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Promoting Cultural Heritage Through a Micro-Business by Means of a Digital Twin

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Abstract. Over the ages, every nation and civilization has accumulated its cultural heritage, primarily through figureheads such as monuments, structures, and famous individuals. Physical monuments have a unique significance. Digitalization has impacted nearly every aspect of the economy and society by providing a different perspective on the real world. An increasing number of processes are being digitalized as a result of mobile devices' growing capabilities and declining costs. The preservation and maintenance of cultural heritage have also been embraced by digitalization, which facilitates the management of tangible monuments as inventory items. These "digital twins" have numerous applications once they have been generated. In this paper, we derive the product emergence process of decorative items based on digital twins, which are highly demanded in countries with strong tourism, such as Croatia. Most of these are craft businesses that have been managed for many generations by members of one extended family. The specific expertise is in the processing of stones and metals. A company that employs three people and creates "metal art" would like to grow by adding small-size replicas of any kind of cultural heritage object, such as busts, sculptures, monuments, or profiles. The technique of creating a replica from the desired material in the required scale (1–5) must be developed to replicate the original (physical object, 3D model, or photo). Market entry strategy should be also created, encompassing marketing and license sales to other companies. This paper explains how this intricate procedure was used in a pilot project by using low-cost tools and licenses.

Keywords. Cultural heritage, Digital Twin, Reverse engineering, Micro-business, Transdisciplinary Engineering.

Introduction

Every country and culture have accumulated its cultural heritage (CH) over the centuries, mostly through figureheads: monuments, buildings, famous people, and other artworks that are imprinted in the memories of generations. According to UNESCO “Cultural heritage includes artefacts, monuments, a group of buildings and sites, museums that have a diversity of values including symbolic, historic, artistic, aesthetic, ethnological or anthropological, scientific and social significance. It includes tangible heritage (movable, immobile, and underwater), and intangible cultural heritage (ICH) embedded into cultural, and natural heritage artifacts, sites, or monuments. The definition excludes ICH

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related to other cultural domains such as festivals, celebrations, etc. It covers industrial heritage and cave paintings" [1]. The material assets composing a country's cultural heritage have a vital and irreplaceable intrinsic value, but due to their very physical nature, they are subject to aging, damage, significant modifications, and even loss [2]. Physical monuments such as the Eiffel Tower in Paris or the Statue of Liberty in New York are good examples that shape memories worldwide.

Digitalization as a method for an additional, alternative description of the real world has affected almost all areas of engineering, economy, and society, which is regularly reported on in the TE conferences [3]. Increasing functionality and falling prices for hardware, in particular for digital devices, pose an opportunity for more and more processes to be digitized. In this way, digital devices spread from the purely personal domain to multiple sociocultural domains and, therefore, provide a means for transdisciplinary approaches. Through their use, new cultural practices have emerged between consumers and these devices, and devices and markets, that lead to change, in terms of consumer demand, consumption norms, and issues of ethics, culture, and power [4]. In this sense, digital devices can be understood as carriers of the digital twin of Cultural Heritage.

Digitalization has also encompassed the protection and maintenance of cultural heritage and helps to view physical monuments as quasi-objects in the inventory [5][6]. The need to replicate works of Cultural Heritage has been satisfied over time in a variety of ways, including sketches, casts, photos, and postcards. Once such objects have been digitally recorded, such "digital twins" can be used in a plethora of methods. In the virtual world, such a twin can be used e.g., for the creation of virtual walk-throughs, digital museums, and augmented reality (Fig. 1). Since computers have become the language of our day and are opening up a wide range of scenarios and options beyond the simple copying of works of art, the desire or necessity to generate twin copies is now fulfilled digitally [2]. Such twins provide not only enlightenment and experience but also a technological basis for the maintenance of the material asset (physical twin).

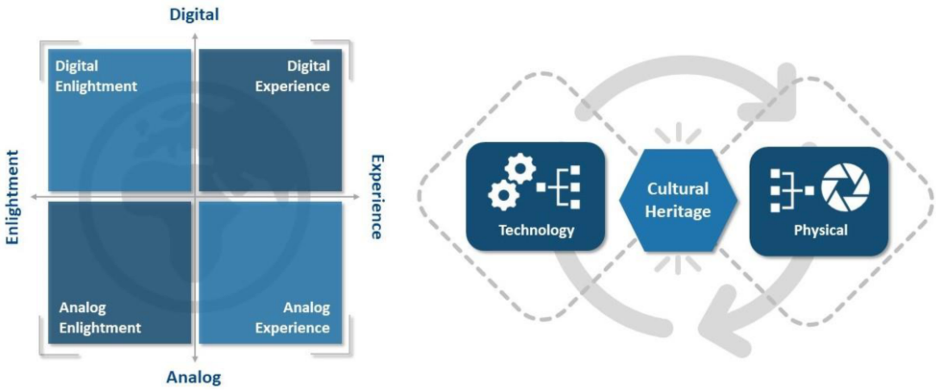

Figure 1. Merging physical and digital Cultural Heritage, derived from [2].

Digital twins of heritage assets can be replicated in different ways e.g., to create a physical replica of the original asset for various purposes (e.g., exhibition, training, education, decoration). One of the possible applications is the production of related decorative items (souvenirs, sculptures, sacral gifts, bells, chess, relics, crests, and plaquettes), which are highly demanded and developed in countries with strong tourism, such as Croatia [7]. The market demand for such products is subject to strong fluctuations, which depend on unforeseeable events, fashion trends, and consumer behaviour [8].

The vendors of such products are mostly micro-businesses, in particular craft businesses that have been inherited over generations and operated by an extended family that produce and sell their products in their respective regions. Their specific know-how lies in metal processing (preferably metal casting and surface refinement) and stone processing.

This three-person business, which produces decorative items in metal and stone (casting brass, aluminium, granite, marble), wants to add small-scale replicas of any object from the cultural heritage category, such as monuments, busts, sculptures, or profiles, to its product portfolio by using digital tools.

It is necessary to develop a low-cost, flexible, and user-friendly process chain that takes into account the unique constraints and requirements of a micro-business to respond to highly variable demand by transforming the original (physical object, 3D model, or photo) into a product (replica) made of the desired material with a specific surface treatment in the required size range (scale approx. 1 to 5).

For the final products developed, a market entry strategy should be proposed, which also includes the marketing and alternative channels of commercialization (e.g., sales of licenses to other producers) [9].

In this context, this paper discusses the conceptual approach "Design-for-Culture" to promote the cultural heritage utilizing digital twin which is inherently transdisciplinary [3] because it combines the fulfillment of cultural needs with technical solutions in compliance with strict cost limits. The outline of the paper is as follows. In section 1, the background of digital twins for cultural heritage and the transdisciplinary approach is introduced. In Section 2, the need for action is formulated, followed by the description of the conceptual solution in Section 3. In section 4, the way of implementation is explored, followed by a discussion of economics and market aspects in section 5. Conclusions and outlook are presented in section 6.

1. Background

In the world of cultural heritage, the term digital twin means not only an exact copy of the physical work of art. It is a lot more because it has opened innovative scenarios on multiple fronts. Thanks to digital twins, damages can be repaired, lost pieces replicated, museum halls visited, 3D copies printed, the security of works of art monitored and managed, and a large volume of valuable data acquired that can be used to conduct research and create multiple outputs, but digital twins have also become works of art themselves [2]. For this purpose, a plethora of well-known computer-assisted technologies are used (Figure 2).

Figure 2. Most used technologies for Cultural Heritage, derived from [2].

Applying techniques such as artificial intelligence, deep learning, and computer vision on digital image data can help monitor and preserve CH sites. Defects such as weathering, removal of mortar, joint damage, discoloration, erosion, surface cracks, vegetation, seepage, and vandalism and their propagation with time adversely affect the structural health of CH sites. This review summarizes the damage assessment techniques with case studies using image processing techniques, focusing mainly on DL techniques applied for CH conservation [6].

An emerging challenge is the need to define a digital framework for multi-source data integration, associated with a single heritage asset, but generated by various tools and methods which are often pursued by different research groups and at different times. This digital framework is discussed as the digital twin of a heritage asset, comprising the documentation data associated with a heritage asset and its virtual representation. To best describe and define a Heritage Digital Twin ontology and its associated knowledge graph, a specific example drawing from art historical and analytical investigation of a 13th-century Italian painting masterpiece is used [5].

A profound review explores the association between digital twin and heritage conservation, classifying digital twin techniques into six levels to tackle three tasks [10]: data acquisition [11], visualization [12], processing [13], and application [3]. It systematically reviews Chinese heritage digitization practices, considering variations in complexity and purposes, and demonstrates typological and chronological characteristics as well as the composition of stakeholders. Through the review of various case studies of data acquisition methods (survey, photogrammetry, laser scanning) and their outputs, issues of reflexive approaches to the construction of archaeological knowledge are discussed, and the implications of the different methods under review, in the work process of the archaeologist and our understanding of heritage discussed [14].

The most peculiar characteristic of a cultural heritage is represented by its uniqueness. To ensure that an object is preserved against environmental deterioration, vandal attacks, and accidents, modern Cultural Heritage documentation involves 3D scanning technologies. In the case of fragmented artifacts, the digitization process represents an essential prerequisite for facilitating an accurate 3D reconstruction. A further source [15] presents a framework that enables accurate digital reconstruction of fragmented or damaged artifacts using ornament stencils obtained from 3D scan data [16]. The case study makes use of the 3D dataset acquired, using a structured light scanner to extract vector displacement maps, which are then applied to the 3D computer-aided design (CAD) model. The proposed framework addresses problems that are associated with 3D reconstruction processes, such as self-intersections, non-manifold geometry, 3D model topology, and file format interoperability. Finally, the resulting 3D reconstruction has been integrated within virtual reality (VR), augmented reality (AR), and mixed reality (MR) applications, as well as computer-aided manufacturing (CAM) based on additive manufacturing to facilitate the dissemination of the results [15].

For reconstruction of a damaged or destroyed historic site, advances in technology now make it possible to develop a detailed digital copy of an object of our cultural heritage, creating an unaltered prototype material to be studied by all, while offering in parallel the ease of reproducing precise copies, ensuring even museum quality standards, imparting the necessary and unique human artistic character [17].

From the users' perspective, three dimensions of Digital Cultural Heritage can be observed: matter, space, and time. While the historical monuments and sites exist(ed) in reality (Fig. 3), their digital counterparts can exist both in wide areas of virtuality and reality (augmented and alternative) [2].

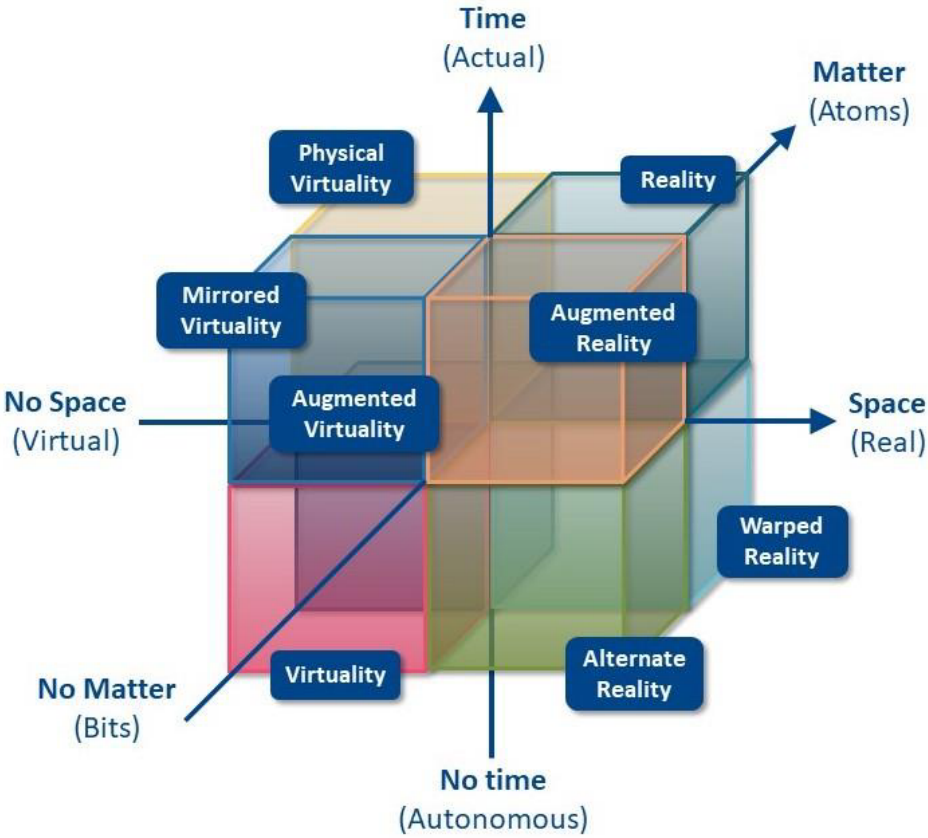

Figure 3. Different technologies for different dimensions, derived from [2].

Digitalization is not meant to be a replacement, but rather a positive addition to the relationship between the art and the viewer [2]. Therefore, it can be seen as the process of "postponed" modeling, transition in the "normal state" which consists of both real and virtual worlds. Today, digitalization not only provides copies, but those copies have their own "intelligence". The goal of creating a physical copy is only one of the important aspects of digitalization; by scanning a work of art, we can acquire multiple pieces of information that can be used for different purposes, from conservation analysis to the study of the creative passages involved in that piece [2][3].

2. Problem definition

The creation of a process chain for the creation and reuse of digital twins of monuments under limiting conditions that are tailored to microbusiness's capabilities (Table 1) while taking particular reverse engineering constraints into consideration is the main focus of this research [18]. Customers, owners, cultural heritage officers, and media specialists provided input that resulted in the widely accepted set of five fundamental, diametrically opposed requirements. Only internal processes are impacted by modularity [19]. Early on, it was clear that the solution would involve a digital process up front and traditional casting in the final stages. There are several explanations for this:

Table 1. Criteria for definition of a process chain.

	Criterion	Value/Range	Impact
1	Feasibility and competitiveness	Low-cost solution for each step and integration	K.o.
2	Duration of the production process	A few days - 2 weeks	High
3	Batch size in a wide range	One to hundreds	High (cost per unit)
4	Different materials	Brass, aluminum, plaster, plastics	Mid
5	Low share of finishing operations	Without manual operations, if possible	Mid
6	Modularity of the process chain	Singular work packages should be considered modules	Mid

- Manufacturer's low financial capabilities prevent any ambitious invest (e.g. production by 3D print).
- Missing/low IT knowledge
- High pressure regarding time-to-market
- Environmental regulations

In contrast, a small, hand-crafted business has many advantages regarding flexibility, innovativeness, robustness, and cost structure. To reliably overcome the above-mentioned obstacles, it was decided to select the investment casting as the fundamental manufacturing process again (the cube right above in Fig. 3) and aggregate all other tasks covering the inherent process variety in a virtual sub-process, substantially supported by an external partner.

3. Possible Solution

Apart from the commercialization that covers all non-technical activities to fulfill the customer order, the overall (technical) project outline comprises 6 work packages (modules) (Fig. 4). Two packages appear in the virtual world (right column), 2 in the real world (left column) and 2 in the mixed world (mid column) where the manufacturing sub-process as such remains almost unchanged.

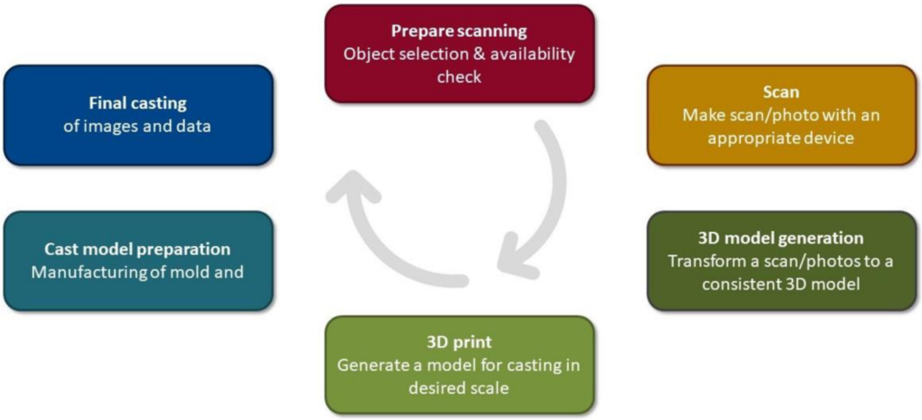

Figure 4. Working blocks for the production of decorative articles.

While process flexibility is of crucial importance (criteria 2 & 3 in Table 1), the singular blocks should be considered as modules and become interchangeable [20].

These three modules and, additionally, the commercialization need to be described more in detail as follows.

3.1. Manufacturing technique

To preserve the traditional way of work of a hand-crafted business, investment casting should be used as the preferred technology to manufacture the final products [21]. In general, this is the preferred technique for producing parts with complex geometries, fine details, and tight tolerances. Investment casting is widely used in industries such as aerospace, automotive, jewelry, and medical, where precision and intricate designs are crucial. This technique provides a high degree of design flexibility which is necessary for handling unknown forms and is capable of producing parts with excellent surface finishes. However, it can be more time-consuming and expensive than other casting methods, making it suitable for applications where these factors are outweighed by the need for precision and intricate details.

3.2. Shape acquisition (scan)

For shape acquisition, a plethora of devices are available on the market based either on scanning or photogrammetry. In general, a scanner is accurate, slow, difficult to use, and expensive. In contrast, a camera allows quick operations, is cheap, and is easy to use. Only its accuracy is questionable [22]. Meanwhile, a few tools are available, open-source or low-cost, that are capable of generating 3D point clouds from a set of photos. This approach paves the way that almost everybody can record a desired object everywhere and then submit the photos for further procedure. Therefore, photos from a simple consumer camera will be used for the first pilot.

3.3. 3D print of molds

3D molds for investment casting can be made using temperature-resistant 3D printing materials with Fused Deposition Modelling (FDM) 3D printers. 3D printing can create molds fast and cheaply, but layer lines will lead to a low-quality surface finish which requires additional sanding. A 3D-printed mold will probably endure about 100 shots, while aluminium tooling may be able to handle 10,000 part runs in certain situations. The most popular material for 3D printing molds is resins. They are able to create precise, high-quality parts with a range of characteristics, such as flexibility, chemical resistance, heat resistance, and hardness.

3.4. Commercialization: market entry strategy

The solution should be commercialized by an interest group, composed according to the European Economic Interest Group (EEIG) model to ensure the sustainability of the product after the end of the pilot project, and will be delivered in three models [23]:

The Direct delivery model: The products will be directly delivered to new customers. The main channels will be the trade networks. Each industrial partner will act as a "Focal Contact Point".

The Cluster delivery model: Clusters (tourism cluster, SME cluster, etc.) will promote and operate the full offering using existing channels.

The Research, Innovation, and Initiatives model: For the sake of popularization, the virtual methods will be offered in the research community for research purposes as open source with full access.

The large scale of potential products in a range of volumes and applications recommends the cluster model where the agents (commercialization partners) will be granted a fee.

4. Pilot project and results

For the pilot project that should prove the feasibility of this approach, an example of a medium-sized bust was selected. This bust represents Franjo Tuđman (1922-1999), the first President of the Republic of Croatia, who remains very popular in the country and is immortalized in a few dozens of monuments with different dimensions and materials. For this project, a bust located in Pisarovina (Croatia) was selected due to these differentiating characteristics: size, material, and a few detail features (Fig. 5, left). Furthermore, it was expected that a product linked with a famous personality would attract potential customers.

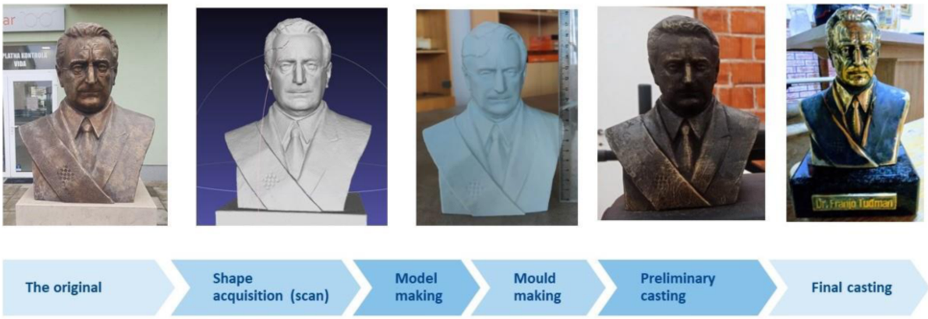

Figure 5. Process chain for production of decorative articles – as built.

In the first attempt, the shape acquisition was done most cheaply – by making several dozens of standard photos with a smartphone. In good environmental conditions, this operation lasts 10 minutes and can be done by everybody. The bust model was created in 3D by photogrammetry (Fig. 5, second from left). In general, the photogrammetry provides good results but some small issues (outliers in the point cloud) occur that can't be assigned to a dedicated reason. Therefore, the resulting model must be updated and slightly refined by using CAD. Nevertheless, the use of a scanner (daily rental fee in the range of 1000 Euro) is not necessary for an object with these characteristics.

The change to the physical process was the most challenging step in this project. At first, it was decided to create the final product in scale 1:2 to the original. This dimension was determined by the capabilities (workpiece extension) of the available 3D printer. The production in the original size would require two or more pieces to be stuck afterward. After several attempts failed to print a thin shell workpiece that could be used in a lost-wax process, a mold was created with a 10 mm shell (Fig. 5 mid). The further steps were made as usual benefiting from the craft skills of the worker. The preliminary casting was made in plaster and painted with a brass-like color (Fig. 5, second right). Finally, an object in brass (Fig. 5, right) was cast, treated with chemicals for a specific appeal, and attached to a fundament from granite. The bust of 18 cm on a fundament weighs 8,6 kg in total. To collect customer experiences, a small series of 10 products was produced and widely distributed. The first feedback was overwhelming.

The findings and experiences from the project are summarized in Table 2 as a reference to Table 1. In general, it is possible and feasible to produce a small series of 10 products with these characteristics. Nevertheless, no criterion could be fully fulfilled. Such a “try-and-error” approach poses many obstacles and should be improved further e.g., by processing further objects. The overall process design like in any kind of manufacturing gets a particular importance [24]. Many systems breaks in the process still exist and should be consequently avoided. The virtual sub-process has a high potential for overall productivity; it seems too complex for a micro business and, thus, is a candidate for outsourcing [25]. Finally, the modularity of the process chain can be achieved when many obstacles are resolved.

Table 2. Findings from the pilot project.

	Criterion	Result	Comment
1	Feasibility and competitiveness	Successful use of open-source and low-cost solutions - implies many risks	Needs further elaboration
2	Duration of the production process	Estimated: 1 week	Heavily depends on the points 1 & 5
3	Batch size in a wide range	A ramp-up from 1 to at least 20 is easily achievable	Depends on the capacity of the foundry
4	Different materials	Brass, aluminum, plaster, plastics	Brass and plaster work finely
5	Low share of finishing operations	Unthinkable without manual rework	Needs further process improvement
6	Modularity of the process chain	Partially achieved	Interdependencies higher than expected

5. Conclusions

Digitalization is already recognized as an appropriate means to preserve and maintain cultural heritage. Digital replicas of public spaces and museums provide a unique impression for a virtual visitor. Many stakeholders in the society and economy can benefit from the concept of the digital twin, especially when taking into account a 3D representation of the current state. Last but not least, there are manufacturers of decorative items that could heavily simplify their processes with a digital library of objects of their interest. At this moment, they need to use techniques of reverse engineering to get a model of a cultural asset.

The next step towards the higher efficiency of all newly created digital information could be an ecosystem with uniform reference norms and standards where the manufacturers of decorative items could find their place [2]. This includes new business models as well as extensions of existing ones as we already have experience in the manufacturing industry. The actual challenge lies in putting in place an interoperability architecture that is built on shared models, standards, application programming interfaces, and the distribution of open data. By combining various services and topics, the interoperability framework would facilitate seamless communication between the various systems and services within the ecosystem, eliminating the need to "translate" formats [26]. It would also encourage the creation of novel applications by removing the barrier of having to worry about communication protocols or formats. It challenges producers and designers to embark on a journey that enhances their goods and advances the local communities' cultural fabric [27].

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