



Digital Twin, from Industry to Cultural Heritage

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Abstract. This paper provides a comprehensive overview of various case studies utilizing the Digital Twin solution across different industries, including manufacturing, IT, Cultural Heritage, and more. The goal is to showcase the versatility and adaptability of the Digital Twin concept, and to provide a streamlined workflow for future implementation in a variety of contexts.

Key words. Digital Twin; HeritageDT; workflow

1. Introduction

The concept of Digital Twin is increasingly popular. Starting from the industrial field, it has now overstepped that boundaries, gradually expanding the areas of possible application. The Digital Twin (DT) is a one-to-one digital copy of an existing entity, integrating all knowledge resulting from mathematical models, combined with working data captured during real-world operations (Semeraro et al. (2021)). Its main feature is the dynamic behaviour: the Digital Twin is closely connected with its real counterpart, in a relationship that generally follows the logic of the Master-Slave. The fulcrum of this relationship is the physical entity (Master); while the Digital Twin, which plays the role of the Slave, faithfully copies its behaviour, constantly updating its parameters. Digital Twins can be used for tasks such as: - Predictive maintenance: by simulating the operation of an asset

over time, it can be used to identify potential issues and schedule maintenance before they cause failure. - Process optimization: a digital twin can be used to optimise production processes and reduce costs by simulating different scenarios and identifying the most efficient options. - Design and testing: Digital Twins can be used to simulate the behaviour of an object or system under different conditions and loads, allowing engineers to test designs and identify potential problems before building the physical object. These characterising aspects of the Digital Twin are well delineated and highlighted by considering a modelling of the Digital Twin, called The Five-Dimension Digital Twin Model. According to this model, a Digital Twin of an existing entity can be defined by giving the following five elements: a physical entity, a virtual model, the data, the services, and the connectivities (Qi et al. (2021)). In the following, more details will be given and a development framework based

on this model will be presented. In a world of growing complexity, moreover, simple digitization of segments of reality is no longer enough; reality must be brought into the digital realm with all its multiple facets, adding levels to levels. Furthermore, the levels have to be integrated and probed and explored from multiple perspectives by exploiting numerical simulations that operate on the physics of the systems, and the suggestions that can come from the application of artificial intelligence algorithms. Creating the Digital Twin of a production line, which was initially already considered a complex job, pales in comparison with the ambition of making the Digital Twin of the Earth, for example, and yet it now seems an inevitable and necessary effort to deal with some degree of success with the great challenges that humanity has to manage. The present contribution aims at presenting a brief overview over some case studies applying the Digital Twin solution and spanning through different areas, starting from the industrial sector to the IT one, passing through Cultural Heritage and the presentation of a possible development workflow, adaptable to multiple contexts.

2. Applying the Digital Twin concept to Cultural Heritage at VisitLab Cineca

In recent years, Digital Twins (DTs) have found a valuable application in the field of Cultural Heritage (CH). The restoration project of Notre-Dame de Paris cathedral, for instance, employed DTs to correlate multiple resources, generate new knowledge, study available materials, and record changes that occurred over time, from the origin up to now (De Luca (2020)). Restoration is one of the sectors where DTs can be particularly useful (Falcone et al. (2021)). However, when dealing with CH, we must consider the problem of time scale and the relationships among time, space, and culture in heterogeneous spaces with a lot of spatially-related information. In CH, it is not enough to know what we have now, it is crucial to understand how things came to be, that is, the processes behind. Since the digital twin is a virtual representation that serves

as the real-time digital counterpart of the physical object, it should represent a unique asset in a specific instance, integrating the semantic structure and data, the virtual research environment (visualization, analysis, modeling, and simulation), sensor data, and interactivity. HeritageDTs, unlike DTs designed for industries, might contain both observations and interpretations of these observations; therefore, they should also integrate the processes used to reach those interpretations (Niccolucci, et al. (2022)). HeritageDTs are the ideal environment for reporting realities of high complexity and intricacy. VisitLab Cineca, which has always been dedicated to scientific visualisation, brought the idea of a Digital Twin closer to Cultural Heritage in the early 2000s. Since then, a series of projects has developed at least its basic concepts. Forerunner was the project of the virtual Museum of the Certosa di Bologna, which reconstructed in 3D some monumental areas of the monumental cemetery of Bologna to convey the historical and artistic information connected to them as well as those of the people buried there¹. Unfortunately in 2004 the times were not yet ripe and a significant element for a more complete expression of a Digital Twin was missing. At the time, the connection with the cemetery management database was also hypothesised, but it was never realised (Borgatti et al. (2004)). A more recent experience has been the one developed for the CSAC Archive in Parma². In this case, a real exhibiting space has been virtually reconstructed and the first phase of development foresaw the reproduction of the exhibition dedicated to Ettore Sottsass³. The items on display were linked to the already existing database of the archive. Future developments, starting from the virtual setup, aim at creating a tool for curators enabling them to design new exhibitions by tapping directly into the archive contents in order to arrange them in the display. But it is with the Isabella d'Este

¹ <https://www.storiaememoriadibologna.it/scenari>

² <https://www.csacparma.it/>

³ <https://cultural-heritage.it/university-of-parma/>

Virtual Studiolo project that all the levels of complexity, part of the complete concept of a Digital Twin, can be mapped and explained.⁴

3. Isabella d’Este Virtual Studiolo, a Digital Twin use case

To inspire new research frameworks, the Digital Twin paradigm can give us some unexpected hints in order to effectively design and implement frameworks applied to Digital Humanities projects which feature challenging requirements. Isabella d’Este Virtual Studiolo (Guidazzoli & Liguori (2021)), part of the IDEA Isabella d’Este Archive project directed by Deanna Shemek, has accepted this challenge. The IDEA project is an exercise in imagination, discovery, and critical engagement: an ensemble of instruments for scholars, students, and generally curious visitors. Taking as inspiration and focus on one of the most influential figures of the Italian Renaissance, Isabella d’Este (1474-1539), IDEA studies new ways to explore the history and culture of early modern Italy through digital access to original documents and artworks, essays, data mining, sound recordings and even through immersive environments. The Isabella Virtual Studiolo aims at recreating her personal studiolo at Mantua’s Ducal Palace that, for centuries, has been accessible only in dispersed pieces and in spaces depopulated of major works and artefacts. A 3d web application has been developed by Visit lab team Cineca⁵. This web application can be launched from the browser without the need for installing it.

Three navigation modalities are available: the first mode is the first-person one, which simulates the vision of a visitor physically present in the space. Also in this mode, the map tool shows interactively the plan of the Studiolo, the position, and the orientation of the visitor. The second mode is the third-person one, where the camera orbits around our avatar, Isabella’s silhouette. In this modality, we can move away from the avatar, even crossing the

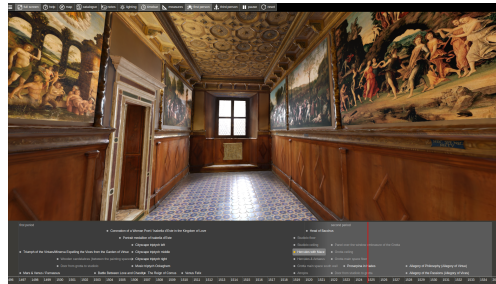


Fig. 1. Isabella Virtual Studiolo: 3D Web application interface.

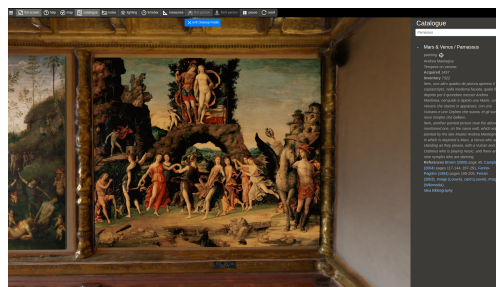


Fig. 2. Isabella Virtual Studiolo: the catalogue.

walls, to have an overall view and the presence of the avatar helps us understand the dimensions of the space. The third modality is called “closeup” and allows us to get close to a specific object, rotate around it, and see all the details. The catalogue allows us to access all the information available to us for each of the artworks currently displayed in the Virtual Studiolo.

Bibliographic references are present to refer to the source of the information and a search function ensures a bi-univocal connection between each item and the catalogue itself. The time bar allows visualising the different items according to their acquisition by Isabella. The time interval goes from 1496 to 1534. The light control tool allows the simulation of natural light, it enlightens the space during the day and over different seasons. Moreover, two types of measuring instruments are available: the first one shows us a set of indications directly in 3D space while the second one operates outside the 3D space through appropriate calibrated images and allows us to measure

⁴ <https://vimeo.com/178788050>

⁵ https://ideastudiolo.hpc.cineca.it/isabella/virtual_studiolo



Fig. 3. Isabella Virtual Studiolo: a 3D model visualisation.

exactly even the smallest details. The last tool currently implemented is conceived for the inspection of the 3D models.

To sum up, the Digital Twin perspective, applied to Isabella d'Este's project and in particular to Isabella's world represented by her Studiolo, can be summarised with the expansion both of data sources and the collection of simulations and knowledge (see fig.1, 2, 3) Thus, on one hand, we can have more content, more artworks, more databases, and more structured and unstructured data; on the other hand, we can gather more scholarly expertise, and more simulations - covering different aspects and even see them in one ensemble of models. This approach can give us a greater value than the sum of the single parts and it's a common approach in the field of weather forecast models. Regarding the Isabella d'Este Virtual Studiolo we are just at the beginning of an early minimal simulation stage, ideally aiming at its unreachable Digital Twin. Nevertheless, the online application delivers a sense of being overwhelmed by such a richness of colours and artworks thanks to a sense of embodiment even if partially given by the 3D navigation and the perception of all the different layers of interpretation.

4. Applying the Digital Twin concept to the Industrial field

The Digital Twin finds one of its greatest expressions in the Industry: how? To answer this question, "MARTE", the Virtual Reality laboratory of the University of Naples, has designed and implemented some interesting



Fig. 4. An operator interacting with digital models.

Digital Twin industrial applications, dividing them into four categories: Digital Twin of product, Digital Twin of process, Digital Twin of performance, Human Digital Twin. The product Digital Twin finds interesting applications throughout its life cycle, from Design to mass production. In particular, with a view to the continuous optimization of a product, its Digital Twin can be used to analyse its current state, evaluate any critical issues and immediately test possible changes and improvements in real time. In this regard, it is possible to live a multi-user experience within an immersive VR environment: members of various teams, departments, or companies can collaborate and interact in the same virtual environment, connected from different sites. The Digital Twin process consists of the digital copy of an entire production process, offering the possibility of storing, modifying, and validating it but, above all, ensuring the traceability of each component and reducing the human error percentage for distraction or forgetfulness. In this regard, we have developed Virtual Storage Assistant (V.S.A.): a digital procedure for unloading/reloading customs containers⁶. This application, compatible with the Hololens2 Mixed Reality device, allows the operators to create the unloading procedure by interacting with digital models of the packs, and panels with textual instructions and numbers to identify the unloading order. See Fig. 4. Thanks to the use of the same Software/Hardware architecture, any other operator will be able to reload the container

⁶ VSA Virtual Storage Assistant —5G Academy Università di Napoli Federico II: <https://www.youtube.com/watch?v=nK8uMe04ks0&t=129s>

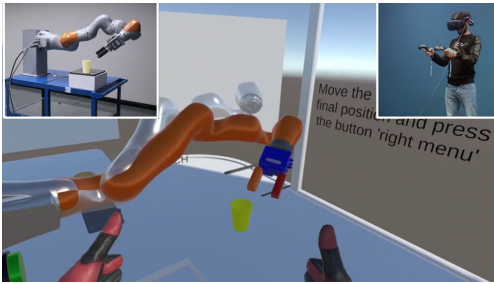


Fig. 5. The VR teleoperation system

properly with the support of the same digital hands-free procedure, accessible on the cloud. The performance Digital Twin allows for constant monitoring of the status of a system, using this information to act promptly in case of unforeseen situations, such as breakdowns or accidents. The performance Digital Twin finds great application in the industrial world in the context of Human-Robot collaboration. In this case, the operator benefits from the use of Virtual and Augmented Reality techniques to display information on the status of the robot, within a Human-Machine Interface that must be suitably designed, to provide all and only the necessary information. An example is the Virtual and Augmented Reality Control System (V.A.R.CO.S.) See Fig. 5.

The operator, being remotely connected to the robot's site, is immersed within a virtual scenario that faithfully reproduces it, with the ability to navigate and interact with digital copies of real objects. The added value of V.A.R.CO.S. is the possibility for the user to switch through the menu between two different control modes: the first shows the preview of the robot's planned trajectory, with the possibility to confirm or abort it; while the second enables a direct velocity control on the robot's end-effector. The Human Digital Twin is more than just a digital avatar, but allows the conduct of ergonomic analyses on the operators to evaluate their working environments' adaptability, usability, safety, and comprehensibility (Caputo et al. (2006)). To ensure the reliability of the data collected and the analysis carried out, every human movement must be accurately reproduced by its Digital Twin. For this

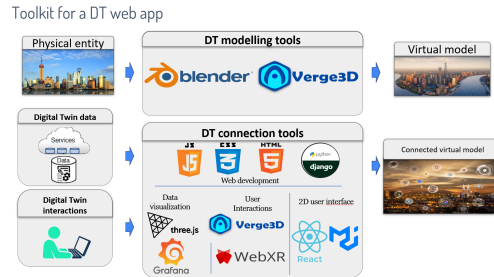


Fig. 6. Main tools of the proposed Digital Twin web application development workflow

reason, it is necessary to set up a tracking system on the entire body or a specific part of the user.

5. A flexible workflow to develop a Digital Twin web application

The creation of a Digital Twin of an existing entity can be implemented through several IT solutions and similar solutions can be adapted to completely different realities. Following the Five-Dimensions Digital Twin Model presented in the introduction, we present an open-source toolkit to deliver an adaptable and flexible workflow for the creation of a Digital Twin 3D web application. The presented toolkit and workflow, shown in Fig. 6, prove to be suitable for industrial Digital Twin, such as a production chain or a data centre, but it can be quickly and easily integrated with other tools, for example, to implement the Digital Twin of a city. As a use case, we present the prototype of an application for Cineca's Marconi 100 supercomputer. The choice to deliver a web application has been motivated by the fact that it is easy to deploy and maintain and at the same time it can be reached by an end-user through multiple devices, such as smartphones, tablets, and XR devices. The first step of the workflow is the creation of a virtual model of the physical entity, reproducing its physical geometries, properties, behaviours, and rules. For industrial Digital Twin, the starting point for this phase is usually CAD/BIM models and DWG files. The BIM/CAD parametric models have to be converted into mesh-based mod-

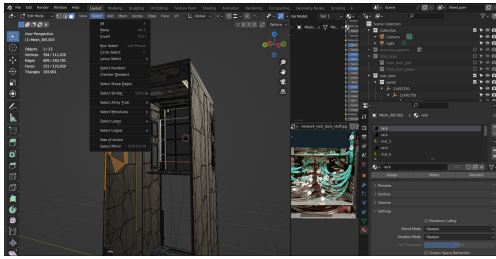


Fig. 7. MTools for geometric elements selection in Blender, used for a rack model.

els, preferably glTF files⁷ since this file format preserves the model objects hierarchy, employing open-source software such as CAD Assistant⁸ and FreeCAD⁹. DWG files are usually used as a reference for positioning components of the physical entity or for the creation of buildings and thus it is sufficient to convert them into PDF and then JPG/PNG files. This is achieved by using free software such as DWG TrueViewer AutoDesk¹⁰ and open-source software GIMP¹¹ for the editing part. After that, these derived files are imported into Blender¹², an open-source 3D Computer Graphics toolkit. It allows for easily simplifying the often-redundant geometry derived from CAD/BIM models. See Fig. 7: it can be done manually thanks to the completeness of the geometric elements editing and selection tools or automatically, by employing geometry decimation tools. This step is fundamental in order to obtain a lightweight model for a web application and Blender has also other tools, such as texture baking options, to obtain a visual faithful replica of the physical entity, preserving its appearance with a coarse geometry. Moreover, Blender supports an add-on called Verge3D¹³ that allows one to directly import a Blender scene in a web browser and obtain almost seamless the same graphic render-

⁷ <https://www.khronos.org/glTF/>

⁸ <https://www.opencascade.com/products/cad-assistant/>

⁹ <https://www.freecadweb.org/>

¹⁰ <https://www.autodesk.com/viewers>

¹¹ <https://www.gimp.org/>

¹² <https://www.blender.org/>

¹³ <https://www.soft8soft.com/verge3d/>

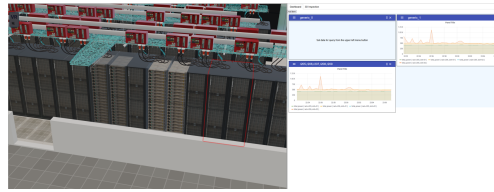


Fig. 8. Mapping of alerting data onto the 3D model of Cineca's supercomputer through post-processing effects (red highlighting of two racks) on the left side and time series data visualisation with a Grafana-powered dashboard system on the right side.

ing as the Blender rasterization engine allows. Verge3D also imports the dynamics of the models as defined in Blender through animations, therefore the virtual model can perform a set of actions and logic to fulfill functions, respond to changes and interact with the user. Another Verge3D useful feature is the possibility to easily create arrays of identical model components without the need to model each of them in Blender. This feature can be further enhanced by leveraging the Verge3D underlying library, ThreeJS¹⁴, available through the Verge3D embedding of its APIs. Creating a large number of identical model components, different from each other just for appearance or geometrical transformations, is allowed by ThreeJS to create instances instead of just duplicating them and thus increasing the total geometry within the scene. According to what has been said and concerning the Five Dimension Digital Twin Model, Blender and Verge3D have multiple functions within the framework, allowing to perform geometric and behavioural modelling for the creation of the virtual model and its environment. The connections of the Digital Twin with several heterogeneous data can be performed in various ways, depending on the data type and its visualisation and presentation to the user. The data can be mapped directly onto the 3D components of the model leveraging Verge3D features such as the post-processing effects, for alerting data for example, or it can be used by a dashboard system such as the open-source vi-

¹⁴ <https://threejs.org/>

sualisation web application Grafana¹⁵ for time series data type. Fig. 8 shows both examples. Grafana is particularly useful since it allows the use of several database sources and the data visualisation type can be easily customised from within the Grafana web interface itself and then embedded in another web application, whose front-end is based on other JavaScript frameworks. Concerning the connections and interaction of the Digital Twin with the user, it is realised through Verge3D for the interaction with the 3D model through the common input devices of the keyboard and mouse. Moreover, Verge3D is embedded into the front end of the web application, realised through the JavaScript library ReactJS¹⁶, which allows the creation of a responsive user interface. For the XR devices interactions, such as those of head-mounted displays and cardboard, are performed leveraging the Verge3D support for WebXR, a set of standards that are used together to support rendering 3D scenes to hardware designed for presenting virtual worlds (see fig.?). For what concerns the back-end of the application, we have chosen Django¹⁷, a high-level Python web framework for the possibilities to leverage Python to pre-process some data from the data sources within the back-end of the application. Finally, the whole application has been deployed producing a Docker image since it allows for easy maintenance and deployment.

6. Conclusions

The case studies presented, both from a theoretical and practical standpoint, demonstrate that the digital twin paradigm, which was originally developed in the industrial field and continues to evolve, can also be effectively applied in other contexts. As more and more experiences are gained, more areas will be able to profit from the concept of DT, leading to an expansion of the perspective, including the in-

volvement of artists who will be able to add new dimensions that are not only aesthetic.

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¹⁵ <https://grafana.com/>

¹⁶ <https://reactjs.org/>

¹⁷ <https://www.djangoproject.com/>