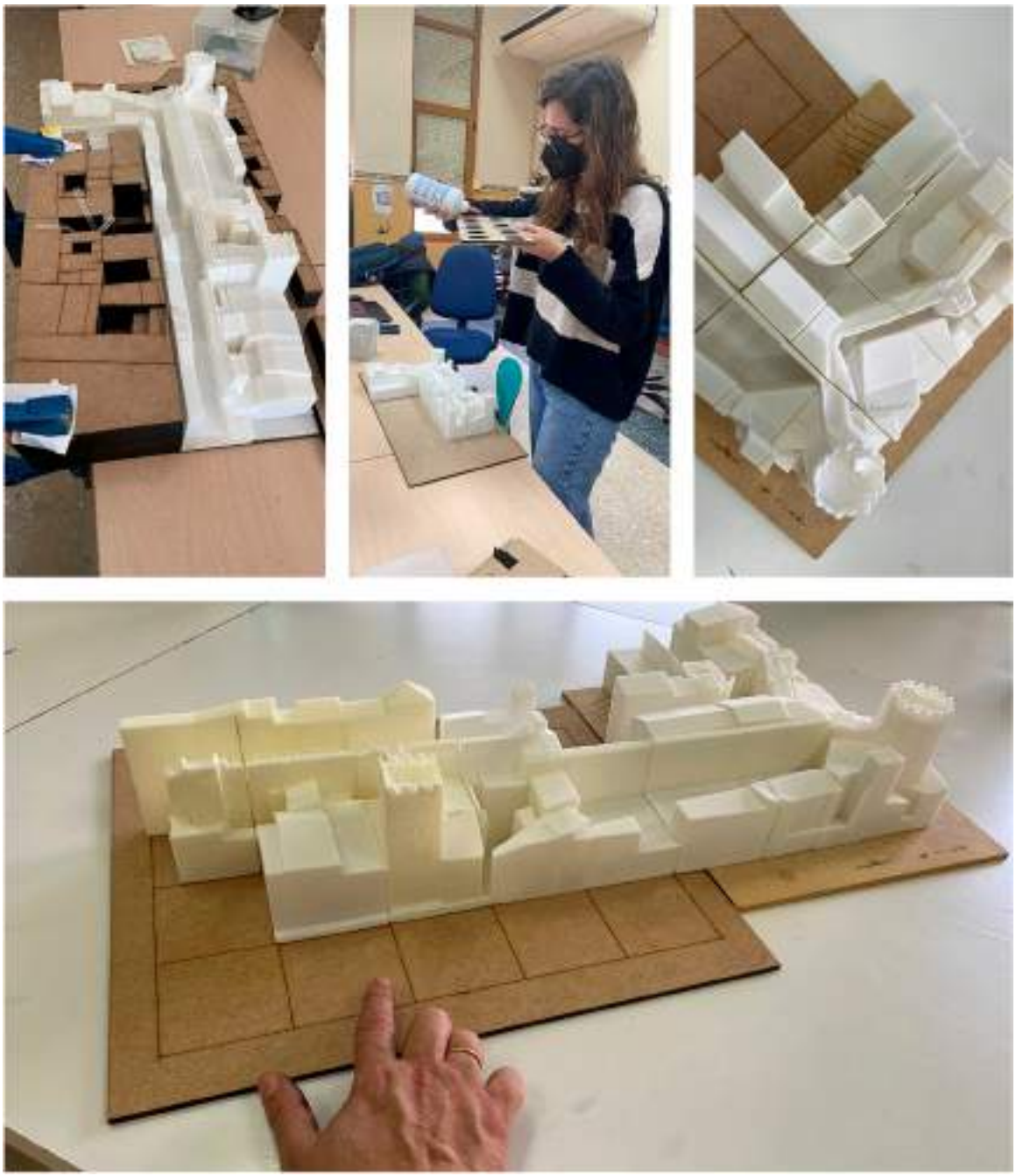

Figure 15. Process of assembly and assembly of the physical prototype.

In this way, we are going to have two diffusion lines. First of all, the model itself, obtained by our research group using SLA laser technology (selective exposure to light by laser). In Figure 16, we can see the final results and the work shots. Secondly, as we have said, the work would be philosophically serious; the vocation of this work is the free distribution of this knowledge in order to generate an international knowledge matrix. For this, the use of different platforms has been proposed [13].

Figure 16. Finalist prototype and taking of previous photographs.

As we have said within the working group, different platforms have been studied that are used to house digital twins. We highlight the result of the article presented in the journal Applied Sciences with the name: Protocols for the Graphic and Constructive Diffusion of Digital Twins of the Architectural Heritage That Guarantee Universal Accessibility through AR and VR [13,53]. Among the results obtained, we highlight the following two platforms: Thingiverse (www.thingiverse.com, accessed on 2 December 2022) and Sketchfab (www.sketchfab.com, accessed on 15 December 2022). The first, thingiverse, is a free online website dedicated to the creation and publication of digital STL files, designed and published by the users that make up the community. When a community member decides to upload a file, they will be able to choose the type of license they want to add to it. Second, the Sketchfab Platform is an outstanding platform, due to the great variety of content that it incorporates, as well as its 3D model viewer. Sketchfab allows downloading of files from the web if the users (owners of the models) allow it. We want to highlight the VR functionalities provided by this second platform.

4. Discussion

We are at a time of change, in which the tools that are made available to the architect to protect heritage are immeasurable. These tools allow us to generate extensive 3D databases that allow heritage protection from knowledge.

In this communication, we present a workflow for the generation of three-dimensional models and their dissemination. These workflows generate new possibilities that extend the concept of universal accessibility. We want to highlight the following possibilities:

First of all, in this expanded concept of universal accessibility, the situation arises in which anyone, regardless of their economic situation or where they live, can enjoy these cultural elements.

In second place, in a teaching level, it is a step forward in the tools that we provide to teachers. All these resources are already interactive, as we have said, and AR, VR [13], or physical are revolutions in the classroom, which that allow a teacher from anywhere in the world to print a wall like the one at hand for their students, so that they can study and document it.

In our experience as professors at a university of technical education (architecture), the student's training in construction subjects improves when they have construction details in their hands. Incorporating printing technologies as activities in teaching have very profitable results by incorporating transversal skills into teaching that substantially improve the abilities of students (See Figure 17).

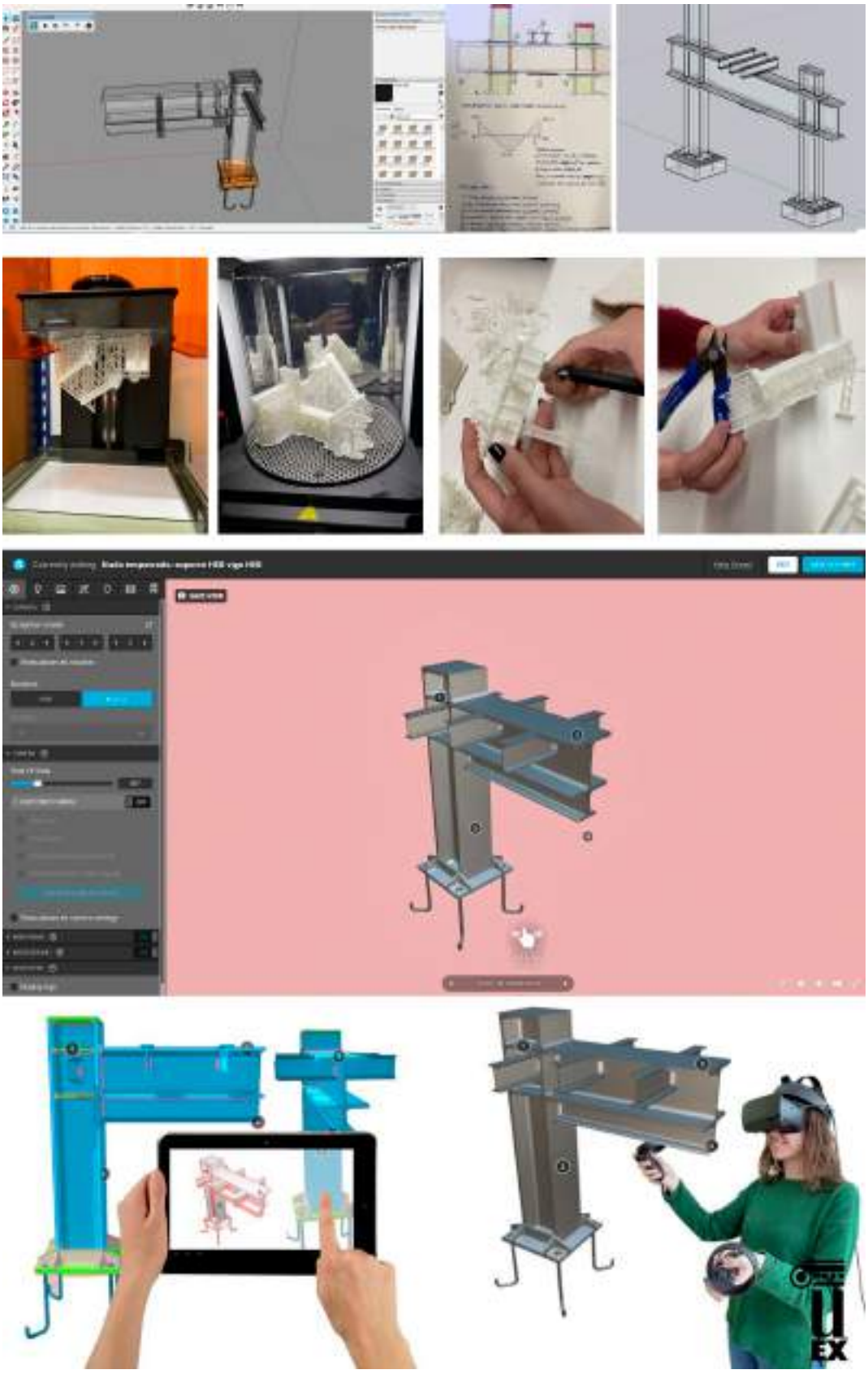

Figure 17. Work process within the classroom experiences at the University of Extremadura with construction students. Prototyping process, generation of physical models, uploading these models to the open platform sketch fab, and immersive experiences with students in VR.

Thirdly, considering open digital repositories such as Sketchfab or Thingverse is a very interesting altruistic proposal for universities around the world. Indeed, 3D printing cannot replace reality, but it is an aid for the teacher that, as we have been saying, breaks the barriers of space and money. It is a way of offering new interactive resources to our teachers and students.

Fourthly, all of these 3D model databases can also be expanded in that aforementioned universal accessibility to blind people, guaranteeing an open repository at a global level [54].

Three-dimensional printing technology is already an undeniable reality in our society. This "advanced science" has made its way over the last few years and, little by little, the "maker" culture has transformed into a fresh and energetic movement that is revolutionizing many areas of our lives through its ideas. This culture is changing the way we understand teaching, architecture, or engineering through new proposals for dealing with design, new methods of understanding prototyping, and new ways of motivating new generations [55].

These original proposals to motivate current students are a challenge in teaching because they propose alternatives to traditional teaching, specifically, in this case, teaching under construction. These alternatives are neither better nor worse; they are always complementary to the traditional ones, but absolutely necessary as transversal training for future technicians.

The incorporation of these activities into teaching is very beneficial, as it incorporates cross-cutting skills into teaching that substantially improve students' abilities: these new abilities will help our technicians in future academic and vital projects.

To each time its art, and to each art its freedom
(«Der Zeit ihre Kunst, der Kunst ihre Freiheit»)
(Gustav Klint, friso de entrada al edificio de la Secesión vienesa, 1897–1898)

5. Conclusions

The proposed methodology is divided into two phases. The first phase is data collection and the generation of a physical twin. Note that this first phase has been extensively developed in other bibliographies that are cited during the text, and in other publications of the research group to which we refer. Regarding the first phase, we state that:

- First of all, as a society, we have the obligation to digitize the world in which we live in order to preserve it as a digital twin for future generations: a database of the present.
- Secondly, we have the opportunity to recreate from these digital twins lost architectural environments and future digital environments: foundations of the past and the future.
- There are many digitization methods, each with its advantages and disadvantages [4,17,26,56–58]. In the present study, a low-cost methodology based on the use of UAVs has been chosen [8,59], which has been outlined and incorporated into the workflow. This scheme is supported by other works and the professional experience of the authors [1,25].
- For some time now, new representation technologies have allowed us to create resources and content that reflect how our heritage is and could be. These digital twins, both the digital copies of the present and the digital proposals of the past and future, give rise to enormous databases that have traditionally been used for the development of restoration projects, such as the one studied at the Hermitage of Vaquero, but once the work was completed, it was complex and difficult to implement as a knowledge tool.
- The proposed methodology allows us to increase our capacity to divulge, protect, and conserve our heritage. Digital borders are crossed, and we obtain prototypes that can be distributed in open source to promote knowledge regardless of place, physical, or economic conditions.
- On the other hand, these proposals represent a revolution at the educational level; our students can have in their hands replicas of the monuments with millimetric quality.

At present, education is in a permanent change. It is necessary to incorporate all these novelties to improve the skills of our teachers and our students [60].

- On the other hand, these physical prototypes are a tool that opens the doors to that aforementioned universal accessibility through typological models of our heritage.
- As has been seen in the discussion of results, this way of working can be extrapolated in different subjects, such as teaching, construction, architecture, pathologies, history, etc.

In short, all of this article illustrates a new system for the generation of physical prototypes that will allow us to conserve art in new ways, and allow us to improve our teaching and outreach tools.

"Beauty perishes in life but is immortal in art"—
Leonardo Da Vinci.

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