Long Paper

Photogrammetric 3D Digitisation of Models from an Architectural Collection

Andreas NOBACK, Technische Universität Darmstadt, Germany
Chris DÄHNE, Technische Universität Darmstadt, Germany
Roger WINKLER, Technische Universität Darmstadt, Germany
Stephan TITTEL, Technische Universität Darmstadt, Germany
Annika BEISSNER, Technische Universität Darmstadt, Germany
Katja LEISKAU, Deutsches Architekturmuseum, Germany
Hasan KUTLU, TU Darmstadt & Fraunhofer Institute for Computer Graphics Research IGD, Germany
Reimar TAUSCH, TU Darmstadt & Fraunhofer Institute for Computer Graphics Research IGD, Germany
Martin SCHURIG, TU Darmstadt & Fraunhofer Institute for Computer Graphics Research IGD, Germany
Matevz DOMAJNKO, TU Darmstadt & Fraunhofer Institute for Computer Graphics Research IGD, Germany
Pedro SANTOS, TU Darmstadt & Fraunhofer Institute for Computer Graphics Research IGD, Germany

Abstract: The specialised information service FID BAUdigital develops a 3D scanning and data publishing service for architectural models. Starting with an automatic acquisition procedure featuring photogrammetric methods implemented in the CultArm3D it goes on to postprocessing and data enrichment and further to a repository infrastructure providing access guided by FAIR data principles. Such an undertaking demands a metadata model informed by the digitised objects and utilisation of the resulting digital assets in architectural research. Therefore, this contribution identifies at least four relevant perspectives on digital architectural models: 1. As digital objects as result of a scanning procedure. 2. As representation of artifacts emerging from a certain cultural context. 3. As items within a collection. 4. As representations of build or unbuild architecture. These perspectives have to be taken into account in metadata models and as starting points for open linked data. Examples are given reflecting these perspectives as well as use-cases for digitised models. These digital versions provide more access to architectural models and more interoperability for semantic web applications. But they are not exclusively seen as medium for scholarly or museal use but as research data allowing new digital methods. The FID BAUdigital aims to further develop this service alongside with suitable metadata models driven by the demands of the research community.

Keywords: *Digitisation—Architectural Models—Photogrammetry—Research Data Management—Specialised Information Service.*

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Introduction

For research in architectural history, 3D items as models and building details found in architectural collections between drawings, photos, correspondence and other 2D archival materials are important sources of information. Alongside the digital preservation and dissemination of digital born data retro-digitalisation of museal collections and archives is a major task in providing more access to this kind of cultural heritage and foster the development of a semantic web of museal and historic information. While existing techniques and infrastructure provide adequate means for the digital acquisition, preservation, dissemination and display of data and metadata from 2D archival materials, architectural models are represented in the digital realm almost entirely by photographs, ignoring their most important characteristic. And while scholars in architectural history use data collections of 2D items on a daily basis, the utilisation and potential of 3D digitised architectural models has still to be explored.

Developing a digitisation service for architectural models within a national research data infrastructure

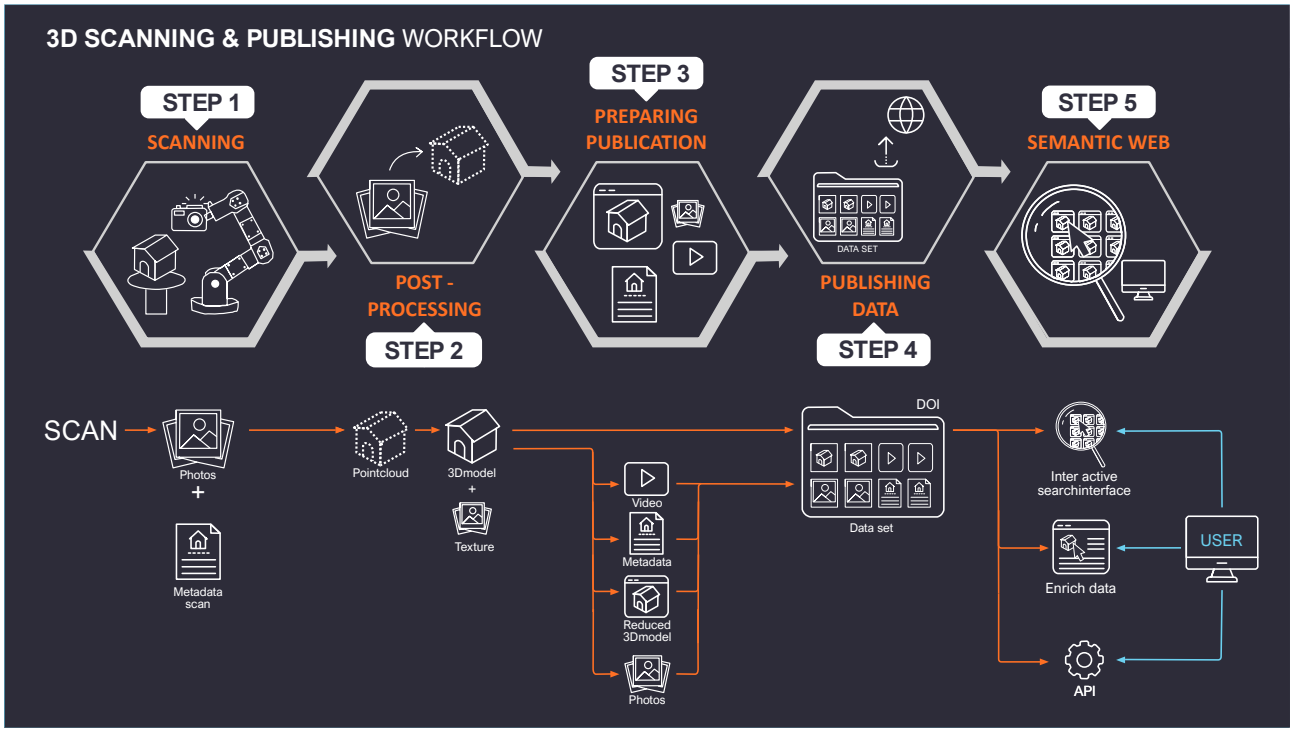


Fig. 1. The Scanning and data publishing workflow developed by the FID BAUdigital. Scanning and postprocessing is accomplished with hard and software developed by the Frauhofer IGD. Preparation, preview generation, metadata enrichment and upload to the repository is performed within a self developed workbench. The resulting dataset is available via the webservice platform of the FID BAUdigital. (© TU Darmstadt).

Against this background, the Specialised Information Service (FID) BAUdigital (Arndt et al., 2022) aims to provide a service for the retro-digitisation of architectural models (Fig. 1) complying with FAIR data principles (Wilkinson, et al., 2016). Through the Specialised Information Services (FID) program, the Deutsche Forschungsgemeinschaft (DFG, German Research Foundation) funds libraries that support scientific communities with infrastructure for literature search, publication and research data management. Furthermore, the FID program shall contribute to the National Research Data Infrastructure (NFDI), another DFG program, whose “aim is to systematically manage scientific

and research data, provide long-term data storage, backup and accessibility, and network the data both nationally and internationally."[1] The FID BAUdigital is developed by the University Library Braunschweig, the University and State Library Darmstadt, the TIB – Leibniz Information Centre for Science and Technology and the Fraunhofer Information Centre for Planning and Building. It provides services for research communities in civil engineering, architecture and urban studies with a focus on digital technologies. These research communities are linked the consortiums NFDI4culture – for art history, architecture etc. – and NFDI4Ing – for engineering – within the NFDI program.

Alongside support for digital born data (Noback and Grobe, 2022) the services of the FID BAUdigital will include retro-digitisation of plans and – the focus of this presentation – architectural models.

For the development of the digitisation service for architectural models the FID BAUdigital cooperates with the Deutsches Architekturmuseum (DAM) and the Fraunhofer Institute for Computer Graphics Research IGD. The collection of the DAM – comprising almost 1600 models and an accompanying database – serve as a case study (Elser and Cachola Schmal, 2012). The Fraunhofer IGD provides the CultArm3D a robotic solution that allows the digitisation of not only a few, but a *significant portion* of the 3D items of the collection allowing to respect to the semantic conjunction within this collection that is key for research purposes.

3D acquisition is only the first step in the pipeline of a retro-digitisation service. A microservice driven digital workbench will allow to add metadata, generate web-enabled 3D representations and to upload to the repository and digital preservation infrastructure. A web platform will allow to search and display data and metadata and will offer support for research communities developing around these digital items. It is developed in the context of handling similar 3D data in the FID BAUdigital and in cooperation with users and the growing family of similar research data initiatives.

The acquisition of exemplary models of the DAM is combined with a survey of the collection. The case study shall provide insight in two main aspects:

1. Finding distinct challenges for digital acquisition of architectural models. Directed tests based on an overview of their common sizes, materials and typical spatial structure allow to develop suitable acquisition procedures and to better understand of the results as research objects.
2. Foster the understanding of architectural models as research objects and collection items, informing the design of search and viewing infrastructure as well as metadata schemata and semantic data models.

Metadata schemata for digital assets and architectural models as collection items, artifacts and representations of architecture

The FID BAUdigital understands the results of the scanning process as *digital assets* and as research data objects. Metadata for these objects shall be recorded or aggregated based on community needs. It is related to distinct perspectives on architectural models and to scholarly applications concerning these assets.

[1] https://www.dfg.de/en/research_funding/programmes/nfdi/

The FID BAUdigital establishes a repository that is based on the open-source data management system CKAN.[2] CKAN provides an extension that allows to describe the data catalogue with the RDF vocabulary DCAT.[3] This extension provides a metadata endpoint for each item under the URL path /dataset/name.xml.

In addition, each dataset is receiving a DOI. This implies support for the DataCite Metadata Schema.[4] Collection metadata will be represented by the Dublin Core Collection Description Application Profile[5] and LIDO according to DFG guidelines.[6]

As the data model shall support open linked data and the FID BAUdigital intends to harvest (or aggregate) data and metadata, the FID BAUdigital leans to borrow from the Europeana data model (EDM) that includes OAI-ORE among other useful standards.[7] FID BAUdigital expects to use metadata schemata described in CIDOC CRM[8] and intend to annotate build structures according to the IFC standard.[9] The FID BAUdigital develops a thesaurus that integrates other controlled vocabularies.

The metadata in the research data objects shall support at least for distinct perspectives on digitised architectural models:

1. As *digital assets* relating to scanning and postprocessing, licenses, file formats etc.
2. As *artifacts* that relate to creators, design processes, techniques, materials etc. Not in every case the creators of a model and their historic context are identical to those of the architecture they represent.
3. As *collection items* they are related to other objects, e. g. within an architect's estate, a competition or a group of works. The metadata can further include information about provenience, restoration, storage etc.
4. As *representations* of real – or fictional – architecture they are related to their locational, environmental, historic and social context etc.

Not all of these metadata have to be stored at the same place. It can be linked from museums, architectural databases and so on, vocabulary may be linked to norm data providers.

Generating data and metadata for digital assets: A portable robotic setup for photogrammetric acquisition

For digitisation photogrammetric acquisition is applied utilising the CultArm3D, a fully automatic and colour-faithful 3D-scanner developed by the Fraunhofer IGD (Tausch, et al., 2020). The CultArm3D is capable of scanning arbitrary objects at reproducible high resolution by using its autonomous view planning feature that estimates camera focus, position, and orientation. This ensures that an optimal

[2] https://ckan.org
[3] https://www.w3.org/TR/vocab-dcat/
[4] https://schema.datacite.org
[5] https://www.dublincore.org/groups/collections/dccd/
[6] https://cidoc.mini.icom.museum/working-groups/lido/lido-overview/about-lido/what-is-lido/
[7] https://pro.europeana.eu/page/edm-documentation
[8] https://www.cidoc-crm.org/Version/version-7.2
[9] https://standards.buildingsmart.org/IFC/DEV/IFC4_2/FINAL/HTML/

set of images for the photogrammetric reconstruction is captured. Therefore, it ensures sharp texturing on the whole visible surface of the scanned object.

The robotic setup consists of a computer-controlled turntable and a robotic arm with a lighting and camera system attached (Fig. 2). The lighting and camera system feature crossed polarized filters to supress specular reflections. The light is nearly shadowless. The setup can be collapsed to fit into compact transport boxes that allow scanning on site.

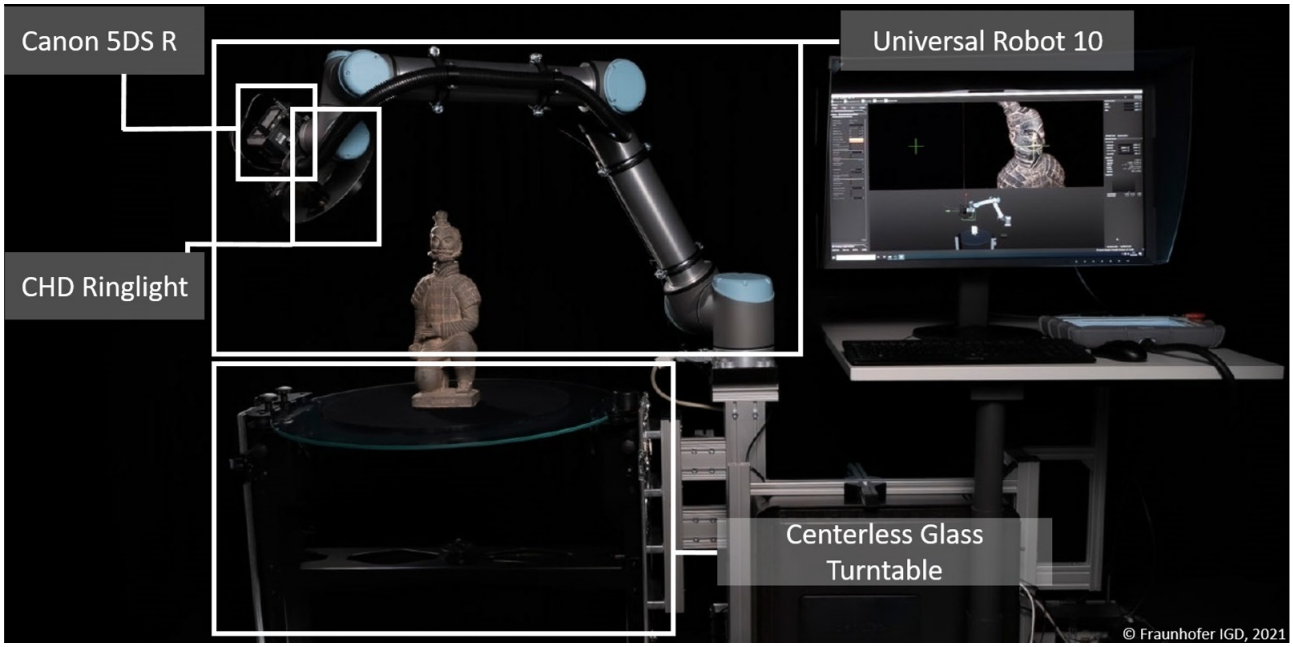


Fig. 2. CultArm3D. Automatic acquisition of an architectural model with the robotic setup consisting of a computer-controlled turntable and robotic arm with a lighting and camera system attached. (© Fraunhofer IGD).

The 3D scanning and publishing workflow is implemented in the following way:

1. The scanning procedure allows for multiple adapted workflows with multiple refinement steps. It is supported by a customized graphical user interface. After colour and spatial calibration, a safety zone for the model in hight and diameter is defined. In a first step the form of the model is estimated with multiple profiles generated from orthogonal photos. The first set of images is planed accordingly and results in a preliminary model that the base of further viewpoint planning. This procedure is repeated with the application of different algorithms to detect areas of insufficient data. Manual intervention is possible as well.
2. The photographic measurement procedure results in data in the form of raw images along with metadata such as camera positions, optical properties and calibration data. Metadata concerning the models can be recorded. Both are fed into a separate post-processing procedure.
3. During post-processing, colour calibration, optical correction and photogrammetric geometry reconstruction is applied. A specialised software component supports masking of pedestals and captured background. The processed data consists of a point cloud, a derived 3D model in form triangular mesh and a colour – or texture – map (Fig. 3). Post-processing can be repeated with further developed algorithms.

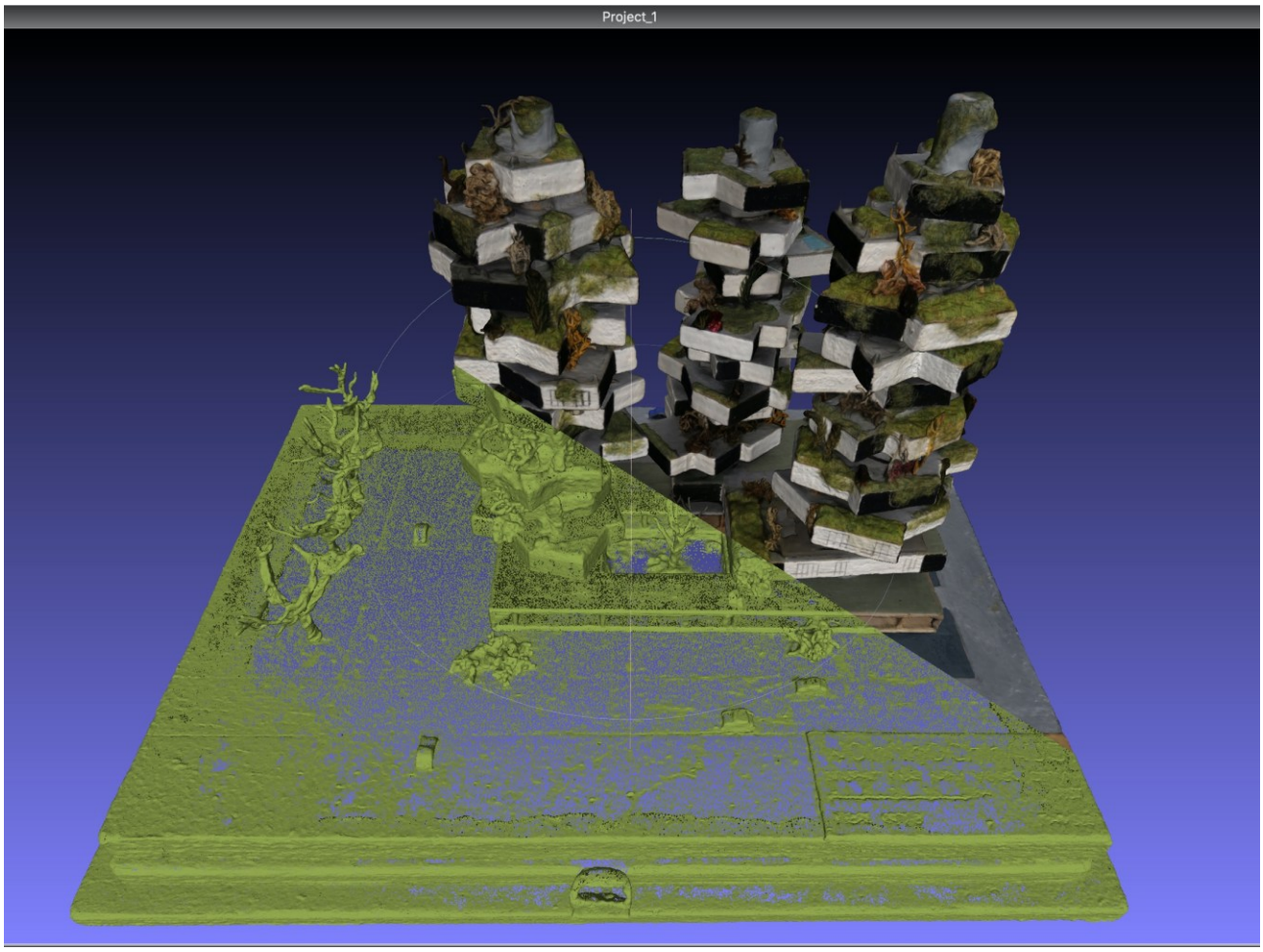


Fig. 3. "Wohnhochhaus" by Frei Otto as an exemplary digital model. The geometric structure of the complex building is preserved. Fine detail as the moss is coarsely represented. Acrylic glass that forms railings at the top levels vanished in the digital model. The resolution of the triangular mesh and the mapping is significantly lower than that of the measured data. (© TU Darmstadt).

4. To prepare the results for publication, further meta-data might be added as well as reduced 3D web previews, videos, fixed 3D views and other derived formats related to applications as VR and AR file formats.
5. A DOI is assigned to the resulting dataset and it is uploaded to a CKAN repository.
6. The web-service platform of the FID BAUdigital provides infrastructure for searching and viewing 3D models and metadata. It further provides an API for this task and links for semantic web applications.

Artefacts in the museum's collection: Size, spatial structure and materials of architectural models in the context of 3D acquisition

The current setup provides a scanning volume with a diameter of 45 cm and a height of 60 cm. This would allow us to scan about 22% of the collection. Other models have to be acquired manually. Often the outer limits are defined not by the model itself but by the ground plate of the original model or the base of a glass cover. The hight of the scanning volume is less often a limiting factor, but models of high-rise buildings can be challenging. To scan 80% of the collection a diameter bigger than 1.30 m would be necessary (Fig. 4).

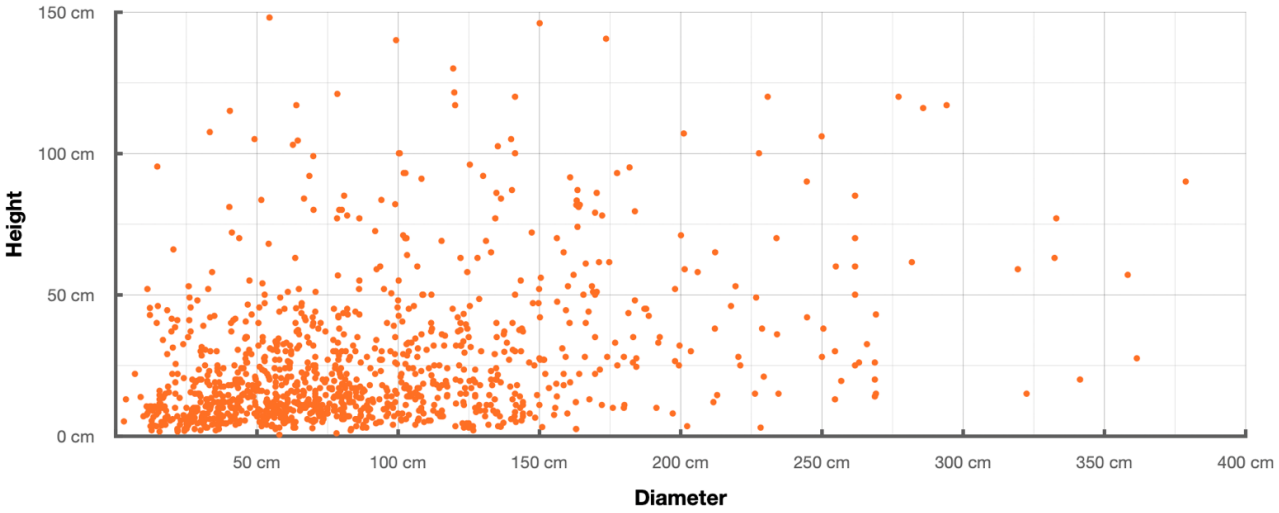


Fig. 4. Diameter and hight distribution of the models in the collection of the Deutsches Architekturmuseum. (© TU Darmstadt).

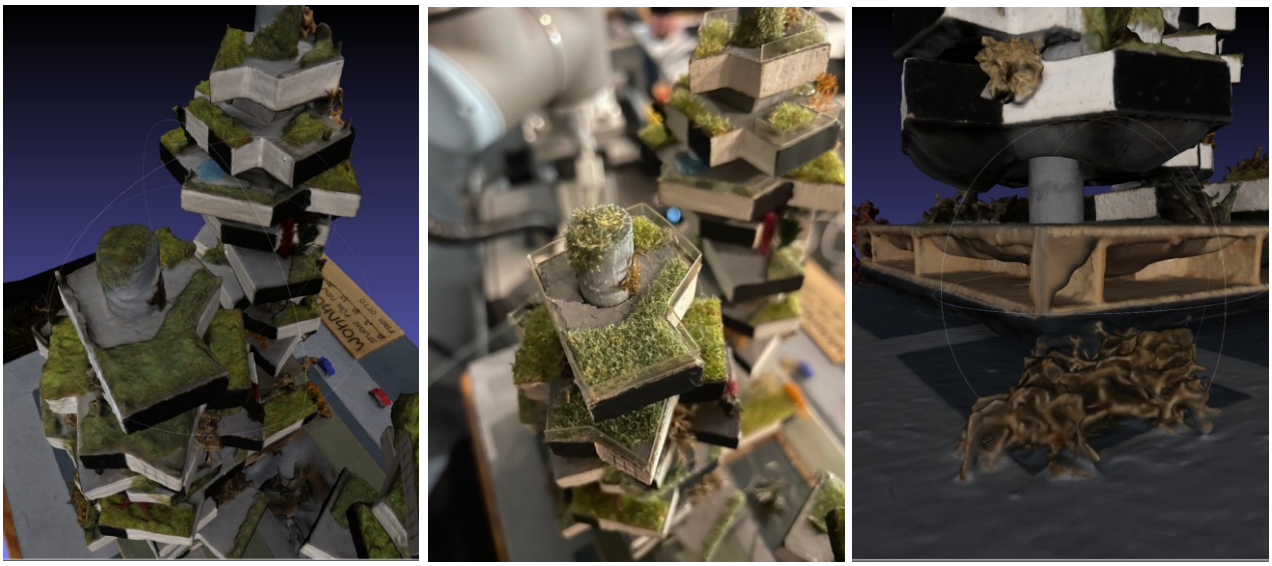
Architectural models often show complex spatial structures with multiple building elements, courtyards, raised parts etc. Many models – especially of larger scales – allow insight into interior spaces resulting in deep cavities (Fig. 5 c). Photogrammetry in general requires an object surface point to be seen and triangulated from multiple camera angles. That means, deep cavities can cause problems in photogrammetric reconstructions, because most camera angles are occluded. The CultArm3D automatically resolves these occlusions wherever possible in an iterative view planning approach.

Modern architecture often features light-weight constructions or includes trees, plants, and wires in its design. Thin and fine-scaled representations of these elements challenge the spatial reconstruction algorithms and are not easy to model with triangular meshes (Fig. 5a and b). While the results are accurate in regard to the overall form of these elements, they tend to feature somewhat coarse detail. To capture even more details in sufficient resolution, a microscopic camera setup would be required. However, this would limit the measurement volume and thus significantly increase in scanning duration. More study is required to solve this trade-off problem between the measurement volume and the scanning duration.

Architectural models are comprised of a wide range of materials, typically in mixed arrangements. Some materials cause problems in the acquisition process, namely highly specular and glossy surfaces. Featureless surfaces provide challenges as well, however tests with white plaster models gone surprisingly well. To suppress specular reflections, the lighting and camera system of the setup is equipped with crossing polarisation filters. As a side-effect this causes transparent acryl glass to vanish. The same is true for the fine relief of wood grain that is visible through small shadows that are suppressed by the lighting system (Figure 5a and b).

Exemplary applications of digitised architectural models

The strengths and limitations of this acquisition method are only meaningful in the context of its *application*. As a new method it has to provide additional means for research: 3D digitisation offers a more ample access to this cultural heritage and unique possibilities for VR and AR applications. A few examples can be given that reflect different capabilities of digitised architectural models:



a b c

Fig. 5. Compared to the original a) the digital model b) is lacking some fine detail as can be seen in the representation of the moss. Transparent materials as the acrylic glass are not represented. Deep cavities c) are challaging for photogrammetric methods. (© TU Darmstadt).

- In the viewing infrastructure the digital models can be treated at will – turned, zoomed, composed, decomposed, compared etc. That includes augmented reality applications for educational, museal and scholarly purposes (Fig. 8a).
- In the digital realm it is possible to virtually combine the different models of a competition with the environment model to understand the juror's decision. The example shows a city model of the centre of Frankfurt from the DAM collection. It features two recesses for inset models relating to two important architectural design competitions in the 1980s: one for the Museum für Moderne Kunst and the other for the Dom-Römerberg area including the Schirn Gallery. The recesses are filled with inset models from the winners of the competition, but the collection of the DAM also comprises models of further entries as shown in the graphic. These models are related to each other by the cultural context of their production and the collection reflects this relation (Fig. 6).
- Models represent architecture; therefore, you might want to inspect them within their urban environment with eye-level views, access to floors and the possibility of walk-throughs. It might help to understand a design if you can view a model at its designated location from street level (Fig. 7).
- With the digital assets you can dare research that is impossible the physical models. For example, in a daylight simulations of Frei Ottos high rise apartment building study for New York from 1957 you can quantify the casting of shadows among the towers and relate them to the architect's claims (Fig. 8b).

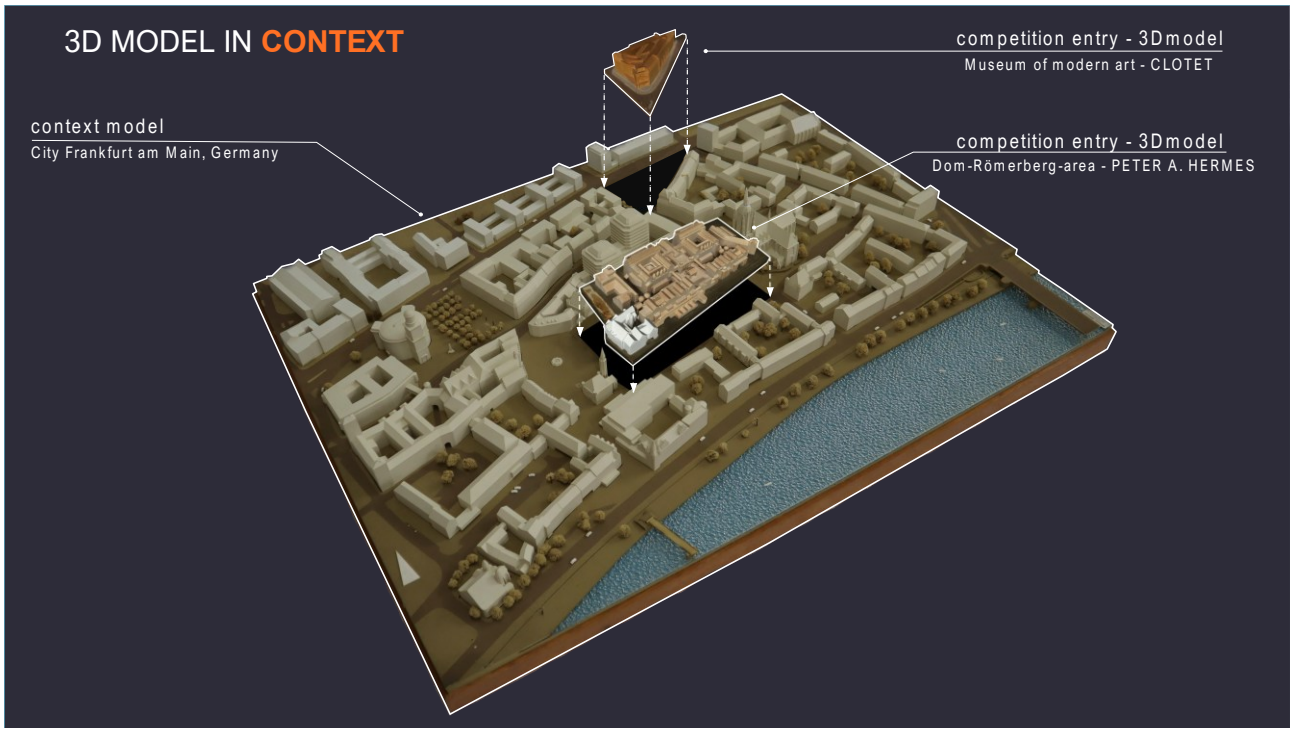
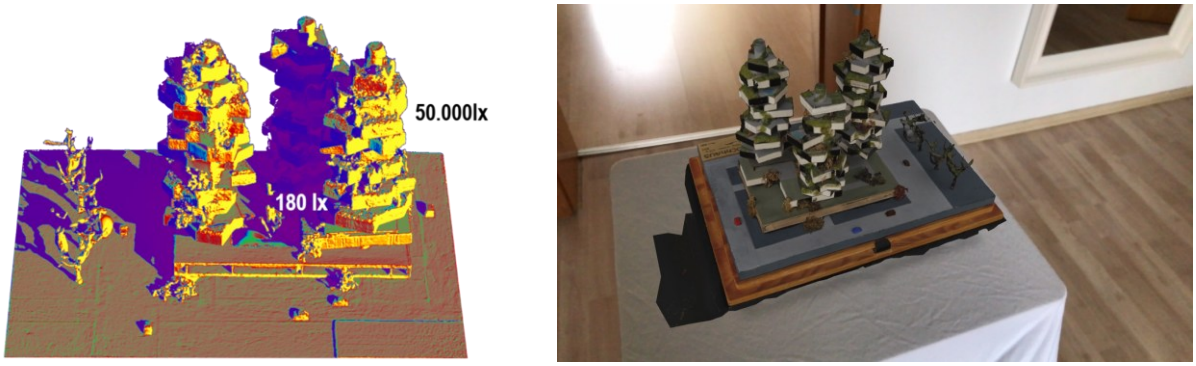


Fig. 6. A city model from the collection of the DAM as an example for the context of production and collection of architectural models. The model allows the insertion of mass models from two competitions. Digitals models allow to study different competion entries in this context. Metadata models shall express such coherences. (© TU Darmstadt).



a *b* *c*

Fig. 7. Augmented reality applications allow to study models as representation of architecture in its intended context. The winning competition entry from Hans Hollein a) can be replaced by other contributions as from Lluís Clotet and Óscar Tusquets Blanca b) or Heinz Tesar c). (© TU Darmstadt).



a *b*

Fig. 8. Digitised Models as treated as artifacts in augmented reality applications a) and used in research with daylight simulation b). Model: Frei Otto: Wohnhaus Studie für New York City. (© TU Darmstadt).

The further understanding of 3D representations of architectural models as research objects and their useful application is instructive for the development of enhanced metadata schemata and viewing infrastructure and a task for the historic architecture community as a whole.

Preliminary conclusions and outlook

The digitisation of a significant portion of models from an architecture collection is a challenging task. The heterogeneity of the objects requires further systematic study and probably a range of distinct adaptations of the acquisition procedures. Naturally, digital representations are not 1:1 copies of the originals, they do not replace photography or the personal inspection in the archive and they are limited means of preservation. It is a part of further study which geometric properties, level of detail and material qualities of architectural models can be adequately transferred to the digital realm.

Metadata schemas depend on our understanding of the new digital representations as a medium to explore architectural models as collection items, cultural artifacts and representations of architecture. If the new research data objects are understood as nodes in the semantic web a further question arises: to what shall they be linked to? The ICOM states that “Museums are the sole authority with responsibility for establishing globally unique and persistent identities (URIs) for each of the objects in their collections” Not all collections provide such a service, fewer describe their items in detail using a standardized ontology or controlled vocabulary. Is it in the scope of our service to do that? Is it our area of authority to choose a standard for data and metadata? Furthermore: are the applications shown here appreciated by scholars, or do they need different applications and therefore metadata.

It is obvious that only a community effort can decide upon a separation of concerns and standards for data and metadata. The development of data communities is as important as the development of tools, services or repositories. Therefore, help and involvement from the community is highly appreciated.

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Conflict of Interests Disclosure

The authors declare no conflict of interests.

Author Contributions

Investigation: Stephan Tittel, Reimar Tausch, Martin Schurig, Matevz Domajnko, Pedro Santos
Writing – original draft: Andreas Noback
Visualization: Annika Beissner
Writing – review & editing: Chris Dähne, Roger Winkler, Katja Leiskau, Hasan Kutlu

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