Typical Workflows, Documentation Approaches and Principles of 3D Digital Reconstruction of Cultural Heritage

Mieke Pfarr-Harfst(✉)

Technische Universität Darmstadt, Digital Design, Darmstadt, Germany
pfarr@dg.tu-darmstadt.de

Abstract. Three-dimensional, scholarly computer models are part of digital cultural heritage. As such, they should be considered as a medium of communication and put under the scrutiny of academic research. Starting by outlining the background to the Author's research, specific topics such as typologies of three-dimensional models, their use in scholarship and relevant work processes are considered in detail. Based on current studies and investigation of working processes, a definition of typology terms and guidelines are discussed.

Keywords: Cultural heritage · Digital reconstruction · Workflows · Guidelines · Working process

1 Background

Three-dimensional (3D) computer models have been used as a medium of communication in the area of cultural heritage research and knowledge transfer since 1980s. Despite the initial strong resistance within the mainstream academia [1] this method of representation has been widely established in popular science, e.g. in the context of exhibitions.

It is possible to communicate knowledge available about a cultural heritage object, raise awareness of it and generate a new knowledge, by means of three-dimensional models. This, in turn, may in part become a component of the scholarly process. The models themselves become the conveyers of information, and part of digital cultural heritage [2], a source for scholarship and means of information transfer. Knowledge itself is always connected to a medium and representation [3, p. 6]. If one considers the models to be bearers of knowledge, they are then, in the interaction with speech and written language, another form of expression, a digital medium for representing knowledge.

Space, in its entire complexity, constitutes a research theme that is central to build cultural heritage. The interaction of space shaping elements, their rhythm, design and organization, as well as their appearance, depends on the individual perception of space and can often be only experienced, and understood, in near-realistic three-dimensionality. Research into cultural heritage objects and their spatial positioning also play a significant role. Here as well, the process of modelling the digital object stimulates a discovery of knowledge.

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The workflow that results in the computer model is a great opportunity for studying architectural design and other characteristics of a building, the architectural language of an architect and the inclusion of his concept in the urban plan, or other scheme, in more detail [1, pp. 133–145].

This learning process, at the end of which one acquires new knowledge, is for the most part an incidental by-product of the many visualization projects for use in museums and exhibitions [4, pp. 13–22]. Three-dimensional models are purposely being used for gaining knowledge of built or object-related cultural heritage. Cultural heritage researchers increasingly recognize the potential of scholarly methods of visualization.

The areas of application and scope of three-dimensional computer models have become far more complex and multi-faceted, also within the history of art, than were conceivable at the inception of 3D digital visualizations. Alongside educational use, two additional areas of application have been established: the examination and preservation of cultural heritage. Due to technological developments within these three areas, the range of applications of three-dimensional models of cultural heritage have become diverse. Application areas and potential use generally overlap because, in an ideal scenario, a digital model or dataset may serve various applications and output formats.

Diversity of possible applications presupposes the heterogeneity of methodologies and workflows available. A fundamental approach and rudimentary research are required, depending on how information about a model, and new knowledge it may generate, are dealt with in the future.

2 Correlation Model

The workflow and methodology relate directly to chosen application, its characteristics and potentiality that can be juxtaposed in a correlation model (Fig. 1). In this way, structuring of what appears impenetrable may be achieved. The correlation starts with the characteristics of three-dimensional models from which potentials can be generated. These potential use can be transferred to the possibilities of technical applications as well as three application fields. These areas of application – research, communication of knowledge and preservation – can be traced back to recognized principles of CH visualizations.

Digital three-dimensional models display three characteristics: products of digital technology, three-dimensionality and graphics.

A dataset consists of a sequence of numbers that can be fragmented and reassembled without damage. This opens up many possibilities for application of data.

Three-dimensionality makes it possible to experience spatial interrelationships within the entire complexity. Thus it refers to space as a question central to the discussion of architectural heritage. So the contextualization of object and space becomes comprehensible.

The language of images is universal and requires no encoding to be understood. This is in contrast to blueprints and architectural plans, which are subject to normed encoding and are thus not readable to everyone.

The three characteristics of three-dimensional computer models of cultural heritage, identified above, offer a range of possibilities to:

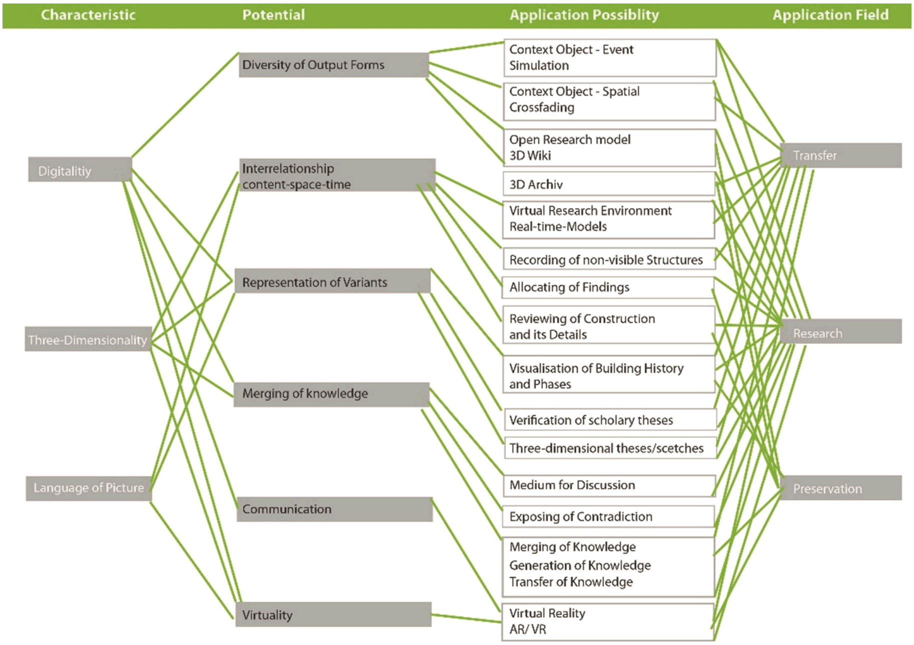

Fig. 1. Correlation model

- Diversity of formats of output
- Clarify complex interrelationships of content and space
- Represent variants
- Combine and verify existing knowledge and generate new knowledge
- Communicate and transfer knowledge
- Experience virtuality

2.1 Diversity of Output Formats

Many different output formats are possible for a digital dataset, such as renderings, simulations, film sequences, web-based applications, haptic models, 3D PDFs, Virtual Reality (VR) and Augmented Reality (AR) applications. These output formats have supported knowledge transfer for many years. The output format may be chosen to suit the requirements of particular scholarly questions, which offers many research opportunities. Examples of possible output formats include:

- **Simulations** put events into the context of their built surroundings;
- **Crossfading** of 3D models with images can clarify spatial relationships, also *in situ*;
- **Models accessible in real time** make the space, object and concept perceptible;
- **3D Wiki** provides a basis for an open research model that may be revised and updated;
- **3D PDF,** coupled with a database, may constitute a 3D archive, contributing primarily to the preservation of cultural heritage.

Owing to ongoing and rapid technological advances, further applications are being developed.

2.2 Clarification of Complex Spatial and/or Temporal Relationships

The potential of computer models of cultural heritage for clarification of complex spatial and/or temporal relationships is based on three-dimensional and graphic characteristics of the models.

By means of these characteristics, structures, that have not survived or were never built, can be visualized and understood, thus contributing to enhanced understanding of the broader context. A further application may also be possible through interlinking of different data. Thus, it is possible to investigate and verify construction details and principles, or the relationships, between the object and its space. The investigation and superimposition of different phases in the construction history, as well as the inclusion of temporal data may be possible.

2.3 Representation of Versions

Owing to the digital nature of media employed to create the virtual space, different versions of design or building phases may be represented within a single architectural computer model. Three-dimensional propositions or sketches may be created to support cognitive processes and facilitate systematic scholarly verification of existing assumptions about the subject of representation. Different design solutions may be juxtaposed. The model may thus serve as a medium of scholarly discourse and contribute to discovery of new knowledge.

2.4 Fusion, Generation, and Verification

Scholarly three-dimensional models rest upon fundamental knowledge that is generated from sources of varying nature, origin and authorship. An opportunity therefore arises to fuse and verify the existing knowledge, generate and communicate new knowledge. The associated research process involves consolidation of earlier findings, the creation of a basis for further research, generation of new knowledge and the preservation of knowledge about cultural heritage. Over and above that, this knowledge can be processed through the transfer of the dataset in appropriate output formats for transfer in a popular-scientific manner.

2.5 Virtuality

The digital and graphic nature of three-dimensional computer models brings further opportunities for the research process: communication, interaction and intuitive interaction within virtuality. Precisely such models have been developed e.g. for design production since year [5]. Communication, interaction and intuition are becoming important research components of these models. Devices such as tablets and smartphones are directly based on such functionalities. For research applications, these technical developments may mean communication, including a meeting of the involved parties in virtual space, in which one can touch spatial elements and discuss questions and solutions.

The characteristics of computer models and a wide range of their applications to scholarship, outlined above, do not pretend to be exhaustive. Further research is being undertaken. The preliminary correlation model (Fig. 1), presented here, displays a considerable complexity. It demonstrates the heterogeneity of three-dimensional computer models used in cultural heritage studies alongside relevant workflows and methodologies.

3 Interdisciplinarity

Owing to the interdisciplinary nature of most research projects in this area, the heterogeneity and complexity should be emphasized. Research into cultural heritage involves not only disciplines traditionally preoccupied with reconstruction of the past, such as the history of art and archaeology, but also borrows methods of architecture and computer science. The scholarly role is generally taken on by art and architectural historians and archaeologists, while the architects deal with the creation of models and technical information systems. The composition of the interdisciplinary team is becoming ever more complex and varies according to given research questions. In addition to the theses disciplines that pioneered digital architectural reconstruction, the following can be included: computer graphics, geodesy, artists, historians – to mention only a few. One may however ask, what are the advantages and the effect of these 3D models on the technical development and the scholarly methodology chosen for the investigation?

In order to establish the long-term standards and guidelines for a workflow and methodology, the influence of other factors, such as a situation given, the project goal, the project partners – i.e. the project context – must all be considered. In addition to the aspect of workflow and methodology there are so many challenges to fundamental scientific theory. It should be possible, subject to further research, to construct a model of disciplinary contribution that considers the participation of the individual disciplines within the given context of a project, as in the correlation model. Alongside the dependency on disciplinary participation and the said context is directly connected to the question of common working methodology for these models of disciplinary contribution.

4 Models as Sources of Information

If models may be understood as sources of information, it may be useful to categorize this information. Thus, the following types of information can be identified [3]:

- information contained within models
- information about models
- information that may be derived from models.

The information contained within models is primarily the information gathered and generated therein as a result of information acquisition from sources, the process of generating and the project context. The information about models concerns the context of the given project and its background. information from models can be gained through combining the information contained within and about models.

The information in and about the models could be lost if an individual person, who generated these models is not involved in the project or the process of generating anymore [3]. Thus, the information contained within models is subject to a codification that can be deciphered through secondary information that may be assumed from models. If one takes Mahr's concept of knowledge – mentioned above - and applies it to a three-dimensional model considered as a source of information, the model should be of something and for something.

A three-dimensional computer model of built cultural heritage is a model of a built structure or an object. From the point of view of the general public it is important whether this object or building still exists or not. Yet not only the model, but also its spatial, historical, social contexts and the associated secondary, even tertiary information are components that must be taken into account in any case. However, the model should also reflect various other factors that impact upon its development [6].

The principle of a "model for something" is far more complex. The computer-generated model can itself become a model for further research. In order to further substantiate Mahr's concept of knowledge, the understanding of the model as representation of something, while at the same time illustrating something, must be directly included in the correlation model. This confirms the complexity of the field.

According to the UNESCO definition of cultural heritage, all knowledge that computer models impart constitutes cultural heritage [2].

5 Loss of Information

The lack of standards and guidelines is like "missing rules of the game for the community" [3, p. 7]. In the process of knowledge acquisition and methodology the lack of common guidelines is directly connected to the loss of information within, about and from the models. The heterogeneity and complexity of the field includes a series of paradigms that favor the loss of knowledge. A further factor contributing to the loss of knowledge has most certainly been in recent years the technological development and the subsequent proliferation of models. Owing to the availability of open-source software for three-dimensional applications, a non-academic user community has expanded. One can observe a noticeable increase of non-professional models and the associated problems.

According to the website of the online archive Google 3D warehouse, there are "millions of 3D models" [7] in a wide range of categories. Three-dimensional computer models of built cultural heritage can be found there mainly under the designation "reconstruction". However, to be considered a reconstruction in the academic sense, they lack a documented verification of sources and a record of the creation process. At the time of writing the archive lists 402 models in the category "Castles of the World" and 237 models of “Churches”; a search for “Town” yields approx. 700 visualization projects [7]. This proliferation of models, paired with the overall heterogeneity of the field and the unhindered access to information, forebodes the far-reaching consequences for the quality of three-dimensional models of cultural heritage and their scholarly and pedagogical values. Here we are facing the democratization of information and the ever increasing volume of unverified information. The universal language of images is a decisive factor in the dissemination of potentially incorrect information. Pictures lodge in our minds and are more rapidly absorbed than texts. Thus, no “model can do without a system of order to qualify as knowledge” [3, p. 7]. This idea of Mahr can be directly applied to three-dimensional models. The information contained in models and the associated digital cultural heritage, as well as the loss of control over the quality of information conveyed has already become reality. Although 15 years ago there was an initial theoretical debate concerning this topic, as summarized in Frings’s “Der Modelle Tugend”, these efforts seem to have been in vain or negated [1]. Three-dimensional models of cultural heritage have a life of their own. A scholarly theory is lacking.

A study of the subject, which investigates 452 digital reconstructions and three-dimensional models, should be noted. It is striking that very few studies deal with theoretical questions of universal interest, but rather with technical implementation and production [8]. This lack of theoretical framework affects all scholarly levels in the field of CH visualizations. Rudimentary issues currently affecting research have been identified through a survey of the members of the working group “Digital Reconstructions” which has been established in Germany in 2013. The issues range from a definition of a theoretical frameworks and system of documentation to scholarly structures for methodologies and localization of 3D models [9].

In 1995 Koob published the paper, “Architectura Virtualis”, in which he noted the lack of: a guiding theory and generally accepted principles, generally accepted principles that could be coupled with appropriate systems of documentation and archiving:

- “Wir forschen und arbeiten an der neuen Technik, dokumentieren unser Wissen mit der alten Technik”. [We are investigating and working with new technology, but document our knowledge with old technology]. [10, p. 19]
- “Wir betreten ein neues Territorium und haben noch keine Regeln.” [We are entering a new territory, but do not yet have any rules]. [10, p. 21]

Despite more than twenty years of applying three-dimensional computer models to the study of cultural heritage, Koob’s observations are still valid. This is also based on the fact that further development of technology has had precedence over rudimentary research, in recent years in particular. Most research projects are either technology oriented or based on a special research question, but not really universal. Researchers concentrate on a concrete problem that is generally irrelevant to other questions. A superordinate, universally accepted theoretical approach is generally lacking. However, both levels, the theoretical and user-oriented, are indispensable for establishment of three-dimensional computer models in the three areas of application – preservation, transfer of knowledge and research. The reasons for the absence of such basic principles can be found, among other motives, in the lack of recognition of this research method.

6 Documentation, Sustainability and Preservation of Information

The scholarly use of digital models and development of relevant methodologies necessitates a scholarly approach, transferability and sustainability of data. For several years, scholarly papers and research projects have been focusing on archiving, documentation and sustainability of three-dimensional computer models. Theoretical work must be distinguished from projects that address specific questions. Sustainable preservation of three-dimensional models should distinguish between possible loss of technical functionality of software and/or hardware, and the loss of content. Each model is created using a certain technical system and depends on its requirements. When the technical system stops working, data may be lost. The notorious obsolescence of three-dimensional models of the first generation poses the problem of data that are no longer readable. Had the models been stored in a different manner, the knowledge about the digitally reconstructed buildings and structures would not have been lost alongside the data. This represents a loss of content. The lack of documentation strategies and standards results in the loss of knowledge represented by the models and the knowledge about the models. This subsequently hinders passing the knowledge on; therefore, knowledge cannot be reused in later research.

The development of suitable documentation systems and strategies must be undertaken on both the theoretical and applied levels. Implementation must always respect the interaction between theory and practice. The theoretical scholarly approaches to digital reconstruction involve a definition of possible basic components of a documentation system. Four parts must be covered and integrated in such a documentation system in order to preserve the knowledge represented by the models in a sustainable manner. The four part documentation [11, pp. 83 ff.] should cover the background, its sources and contexts, as well as record the processes involved. The four part documentation should derive directly from the defined principles of scholarly documentation. It should be structured, reproducible, transparent, sustainable, editable, true, complete and clearly presented.

The first part should concern the background to the reconstruction i.e. the basic information about the project, including the contributors, the start date, the technical system used, the project rationale, aims and objectives that have direct influence on the results.

The second part should document the cultural, historical and architectural contexts of the building and its objects to be reconstructed.

The third part should concern the documentation structure of reconstruction project- The documentation structure must be adjusted individually to the conditions of each research project. This is also applicable to three-dimensional computer models. Each project has its own system of order, terminology and structures that affect documentation and must be controlled.

The fourth part of documentation should concern evaluation and should demonstrate direct connection between the sources, processes and the model. The four part documentation fulfils the documentation requirement of an explicit allocation of object to document. Here the simplest form is the source or method catalogs for the individual objects, structures and buildings. The allocation of a source to objects takes place in a tabular source catalogs. In the method catalogs the object is linked to a process and source. The process steps, as well as the interim results, are shown by means of a simple input-output representation. These tabular catalogues are entered and linked to a simple datum archive that has been defined in part three.

Bearing in mind that data are individual to a given project, which steps in the development of a 3D model should be archived. This question should be carefully considered in order to avoid an unnecessary overload of data. Milestones in the development of models may serve as reference values of basic decisions made in the course of modeling process. In recent years numerous pilot projects [12–14], with various aims and approaches were realized and solutions these certain projects developed. The pilot projects are being only mentioned here; their evaluation in terms of sustainability, applicability and validity, is yet to be carried out.

It will be necessary in the future to bring the theory closer to practice and enhance user-friendly applications. The goal is to design a documentation system that requires minimum effort to generate maximum knowledge that can be sustained and preserved.

7 Study of Workflows, Principles and Typologies

It has been argued above that, the development process of three-dimensional models is generally associated with generation of new knowledge. The application of these models to research into cultural heritage, as virtual research environments (VREs), has increased during the past decade. The general use of the models as VREs has long been established e.g. in aircraft industry, and recognized as a development tool [5]. In order to employ VREs in basic, object-oriented investigations into cultural heritage adequate methodological principles are necessary. Here, however, studies and evaluations related to status quo of existing workflows of VREs in CH are required. Within the scope of research conducted by the Action "Colour and Space in Cultural Heritage" (COSCH) [15], the workflows of various research projects were investigated at three leading academic institutions. The result was a definition of a workflow and of methodological principles and typology of three-dimensional visualization of cultural heritage. Twenty-five research projects conducted in the 2000s and 2010s were investigated. The study was conducted by the Author in 2015 at the following institutions participating in the COSCH Action:

- Digital Design Unit, Technische Universität Darmstadt (formerly: Information and Communication in Architecture)
- Department of Digital Humanities, King's College London
- Centre for Humanities, University College London
- Department of Computer Science, University of Sarajevo.

The outcomes of workshops held bilaterally with colleagues from these institutions were included in the study.

The following research questions guided the investigation:

- Are there any similarities between different methods and workflows?
- What are the similarities (definition) and differences (definition)?

- What are the reasons for the identified differences and similarities of the 3D modeling work?
- Are there any dependencies between the properties and scope of workflows, capacity, and possible applications?
- Is it possible to identify some general phases of a workflow and define key concepts?

The investigation involved:

- Part I: analysis, evaluation and comparison of different projects of the three institutions
- Part II: workshops and discussions with research staff at the three institutions.

The various conditions of the 3D-modeling process were an essential part of the investigation (part I). Initially, the conditions were defined as a basis for the systematic and objective investigation of the projects.

In the meetings (part II) typical visualization techniques were discussed (3D modeling, laser scanning, photogrammetry, 3D imaging, BIM), as well as different workflows and the problem of how knowledge may be evidenced.

The investigation of the 25 research projects was based on the defined objective criteria:

- Project background
- Project [organisational/historical/other] context schedule of work
- Contributors
- Aims and objectives of the project (research, transfer of knowledge, preservation)
- Application field(s)
- Application/preservation format
- Area of possible application
- Type of 3D visualization method(s)
- Technical system
- Visualisation methods and the workflow
- Outcomes

These criteria have been identified in the course of earlier research by the Author and through a review of literature [16]. Establishing these criteria is essential for ensuring visualisation-based research is as reliable as possible and for the results of respective projects to be comparable.

To design a proper documentation system or assure scholarly content of desired quality, fundamental questions need to be addressed first.

These questions pertain to the following:

- Workflows
- Typologies of 3D visualization
- Capacity of 3D scholarly visualization
- Possible application fields.

Based on the Author's investigation, it was possible to define the working process as an input-output design. Comparing different workflows of the projects conducted in Sarajevo, London and Darmstadt a similarity of the respective workflows was observed.

It was possible to identify four broad phases: preparation, collection, processing, finishing (Fig. 2).

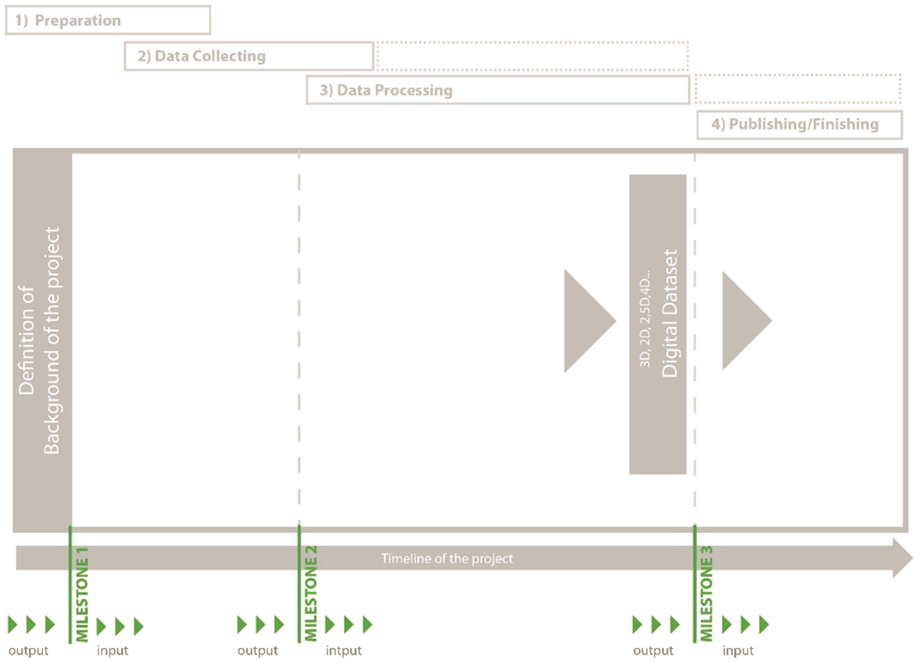

Fig. 2. Workflow and milestones

For a project to reach completion, all criteria identified above - aims and objectives, human and financial resources, work plan and provision of technical infrastructure, etc. - should be addresses during the preparation phase. The output of this phase is the input for the next phase, and defines the method of and technology for collecting the data.

The input of the "data processing" phase is based on the results of "data collection" and the chosen method. During the "data processing" phase the collected data may be used in different ways, depending on the objectives and the aim of the project. The result of "data processing" is a digital dataset (2D or 3D), which subsequently becomes the basis for the "finishing" phase and the final result of the workflow. The different application fields and possibilities of use offer a great scope for processing the digital dataset.

During and between these phases there is a principle of input-output. The background of the project generates the framework for the project and its workflows.

At the beginning of a project some milestones should be defined to manage the project effectively.

8 Principles of a Workflow

The discussed study of the Author is the basis for first principles and guidelines for working processes and methodology. In the future, recognized guidelines [17] will be indispensable for ensuring scholarly quality of the models and to alleviate the loss of knowledge. Similar technical rules have long been established, and generally accepted, in architectural practice. In connection with quality assurance, Mahr refers to “rules of conduct in the community” into which project context and working process are incorporated [3]. The following initial methodological guidelines have been compiled through experience and theoretical considerations:

- Choosing the technical system
- The process of creation of a three-dimensional computer model depends on the aims and objectives of the project. These, in turn, influence the choice of hardware and software, depending on the type of representation required and the type of associated media.
- Determination of LODs (level of detail) of the model
- The research results and desired scholarly objective refer to the structures of the model. A detailed digital reconstruction of the building is often not possible. The design of the model structures and the required level of detail facilitate the workflow and archiving.
- Terminology
- Data exchange during a research process, data entry into databases and the structured documentation of a digital dataset and results are only possible through a suitable vocabulary for describing 3D, scholarly models. This topic is directly linked to challenges related to documentation strategies.
- Classification of and structuring the sources
- The 3D-model, the working process and the underlying resources must be divided into meaningful classes specific to a given project. Only then the catalogs of sources and methods can be compiled
- Recording the milestones
- As described above, in the section on documentation, keeping a record of significant steps in the production of models is absolutely necessary for the transparency of the decision-making process and workflows. A suitable filing system (file structure or database) supported by principles of classification, model structuring and referencing process is a further guideline. This provides a basis for the verification of technical and scholarly standards and sustainability of 3D-models.
- Documentation of the working process in a uniform system
- The progress of work should be recorded (alongside the model status) according to the milestone principle. The introduction of a simple mask (Fig. 2) subsequent to the input-output procedure fulfils scholarly criteria.

After the above-mentioned guidelines or principles have been implemented, all data can be contained in a repository, consisting of sources, description of the workflow and the model. The structure of the repository should be adapted to the given project.

There is no claim to completeness of the guidelines presented above. They have rather been conceived to stimulate a discussion of future directions. Adherence to these basic principles is expected to help with archiving, sustaining and reviewing of data, without complicated technical systems. The latter would require staff and financial resources. Before an adequate documentation system becomes available, the first step proposed here is expected to counteract the loss of technical and subject-related knowledge that is already present and growing.

9 Typology, Localization and Definition

The initial objective of the present book was to examine how one should deal with data and knowledge represented through three-dimensional computer models. Knowledge implies a search for universally recognized rules. The lack of a theoretical basis for producing three-dimensional models of cultural heritage is an issue that arises alongside questions concerning their documentation and archiving. These include questions of typology, conceptual definition of basics and ultimately localization in the research environment. The range of possible applications available for these models (considered as a research tool and method of preservation of cultural history, as well as a medium of knowledge) have increased significantly. This expansion clearly makes it difficult to see such 3D models as tools of a particular academic discipline. Research funders still regard the 3D model only as a visualization method, but not as a research method or archiving tool. Those applying for grants and grant awarding bodies both face a problem of allocating the projects to the appropriate grant program. For this purpose, a theoretical-superordinate approach with the goal of extracting typologies and generally valid definitions is necessary; these are found directly at the intersection of methodology and workflow as research process.

As mentioned above, the applications of three-dimensional models of cultural heritage are many. Eight different typologies have been defined so far (Fig. 3).

- **Type A**: Images, renderings or films resulting from a 3D dataset; original film or image as an object in itself
- **Type B**: 3D images or panoramic photos as a 2,5D visualization
- **Type C**: 3D data resulting from photogrammetry

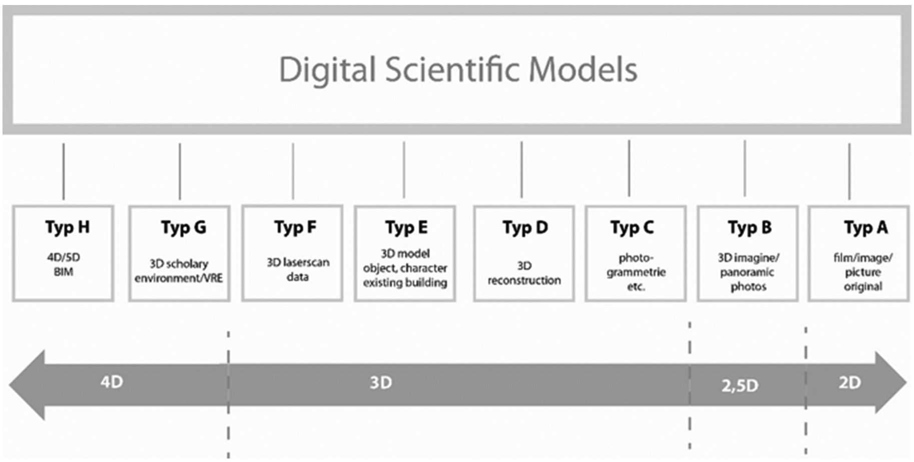

Fig. 3. Typologies of CH visualizations

- **Type D**: 3D reconstruction of a no longer existing building or object
- **Type E**: 3D model of an existing building or object; 3D model of character as an avatar
- **Type F**: 3D data resulting from laser scanning as a method of preservation and recording method
- **Type G**: Virtual research environments or 3D scholarly environments
- **Type H**: Building Information Modeling (BIM) and Heritage BIM

The identification of eight types of cultural heritage visualizations represents work in progress. Further investigation is needed to verify this preliminary typology and enhance it with further types, as well as to define all types, based on earlier research and publications.

The question of typology is directly related to the question of a superordinate terminology. The listing of typologies once again shows the heterogeneity of the entire subject area, which goes far beyond pure reconstruction with 3D tools. This again refers to the relationship between applications and potentials, and again digital reconstruction is only a portion of the application spectrum. A possible superordinate concept therefore could be "digital scientific models". In the context of this discussion, digital scientific models could be defined, in a universally valid way, as computer-aided models of historic buildings, structures or construction elements, which collect, merge, summarize and visualize subject-related knowledge. These processes result in new knowledge. The models communicate past research and open the subject to future research. As such they are an innovative and sustainable tool for investigation, communication and preservation of building culture.

Such a neutral formulation does justice to the heterogeneity and complexity of the entire field. It includes all possible application and considers the information represented in the models.

10 Conclusion

However, the heterogeneity and complexity of this subject area requires fundamental research. Communities of practice may first agree upon guidelines based on well-grounded theoretical research. The questions of order structures, methodological guidelines, or even required technical standards of workflows may only be addressed through collaborative research. All three aspects of work – theory, pilot projects and applications – are important and must continuously interact.

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3D Research Challenges in Cultural Heritage II
How to Manage Data and Knowledge Related to Interpretative Digital 3D Reconstructions of Cultural Heritage
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