The potential of reverse engineered physical models

Digital twins as an innovative method for technical and cultural heritages

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Keywords: *physical model — measurement model — digital twin — retro digitization — reverse engineering*

CHNT Reference: Schmid, B., Weber, C., Wenzel, B. and Möller, E. (2022). 'The potential of reverse engineered physical models', in CHNT Editorial board. *Proceedings of the 27th International Conference on Cultural Heritage and New Technologies, November 2022.* Heidelberg: Propylaeum. DOI: xxxxxxx.

Measurement models as last witnesses

Measurement models are a special type of models which were mainly used in the field of civil engineering (and are still used today in a few specific fields) to analyse, understand, literally comprehend and finally even dimension and test load-bearing structures. Like architectural models, they served as a communication medium and planning tool, but unlike these, they were often yet damaged or destroyed in the measuring process. Consequently, and due to the engineers' lack of awareness of their own history and its importance, only a few measurement models or more precisely fragments of these have survived or found their way into protected collections or archives, like the physical model of the Olympic sports hall in Fig. 1. (Bühler and Weber, 2021)

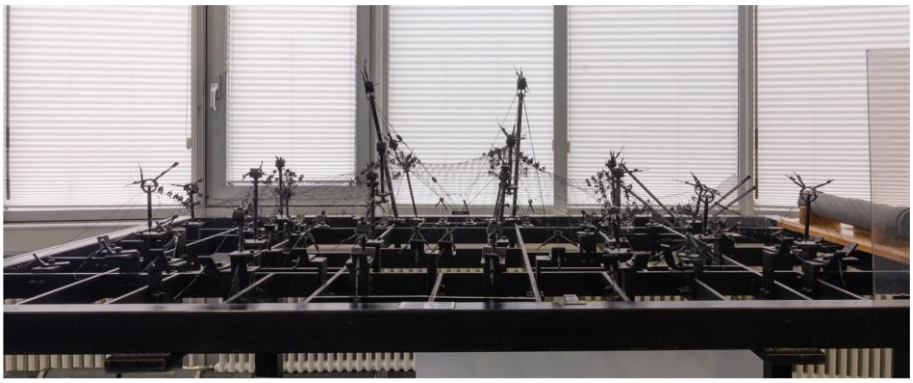

Fig. 1. Physical model of the Olympic sports hall in Munich, visitor centre Olympic park Munich (© Mareike Stöber).

The few still existing models are knowledge stores of engineering practice and therefore shall be recorded and evaluated as the last witnesses of the era of model statics with the aim of developing concepts for their future preservation. As part of the ongoing research project "Last witnesses – physical models in civil engineering" in the priority program 2255 "cultural heritage construction" funded by the German Research Foundation (DFG) digital twins of the few preserved models are produced. In contrast to the physical models, the digital twins are being created using state-of-the-

art digital tools. Algorithms as well as different modelling programmes supports the remodelling of the complex models. To be able to access the outcome in the long term, all the model data will be provided in an open Database format. (SPP 2255, 2021)

Methods of reverse engineering

There are different non-destructive methods of reversed engineering available and have been tested for the generation of a digital twin, adapted to the different types of measurement models to be recorded.

With the method of the structured light 3d scan a 3d model of a face is computed by projecting a simple stripe pattern onto the object. The depth information is calculated by considering the distortion of the stripes caused by its shape. To measure the degree of distortion the projected stripes are compared with the detected stripes to find corresponding stripes respective to find corresponding pixels per vertical scan line. The depth is evaluated for all correspondences with respect to the focal points of the camera. This leads to a cloud of 3d points.

Using a 3d laserscan, a scanner emits a laser beam, which is reflected by the surroundings and picked up by the receiving optics. The beam is deflected by a mirror which is set in rotation. This process takes place hundred thousand times a second. The laser light received by the scanner is evaluated accordingly and lead to a cloud of 3d points.

Since these two methods are difficult to apply to filigree models, it was necessary to turn to the most time-consuming method, as it is manual, but it leads mostly to the best results, the photogrammetry. For the photogrammetric method, an object is first recorded with a camera from various angles. Every externally visible point must be clearly visible in at least two photos. In the photogrammetric evaluation of images, the imaging geometry must be restored at the time of recording. This restoration takes place according to the laws of central projection in compliance with the condition of planarity. By using at least two homologous (corresponding) image points from two different recording positions (stereo image pair), if the mutual position (relative orientation) is known, the two rays can be brought to the intersection and thus each object point can be calculated three-dimensionally.

The difficulty in collecting data for the reverse engineering are often filigree wires or transparent components which are both frequently used for physical models of lightweight constructions. These objects are hard to be recognised by the laser technologies, like it was the case with the physical model of the Mannheim Multihalle. That's why the digital twin in Fig. 2 was produced by using photogrammetry. (Wenzel et al., 2021)

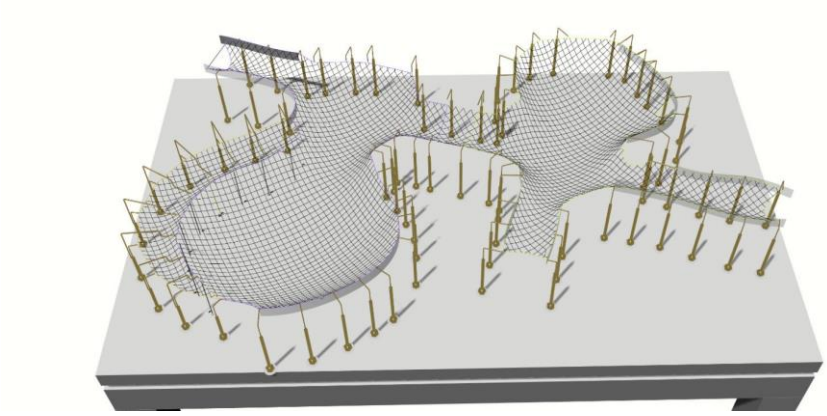

Fig. 2. Digital twin of the physical model of the Mannheim Multihalle (© Baris Wenzel).

Potential use of digital twins

The digital twin is seen as one of the main concepts that should drive the digitization of industrial production. The digital twin helps to simulate and predict the present or future behaviour of a physical object, which in turn allows to optimize the object and increase business efficiency. While the term is used more and more in the aerospace and automotive industries, there are still few known applications in the architecture and construction sector. The industries that are more dependent on industrial production can offer the construction industry an important orientation in dealing with digital planning and management, since comprehensive networking of data sources and the coupling of simulation models are also becoming more and more indispensable in the building process. (Wenzel et al., 2021)

The aim of this paper is to investigate the possibilities and benefits of digital twins of measurement models in the field of civil engineering, restoration science and architectural history. Possibilities such as damage mapping offered by the digital model, but also for the real object provide a valuable basis for the restoration processes. In addition, as an annotation tool the digital models can serve as a useful method in the planning and recording the restoration process by integrating the reports or photo documentations.

From an engineering perspective, static simulations, and calculations of structural parameters for changed conditions caused by climate change such as greater amounts of precipitation and increased snow loads or wind effects could be simulated and evaluated. Like their material brothers, the digital twins are knowledge stores of their own value, carrying information about a lost engineering practice of producing innovation and their communication and transfer into building practice.

Within the research project, for archival purposes, data contained in the digital twins will serve as the basis for cataloguing and categorizing the objects with an easy accessibility on an open database format in long term for an interested public and further generation of researchers. Furthermore, this allows to use the produced scientific results as teaching material or to be explored by a larger audience in exhibitions with virtual reality. A constantly expanding database of digital models can be made accessible in virtual space, for example for academic institutions or museums, to make the objects tangible using augmented reality. In this metaverse, it is possible to complete the mostly fragmentary models and return them to their actual purpose, the performance of tests and measurements. This virtual engineering laboratory can be used instead of the fragile, endangered cultural heritage to preserve and use them for the future, at least in the metaverse, if not in reality. This could also be a medium for getting more and more young people enthusiastic about research and innovation in the construction industry – also regarding a sustainable, research-friendly future viability of the civil engineering. Especially, the pandemic situation has shown the value of a digital collection which is easily accessible to a large audience in full scope.

This contribution will demonstrate the significance and usefulness of retro digitized models or digital twins as a method for innovation in the special field of construction history and the conservation of cultural and technical heritage. In addition, the possibilities of using digital twins in virtual space will be explored and their status in the metaverse declared.

Funding

This research was funded in the priority program 2255 “cultural heritage construction” by the German Research Foundation (DFG).

Conflict of Interests Disclosure

There are no financial or personal relationships with other persons or organisations, such as sponsors, which could have influenced this work.

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