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UAV photogrammetric survey and Image-Based elaborations for an Industrial Plant

The proposed application of the HBIM methodology for digitising a productive-industrial structure is based on the integration of data from different sources. An aerial photogrammetric survey (Unmanned Aerial Vehicle - UAV) was considered the most appropriate technique for the case. Therefore, a Scan-to-BIM modelling was carried out, keeping in mind a subsequent texturisation of the smart objects employing the photogrammetric images obtained from the UAV survey. Currently, applying the BIM methodology to the built environment is still a challenge; indeed, three-dimensional modelling based on survey point clouds is not automatic. Any BIM software is designed for new constructions, whereas the existing Heritage is characterised by unique and distinctive shapes, where each element has a specific and variable inclination, shape and thickness; therefore, it is necessary to adapt the available tools. Creating intelligent parametric objects capable of representing the unique and singular shapes and geometries of historic architecture is a significant challenge of HBIM modelling. A workflow for the acquisition, processing and management of the survey data and the consequent modelling in a BIM environment of a disused industrial plant previously used as a tobacco factory was formalised. The aim was, therefore, to develop a model that is as close as possible to the real one and, at the same time, still keeps the informative aspects in order to promote the conservation and possible refurbishment of the cultural heritage through the use of photorealistic visualisation tools in real-time. The results confirm the proposed strategy hypotheses and seem to lead to promising future developments.

INTRODUCTION

In the current era, the digitisation of the built Heritage and the processes of recording and reproducing the surrounding environment have made tremendous progress, managing to rapidly reach a vast number of users with multiple inputs (Stylianidis, 2020; Teruggi & Fassi, 2022). The built Heritage is one of the main sectors supporting countries' economic and sustainable development. Day by day, it has to undergo numerous interventions, making it necessary to manage maintenance and conservation operations properly. Often these operations encounter obstacles due to the fragmentation or loss of information about the building, making the design of interventions a long and expensive process. Over the years, the approach to restoration has evolved, thanks to both the greater sensitivity developed by architects and engineers and to the new tools available; with the advent of new technologies, the digitalisation of the built environment plays an essential role to the point of codifying new intervention flows. In order to obtain a product that is truly capable of integrating and supporting conservation, maintenance and restoration work, it has been proven beneficial to employ HBIM modelling (Heritage Building Information Modelling) (Jouan & Hallot, 2019; Santagati et al., 2021).

Currently, the application of the BIM methodology to the built environment is still a challenge, as it was not designed to interact directly with the real world, making it more suitable for design. Flexible and adaptive data collection systems are needed to provide an efficient transition between software and physical data (Alshawabkeh et al., 2021). A major challenge of HBIM modelling is then the creation of intelligent parametric objects – to assign the collected information – capable of representing the unique and singular shapes and geometries of historic architecture (Tommasi et al., 2016).

The new advanced surveying technology allows us to face the challenges of getting an accurate and detailed 3D model. Compared to new buildings, existing buildings require the acquisition of additional information for a correct assessment of the current state: the models must be enriched
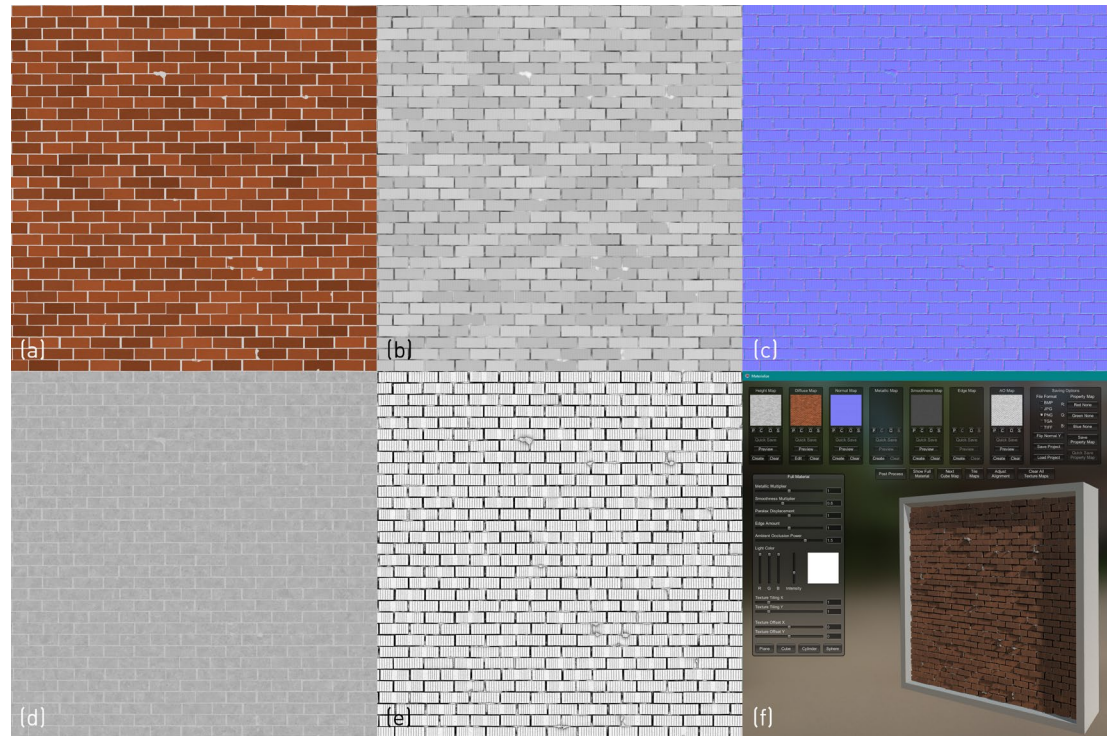

Fig. 1 - PBR generic brick wall: (a) *Diffuse map*; (b) *Height map*; (c) *Normal map*; (d) *Roughness map*; (e) *Ambient Occlusion map*; (f) Physically realistic visualisation within *Materialize*.

with data and information not only geometric, such as historical information, analysis of degradation or deformation and information on maintenance performed or to be performed (Letellier & Eppich, 2011) All these data are crucial for the maintenance and preservation of the building itself. Jon Amdur, vice president and program manager for unmanned aerial systems at AECOM, explained at the Commercial UAV Expo (Las Vegas, 2015) how, through the expanding UAV industry, their flexibility and efficiency, there is an opportunity to increase the volume, accuracy and speed with which to carry sensors and collect data. Quentin F.M. Dupont et al. investigate the potential of the UAVs in

connecting BIM to the real world to improve construction productivity, analysing a review of potential UAV applications (Dupont et al., 2017). UAVs can be the basis for the creation of an interactive database of photos and videos and for the metric reconstruction of three-dimensional geometry. In an attempt to achieve effective and accurate data collection, UAV technology is the main operational tool for the implementation of BIM in existing large infrastructures (Barazzetti et al., 2016), with the aim of establishing links between surveyed data and BIM models, thus improving model productivity.

The digitisation of the built environment is usually based on a Scan-to-BIM process (Yang et al.,

2019; Barba et al., 2021), and although no unified method has yet been identified, the most common practice for this type of application consists of manual modelling, involving the insertion of intelligent objects one by one, whose parameters are carefully adapted to the characteristics of the object of study. Because of these problems, many researchers have opted for customised parametric object modelling based on point clouds imported through plug-ins within the *Autodesk Revit's family editor*. There is no shortage of studies concerning the semi-automated generation of NURBS from transforming masses capable of hosting photogrammetric textures applied as decals in *Revit* (Barazzetti et al., 2015; Sun et al., 2019), as well as plug-ins developed through *Revit*'s programming interface (API), such as *GreenSpider*, capable of recognising points and curves from surveyed points.

The most recent research mainly addressed restoration interventions aiming at identifying areas affected by degradation phenomena, determined according to shared protocols, which are based on the projection of photogrammetric orthophotos on BIM objects which, although geometrically accurate, are not parameterised. An attempt, in this sense, to preserve access to intelligent objects has been made by Ferreyra C. et al. with the purpose of dissemination and conservation of cultural Heritage for real-time visualisation (Ferreyra et al., 2021).

Although the practice of BIM modelling the existing asset is becoming increasingly common, there still lacks a direct connection between the rich graphic geometrically accurate data surveyed on-site and the discretised synthesis that even an as-built type of model is capable of storing and reproducing. In other words, a BIM model often feels like too much of an abstraction of the real world; thus, its practical use as a support tool for refurbishment purposes becomes quite limited, if not almost inexistent. Hereby we propose a methodology in the form of a set of procedures to link the UAV survey data, via full-size orthoimages used as a "texture", to the main subcomponents of a built asset, such as a façade and to its own subparts, may they be projecting decorative and/ or structural elements, just by adjusting the origin of said texture.

Werner Heisenberg would point out that *"quantum physics tells us that nothing that is observed is unaffected by the observer"*. Thus, a mere projection of orthoimages onto parts of a model is most likely not sufficient for us, i.e., the observers and the assigned operators on the built Heritage, to fully understand the nature of each crack and each spot that may plague the object of study (Martos & Cachero, 2015). Here is where the Physically Based Rendering (PBR) materials may come in handy (Apollonio et al., 2021): they indeed represent a way of shading and rendering capable of simulating a more accurate representation of how light interacts with surfaces by employing a number of ad-hoc additional raster images, defined as maps (Mc Dermott, 2018). Furthermore, PBR techniques have recently joined the photogrammetric workflow to enhance surface information provided by the texture mapping process, creating photorealistic effects for their visualisation. In a PBR pipeline, the most common textures generated for simulating the properties of the physical object are usually (Farella et al., 2022; El Saer et al., 2020) (see Fig. 1):

- *Albedo map* or *Diffuse map*: this texture contains the base colour information of the surface or the base reflectivity when texels are metallic. The Albedo map does not collect any lighting information compared to the diffuse map. Shadows and reflections are added subsequently and coherently with the visualisation scene.
- *Normal map*: this texture map contains a unique normal for each fragment to describe irregular surfaces. Normal mapping is a common technique in 3D computer graphics for adding details onto simplified models. Together with the Height map – a black and white texture map used to enhance protrusions and recesses – the Normal map provides a more accurate reproduction of the surfaces relieves (Bump).
- *Metallic or specular map*: this black and white map, acting as a mask, represents whether each texel is metallic or not.
- *Roughness map* (as opposed to *smoothness map*): this texture map defines how rough each texel is, influencing the light diffusion and direction while the light intensity remains constant.

- *Ambient Occlusion* (AO) map: this map is used to provide indirect lighting information, introducing an extra shadowing factor for enhancing the geometry surface. The map is a grayscale image, where white regions indicate areas receiving all indirect illumination.

CASE STUDY

After more than fifty years of experimentation, the themes of industrial archaeology are still a research field full of uncertainties and strongly linked to the strategic management of territories. Current urban policies aim to redevelop disused sites, whose operational characteristics are not always consistent with the historical and documentary values of the existing structures. The Fortunato Farina tobacco factory was built in the middle of cultivated fields, just outside the urban centre of Battipaglia (SA), Italy. The factory was established in 1920 under the management of SAIS, the Salerno Agricultural and Industrial Society. The company's objective was the transformation of agricultural products, initially in the form of the construction of a dairy, until it obtained a concession from the State to build the first tobacco factory dedicated to Fortunato Farina (Ribera et al., 2018). Today the area is owned by the municipality of Battipaglia, an Italian municipality known for being one of the most productive agricultural areas in the Sele Valley,

Fig. 2 - Northern view of the tobacco factory in its current state.

of which it is also the main industrial hub as well as a railway junction. The factory, characterising the landscape and identity of Battipaglia, is now in a state of total abandonment whose effects are devastating, turning memory items into ruins. Today the tobacco factory stands as a succession of rectangular blocks aligned and parallel to the road (see Fig. 2). The original use of the buildings to house the leaf-hardening stage justifies the characteristic spacing of the interior, with heights of up to 14 metres. Tobacco processing required special ventilation conditions, determining the design of the buildings in terms of volume, materials, and arrangement of openings. The eight original SAIM blocks have a continuous, solid-faced masonry outer structure, a mixed pattern interrupted by large openings that created variable air currents. Nowadays, there just remain large blocks whose interiors have been completely emptied of machinery, with well-preserved brick exteriors.

MATERIALS AND METHODS

The objective of the contribution is to achieve a level of graphic and geometric modelling suitable for an as-built model, limiting here only to the so-called geometric level of detail, for the former Farina Tobacco Factory, in order to realistically simulate its materiality. It is possible to identify a schematic procedural pipeline for the acquisition and management of the data, which represents a fundamental step to verifying the actual possibility of using a reverse modelling methodology (see Fig. 3):

1. Data acquisition.
2. Scan-to-BIM approach from a SLAM-photogrammetric integrated survey.
3. Experimental techniques application for data enrichment by integrating a photogrammetric-derived texture into the BIM model.

1. DATA ACQUISITION

To obtain reliable databases from a metric and material point of view of such large areas, the use of TLS (Terrestrial Laser Scanner) tools is too expensive in terms of time and not always very

functional. Fast survey technologies, such as SLAM (Simultaneous Localisation and Mapping) and UAV, make it possible to overcome the difficulties related to reduced accessibility, such as vegetation and narrow spaces (Parrinello & la Placa, 2021). Therefore, an integrated SLAM-UAV survey of the interiors and the exteriors (conducted in 2020) constitutes the reliable geometric database for the subsequent parametric informative modelling of the investigated architectural asset, which followed the well-established Scan-to-BIM approach, increasingly widespread for the digitisation of the existing Heritage. In particular, the image-based survey, fundamental to acquiring the metric and graphic information regarding the exterior and the roof, was carried out, acquiring a total of 271 shots.

The data acquisitions were carried out using DJI Mavic 2 Pro. The UAV, which weighs about 900g less, is equipped with the Hasselblad L1D-20c camera with exclusive Hasselblad Natural Color Solution (HNCS) technology. The sensor is a CMOS with dimension 1" and 20 MP resolution (pixel size of 2.4 microns), 77° Field of view and 28 mm equivalent focal length. Data capture and processing require an accurate, georeferenced database to ensure reliable geometrical and texture results. The first step in planning the survey is to provide a reference network; for this purpose, 5 ground control points (GCP) were surveyed using a *GeoMax Zenith 25*. The GCPs were materialised on the ground using photogrammetric targets (A3 format, 42 x 29.7 cm, with a coded target in red, black, white and yellow) and topographic pegs. The reference system adopted is UTM/ETRF00 with orthometric heights. The precision achieved in planimetry is, on average, subcentimetric, while it is about 2.5 cm in altimetry. As for the acquisitions from the drone, the flight was planned using the *DJI Ground Station* software package, both automatic and setting a double grid: a first one for the acquisition of nadir photogrammetric images and a second one, with the optical axis tilted at about 45°, to detect the vertical walls and any shadow cones. The practice of also acquiring oblique images is an essential requirement for the implementation of texture information on vertical reliefs and simultaneously increases the accuracy of the
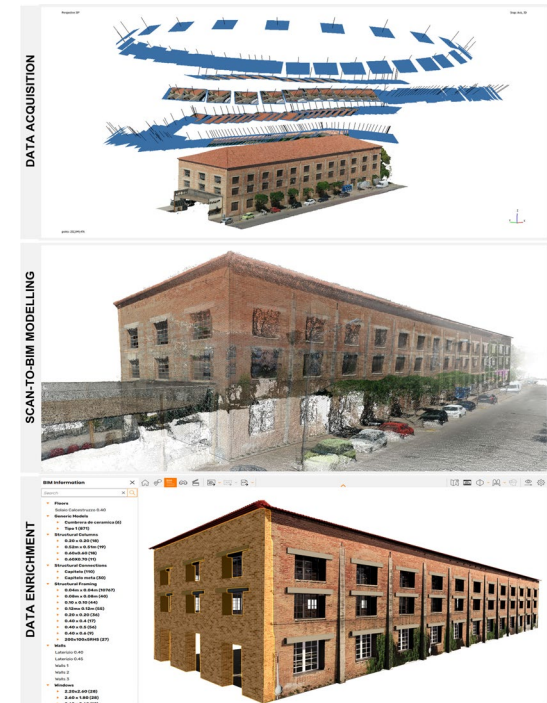

Fig. 3 - Pipeline to achieve Real-Time rendering.

photogrammetric survey (Gujski et al., 2022). The subsequent standard photogrammetric workflow was executed in the *Agisoft Metashape* software. The resulting dense point cloud counts 163,550,794 points, with average GCP errors of about 2.8 cm. A mesh model with 40,409,283 faces is generated, and the maximum resolution possible for the orthomosaics is 6.72 mm/pix.

The survey of the building's interior was conducted using '"Simultaneous Localisation and Mapping" (SLAM) technology, specifically the GeoSLAM Horizon instrumentation. It features a collection rate of 300,000 points per second, an accuracy of 1-3 cm and a range of 100 m. However, for the purposes of the first texturing experimentations conducted on an external façade of the building here presented, these data were not used,

although they were instrumental – once integrated with the external data acquired by the UAV – in the previous Scan-to-BIM modelling phase of the entire complex (Guida et al., 2021), which will not be further discussed here.

2. SCAN-TO-BIM MODELLING

The informative parametric modelling of the built Heritage under investigation followed the well-established scan-to-BIM approach. The software used for BIM modelling is *Autodesk Revit*, which, due to compatibility with *Autodesk Recap Pro*, enables the direct import of the point cloud (Guida et al., 2021).

Three-dimensional modelling based on survey point clouds is not an automatic process; any BIM software is indeed designed for new constructions, and this poses a considerable challenge when modelling existing buildings, which are characterised by unique and distinctive shapes, where each element has a specific and variable inclination, shape, and thickness, therefore it is necessary to adapt the available tools (Allegra et al., 2020). As the strengths of BIM are based precisely on standardisation, a simplified parametric approach was explored to provide future reproducibility of recursive elements.

3. DATA ENRICHMENT

Integrated multi-source models, once suitably optimised, can be structured semantically, representing the perfect starting point to develop a smart 3D model of the object of study, capable not only of guaranteeing a metric and geometric response on the built object but also of implementing the information content of the space for better management and more informed exploitation (Parrinello & Picchio, 2019). Thus, in an attempt to combine parametric modelling and photorealistic visualisation within a BIM environment, it was decided to include the photogrammetric texture as stratified information, integrating the emerging technologies in terms of Virtual Reality plug-ins and Real-Time Rendering, capable of operating within a BIM workspace. In this way, the texture assumes a semantic character, providing information about the state of
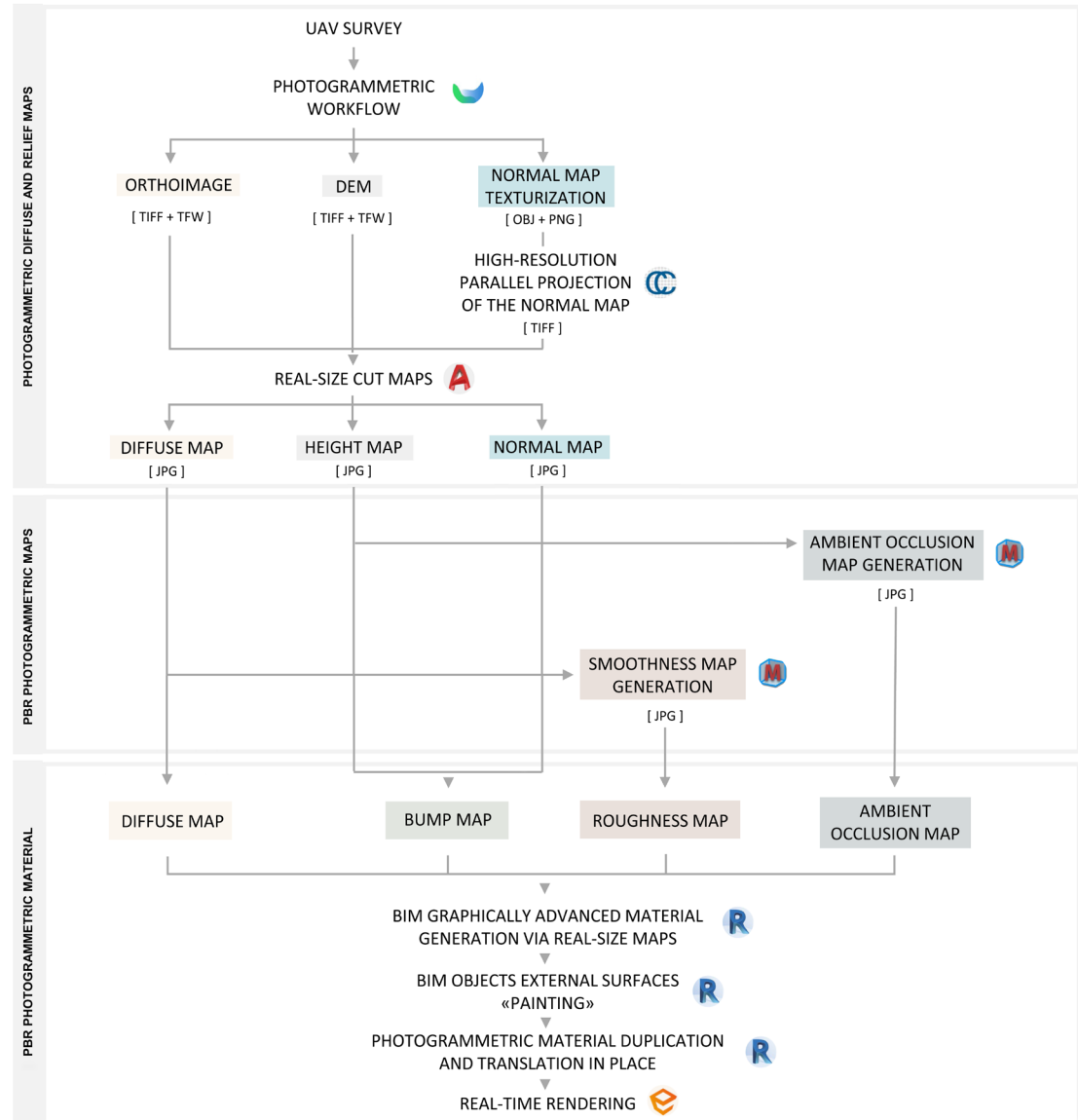

Fig. 4 - Methodology for data enrichment of the HBIM model employing photogrammetric elaboration.

conservation of the façades and, at the same time, supporting a better definition of the geometric level of the model (LOG). Specifically, the real-time rendering plug-in *Enscape for Revit* was used.

Starting with a 3D survey carried out with UAV, all phases of an effective workflow are developed in order to obtain suitable outputs for the subsequent application. The third phase represents the core of the proposed application concerning the data enrichment of the BIM model via image-based elaborations. It can be further broken down into three subsequent steps summarised as follow. For simplicity, we will explain them by employing a façade as a reference (see Fig. 4).

The first, which takes place still within a photogrammetric environment (*Agisoft Metashape*), concerns the development of the first three maps of a Physically Based Rendering (PBR) material [1], i.e., the "Diffuse map", commonly known as "Texture" or "Albedo", the "Height map" and the "Normal map". The latter two both fall under the sphere of the so-called "Bump mapping", a range of images which graphically encodes the displacement function of each pixel along the normal to the material surface at the same point. The second stage focuses on the generation of a complete PBR material on the basis of the previous photogrammetric outputs; for these procedures, an open-source software, *Materialize* [2], was employed. The last stage finally takes place within the BIM environment, where the resultant photogrammetric PBR material is "painted" as a surface material over the study object, thereby scaling the maps to their real size and setting the necessary translations, also defined as "offsets", along the "x" and "y" axes so that the texture perfectly fits the corresponding façade.

3.1. PHOTOGRAMMETRIC DIFFUSE AND RELIEF MAPS GENERATION

As far as it concerns the maps resulting somewhat straightforwardly from the photogrammetric workflow, we can safely assume that an orthoimage of the surface under study is in direct correspondence with the universally accepted concept of "Texture", also known as "Albedo". It's worth mentioning that within the definition of the PBR material, the classic texture takes the

name of "Diffuse Map". Knowing then the textbook definition of the Digital Elevation Model, being a raster image representing the elevation data usually of terrain via a graded colour scale, it is logical to link this kind of output to the "Height-

type" Bump mapping, generally consisting of a grey-scaled image intended to simulate recess, marked in darker shades, and projections, corresponding to the lighter to white areas. For the vertical elements, such as walls, planar DEM

Fig. 5 - PBR photogrammetric material maps generation within *Materialize*, whose outputs are: (a) *Diffuse map*; (b) *Height map*; (c) *Normal map*; (d) *Roughness map*; (e) *Ambient Occlusion map*.
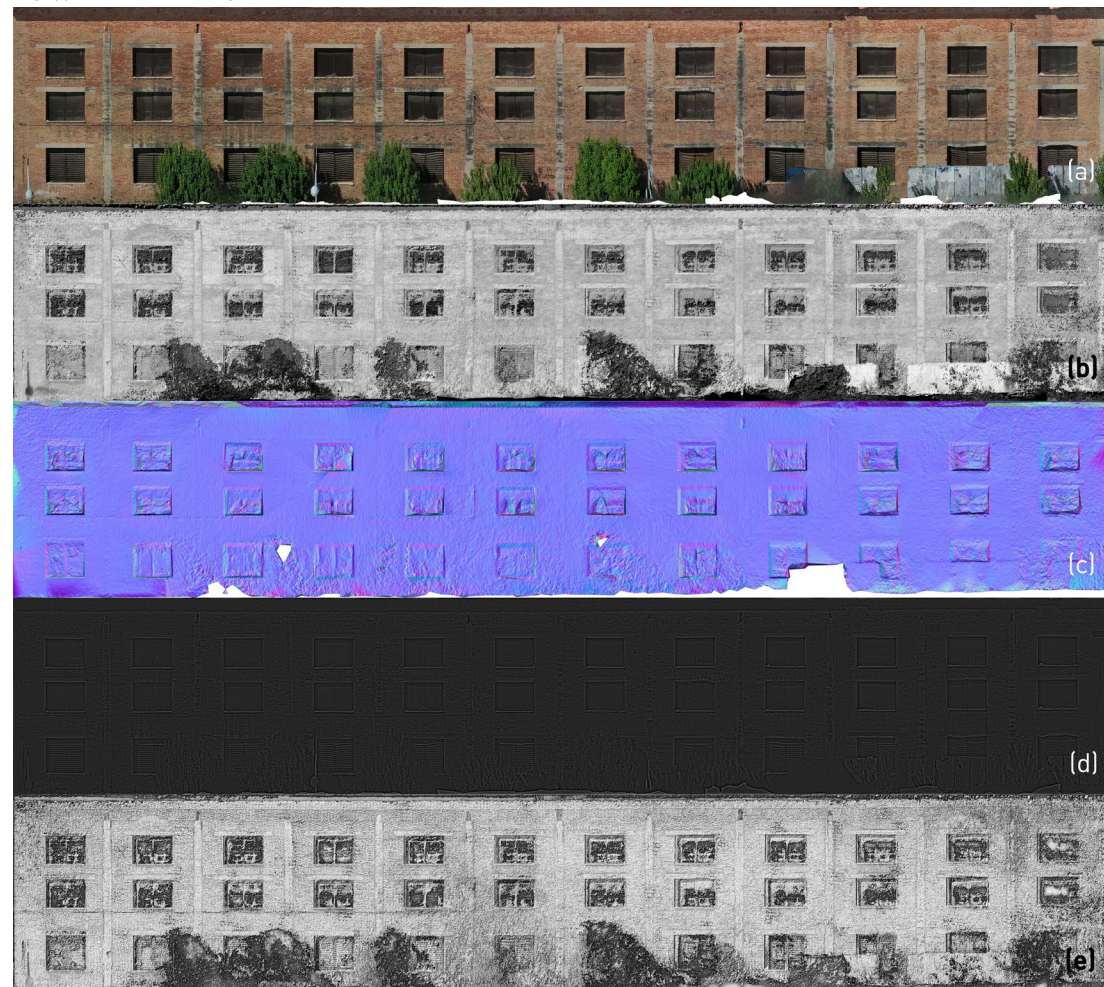
(Digital Elevation Model), whose reference plane is set parallel to the investigated façade, are then to be produced and later colourised using a black-to-white palette other than the most common multicoloured one. The "Diffuse" and the "Height" maps produced within the photogrammetric environment can be exported directly as images in a TIFF format and imported, keeping their actual size in CAD thanks to the attached TFW file. On the other hand, the process of generating the "Normal map" is not as immediate as the previous ones.

Although developers introduced the "Normal map" texturisation feature in recent versions of *Agisoft Metashape*, this application is intended to simulate a high-poly texture resolution for a low-poly mesh and produce lighter models for online visualisation. In detail, the tool employs a high-poly mesh as source data for the texturisation of a decimated mesh model of the very same surveyed object. Namely, for the *Metashape* tool to be suitable for the proposed methodology is necessary to decimate the high-quality mesh model enough to obtain a seemingly plane surface corresponding to the investigated façade and then proceed to texturise the latter keeping the former as a reference. It appears clear that, while the obtention of full-sized orthoimages and DEM consists of straightforward exportation, it is not as simple to produce an orthorectified "Normal map", being just a texture. Hence, the mesh model must be exported in an OBJ format, taking care to also export the associated textures. They must then be imported into an environment for mesh and point cloud editing, such as *Cloud Compare*, where the viewpoint can be set parallel to the façade plane by picking three points on it and then rendered at a selectable resolution. The rendered "Normal map" is eventually scaled over the real-size orthoimage in *Autodesk AutoCAD*.

3.2. PBR PHOTOGRAMMETRIC MAPS GENERATION

For the second stage of the proposed workflow, it is advisable to cut the exact area of the façade to be later textured into the BIM environment. An open-source software, i.e., *Materialize*, can be used for the generation of the missing maps required for a full PBR photogrammetric material with a good graphic degree of approximation.

Indeed, a *Revit* material can be characterised by a "Roughness" and an "Ambient Occlusion" map beside the "Diffuse" and the "Bump" ones. The "Ambient Occlusion map", being the one capable of realistically simulating the light refraction over the texturised surface, needs the "Height" and the "Normal" ones to be generated. On the other hand, the *Materialize* software allows to generate of a "Smoothness map" other than the required "Roughness" one; both these raster images are grey-scaled, with the former employing lighter shades for the smoother areas of the surface as opposed to darker shades for the rougher zones, on the contrary, the latter map uses an inverse grey-scale for the identifications of the same kind of sections. In other terms, it is possible just to invert a "Smoothness map" and use it to simulate the roughness of the material. Of the five maps achievable so far, just four of them can be applied simultaneously within *Autodesk Revit* due to the Relief (Pattern Bump) implementing either the "Height" (as a grey-scale raster image) or the "Normal" one alternatively (as RGB raster image, whose pixel R, G, and B pixel values are interpreted so to simulate the displacement along

an ideal vector perpendicular to the texturised surface and intersecting it in the same pixel). The most suitable map can be indifferently chosen, although it's worthwhile remembering that both concur to the generation of the others, thus the necessity to obtain both of them from the photogrammetric process (see Figs. 5 and 6).

3.3. PBR PHOTOGRAMMETRIC MATERIAL SETTING WITHIN A BIM ENVIRONMENT

The third and final step of the proposed procedure consists of the actual generation of the PBR photogrammetric material in the BIM software, the assignment of the corresponding real-size maps, and its placement over the investigated surfaces. The resulting material is first juxtaposed over the main surface of the modelled wall corresponding to the surveyed façade via the "Paint" tool. At this stage, it is fundamental to set the proper offset from the object coordinate system origin to correctly match the texture to the modelled smart object by operating within the *Revit* "Material Browser" (see Fig. 7).

Fig. 6 - Physically realistic visualisation of the PBR photogrammetric material generated within *Materialize*.
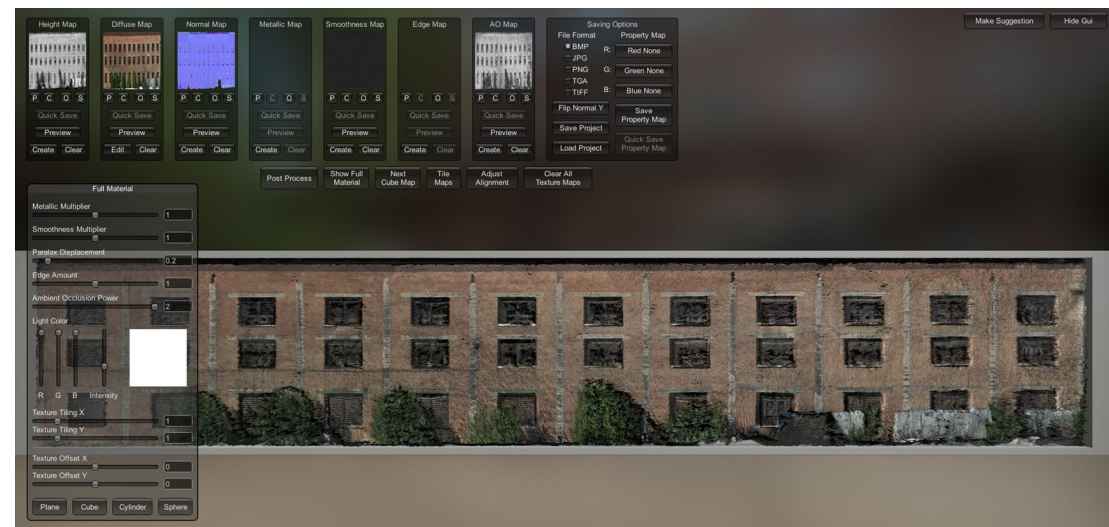
Similarly to the main part of the wall, it is also possible to texturise its details, even if they are modelled employing other BIM objects, i.e., *Revit* families, via the same material duplicated just modifying the vertical and horizontals offsets of the maps to fit each detailed section. In a nutshell, the very same PBR material can be implemented by simply duplicating and "translating" it so as to "project" a geometrically accurate and realistically rendered orthoimage onto any element belonging to the same façade.

RESULTS

For the purpose of the proposed application, we focused on the south façade of the tobacco factory, thus its orthoimage (dimensions 12,307 x 2,568 and a resolution of 6.72 mm/pix) and a coplanar grey-scale DEM (dimensions 12,649 x 6,854 and a resolution of 6.72 mm/pix) were generated still within the *Metashape* environment. On the other hand, the original mesh model had to be decimated down to a 15,496 faces mesh for its own "Normal map" texturisation, a procedure that implemented the high-quality 3D triangulated model as "Data source", a generic "Mapping mode", and a 4,096 "Texture size". The resulting texturised 3D mesh model was exported into an OBJ format, with the corresponding textures in PNG. The OBJ mesh model was then imported into Cloud Compare, taking care to set the normal map as texture, to place the viewpoint parallel to the south façade and render a high-resolution snapshot of it to later scale it using as a reference the full-size orthoimage imported into the CAD environment.
The three maps obtained were then cut using the BIM-modelled wall representing the south elevation and imported into *Materialize*. Due to the reduced number of images taken for the photogrammetric survey, the "Height map" produced from the DEM lacked the depth information necessary to properly reproduce the brick pattern; thus an alternative "Height relief map" was tentatively produced from the "Diffuse" one via the same open-source software. Both the DEM map and the one derived from the albedo were then merged to improve the grey-scale "Bump map". Through *Materialize* and using as a basis the three imported images, it was

then possible to generate graphically accurate "Ambient occlusion" and "Smoothness" maps of the south façade (see Figs. 5 and 6).
The obtained "Diffuse", "Height", "Smoothness", and "Ambient occlusion" maps were then implemented into the *Autodesk Revit* "Material Browser", setting their full-size dimensions to define the PBR photogrammetric material, applied to the southern elevation (see Fig. 7). Giving the intrinsic nature of the material created, it felt appropriate to "paint" it over the external face of the interested wall. It is worth mentioning that, to date, the right placement of the texture is still subject to the manual correction of its vertical and horizontal displacement, defined as offsets within the Revit environment. Therefore, by taking the precaution of duplicating and manually displacing the maps, it was possible to accurately texturise both the main bricked area of the wall and its projecting columns (see Figs. 8 and 9).

CONCLUSIONS

The provided generation of "Normal" and "Height" maps is surely improvable by carrying out a more detailed photogrammetric survey and integrating it with a TLS one so as to enrich the "Source data". This can be achieved, for instance, by generating both a photogrammetric and a laser DEM and opportunely merging them. Anyway, given the geometric accuracy of the proposed application, validated along every step, it hopefully poses as a reliable tool for restoration and refurbishment projects, having the advantage of tangibly connecting photogrammetric surveyed data to the BIM model for an enhanced visualisation within the very same environment.
Further applications will address the representation of other types of information to develop a comprehensive restoration strategy within the BIM environment, as well as consolidate and try to standardise the proposed methodology to achieve a

Fig. 7 - PBR photogrammetric material setting within the *Revit* "Material Browser".
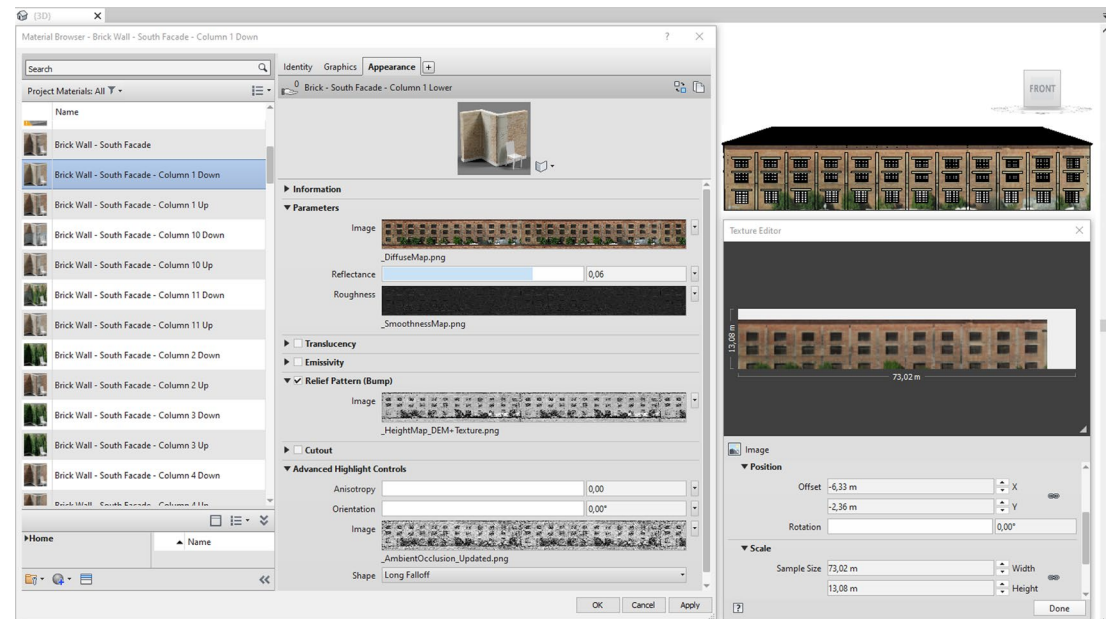
further step in the field of digitisation. Its potential is its applicability in meeting the requirements of truthfulness and accuracy required by the restoration and conservation disciplines, being able to link a complete 3D database of smart objects incorporating attributes and information. Furthermore, the results are already optimised for real-time rendering applications operating within a BIM authoring software so that all applied changes in geometry and material will become visible in a matter of seconds, while it will always be possible to directly access the stored properties from the same rendering window.

In this way, even if the BIM modelling of the built Heritage inevitably introduces geometric simplifications, the texture can restore and effectively represent some of the "lost" details using the necessary graphic primitives. Furthermore, leaving the geometric structure of the digital reconstruction unchanged, the 3D model can be implemented over time by representing any details and geometric variations thanks to the PBR textures.

The incorporation of photogrammetry-derived materials into the BIM environment makes it possible to directly measure the pathologies that may affect the architectural artefact, appreciating, due to the physically photorealistic rendering, even nuances and details that might seem neglectable at first glance. This type of documentation, which goes in the direction of as-built modelling, is proposed as a valid support tool for management and maintenance work and is an effective means of updating the actual state of knowledge about the built environment. Indeed, the aim of the study is also to stimulate interests, synergies, innovations, and collaborations to improve the current techniques of heritage conservation. After all, to quote Werner Heisenberg, *"We have to remember that what we observe is not nature in itself but nature exposed to our method of questioning"*.

Furthermore, it is underlined that the experimented pipeline can have interesting effects not only in the context of the maintenance and conservation processes of the built Heritage but also for its valorisation and dissemination process itself, exploiting the potential of, for example, Virtual Reality, Augmented Reality and Mixed Reality applications (Keep, 2022; Perfetti et al. 2022; Pietroni & Ferdani, 2021; Russo, 2021; Osello et al., 2019; Parrinello &

Fig. 8 - Rendered view of the entire southern façade of the tobacco factory.

Fig. 9 - Rendered view of a detailed area of the southern façade of the tobacco factory.

Dell'Amico, 2021). In this context, the PBR approach would make the digital access and immersion use more realistic incisive and engaging. In addition to the architectural heritage field, the possible application areas can be expanded to include industrial applications, structures and infrastructures, where the metrical graphic representation associated with a digital information model to support the quantification of decay (Lanzara et al., 2021; Malinverni et al., 2019), damage (Delpozzo et al., 2022), fractures, and cracks (Grillanda et al., 2021) is an always current topic of significant interest.

NOTES

[1] *Physically Based Rendering* (PBR) is a method of shading and rendering that provides a more accurate representation of how light interacts with surfaces. It is referred to as *Physically Based Rendering* (PBR) or *Physically Based Shading* (PBS). Depending on what aspect of the pipeline is being discussed, PBS is usually specific to shading

concepts and PBR is specific to rendering and lighting. However, both terms describe the process of representing assets from a physically accurate standpoint (Mc Dermott, 2018).

[2] *Materialize* is a standalone tool for generating advanced materials, open source under the GNU GPL v3. It can be downloaded at: https://boundingboxsoftware. com/materialize/index.php

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