2 Basics and Definitions

Abstract

This chapter introduces key concepts of 3D modeling in the humanities. A 3D model can represent a great variety of objects. The objects of 3D modeling of historical architecture are lost or extant buildings, their modifications, and designs that were never executed. These buildings are as much part of the cultural heritage as their plans. The chapter begins with a survey of source-based historical knowledge as the basis of analysis, historic interpretation, and reconstruction of any historical situation. It then addresses modeling in general as a scientific practice, its use in architecture, and the advantages of its digitization.

Guiding questions

- What are the basic definitions and concepts related to 3D modeling?
- Why and how does it with historic architecture and cultural heritage?
- What are sources, and what is their purpose?
- How is reconstruction done?
- Why model, and how can one do this in a scientific way?
- What is a model? (in general, and in architecture)
- What are the conditions for digital 3D modeling?

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Basic terms

- Historic architecture
- Cultural heritage
- Sources
- Reconstruction
- Modeling and models
- 3D reconstruction versus 3D modeling
- Simulation

2.1 Architectural History

Architectural history explores buildings, constructions, and structures, deals with urban planning, and analyses architectural theory, discourse, and media such as architectural drawings and models. It also explores the people, groups, and networks that were behind all this. Architectural history thus regards architecture as a cultural phenomenon.

As a scientific discipline, architectural history has close ties to art history, archeology, and architectural education. It is thus interdisciplinary and can include social sciences, economics, or technical sciences. This great diversity of disciplines yields a very wide range of possible research questions. As a historical discipline, architectural history deals with the past, including the recent past, and explores things such as appearance and form, placement, functions of built environments, and the influences of people such as patrons or users, on developments in the history of style, of immanent meanings or changes in meaning. In other words, it tries to reconstruct the historical context. In this way, an object is located temporally, spatially, socially, and discursively.

It is important to note that buildings have rarely come down to us as they originally looked, but that they are subject to permanent changes. These changes can be formally visible (e.g., early modern parts added to a medieval building), and purely functional (e.g., an 18th-century monastery building redeveloped for university purposes). For a well-founded historical analysis, the original state must therefore be examined. And if this has not been preserved, it must be reconstructed—whether ideally as pure thought, in descriptive texts, or materially in an architectural drawing or model, either as an analog or a digital reconstruction. This last option is much more immediately vivid—and is the topic of this handbook.

Architecture is a built social order and a reflection of humanity's thoughts and actions. Buildings with religious, political, profane, or other uses embody an important part of the cultural heritage of human societies. Due to its (mostly) physical nature, architecture belongs to a tangible cultural heritage. Even architectural projects that remained on paper belong to the cultural heritage, but in this case to the intangible one. Other examples of intangible cultural heritage are music, dance, customs, or workflows, while natural heritage comprises for example mountains or caves. Representational buildings, whether religious like temples and churches or secular like princely palaces or parliaments, often demonstrate the cultural achievements to which their creators dedicate the most effort and material resources. It is not uncommon for these buildings to be erected on symbolic sites, whether they acquire this special meaning before or after they have been built.

Further reading: Architecture as part of cultural heritage
Architecture is part of our cultural heritage. In general, **cultural heritage** can be understood as traces and expressions from the past, which are used in and influence contemporary society [2]. Cultural heritage can be regarded as property that a person cannot inherit; instead, it must be acquired, e.g., by a society that perceives it as valuable [3]. While cultural heritage traditionally focuses on tangible objects, a broader understanding adds intangible heritage (e.g., dances, customs, workflows) and natural heritage (Fig. 2.1). Architecture, understood as the human-built environment, is the manifestation of social practices and therefore relates to both, tangible and intangible cultural heritage. It serves different purposes and users, takes on different shapes and sizes, and depends on different conditions, but always serves human demands. As diverse as architecture is, so are the possibilities for dealing with it in the sciences and in the humanities. There are some great examples of 3D modeling of intangible cultural heritage, regarding customs and daily life [4, 5] in past cultures [6], but the focus here is on tangible heritage.

Cultural Heritage – e.g., monuments | **Intangible Cultural Heritage – e.g., rites** | **Natural Cultural Heritage – e.g., mountains** | **Digital Cultural Heritage – e.g., computer games**

Fig. 2.1 Types of cultural heritage [1] (Images: Münster (left-middle), right: https://www.europeana.eu/de/item/916118/S_TEK_object_TEKS0057154, accessed on 1.2.2023)

Another important concept is the **digital (cultural) heritage,** of which digital 3D models form part. It comprises technologies to preserve, research, and communicate cultural heritage [7] and it includes materials like texts and images, created digitally or digitized, as well as digital resources of human knowledge or expression (e.g., cultural, educational, or scientific) [8]. This latter facet comprises various digital technologies to study cultural heritage [9]. Around those topics, various scholarly communities have formed during the past few decades such as digital humanities, digital archeology, or digital history studies [10].

In human history, the decay or deliberate destruction of such symbolic architecture is just as constant as the attempts to commemorate it, to preserve its lost meaning or to charge the sites with a new one. Although physical reconstruction is the most consistent and effective form of remembrance here, it remains the exception not least because of the high construction costs. Other forms predominate, such as remembrance in rites, oral traditions, texts, and pictures.

Forms of remembrance that focus on the visual presentation of the destroyed object, primarily drawings and haptic models, can be considered close to the methods of architecture. For a long time, they were the only way for the public to remember buildings that no longer existed or of which only a few remains survived. Information and communication technology has revolutionized the representation and communication of architecture. Graphic data processing has achieved a vividness in the representation of destroyed buildings, especially in interiors, that has rarely been achieved by other media until now. The digital 3D models of historical architecture which resulted from this process are the subject of this book.

Further reading: Research on 3D reconstruction in general Theoretical foundations and epistemological recommendations of 3D modeling of cultural heritage have been studied for a long time, e.g., within various EU projects [11, 12]; on a national level in Germany by the task group for 3D reconstruction of the DHd association [13], the Digital Art History workgroup [14], and the DFG Network for 3D reconstruction of architectural history [15], and by numerous recent publications [16–18].

2.2 Reconstruction

Reconstruction is the process of re-creating something that no longer exists or is unknown, for example, a lost work of music, literature, or art, a destroyed building, or a sequence of events (Fig. 2.2). The term reconstruction describes both the process and its outcome.

The concept of reconstruction can be traced back to the Renaissance and from its very beginning, it was closely connected with archeology. Shortly before his death, the famous Italian painter and architect Raffaello Santi (1483–1520) developed a memorandum for

3D Reconstruction of a non-extant (destroyed) church

3D Reconstruction of a never realized (planned) garden.

3D Digitization of a pottery artefact.

Fig. 2.2 3D modeling versus state of existence (Images: Münster)

an archeological survey of the ancient ruins of Rome. The aim was not to document the buildings in their ruined state, because as such they seemed to be insufficient like "bones without flesh," but to present them in their concluded original appearance, this by using ortho-projected plans [19].

Like Santi's one, a reconstruction always needs to be based on sources, which we need to analyze and interpret. Otherwise, it would be no more than imagination or subjective fantasy. Yet, the interpretative part of the process leads to an inevitable characteristic of a reconstruction: it is hypothetical. Things that have passed are gone and irretrievable. We must always be aware of this: when we reconstruct, we create anew.

Motives to reconstruct can be manifold, and it is important to be aware that they may be ideologically underpinned. Destruction, be they unaccountable as in natural disasters, wanton and deliberate as in wars, accidental or caused by negligence as in fires, is often the occasion to physically rebuild a building or parts of it, following the lost forms as faithfully as the current state of mind allows, desires, or even forbids.

Reconstruction is closely linked to the idea of the original—and Western culture holds the physical original in particularly high esteem. We often value the reconstruction much less and tend to criticize it more easily. Therefore, we must carefully and consciously distinguish whether a reconstruction was carried out from the ground up, including the time interval between the reconstruction and the destruction, or whether only parts of a building were reconstructed—this is where the concept of restoration begins to blur. And we must consider the significance of buildings for cultural identity, as well as the ideologies and mentalities that led to a reconstruction.

Reconstruction is not limited to the 1:1 translation of physical remains into a virtual model. What has been lost can be reconstructed in writing descriptive texts, visually as drawings, or haptically in scaled-down models. These forms have long been used by architectural history researchers. With the expansion of new media in recent decades, digital, virtual reconstructions create new technical capabilities to expand, modify, and add.

Digital media reconstruction of historical architecture is part of the digital humanities. According to the Principles of Seville, virtual reconstruction is a digital process that is fundamentally analogous to physical reconstruction. “A virtual model is used to visually reconstruct a building or object built by humans at a certain time in the past, starting from the available physical evidence of these buildings or objects, scientifically justified comparative conclusions and, in general, all the studies carried out by archaeologists and other experts related to archaeological and historical science” [20, p. 2]. Of course, this does not apply to archaeology and antiquities alone, but to all historical disciplines. Medieval archaeology is therefore just as affected as the restoration and conservation of historical monuments, buildings, and objects.

Virtual or digital reconstruction not only strives to restore an artifact to how it looked at the time of its creation but can also reconstruct successive phases of use of an object and thus the sequence of building states. Reconstructing lost or altered architecture virtually using digital models brings an enormous advantage for visualization: a digital model is easier to change than a physical (i.e., material-based) model. The visualization is no longer static but can be dynamically adapted to different angles and converted into different formats. Digital 3D reconstructions of historical architecture support the understanding and research of lost or disappeared building conditions, sources, and historical objects. During a digital reconstruction, the provenance, consistency, and correspondence of sources are checked and discrepancies—for example between ground plans and elevations or vedutas—are revealed (→ Scholarly Method).

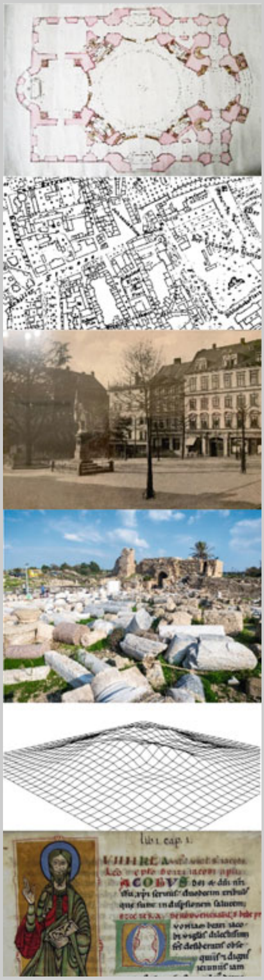
2.3 Sources

Sources are the very basis for any study in architectural history and consequently for every reconstruction. This section explains the different categories and types of sources and the methods for their use. It gives insights into collaboration between disciplines involved in reconstruction processes (the humanities and technical sciences) which all use the same sources, with different methods and aims.

All historical research is based on sources [21]. Sources are a specific class of cultural heritage items that provide information about past events, phenomena, or objects. In most cases they are tangible (e.g., administration files from archives, historic letters, architectural drawings, plans, or old photographs, inscriptions and other traces on the object itself), but they can be intangible (e.g., oral history provided by former users or inhabitants of a building).

Sources are always biased, by the creators’ intention or limited view. Understanding by means of sources is therefore never a neutral act, but requires critical reflection [22], as formalized by source criticism, which analyzes and interprets historical sources e.g., in their contemporary historical context.

Further reading: Sources for 3D reconstructions



Architectural drawings: if available, ortho-projected plans and drawings are the most important source for geometrical reconstructions of non-extant architecture and allow unbiased access to geometrical properties.

Cadaster and maps: ground plots and cadastral information provide directly measurable information, although mostly of lower detail.

Historical photographs and vedutas enable a natural impression of an architectural object and contain information about materials. In contrast to plans, geometrical information is distorted by perspective.

Material evidence (e.g., archaeological remains, similar buildings): if available, physical remains contain comprehensive information about geometries, materiality, and behavior of an object. In many cases they enable (semi-)automated 3D digitization.

Geographical information (e.g., elevation models) are usually very stable, less change-dependent, can provide information, e.g., about outer dimensions of building or an arrangement of floors.

Textual descriptions are in some cases the only sources available or can provide unique information e.g., about spatial arrangements or materials.

Fig. 2.3 Sources for 3D reconstructions (Images: P. H. Jahn, ThULB, Münster)

Sources are classified by the type of textual, image, or audiovisual media, or object sources such as physical remains of buildings [23, 24]. For 3D reconstructions the most relevant and often-used sources are visual (architectural drawings, views, photographs, etc.), textual (historic descriptions, files from building administrations, etc.), and physical (the still existing object or preserved parts of it) (Fig. 2.3).

Technical data from the natural sciences and engineering are also sources. Laser scans and surveys record the actual state of a building. They can serve as sources for the humanities (e.g., to review historical plan sources). The scientific advantage of a digital 3D model of historical architecture is interdisciplinary collaboration [25]. A digital 3D model is often created within a cooperation of several fields (3D modeling, architectural history, monument preservation, surveying technology, etc.) (→ Scholarly Community).

Another main distinction is between primary and secondary sources. Primary sources date from the period being studied or were created by participants to describe the object being studied. They reflect the individual view of the author [22]; examples are drafts, building surveys, or texts such as personal diaries. A secondary source describes, interprets, or analyses a historical object, event, or phenomenon (e.g., a historic text which describes an even older [primary] source that no longer exists). Scientific texts about an architectural object are secondary literature. Occasionally, tertiary sources are mentioned: these are published in collections of material based on secondary (or primary) sources, e.g., compilations or (digital) repositories of sources [26, 27]. Tertiary sources thus include all the contemporary analogies and logics which are often used to bridge gaps of primary sources. In architecture, this includes typologies, building styles, and construction logics.

A distinction should be drawn between (a) **3D digitization**—also called retro-digitization—where an extant cultural heritage object is a source, and (b) **digital 3D reconstruction**—also called source-based reconstruction, where the modeled object can only be envisioned through other sources describing it (e.g., planning documents describing a never-realized, destroyed, or altered object) [28, 29] (→ 3D Modelling).

Sources serve to critically review the model (or its process of creation), and to falsify the content of a source (i.e., as an additional means for source criticism). An example would be a digital 3D reconstruction based on laser scanning, a technique that provides a very precise image of an object that still exists or based on exact recent building measurements. If this model is then compared with historical plans, their accuracy can be checked: whether they were measured as precisely as today's building surveys or only copied from older plans without checking the spatial dimensions, etc.[1] The conclusions we can draw from comparing a constructed 3D model and historical plans can complement, confirm, or refute each other. In the course of a digital reconstruction, not only the provenance but also the consistency of the sources is checked. For example, discrepancies between floor plans and elevations or vedutas can be uncovered. The most fundamental prerequisite for a critical review is the disclosure of the sources and scientific reasoning underlying the model and documenting the creation process of the 3D reconstruction.

[1] This also works the other way around: reconstructed buildings (e.g., after partial destruction) are measured and compared to historical sources.

Further reading: Linking models and sources as a research prospect Source data should be embedded into 3D models to develop new research questions and to generate new insights. Since the source basis for creating models (architectural drawings, photographs, texts, etc.) is now increasingly available in digital formats, they could be directly incorporated into or linked to the models [30, 31]. The digital 3D model thus acquires a platform character and can provide:

- A working space in which the function, affiliation, or interpretation of individual elements (picture, plan, written document) can be tested.
- Access to further media formats (image and text sources), which allow the model to be assessed.
- Presentation of an overall result (or interpretation of only a section, by hiding certain areas).

2.4 Models and Modeling

Why do modeling? And why digitally and in 3D? The aim of this section is to understand the basic way of thinking when modeling is practiced. The term derives from physical models and develops from downscaled ones used since at least the late Middle Ages in the arts and in architecture to visualize a draft physically, haptically, and spatially.

Modeling as a principle dates back to Antiquity, for example, downscaled models of farms as symbolic burial objects in the Old Egyptian funeral cult which refer symbolically to the alimentation of the defunct [32, pp. 7–8, figs. 1.8–1.12, 33, pp. 49–51, Fig. 2.2]—and the world of toys with which mankind is traditionally amusing and teaching its children is well known to everybody. But in its wider sense modeling is a special procedure or approach to generate and/or communicate knowledge using simplified representations of reality. Simplifying to gain knowledge seems paradoxical, because how should knowledge increase by such a reducing process like simplification? Vice versa, simplification separates the important aspects from the unimportant ones. In other words: models focus on the task of research or learning by reducing complexity (Fig. 2.4). Only certain properties of the task are modeled as these are bearers of meaning and thus considered. That is why modeling, in general, means creating “the (simplified) replica of an original system” (or an object) which must be “sufficiently similar to the original system with respect to the purpose of its realization” (author translation of [34], p. 18).

An established explanatory scheme of models in three fundamental aspects is provided by the so-called general model theory as codified by Stachowiak [35]. Also, according to this theory, a model represents a simplified or reduced version of an original, but added is the fundamental aspect of the subjective and pragmatic purpose of each modeling [35, pp. 131–133]:

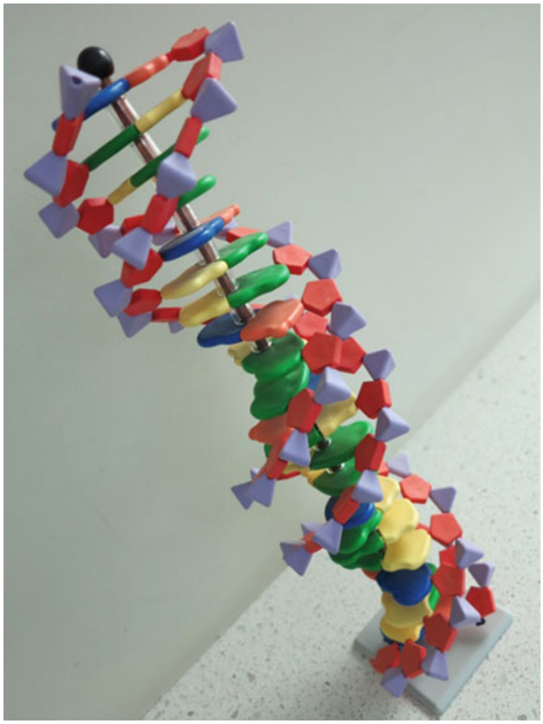


Fig. 2.4 Scientific modeling with the didactic aim: A piece of a DNA model created by the Garvan Institute of Medical Research (Image: Theodore Barons, 2014)

- **Representation**: Models represent originals, whether from imagination (ideas, concepts), expressions, symbols, or physical objects. A model is generally understood to mean the reproduction of an original, and it always refers to an original.
- **Reduction**: Models usually do not include all features of the original but only those considered relevant by the creator.
- **Pragmatism**: Models function as a surrogate of the original within a certain time span, for a certain purpose (transactions), and a certain group of recipients.

Of these three aspects, **representation** might be the clearest: models have always to be more or less similar to the related original like a picture to the depicted (nothing to say that the latter can also be thought of as a model relation).

Reduction (or simplification) is subdivided into different procedures (and always related to pragmatism). Generally usual are for physical models reducing in size by downscaling and transforming into other materials. Downscaling makes the model easier to handle (better moveable, to provide overviews, etc.; on the other hand: for a pragmatic upscaling of very small or even microcosmic objects cfr. Fig. 2.4). Transformation into

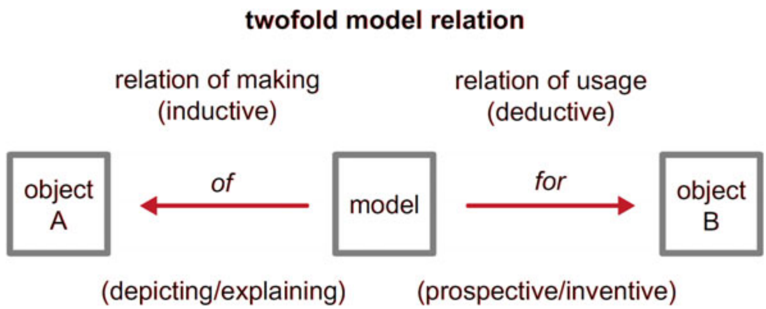


Fig. 2.5 The epistemic twofold model relation, adopted from Bernd Mahr [36] (Image: P. H. Jahn)

other materials is often determined by economic reasons, because during model-based preparatory phases the effort of expensive respectively valuable materials shall be avoided. Didactic models are often much cheaper in their materiality than the represented originals. And if original materials are not stable in their conditions (i.e., bodies of living creatures) they have to be substituted by stable ones in the model. These are only a few examples of a wide range of possibilities for material transformation, but with these the principle might be clear. The result of both, downscaling and material transformation, is the reduction of complexity. As an extreme case of material transformation—one could speak here of a dematerializing *hyper*-transformation—can be regarded as the transformation from the physical into the digital as used in computer-based 3D modeling.

Pragmatism is important: models are always created or produced for a research, teaching, or design task. Therefore, a model can be produced for solving a task (model *for* something) or to represent an object respectively a system (model *of* something) (Fig. 2.5). The time span (as the core aspect of the pragmatic feature) is limited to the duration of the work with the model, its modeling included, or the validity of knowledge stored in the model and expressed by it. Put simply, in time, a model becomes outdated and obsolete e.g. if the original changes or—in case of research—new insights have been gained. Recipients can vary from small teams of scientists or designers (in arts, design, architecture, technics, etc.) and their clients to broader audiences in didactic settings.

For a better understanding of what a model can be, here are some examples:

- A descriptive replica, or reduced model (e.g., of a castle, a car, or a human heart), which is, therefore, a physical and stable object.
- An explanatory model to reproduce part of a phenomenon, even simulate the effects of a physical one (e.g., lighting), or communicate a value or knowledge.
- A predictive model, e.g., to simulate the behavior of (natural or artificial) light to evaluate a lighting system for use in an environment.

- A prototype of an object intended for industrial mass production, which may be a registered model, whose counterfeiting is prohibited by law.
- A dynamic model, e.g., in medicine of the role of the diaphragm in the entry of air into the lungs, in the engineering of floating air over a car or an aircraft design, or in architecture the simulation of façade components like panels for protection against solar radiation.

As we have seen, modeling can also be non-physical, abstract, and therefore only a system of thoughts, or, as often in natural sciences like climate research, a system of calculation. In any case, it is to be mentioned that each modeling must always be thought carefully about what to examine or convey to a target group or audience. Then the model has to be designed according to complexity, level of detail, accuracy, proximity, or distance from reality, and so on. To be aware of these basics is the best way to create good and evident models that will fulfill their purpose.

Further reading: Conditions of scientific models In science and research, models are a helpful and practicable medium of generating knowledge about problems and their solutions or to illustrate results. The latter communicative function is also used in educational situations or museums. To be scientific, a model itself or its producers have to provide evidence about the sources and hypothesis on which it is based, because the arguments need to be traced and verified (inside the model by sources and/or annotations, outside it by commentaries). To guarantee traceability, all primary (analog or digital) data beyond the model should be secured and stored for future research. The model may not be published alone, but with the data and knowledge generated during the preparatory research, and the epistemic results of the modeling process (→ Scholarly Method).

Due to its pragmatic feature, the model should never be the sole medium of research activity. For example, in architectural research, the model of a building may either play an important role in solving a research question about spatial and material properties or in investigating research questions about social, historical, or political contexts. In the former case, formal details may be more important. In the latter case, too, the model could also be significant, but its formal details would be of less interest.

3D modeling as a reconstruction tool of historic architecture, is a method and practice of the humanities. In this research field, a model is generally created "post factum"—after the original [37, p. 335]. In contrast to modeled drafts which are made "ante factum", because they prepare the object to be fabricated, these post-factum-models are created subsequently to illustrate the original including the developed reconstruction of it.

2.5 The Architectural Model

Architecture has been visualized in planning and construction practice using downscaled 3D models for hundreds of years. Architectures are usually dealing with complex spatial structures that are difficult to survey on the outside and difficult to see through on the inside. The first written statements on architectural models come from architects of the Renaissance.

The Florentine Leon Battista Alberti (1404–1472), a universal erudite humanist, who practiced and theorized on architecture, stated about architectural models: “Having constructed these models, it will be possible to examine clearly and consider thoroughly the relationship between the site and the surrounding district, the shape of the area, the number and order of the parts of a building, the appearance of the walls, the strength of the covering, and in short the design and construction of all the elements […]. It will also allow one to increase or decrease the size of those elements freely, to exchange them, and to make new proposals and alterations until everything fits together well and meets with approval” [38, pp. 120–126, 32, pp. 26–30, 33, pp. 121–123].[2]

Alberti refers here to several pragmatic advantages of the 3D and thus spatial architectural model compared to 2D and thus plane, non-spatial drafts. The model, which is conceived as a scaled-down version of the reference original, is intended to make the building to be designed spatially visible, comprehensible, and transparent, thus anticipating ideas of the effect the building may have when constructed. A fine example from Alberti’s time is the model of the Strozzi Palace, built in Florence and still existing today (Fig. 2.6). The scaled-down version is made of wood, can be disassembled into individual stories, and has some interchangeable modules with variants for the façade design. In addition to the reduction in size, for further simplifications building materials are transformed from stone and plaster into wood and details such as door and window frames in the interiors of rooms are omitted.[3]

With his desire for problem-free modification at any time, Alberti formulated a pragmatism that can almost be called visionary in principle, and which digital 3D modeling is only now able to fulfill in practice. In physical modeling, which had been practiced for centuries, modification of the model always involved a degree of manual work—be aware

[2] L. B. Alberti, […] de Re aedificatoria opus elegantissimum, et quam maxime utile, Florence 1485, 2nd book (without pagination); cited after the current English edition: On the art of building in ten books. Transl. by Joseph Rykwert et al, MIT Press, Cambridge, Mass. 1987 [5th edn 1994], p. 34.—For further aspects of Alberti’s theory on architectural modelling [39, pp. 78–81].

[3] Recently displayed on the original site in the Museino di Palazzo Strozzi, on loan from the Museo Nazionale del Bargello, Florence [38], pp. 101–107, 222–224 (cat. no. 79), figs. 37–56; [40], pp. 75–86, esp. pp. 77–78, figs. 2.2–2.3, plate III; [41], pp. 19–73, esp. pp. 32/35, figs. on pp. 72/73p; the catalogue articles nos. 143–145, pp. 519–520 (n. b.: by Amanda Lillie, who is unusually supposing that the preserved alternative stripes for the façades should be fragments of lost two further models of the whole building).

Fig. 2.6 Wooden draft model of Palazzo Strozzi in Florence, 15th century (Image: https://commons.wikimedia.org/wiki/File:Giuliano_da_sangallo_o_bendetto_da_maiano,_modello_per_palazzo_strozzi,_1489_ca,_01.JPG, accessed on 1.2.2023)

that in Alberti's time, model making in wood was the work of a professional cabinet-maker. Exceptionally, in the case of the given example (Figs. 2.6 and 2.7), the architect of Strozzi Palace, Giuliano da Sangallo the Younger, was a trained model maker so he was able to model his own draft.

On the representational deficit of 2D drawings, which the model can compensate for due to its three-dimensionality, the only slightly younger Sienese universal artist Francesco di Giorgio Martini (1439–1502), who was also active as an architect and additionally as an engineer, commented: "As difficult as it is to represent all things in drawings,

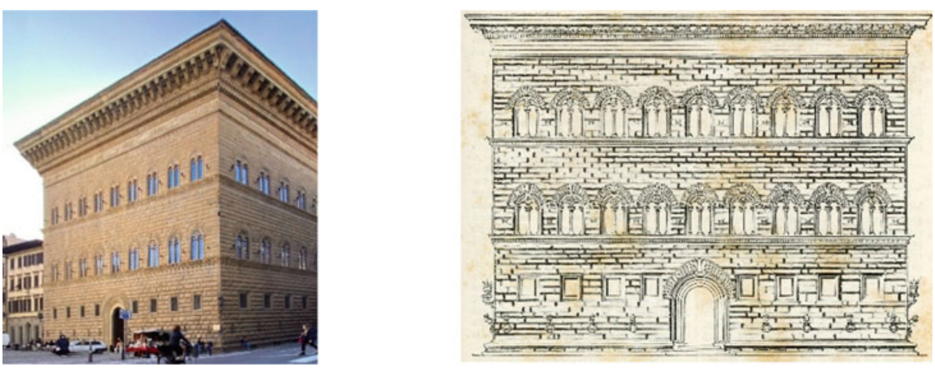


Fig. 2.7 Florence, Palazzo Strozzi, in 2021 and documentary façade elevation in orthogonal projection (Image: Teo Pollastrini, 2021; modifications: P. H. Jahn; Xylography, taken from: Gustavo Strafforello, La patria, geografia dell'Italia, Turin 1894): Compared to Fig. 2.6, the third story is heightened and topped by a more voluminous cornice

the written word is just as unsuitable to explain everything. For too many different things are interrupted and stand opposite each other, so that they overlap. Therefore, it is necessary to make models of all things. [...] in his imagination many things seem simple to the architect, and he thinks they must succeed."[4]

This statement refers to models of machines, but it can easily be applied to architectural models. In any case, 3D visualization is superior to 2D ones such as plan and elevation, it introduces depth as the third dimension and provides furthermore variability in the viewer's perspective. The given historical examples show clearly the still valid concept of modeling in architecture as a three-dimensional representation of a building structure. The modeled building is a draft only represented on paper and touches the basic question of model theory: the model refers either to an imaginary or a real object. Depending on the pragmatic purpose of visualization it ranges in size from a tiny reduced scale to models at the original scale (so-called *maquette*), and formally from schematic to fully detailed surfaces. All these different kinds of representation always refer to the idea of a spatial model.

Digital 3D modeling has the advantage over physical modeling that, if required, the classical 2D orthogonal projections of the architectural plan (floor plan, elevation/view, and sections) can be drawn from a virtual 3D model at any time, namely by switching off one dimension and projecting the model body orthogonally onto an image plane. Creating pictorial perspective views of buildings (so-called renderings) is easy to realize with digital 3D modeling software. Before the digital age, architectural perspectives had to be painstakingly derived from plans or a physical building model using the rules of descriptive geometry. To conclude: before the digital age, a drawing was turned into a model by processing a draft; in the digital age, the process is quite the reverse, from model to drawing. Nevertheless, in digital 3D reconstruction of historic architecture, the conventional modeling from drawing still has to be practiced if visual media as plans are basic sources for the reconstruction model.

Modern research in architectural history as established in the 19th century has adopted the preparatory use of architectural models during the process of drafting reconstruction models, but this not as prospective models to visualize a building project but as *post factum* models of now non-extant buildings or parts thereof, either based on reliable documentation or purely hypothetically. For example, classical archeological research has produced thousands of physical models of complete Antique temples (Fig. 2.8), other buildings of that period, or whole cities that had fallen in ruins.

[4] Florence, Biblioteca Medicea Laurenziana, manuscript 282 (Codex Ashburnham 361), fol. 33r, resp. Turin, Biblioteca Reale, Codex Saluzzianus 148, fol. 33v, edited in: Francesco Di Giorgio, Trattati di architettura, ingegneria e arte militare. A cura di Corrado Maltese. Trascrizione di Livia Maltese Degrassi (Trattati di architettura, vol. 3), 2 vols., Milan 1967, vol. I, p. 142. Thanks to Elaine Sophie Wolff, Innsbruck/Pisa, for providing this source by giving a modern translation from the Italian Renaissance idiom.

Fig. 2.8 Reconstruction 1:20 model of the Parthenon temple in Athens: manufactured 1883–89 by the modelmaker Adolfe Jolly in Paris on commission of the Metropolitan Museum of Art, New York, following a concept developed by architect Charles Chipiez with archeologist Georges Perrot, compiling contemporary research on the Parthenon of Alexis Paccard, Benoit Loviot, and Charles Simart (permanent loan from The Met NY in Munich at the State Museum for Plaster Casts of Classical Sculptural Work) (Image: P. H. Jahn)[5]

Further reading: From the physical to the digital model Physical modeling of architecture had been practiced before digital 3D modeling was invented, and it is still in use, mostly for presentation purposes, and in some cases for preparing designs [42]. Another purpose of this traditional modeling practice is to retrace and continue design processes started prior to the digital age—an example gives the model workshop at the famous La Sagrada Família church building in Barcelona (Fig. 2.9). The special and very complex mixture of neo-gothic and partially bizarre organic forms required a special effort of three-dimensional representation, which was achieved with dozens of models in different levels of detail and scales, this from the beginning of building activity in the 1880ies (cfr. blog by Samantha Hinsbey, 2020: https://www.jovinlim.com/blog/2020/6/18/modelmaking-throughout-history-sagrada-familia). As the given

[5] Inge Kader, Infoblatt: Parthenonmodell, https://www.abgussmuseum.de/de/infoblaetter/parthenonmodell, accessed on 1.2.2023; additionally: https://www.abgussmuseum.de/de/das-modell-des-parthenon, accessed on 28.09.2022.

insight might imagine, modeling with physical materials has always required craftsmanship (Fig. 2.9) (sometimes near to handicraft work), and is a very complicated process, often given to trained model makers [43, esp. pp. 137–159, 44].

Fig. 2.9 Physical modeling: Model workshop in the La Sagrada Família, Barcelona (Image: Münster 2010)

2.6 Computer-Based 3D Modeling

Computer-based, i.e., digital, 3D technologies have become increasingly important for sustaining conservation, research, and broad accessibility of cultural heritage as knowledge carriers, research tools, learning materials, and means of representation over the past three decades [45–47]. An overarching consensus is that 3D modeling represents or translates either a material cultural object or an intangible cultural phenomenon into a spatial, temporal, and semantic virtual model. There are key differences in the assessment of material and immaterial objects (e.g., usages or digital data). As mentioned in the previous paragraphs, another essential difference is between the reconstruction of objects that are no longer existent or that have never been realized (e.g., plans) and the digitization of objects that are still existent [48, 49].

2.6.1 3D as Reference to Space

Commonly, the prefix 3D refers to the spatial model central for digital 3D modeling. In addition to 3D, further dimensions have become established, e.g., in mathematics, computer graphics, and geosciences (Fig. 2.10).

2D refers to spatially two-dimensional scaled models and representations such as elevations or floor plans with the dimensions width and length.

2.5D means in computer graphics the perspective representation of a model on a spatially two-dimensional scaled medium such as a computer monitor or a printout.

3D means the virtual or physical dimensions of height, length, and width. In contrast to 2.5D this yields 3D scaled objects, e.g., 3D printed geometries.

4D stands for a spatially 3D and temporally scaled model. An example contains information about a building's changes over time, such as the construction process.

5D and higher: the semantic enrichment of the model is occasionally mentioned as a fifth dimension. [e.g., 81, pp. 64f.].

Fig. 2.10 Model and visual dimensions of virtual 3D reconstruction (Münster 2019)

2.6.2 Digital Versus Virtual

There is a basic consensus that digital 3D models are created using computers and thus differ from physical reconstructions of artifacts or even paper-based reconstructions such as architectural drawings [50]. In this context, the terms "digital" and "virtual" reconstruction are largely used interchangeably, although the underlying concepts of the digital as "data in the form of especially binary digits" [51] are quite different from the virtual as "existing or occurring on computers or on the Internet" [52]. While the digital thus describes a materiality, the concept of the virtual is based on a reference to reality in terms of content. Empirically, in the German-speaking world, the term virtual reconstruction" is used more frequently, with 61,000 results compared to 13,000 results for "digital reconstruction" in a Google search [53]. "Digital reconstruction" predominates in English with 484,000 versus 181,000 results. In accordance with the practice described, both terms will be used synonymously in this book [54].

2.6.3 Reconstruction Versus Digitalization

3D digitization or reality-based modeling [55, 56] stands for "the process of converting something to digital form" [57]. Digitization describes the technological transfer of a real object to a digital asset. For this purpose, various data acquisition technologies are used [54, 58, 59] (→ 3D Modelling). For tangible objects, the main distinction is between light-dependent and light-independent methods [60]. Light-dependent systems emit light to retrieve information about the 3D surface. This comprises active approaches where coded light is projected onto a surface (e.g., white-light scanners using structured light to determine the surface shape and laser scanning sending laser beams at a varying angle to determine 3D surface points using the time-of-flight principle [61, 62]) and passive methods using imagery as videos or photos [63] without specifically coded light [60, 64]. The outcome is a dense 3D point cloud, which is then processed into a meshed surface [65]. Methods not using visible light comprise a large variety of tomographic methods such as CT scanning to model the internal structures or volume of the object [61]. A taxonomy of the quality of 3D digitization of tangible heritage was developed within the EU VIGIE study [66, 67]. According to this study, the main attributes describing a digitized object are geometry, composition (as material information), and production (as the model acquisition process) [68].

3D reconstruction or virtual-based modeling: Whereas digitization refers to the technological conversion of an object into a digital representation (Fig. 2.11), a digital reconstruction or virtual-based modeling process [56] requires human interpretation of data to create a hypothesis of a past object [48, 69–71] (→ 3D Modelling). The model is then mostly created on the computer using manually controlled graphic modeling software originating from construction and engineering in the case of computer-aided design (CAD), or from design and creative industries in computer-generated imaging and graphics software (CGI). Since those processes are highly labor-intensive, approaches to reduce the workload include generative or parametric modeling (predefining objects by rulesets with changeable parameters) or semi-automated modeling (e.g., from historical imagery) [48, 70].

3D meshing and texturing: Both 3D digitization and reconstruction lead to 3D models representing surfaces and/or volumes of a tangible heritage object. Since the modeling approaches of volumetric models vary significantly depending on the methods used [72], 3D surface representation can be discrete—based on points (point clouds), triangular meshes (vertices, edges, faces), or continuous as e.g., NURBS, geometric solids (constructive solid geometry, CSG), and boundary representations (B-reps) [61] (→ 3D Modelling).

Besides the geometry features of a 3D model, its radiometric parameters and materiality representation are relevant [73]. For surfaces, the main distinction is between

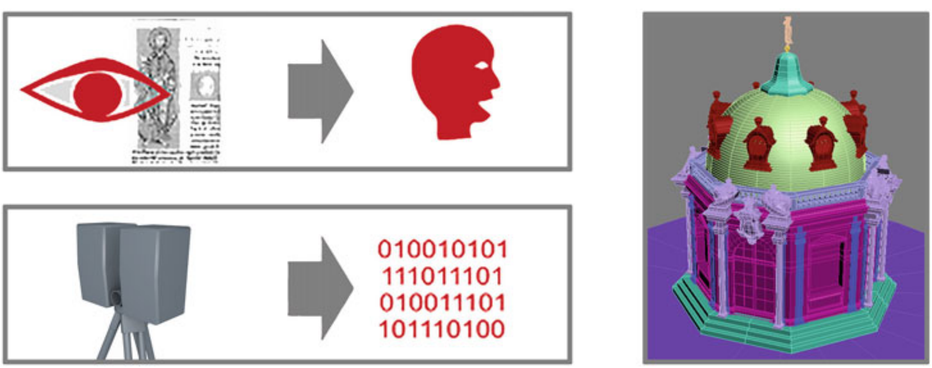


Fig. 2.11 Schematic reconstruction (upper left) versus digitization (lower left) workflow, both resulting in a virtual 3D model (right) (Images: Münster, except right: Rainer Uhlemann, lightframe fx)

synthetically generated procedural textures and reality-based textures (→ Visualization). Related to the latter category, another distinction is between the acquisition of material properties [74] and digital visualization [75].

2.7 Simulation

Simulation refers to a "procedure for reproducing a system with its dynamic processes in a model that can be experimented with in order to arrive at findings that can be transferred to reality" (translated from [76], p. 1; for a definition from humanities [77], see also [78]). Law and Kelton [79] distinguish three types of simulation depending on the models used:

- Static versus dynamic: A static simulation provides a replica of a system at a specific point in time. A dynamic simulation represents a system whose states, attributes, processes, etc. are time-dependently variable [80].
- Discrete (countable) versus continuous (measurable) values.
- Deterministic (always the same output for a specific set of values) versus stochastic (random output at a certain level) values.

In the context of cultural heritage, the term "simulation" is used in various ways:

- **Simulation for analysis**. Examples include:
  - **Object behavior**, often in disaster situations, as in fluid simulation (CFD) to analyze flooding [81], to simulate structural behavior, e.g., of monuments in earthquakes [82] or fire [83], but also to prove requirements for materials in construction [84].
  - Simulation of **environmental effects**, e.g., of lighting to assess conditions in historic buildings [85, 86], degradation by climate features [87], ancient ventilation systems [88], or acoustic conditions [89].
  - Simulation of **cultural effects**, e.g., of crowds [90], mechanical processes [91], or daily cultural life [4, 92].
- **Simulation as calculation of imagery (rendering)** [93] means the computed combination of various features such as material appearance, lighting, and geometrical behavior, either of static scenes (images) or of time variate or dynamic (films or interactive games) to a visual output. This computation of a virtual model to create a visualization is called rendering [94]. Methods include ray tracing [95, 96] and global illumination [97].

A more metaphorical use of the term is the **"simulation" of a building process** when unexecuted architectural plans are analyzed. If such plans are modeled in 3D, this procedure is like an assessment of their buildability [25]. Strictly speaking the term "re-construction" does not fit this kind of architectural 3D modeling because it was not preceded by a construction. Nevertheless, the modeling of unexecuted building plans is also commonly called “construction”. As an established method of architectural history research, it is advantageous in interpreting the buildability as well as spatial and aesthetic effects of the projected buildings.

Summary This chapter introduces key concepts in digital 3D modeling of historic architecture as part of cultural heritage, the use of sources and data as a basis for any reconstruction, and modeling as a scientific method and practice. Architectural plans and models are used for 3D reconstruction of historic architecture; in our digital age, these processes are transferred from physical modeling into the digital sphere.

Concepts

- **Sources**: historical research is always based on sources (and data obtained from them), their critical analysis and interpretation, which will always be subjective views constructed in specific contexts.
- **Model**: a pragmatically reduced representation of an original [65 pp. 131–133].
- **Digital 3D Reconstruction**: “the creation of a virtual model of historic entities that requires an object-related, human interpretation” [70, p. 7].

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