

Lessons Learned from Building a Time-Attributed Partonomy for the 4D-Visualization of the Vienna Hofburg

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This paper reports on the implementation of a 4D-visualization of the Vienna Hofburg ranging from the year 1230 up until 1874. Producing such a visualization is hard, as progressive changes to a building may not only concern its geometry but also the underlying semantics of the different building parts. To represent both aspects, the authors have modeled the progression of building phases as partonomy rather than using only time-attributed geometry. As will be shown, the advantage of this approach lies in the ability to easily express “whole-part” relationships, which might either be purely conceptual or may have associated geometry. Time attribution on the nodes of such a partonomy can then refer to an abstract concept – e.g. “the whole Hofburg” which is an abstract aggregation of its sub-parts – or to concrete nodes containing geometry in the usual sense. While such a representation is advantageous as a data structure, it must also be noted that querying becomes a lot harder than with time-attributed geometry. To report on the lessons learned from using this methodology in a real project is thus our main goal and contribution for this paper, which may serve a wider audience as a reference when implementing their own 4D-visualization.

Key words:

Partonomy, 4D-visualization, Vienna Hofburg.

CHNT Reference:

Gabriel Wurzer et al. 2018. Lessons Learned from Building a Time-Attributed Partonomy for the 4D-Visualization of the Vienna Hofburg.

INTRODUCTION

4D-visualizations of heritage commonly use time-attributed geometry in order to show the progression of building history through successive phases. However, modelling such a progression is hard geometrically and semantically because a building undergoes constant change (i.e. additions, removals, merge and splits of building parts, potentially at a very small level). Furthermore, the notion of a “building part” itself is fuzzy – a room which was known as „First antechamber“ at a certain time, might belong to a completely different part of a building in a next phase due to re-modelling works – even if the function and naming of the room did not change (Fig. 1).

As can be seen from that example, decomposing a building into a strict hierarchy of parts-within-parts is hardly ever possible. The authors have instead opted to use a partonomy – i.e. a structure describing part-whole relationships in an abstract way, where time spans, concrete geometry and documentation may be added as an attribute afterwards. Using this concept, it is possible to inherit information from parent parts; it also makes modelling of building parts having a fuzzy definition easier. However, it would be unfair to say that this data structure solves every problem associated with building history, as was found out during practical work concerning the 4D visualization of the Vienna Hofburg. To share some insights also with view to other projects that might benefit from using partonomies is the authors’ goal in this paper. In more detail,

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- The authors first take a deeper look at partonomies in general (see chapter 'Background') before describing the set-up used in their project (see chapter 'The Hofburg Partonomy'); some of the details found in that context were less than obvious to us, which is why this section forms the main part and thus also the key contribution of this paper
- The authors then present their prototype visualization and take a look behind the scenes so as to show how the visualized data is fetched from the described partonomy (see chapter '4D-Visualization')
- Before concluding, the authors present some of the lessons learned from using a time-attributed partonomy for 4D-visualization (see chapter 'Discussion'); these points may serve as a reference for fellow researchers in building history and heritage

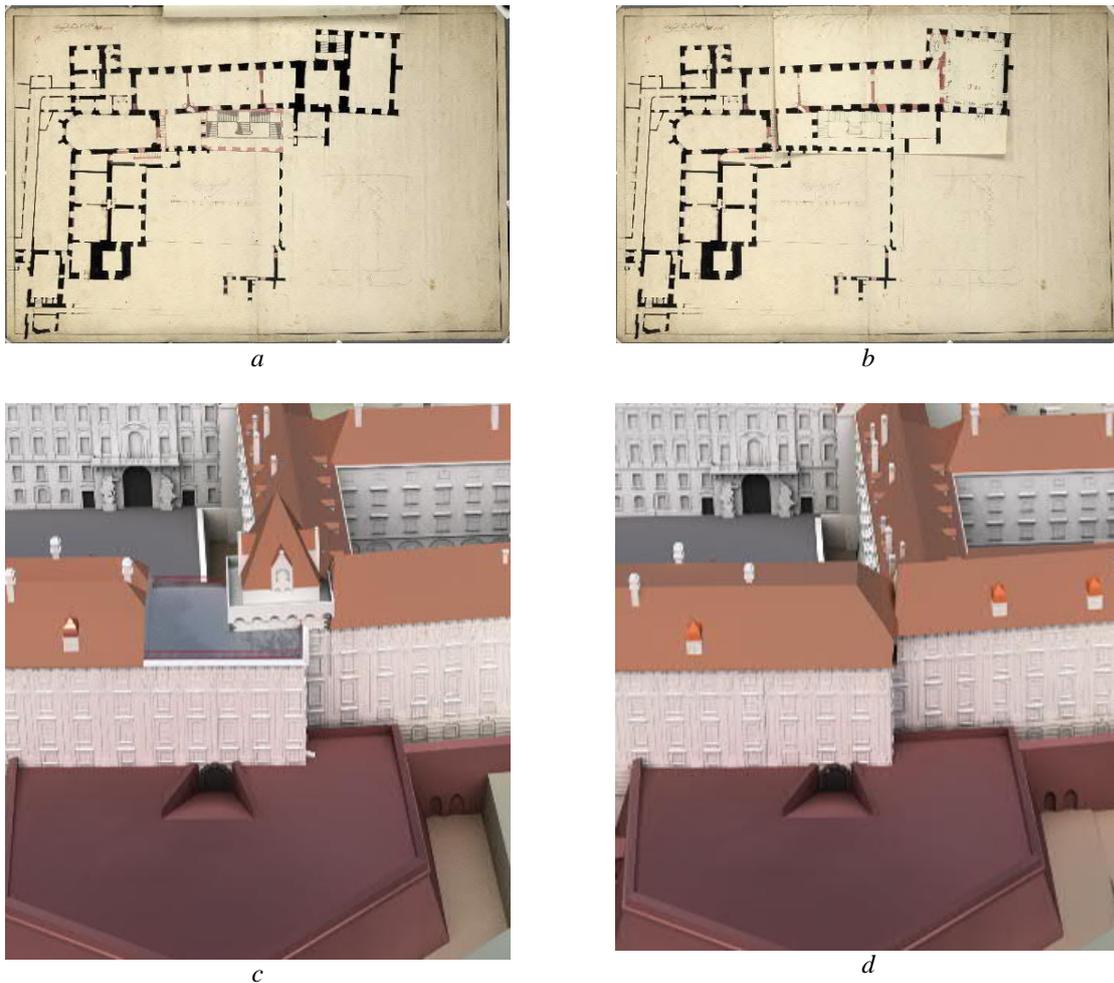


Fig. 1. Plan of the main floor of the southwestern wing of the Schweizerhof, the core building of the Hofburg, before 1748/1749 (a) and after 1748/1749 (b). Detail of the 3D-model of the Schweizerhof around 1740 (c) and around 1792 (d). Notice the disappearance of the Western tower, indicated by the thick walls in (a) which once housed the First antechamber, and, with that, the assignment of this very room in a state now enlarged (b) to another part of the Hofburg

BACKGROUND

Partonomies – or “*whole-part*” relationships – are widely used in software development for describing the composition of complex systems. In more detail, a system can be modelled starting with a term A which is composed of a set of sub-terms $\{B_1, B_2, \dots, B_n\}$, $n \in \mathbb{N}$. Every such sub-term B_i can then be said to be *part_of* A , which itself has n relations of type *has_a* to B_i ($1 \leq i \leq n$). Repeating this process recursively yields a hierarchy with the following properties:

Reflexivity. A is *part_of* A .

Transitivity. If C is *part_of* B and B is *part_of* A , then C is *part_of* A .

Antisymmetricism. If B is *part_of* A and $A \neq B$ then A is not *part_of* B

The two relations *has_a* and *part_of* make partonomies ideal for representing aggregations in a hierarchical manner (see Fig. 2a). Elements of a partonomy may furthermore be attributed with data, where attributes belonging to a part B_i also belong to its aggregate A .

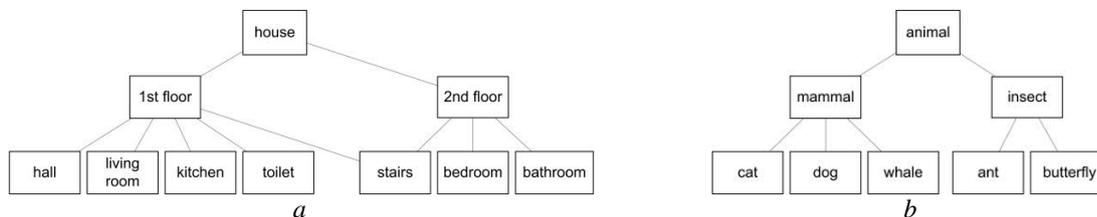


Fig. 2. Examples. a) Partonomy of a house featuring *part_of* relationships between children and parent element. b) Taxonomy of animals featuring *is_a* relationships between children and parent element.

In contrast, taxonomies are used to characterize the *type* of a term in a hierarchical manner (also see Fig. 2b): Let A be an element in a taxonomy and $\{B_1, B_2, \dots, B_n\}$, $n \in \mathbb{N}$ sub-elements of A . Then every B_i ($1 \leq i \leq n$) has a relation of type *is_a* to A . In other words, A is an *abstract* type for which B_i is a *concretization*. Taxonomies are the exact opposite of partonomies when it comes to attributes of an element: A type B_i is *inheriting* all attributes from its parent type A .

In literature, the differentiation between partonomy and taxonomy is a hot topic that is covered by numerous fields ranging from linguistics to psychology (see e.g. [Górska 2003] as an example). However, in practice both are used together e.g. for “Object-oriented programming” (OOP) (also see [Booch 2003]).

THE HOFBURG PARTONOMY

The Viennese emperor’s castle ‘Hofburg’ forms the context for the project (‘Wiener Hofburg 3D-Quellenspeicher’, funded by ÖAW under the go!digital 2.0 call) in which the authors have employed a partonomy. The Vienna Hofburg is complex due to its long history of additions and modifications, which makes it an ideal test case for a partonomy used as a data structure.

The building history of the Hofburg (see Fig. 3), the main seat of the emperors and kings of the Habsburg dynasty in their capital Vienna, starts around 1300 when a fortress with four corner towers was built. Until 1500, the walls were replaced by proper wings and vast gardens separated the Hofburg from the surrounding city. When the fortification system of Vienna was modernized in the early 16th century, a bastion was added to protect the city gate next to the Hofburg. During the following decades, separate palace buildings for the use of the court (like the Stallburg) were erected on isolated sites. Only in the 17th century were these buildings united by halls and proper wings. By the mid-18th century all garden areas had been built over with additional structures. Hardly any traces of the medieval core of the Hofburg were left by the beginning of the 19th century when a new square was laid out in front of the Hofburg by moving the city walls some hundred meters westwards, creating what is today’s Heldenplatz.

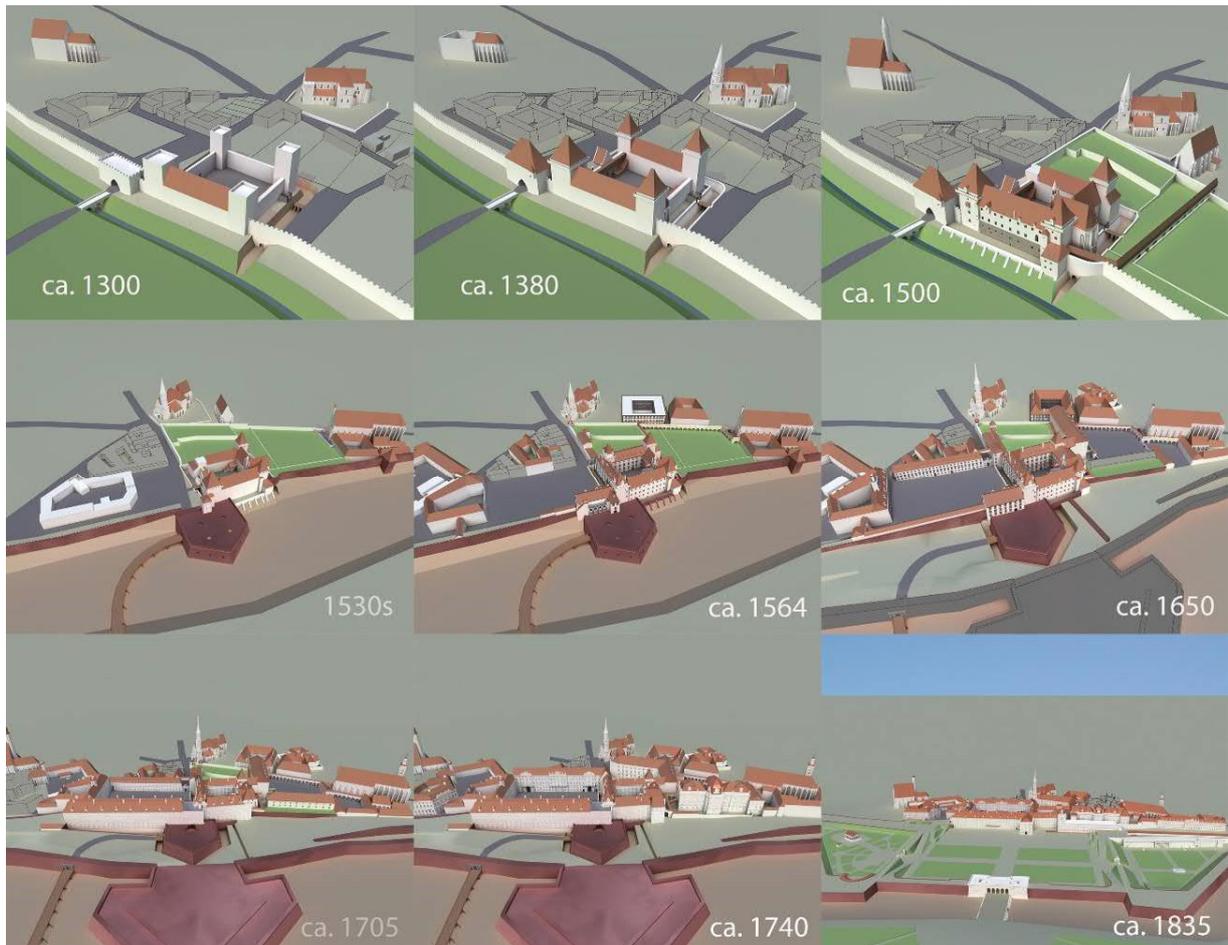


Fig. 3. The architectural evolution of the Vienna Hofburg

As common in digital 3D-reconstructions, the authors' model consists of a number of geometries that together built up the whole model. Additionally, since the appearance of parts of the palace changed in the course of time, the authors need a number of geometries for one and the same building part to be able to present the appearance of the Hofburg at whatever point in time of its construction history one is interested in.

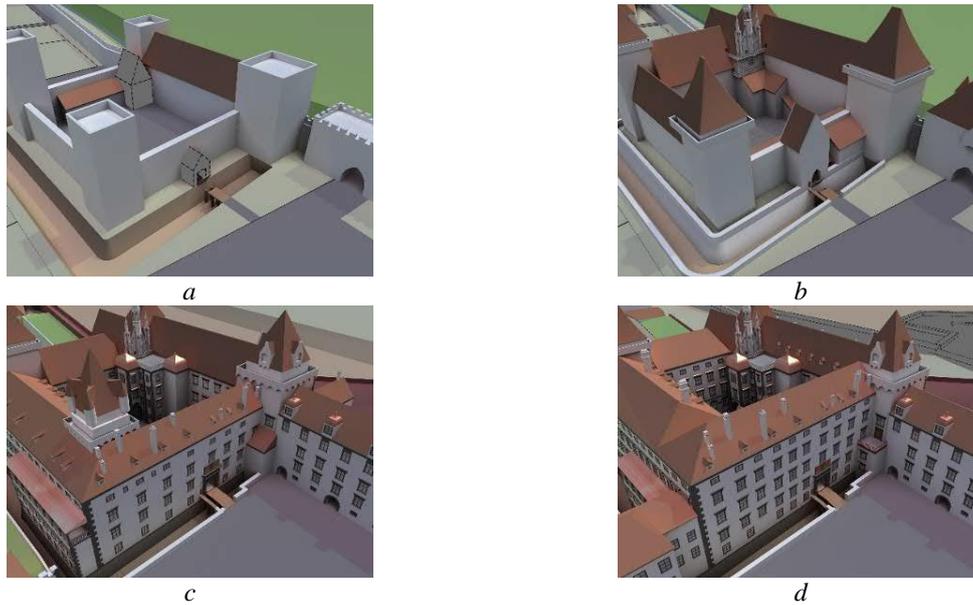


Fig. 4. Constructional development of the “Schweizerhof”: ca. 1300 (a), ca. 1440 (b), ca. 1564 (c) and ca. 1650 (d)

The following explanations take the Northwestern wing of the Schweizerhof, which is the medieval core of the whole palace complex, as an example to explain the structure of the partonomy. Fig. 4 presents the architectural development of this part of the Hofburg from around 1300 until the 17th century. The basic situation (Fig. 4a) consisted of two corner towers linked together by a high wall with the entrance gate approximately in the middle. In the 15th century (Fig. 4b), a larger gatehouse replaced its predecessor and the towers were covered with high roofs. In the beginning of the 1550s, the medieval wall was replaced by a proper wing which housed parts of the imperial apartments (Fig. 4c). By the end of the 16th century, an additional floor had been added to this wing (Fig. 4d) and in the early 17th century, an arcade towards the inner court on ground floor level and corridors in the upper floors enlarged the interior space of this wing – a situation which exists unchanged until the present. For the architectural area between the two corner towers (the medieval wall and the early modern wing which replaced this wall), the authors needed two geometries to show the architectural situation in medieval times, and three geometries to show the different stages of the construction in early modern times (refer to Figure 5a):

The first geometry, called Mauerwerk 439, must be shown from the year 1230 until 1380, and if one wanted to see the state of the Hofburg in 1381, a new geometry needs be loaded to present the new situation. The same applies for the chronology of the following geometries.

However, even small parts of a building can hardly be torn down and built up anew within a single year; so one has to consider destruction and construction phases. If one does not have any information about the precise dates of these construction measures from historical sources he has to hypothetically assume an approximate date. In the example of the northwestern wing, number 448, it is known that the construction of this newly erected wing started in 1551 and was completed in 1554. Therefore, the medieval wall, number 440, must be visible until 1554 when it must have finally disappeared. On the other hand, the newly erected wing must be shown already from 1551 onwards when its construction started. That is why the authors’ partonomy needs to include temporary overlaps of geometries – for which an adequate visualization needs to be found by applying for instance transparency to the geometries.

Summarizing, the often-changing nature of the building throughout time makes it hard to represent in a strictly geometrical way where child elements are *fully contained* in their parent element (also see chapter ‘Discussion’). Instead the authors take *conceptual containment* – child elements belong to their parent element – as basis for the partonomy.



Fig. 5. Partonomy of the Hofburg without (a) and with time-based filtering (b)

ELEMENTS OF THE PARTONOMY

Every element in the partonomy has zero or more parent elements, which establishes a hierarchy as shown in Fig. 5b. As attributes, there are

- An *unique identifier* (e.g. 134) and a *title* (e.g. ‘Hofburg’)
- A basic classification into elements that are *abstract* and those that *hold geometry*; in the latter case the geometry is uploaded as a 3D file.
- A flag that specifies whether this element is considered *interior* or *exterior*; furthermore a flag that specifies that an element is a *regular part* of the partonomy or a *design aid* (e.g. overlay plans).
- A *duration* (existence from [year] – to [year]; mandatory); one may additionally specify an end of construction [year] and a start of demolition [year] which both must lie within the aforementioned duration.
- *References* to other elements (historical predecessor, alternative versions of this element) and logical assignment to a *spatial group*; the latter is interesting because it does not respect the ‘whole-part’ relationship that the partonomy imposes, but rather adds a mechanism for aggregating multiple elements on various levels of the partonomy under a logical term.
- A list of *documents* and *images* associated with that element; as mentioned under ‘Background’, a document or image contained within a child element can be seen as also belonging to the parent element; however, its storage location is nevertheless the child element.

Using the basic *has_a* and *part_of* relationships as well as the list of attributes, one may now begin to query the partonomy. The most commonly-used query is by time (e.g. 1680 as shown in Fig. 5b); the resulting hierarchy of elements containing sub-elements can optionally be filtered so as to be able to get only ‘interesting’ parts of an otherwise large output. For example, one may choose to only receive elements underneath a certain unique identifier having geometry.

4D-VISUALIZATION

The authors' prototype visualization (see Fig. 6) initially queries the partonomy to find the minimal and maximal year using the *duration* attribute of all elements. From this information it can build a time slider (see upper part of Fig. 6). It then goes on to choose a year within this range (in this case: the minimum year) and queries the partonomy for all elements having no parent element (i.e. root elements; see "Hofburg (134)" in Fig. 5b). The resulting hierarchy is then filtered twice – first by elements containing geometry, in order to load the 3D content asynchronously; and then a second time by elements containing documents or figures which are shown as labels.



Fig. 6. 4D-visualization of the Vienna Hofburg

Apart from being able to set the *current year* via the time slider, users may interact with the camera (pan/zoom/rotate) and double-click a potentially 'interesting' building. This sets the *current element* (visualized as breadcrumbs 'Hofburg > Schweizerhof' in Fig. 6) by which the visualization is able to calculate what geometry and labels to show (also refer to Fig. 7):

- labels are only shown for immediate child elements of the current element
- elements carrying geometry (suffix "(geom)" in Fig. 7) are made visible depending on a condition:
 - a) if an element is a child of the *current element*, it is made visible if there is no other element containing geometry between this element and the *current element*
 - b) in all other cases, the element is made visible if it has no parent containing geometry

The *current element* also assembles all documents/images contained in itself and its sub-elements and presents the result in a *document browser* (not shown in Fig. 6). The user may click on the different documents/images in order to open a new window containing the full documentation/image source (in this case hosted in an external document management system).

The set of documents shown in the *document browser* may further be narrowed down using interaction: The user can single-click on a building part to select a sub-element of the *current element*, which filters out any document/image that does not belong to the chosen building part. The prototype also allows for elements containing geometry which are meant as design aid; these are typically floor plans which may be shown as overlay (see left part of Fig. 6).

	<i>label shown?</i>	<i>geometry shown?</i>
Hofburg		
Schweizerhof		
Burgkapelle	X	
Aussenfassade (geom)		X
Hoffassade (geom)		X
Südwesttrakt	X	
Mauerwerk (geom)		X
Dach (geom)		X
Nordwesttrakt	X	
Raum 0134 (geom)		X
Testobjekt (geom)		
Michaelerkirche (geom)		X
Gelände (geom)		X

Fig. 7. Extract of the Hofburg partonomy. The current element is shown highlighted, nodes containing geometry are marked with the suffix “(geom)”

DISCUSSION

When implementing the 4D-visualization in a 3D-engine, the authors first tried to represent the partonomy as a scene graph (i.e. a hierarchy of objects within objects which may or may not contain geometry). However, this was one of the greatest pitfalls the authors made because *setting the visibility of a parent object implicitly overrides the visibility of the child objects!* Thus, one big lesson learned is that the visualization has to have *two* representations – the (hierarchical) partonomy on which it calculates visibilities and the (flat) scene graph in which objects are represented non-hierarchically, so that one may switch visibility of labels and geometry at will.

A perhaps more philosophical point for discussion is that one can only see and click objects that contain geometry; how is it then possible to set the *current element* to an abstract element of the partonomy as one may not double-click on it? The answer is simple (refer to Fig. 8): Clicking a geometry will shift the *current element* (“Schweizerhof”) one step closer to the clicked element. The resulting *current element* would be “Burgkapelle”.

	<i>label shown?</i>	<i>geometry shown?</i>
Hofburg		
Schweizerhof		
Burgkapelle	X	
Aussenfassade (geom)		X
Hoffassade (geom)		X

Fig. 8. Switching current element by clicking on a geometry

The next point for discussion concerns the advantages of using a partonomy over a more conventional (geometrical) hierarchy. As mentioned, strict (geometrical) containment cannot account for cases in which elements are shared between parents (see “stairs” in Fig. 2a). Such a structure is considered a *semi-lattice* and has been a discussion point e.g. in architectural representation of cities (cf. e.g. [Alexander 1965; Minett 1975]). However, even in such a semi-lattice there are cases which are not representable (e.g. cyclic relationships); the authors have therefore added the attribute of *spatial group* which is completely decoupled from the hierarchy, as tagging mechanism for elements belonging together.

CONCLUSIONS

This paper presents a 4D visualization of the Vienna Hofburg that uses a time-attributed partonomy for representing building history. As the authors have shown, the main advantage lies in the possibility to represent conceptual “whole-part” relationships rather than strict (geometrical) containment hierarchies (“objects within objects”). However, this benefit also comes with a downside, namely higher effort for implementation in a visualization.

ACKNOWLEDGEMENTS

This work was made possible through the ÖAW go!digital 2.0 project “Wiener Hofburg 3D-Quellenspeicher”.

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Imprint:

Proceedings of the 23rd International Conference on Cultural Heritage and New Technologies 2018. CHNT 23, 2018 (Vienna 2019). <http://www.chnt.at/proceedings-chnt-23/> ISBN 978-3-200-06576-5

Editor/Publisher: Museen der Stadt Wien – Stadtarchäologie

Editorial Team: Wolfgang Börner, Susanne Uhlirz

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