III case study

The “SpSya1250” project, conducted between January and May 2021, reconstructed the Speyer synagogue’s second Romanesque phase using various software.

A handout detailing the reconstruction workflow was created and to be applied to that reconstruction, but with the aim to make the process replicable also in other cases. Models were tested across different software and then uploaded to the DFG repository together with documentation referring to it. Uncertainty levels were documented employing different techniques.

A proposed uncertainty scale categorises reconstructions based on available sources and work required, aiding in visualising uncertainty levels in the models.

‘Solving a problem simply means representing it so as to make the solution transparent.’

HERBERT SIMON, *The Sciences of the Artificial*, Cambridge: M.I.T. Press, 1968.

III

case study

dfg viewer and uncertainty scale

In the framework of the project *SpSya1250*, developed from January to May 2021, the Speyer synagogue in its second Romanesque phase has been reconstructed with different software: Blender, Rhinoceros, SkecthUp, Archicad (**FIG. 82**). The participants in the project were the author of this dissertation together with Igor Bajena and Stefan Wetherington. The coordinator was prof. Piotr Kuroczyński.

A handout[1] was set up with the workflow to adopt to reconstruct this synagogue, even though it can also be – and it has been – applied to other reconstructions. The models resulting from this process have been uploaded to the DFG repository (**FIG. 81**). Using different kinds of software, it was also possible to test the application of the workflow in a range of digital environments.

The part of work here presented is the one initially done with Rhinoceros. Every step of the work has been documented with screenshots and descriptions; every reconstructed element was added in the documentation tables with data about uncertainty and explanations of the choices that have been made[2]. Since Rhinoceros is not a BIM and a parameter related to uncertainty could not be added, layers were used to assign uncertainty values. Colours are the simplest ones according to the RGB scale: maybe not the most appealing, but those with the most easily shareable codes. Other visualisations with different techniques to

---

1 Presented in Appendix 3: Handout for the reconstruction of the Speyer Synagogue (1250)

2 See Appendix 4: Workflow and documentation of the reconstruction of the Speyer synagogue.

Published in: Irene Cazzaro, Digital 3D reconstruction as a research environment in art and architecture history: Uncertainty classification and visualisation, Heidelberg: arthistoricum.net, 2025. https://doi.org/10.11588/arthistoricum.1440

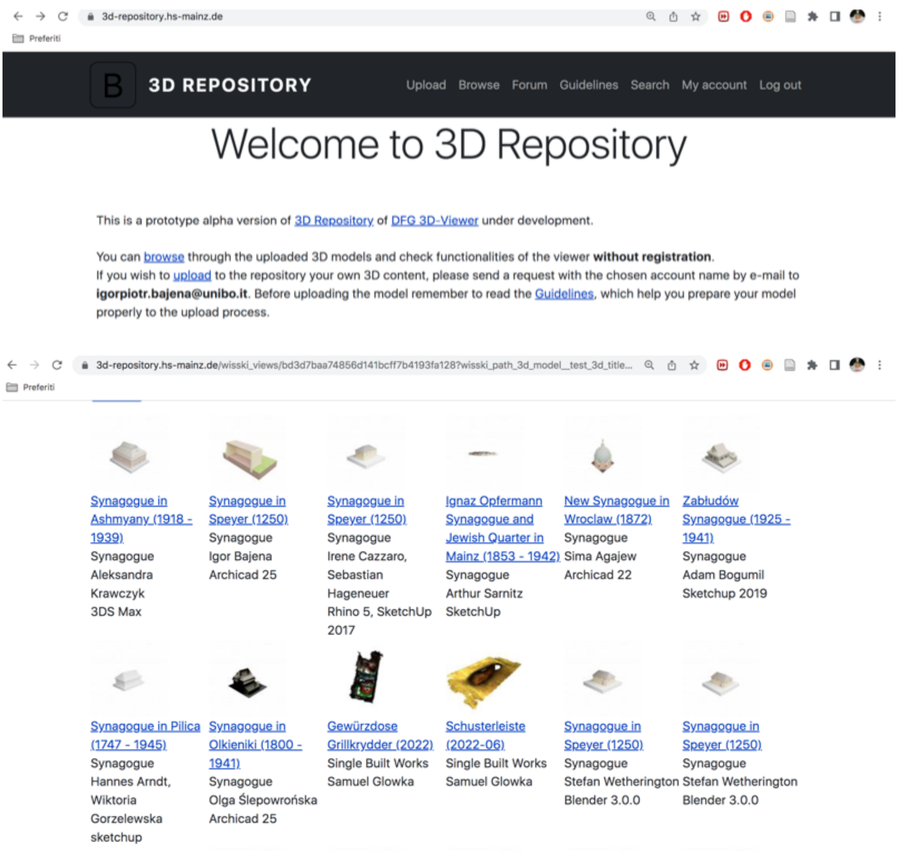


FIG. 81: The interface of the DFG viewer and some of the uploaded models. <https://3d-repository.hs-mainz.de/> (accessed 14.11.2023).

show uncertainty have also been produced, but, as the studies by prof. Fabrizio Apollonio and his research group have already proved, the use of a colour scale seems to be the most effective technique in this context. Different colour scales, transparencies and/or patterns may be an alternative for colourblind and people who don't properly perceive colours, even though these cases are difficult to standardise and should be treated almost case-by-case (Apollonio, Fallavollita, and Foschi 2021).

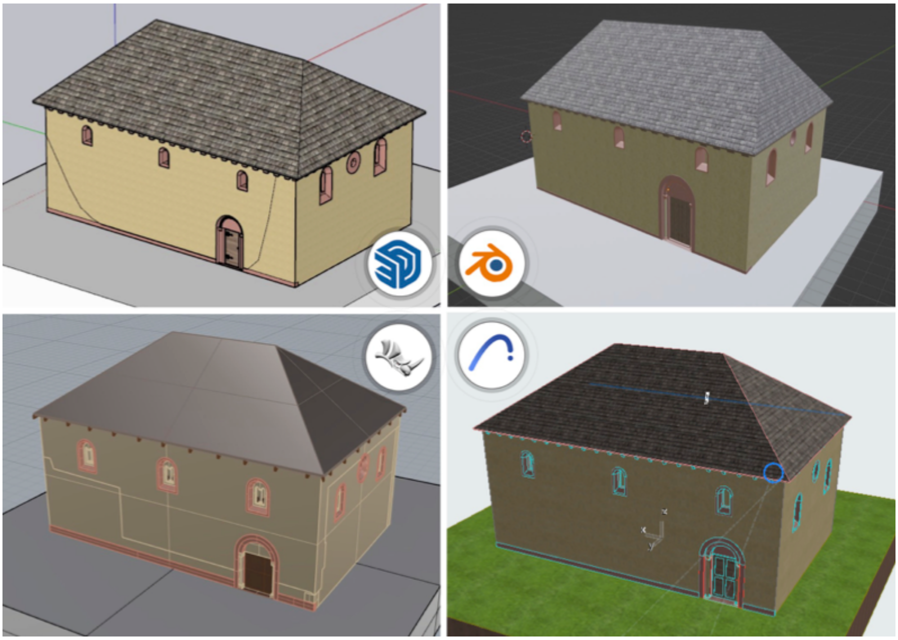


FIG. 82: Virtual reconstruction of the Speyer synagogue in its second Romanesque phase (about 1250), in the context of the project SpSya1250. The different kinds of software that have been used are, from top left clockwise: SketchUp, Blender, Rhinoceros, Archicad.

A.
DESCRIPTION FOR WIKIPEDIA AND WIKIDATA

The following description, written by the author, is being published as a Wikipedia page with the aim of connecting the reconstruction and its metadata to the main sources referring to the reconstructed object on the web. All the hyperlinks have been deliberately maintained.

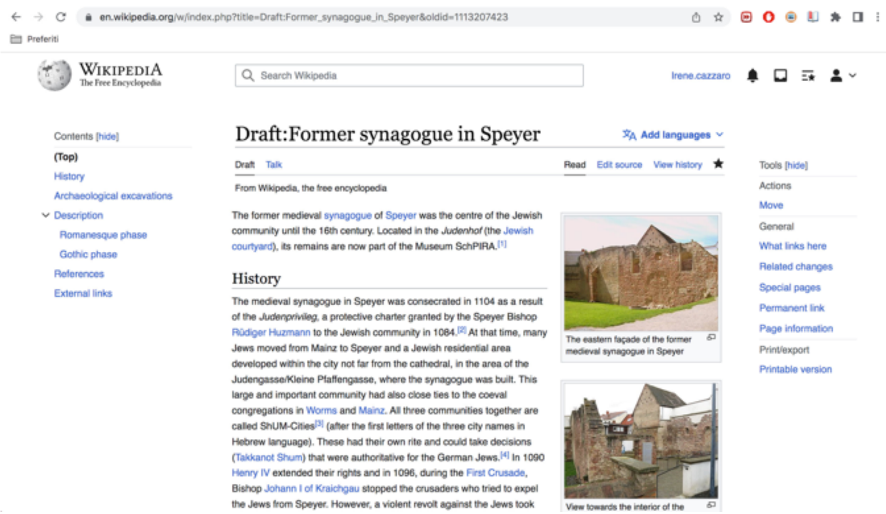


FIG. 83: Screenshot of the Wikipedia page that is under development (accessed 25.01.2023).

Former synagogue in Speyer[3]

The former medieval synagogue of Speyer was the centre of the Jewish community until the 16th century. Located in the *Judenhof* (the Jewish courtyard), its remains are now part of the Museum SchPIRA.[1]

History
The medieval synagogue in Speyer was consecrated in 1104 as a result of the *Judenprivileg*, a protective charter granted by the Speyer Bishop Rüdiger Huzmann to the Jewish community in 1084.[2] At that time,

3 The title proposed for the Wikipedia page is the same already used in the Wikidata page.

many Jews moved from Mainz to Speyer and a Jewish residential area developed within the city not far from the cathedral, in the area of the Judengasse/Kleine Pfaffengasse, where the synagogue was built. This large and important community also had close ties to the coeval congregations in Worms and Mainz. All three communities together are called ShUM-Cities[3] (after the first letters of the three city names in Hebrew language). These had their own rite and could take decisions (Takkanot Shum) that were authoritative for the German Jews.[4] In 1090 Henry IV extended their rights and in 1096, during the First Crusade, Bishop Johann I of Kraichgau stopped the crusaders who tried to expel the Jews from Speyer. However, a violent revolt against the Jews took place in 1195 and the synagogue was destroyed. It was rebuilt in the following years in Romanesque style, like the previous one. Only in the second half of the 13th century the Jewish community was again prosperous: in this period, a Gothic women's synagogue was built next to the men's one, which was converted in Gothic style as well. In the following centuries, especially in 1282, 1343 and from 1435, there were other persecutions (pogroms) against the Jews and by 1500 only a small number of Jews still lived in Speyer. After the dissolution of the Jewish community, in the early 16th century, the area fell into municipal ownership and the synagogue was converted into an armory. In 1689, when the whole city of Speyer was destroyed in the Palatinate War of Succession (in the framework of the Nine Years' War), the former synagogue also fell into ruins.[5]

Archaeological excavations

In 1999 the city of Speyer managed to acquire the synagogue, making it possible to do research on it. An archaeological excavation carried out in the spring of 2001 primarily served to clarify questions about the former interior design and furnishings. The preserved outer walls were partially renovated and could thus be examined in terms of building history. The work was stopped in 2004 and resumed in 2010.[6] On November 19, 2004, the Historical Museum of the Palatinate opened the exhibition „Europas Juden im Mittelalter" („Europe's Jews in the Middle Ages").[7]

The remains of the Speyer synagogue are still visible, making it one of the best preserved synagogues of the 12th century in Europe. The perimeter walls are partially standing, whereas the roof is completely destroyed. The two windows on the western façade are copies of the original ones, now preserved in the nearby Judenhof museum. Those windows are part of the second construction phase that took place after 1195. A portal was situated on the northern wall. On the eastern façade the remains of an arch that was part of the Torah ark are still visible. The two windows located above it were replaced with higher ones during the reconstruction in Gothic style after 1250.[8] We can thus recognize two construction phases: the Romanesque and the Gothic one.

Romanesque phase
The synagogue, consecrated in 1104, was a hall building with a barrel-vaulted niche protruding to the east by a little more than the thickness of the wall. Large parts of the walls of this first building have been preserved to this day. In the eastern wall, a layer of fire, which can be traced back to 1195, shows the upper end of the masonry built up to 1104. The western wall of the synagogue had been rebuilt after the destruction in 1195. The Christians who had to rebuild the synagogue after 1195 evidently used the existing building material and also put the windows from 1104 back into the masonry. The windows, consisting of two coupled round arches, were removed in 1899 and kept in the Historical Museum of the Palatinate. Only a small amount of masonry has survived from the north and south facades, so that there are no findings related to windows and doors. The Romanesque entrance must have been on the northern side. The fact that the synagogue was probably plastered was shown by small remains of plaster that could be found on the exterior. The design of the interior turned out to be much more complicated, because here meaningful findings in the rising were hardly preserved. The location of the bimah was identified in the middle of the room in the archaeological findings as a defect in the Romanesque sandstone slab floor. The original extent of the Torah niche could only be seen in outline on the rising masonry.[9]

Gothic phase
Around the middle of the 13th century, a brick women's synagogue was added to the southern wall of the men's synagogue, following the example of Worms, where a separate synagogue for women was built in 1212-13. Around the same time, the men's synagogue was also renovated in Gothic forms. The eastern wall received a large round window with a trefoil tracery above the Romanesque oculus. The smaller Romanesque windows that were probably originally present on the right and left of the round windows were replaced by larger Gothic ones, whose upper end is not preserved. Six listening slots were installed in the southern wall towards the women's synagogue, through which the women could follow the men's service acoustically. Two of them are still preserved. In the first construction phase, the eastern facade of the women's synagogue had a high-lying window with a round arch in the middle

of the wall. This is bricked up, nothing of the walls is visible. There were two entrances on the west side, one of which led into a small courtyard and the other directly to the outside. Both entrances are clogged today. Similar to the Romanesque building phases, the finds on the interior decoration are only sparse. As in the women's synagogue, the men were also given brick benches, which have been preserved in a very fragmented form. The Torah shrine was probably redesigned in Gothic forms. Whether the bimah was also renewed was not clear from the findings. In the women's synagogue, large parts of the brick bench are still well preserved. It originally ran along the northern, eastern and southern walls. The women's synagogue received a vault in 1349. The window in the central axis was bricked up and replaced by two new, tall, rectangular windows divided by mullions. Two fragments of a keystone, which, however, did not fit directly together, and several vault ribs were found during the excavations.[10]

References
[1] "Museum SchPIRA_Stadt Speyer". Retrieved 7 June 2022.
[2] Heberer, Pia (2004). "Die mittelalterliche Synagoge in Speyer, Bauforschung und Rekonstruktion". Europas Juden im Mittelalter. Ausst.-Kat. Speyer (in German): 77–81.
[3] "ShUM-Sites Speyer, Worms, Mainz". Schum-Städte. Retrieved 4 July 2022.
[4] "Speyer (Rheinland-Pfalz) Mittelalterliche Judengasse - Synagoge und Judenbad". Alemannia Judaica. Retrieved 4 July 2022.
[5] Museum SchPIRA. "Mittelalterliche Synagoge". https://nat.museum-digital.de/index.php?t=objekt&oges=51446. Retrieved 30 June 2022. {{cite web}}: External link in |website= (help)
[6] Heberer, Pia (2010). ""... war gezieret an den getünchten Mauern mit Gemählden". Die Synagoge in Speyer". Befund und Rekonstruktion (22): 182.
[7] Europas Juden im Mittelalter. Ausst.-Kat. Speyer (in German). Hatje Cantz Verlag. 2004. ISBN 978-3775791908.
[8] Preißler, Matthias (2013). Die SchUM-Städte Speyer - Worms - Mainz. Schnell & Steiner. p. 34.
[9] Heberer, Pia (2010). ""... war gezieret an den getünchten Mauern mit Gemählden". Die Synagoge in Speyer". Befund und Rekonstruktion (22): 182.
[10] Heberer, Pia (2010). ""... war gezieret an den getünchten Mauern mit Gemählden". Die Synagoge in Speyer". Befund und Rekonstruktion (22):182.

The Wikipedia page will be then linked to the already existing Wikidata entry “Former synagogue in Speyer”[4] (**FIG. 84**).

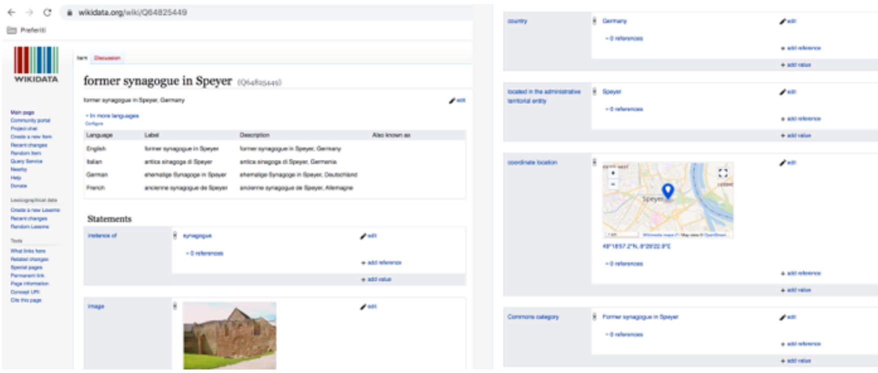


FIG. 84: The already existing Wikidata page about the former synagogue in Speyer.

During on-site analyses and surveys a part of documentation was collected: we especially refer to photographs, drawings extracted from the archaeological reports, findings and related documentation available in the Judenhof museum in Speyer.

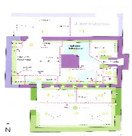
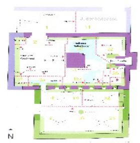
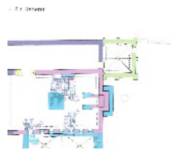
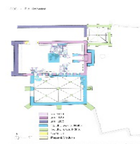
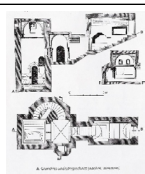
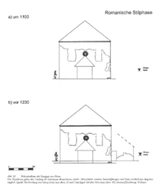
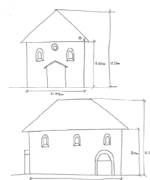
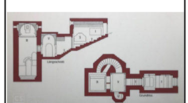
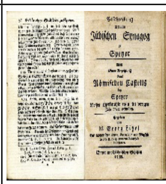
Bibliographic and archival research integrated the collection of sources with written texts and drawings, but also photographs of similar buildings useful for analogies.

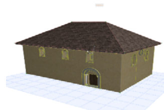
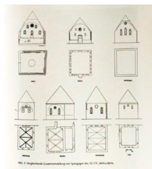
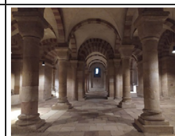
The previous reconstruction by Architectura Virtualis (2004)[5] was also consulted, as well as the documentation related to the reconstruction for the “Digital Urban History Lab” exhibition at Landesmuseum in Mainz (2021)[6], developed by the Institute of Architecture of the Hochschule Mainz under the supervision of Piotr Kuroczyński.

All the collected sources have been grouped into tables and sorted

4 <https://www.wikidata.org/wiki/Q64825449> (accessed 04.11.2024).
5 In cooperation with the University of Darmstadt, for the exhibition „Europas Juden im Mittelalter“ in Speyer. <http://www.architectura-virtualis.de/rekonstruktion/synagogespeyer.php?lang=de&img=0> (accessed 04.11.2024).
6 In cooperation with the General Directorate for Cultural Heritage of Rhineland-Palatinate. <https://architekturinstitut.hs-mainz.de/projects/mainz-worms-speyer> (accessed 04.11.2024).

out according to their nature (photograph, drawing, etc.); we present a selection here and the complete list in Appendix 3.

Photographs				
	All pictures taken by Irene Cazzaro, January 2021			
Archaeological reports				
	On-site information	After the 2000-2001 archaeological excavations	From the book „Die SchUM-Gemeinden Speyer, Worms, Mainz“	From the book „Die SchUM-Gemeinden Speyer, Worms, Mainz“
Drawings				
	Floss 2005	Engels 2001	AI Mainz archive	On-site information
Written texts				
	Litzel 1759	Porsche 2003	Heberer 2012	Pia Heberer and Ursula Reuter (eds.), 2013

Previous recon-structions		 		
	Banner in the building location (*Architectura Virtualis*)	Recon-struction by *Architectura Virtualis*	Model for animation, AI Mainz	Model for 3D printing, AI Mainz
Analogies				
	Eastern portal of the Mainz cathe-dral	Portal of the Worms syna-gogue	Structure of medieval Ger-man synago-gues	Crypt of the Speyer cathe-dral

The proposed methodology, which leads to the creation of a "scientific reference model" (Kuroczyński et al. 2023)[7], starts therefore with the identification of the object to be reconstructed and the collection of the related sources.

At this point, based on the documents that have been found and to the level of detail we want to reach, the structure of the model has to be accurately defined: its semantic segmentation into a hierarchy of elements will be at the basis of the scientific documentation of the reconstruction and of the process that led to it.

Similarly, during these initial stages, texturing (i.e. issues related to the visualisation of the materials that are assumed to compose the object) has to be considered, together with context, that is whether – and, in case,

---

7 The paper S*cientific reference model – defining standards, methodology and implementation of serious 3D models in archaeology, art and architecture history* by P. Kuroczyński, F. I. Apollonio, I.P. Bajena and I. Cazzaro, has been presented in the conference CIPA 2023 *Documenting, Understanding, Preserving Cultural Heritage* – Florence, June 25-30, 2023.

how – to represent the surroundings and whether there are elements that are excluded from the reconstruction.

It is important to use a controlled vocabulary when defining the elements and the relationships between them: in this case, the Art & Architecture Thesaurus Online developed by the Getty Research Institute[8] has been employed. The synagogue has been structured into a 3-level hierarchy (categories, elements, types) as explained in **FIG. 85**.

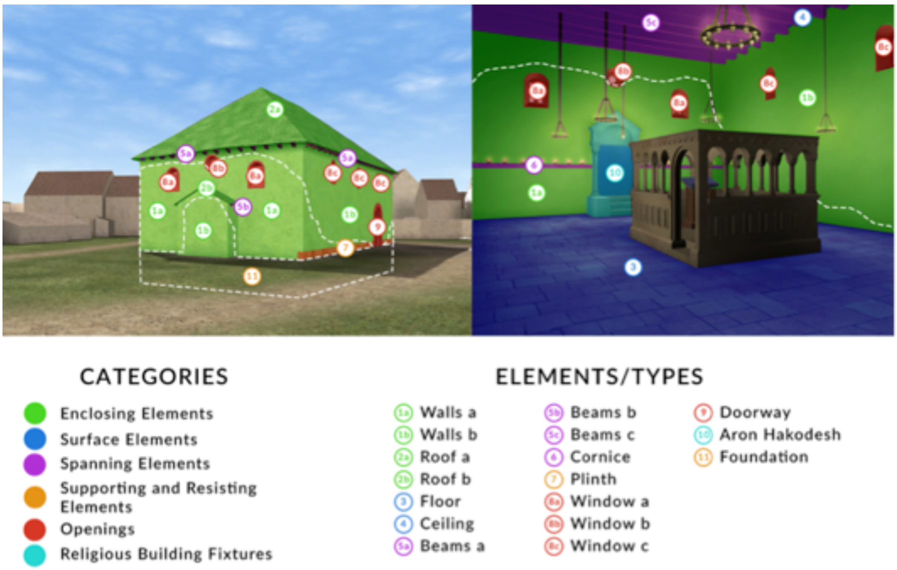


FIG. 85: Applying different structural categories to the building and identification of the types of structural elements. Visualisation by Igor Bajena.

8 <http://www.getty.edu/research/tools/vocabularies/aat/> (accessed 04.11.2024).

B.
PROPOSAL OF A METHOD TO DECLARE UNCERTAINTY

The need for clear documentation of the uncertainty level in the reconstruction of the Speyer synagogue had already been expressed (Heberer 2012)[9]:

> «In the course of the processing, it was repeatedly discussed whether and – if so – how the viewer can be informed about how far the reconstruction is secure and where more or less daring hypotheses begin. It seemed urgently necessary, at least on the behalf of the researchers, to find a way of differentiation. However, the demand for an atmospheric [photorealistic] model left little room for manoeuvre. As a result, Architectura Virtualis suggested superimposing the images of the current situation with those of the reconstruction, so that it becomes clear what is still existing and what is reconstruction [...]. Although this solved one of the problems, there was still no distinction made between the reconstruction secured by sources and the highly hypothetical reconstruction».

In order to declare to which extent the collected documents allow an accurate reconstruction, we propose the use of an uncertainty scale[10] (**FIG. 86**), which has been included in the handout for the reconstruction of the synagogue addressed to scholars, researchers and students who

---

9 Author's translation. Original version: «Im Lauf der Bearbeitung wurde immer wieder diskutiert, ob und – wenn ja – wie dem Betrachter vermittelt werden kann, wie weit die Rekonstruktion gesichert ist, und wo mehr oder weniger gewagte Hypothesen beginnen. Es schien, zumindest von Seiten der Forschenden, dringend notwendig, eine Möglichkeit zur Differenzierung zu finden. Der Anspruch an ein atmosphärisches Modell ließ hier aber kaum Spielraum. Im Ergebnis kam von Architectura Virtualis der Vorschlag, die Bilder der heutigen Situation mit denen der Rekonstruktion zu überblenden, so dass deutlich wird, was Bestand und was Rekonstruktion ist […]. Damit war zwar eines der Probleme gelöst, allerdings war immer noch nicht zwischen der durch Quellen abgesicherten und der stark hypothetischen Rekonstruktion unterschieden» (Heberer 2012).

10 Based on (Apollonio, Fallavollita, and Foschi 2021), as already declared in **CHAPTER II**.

contributed to the project. In our example, the uncertainty level of an element is not attributed according to the nature of the sources that are used (photographs, drawings, written descriptions...), but rather according to the physical (on the object) or mental (on the sources) work we have to do to reconstruct an element, following this classification into four (plus one) levels:

- 4- blue: survey and/or physical analysis of the still existing elements;
- 3- green: deductions or inferences based on sources that are directly related to the object (written texts, drawings, photographs) or on other elements still on site that are similar to the missing ones;
- 2- yellow: analogies based on similar structures or sources, which are not directly related to the analysed building, but they may refer to the same historical period or structural system;
- 1- red: hypotheses concerning the elements for which no sources are available;
- 0- **black**: if necessary, an additional level groups those elements that are not taken into consideration in the uncertainty assessment. This could be the case of the 25x25 m fragment of terrain where the model of the synagogue is situated.

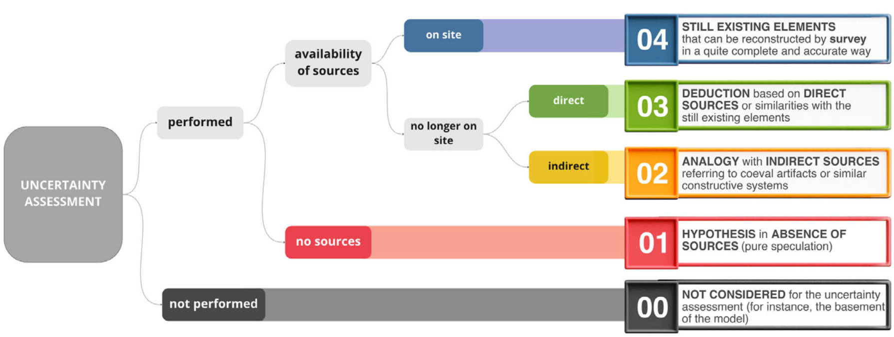


FIG. 86: Simple uncertainty scale elaborated for the models to be uploaded to the DFG viewer. Author's visualisation.

Uncertainty visualisation also depends on the level of detail (geometry) of the model: in the case of the Speyer synagogue, a level of uncertainty is assigned to each element that composes the structure of the model. The only exception is the external wall, which is only partially standing: in this case, a distinction is proposed between the existing part, reconstructed by survey (from the documented still existing remains) and the missing part, reconstructed by inference (assuming that it is similar to the still existing one).

Both a colour and a value are associated with each uncertainty level: if possible[11], the colour should be implemented in the visualisation of the model, the numerical value in the attributes of each element.

C.
APPLICATION AND VALIDATION

The main elements have been identified and modelled. Some documentation sheets have been produced in order to keep track of all the decisions made during the modelling phase.

In particular, for each phase of the activity a screenshot and a short description have been collected. In addition, for each identified element a description of the process was added highlighting the sources that have been used, their uncertainty level and any other useful information for modelling it.

11 Depending on the possibilities of the used software: in the cases here analysed, Rhinoceros doesn't allow the creation of attributes; BIM software such as Archicad have a lot of possibilities as far as attributes are concerned; Sketchup needs an extension for City GML: we will analyse this in **CHAPTER III**.

D.
RESULTS

At the end, the output was uploaded to the DFG repository, where all the metadata and documentation of the process were included (**FIG. 87**), enabling the online publication of the results.

This takes place through an interface where the information about the model (metadata) is entered by the user in pre-formatted fields and the 3D data set is attached.

Some renderings of the model (**FIG. 88**) were also uploaded to Wikimedia Commons and linked to the Wikipedia page that had been created.

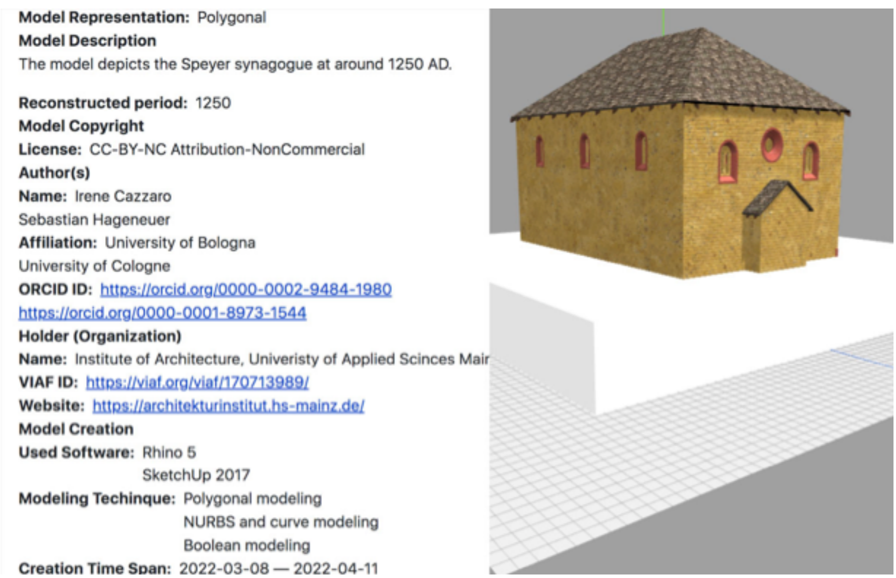


FIG. 87: The model of the Speyer synagogue uploaded to the DFG Repository, with its metadata.

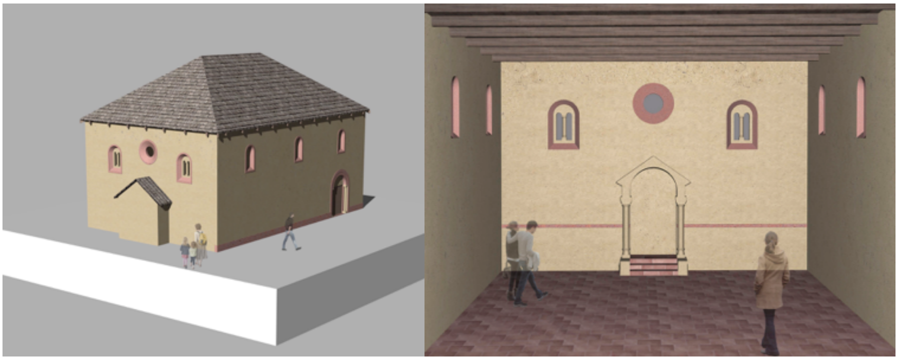


FIG. 88: External and internal view of the synagogue. Renderings uploaded to Wikimedia Commons. Author's visualisations.

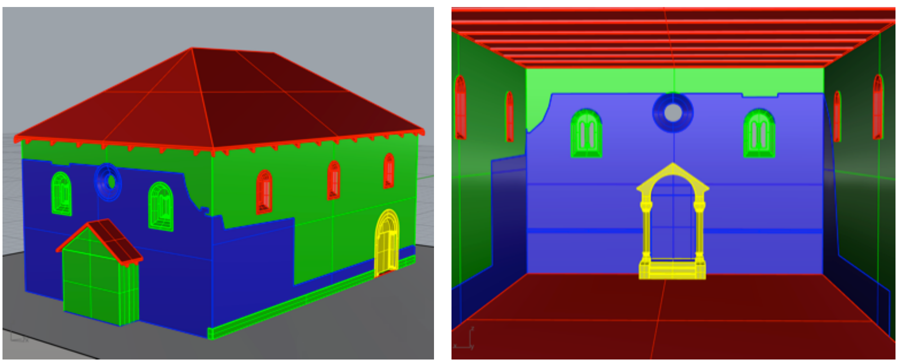


FIG. 89: Application of the uncertainty scale to the exterior and interior of the synagogue. Author's visualisations.

The decisions made during the reconstruction process have been captured by screenshots, so that the entire activity can be retraced step by step. The scientific documentation of the reconstruction process is delivered together with the 3D model in the form of tables – one for each element defined in the semantic segmentation. These tables have been provided as a template, which had to be filled out with the list of sources used for the reconstruction of every element, an evaluation of the level of uncertainty and argumentation in the form of a short text (**FIG. 90**).

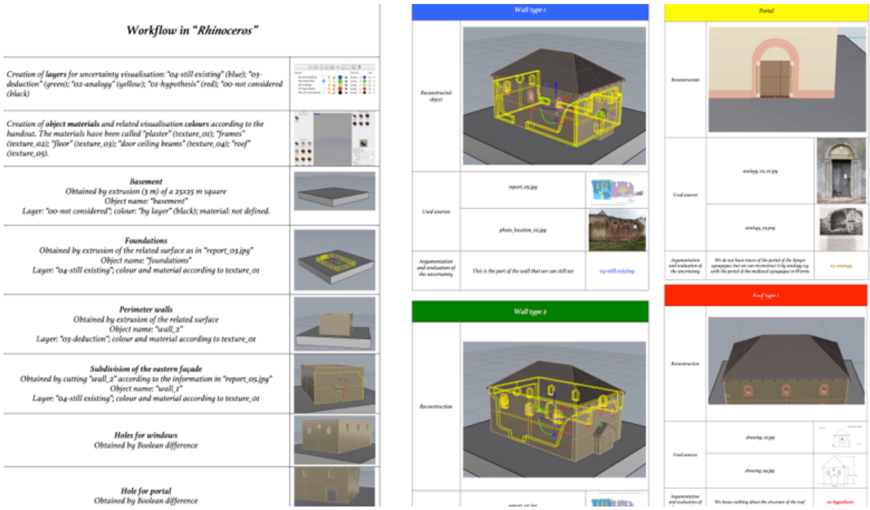


FIG. 90: Tables documenting the reconstruction steps and the choices made to reconstruct every single object as defined in the semantic segmentation. Author's visualisations.

D.1. Uncertainty evaluation in detail

Our uncertainty scale based on 4+1 levels is an extreme simplification of an assessment grounded on multiple factors.

As we saw in **CHAPTER II**, uncertainty can refer to the position of an element, its shape, its texture, its historical period, etc.; it can be assessed by analysing different sources, such as physical remains, pictures, drawings, written texts. It is also connected to the semantic segmentation of the model, thus it depends on its level of detail.

Here we explain how the various elements have been evaluated using a more complex matrix (**FIG. 91**).

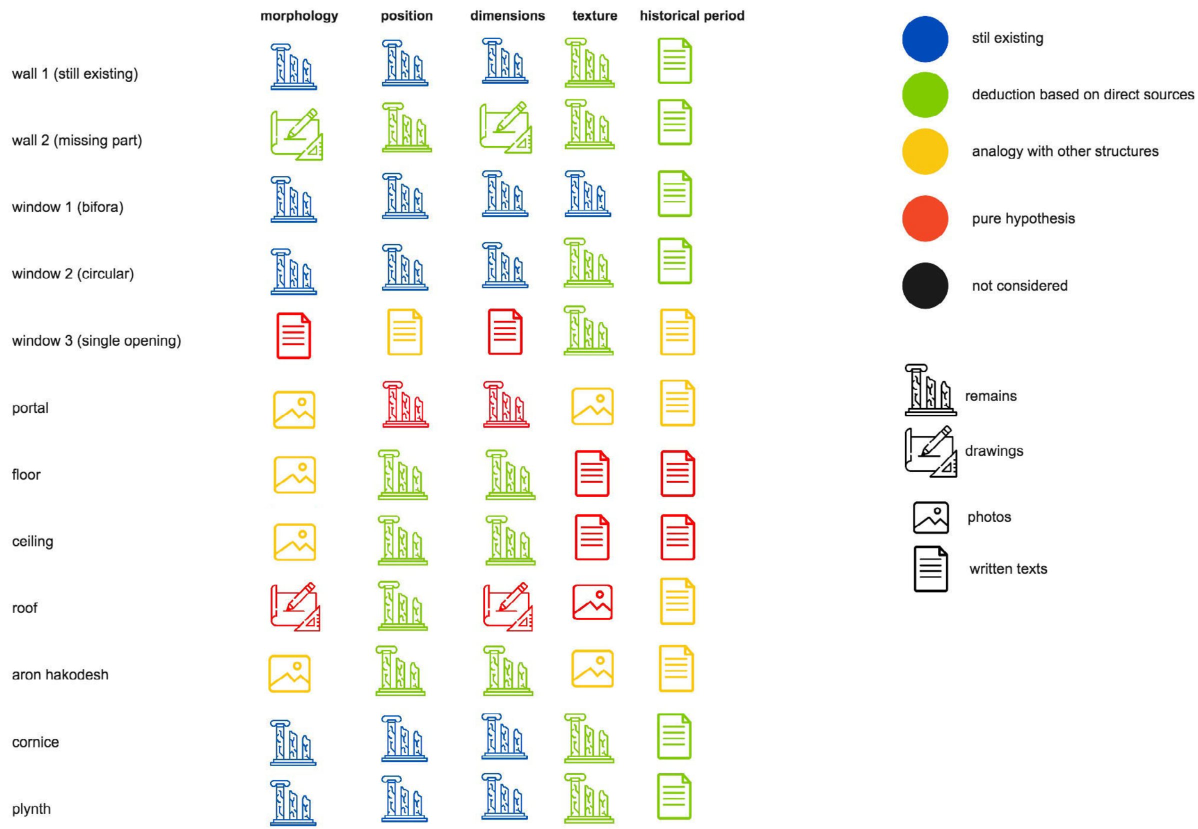
"Wall 1" refers to the part of the perimeter wall that is still on site. Its morphology, position and dimension have been reconstructed starting from the remains themselves. The corresponding uncertainty level is thus "4-still existing". The texture is deduced from some traces of plaster, thus the uncertainty level is "3-deduction". The historical period has the same uncertainty level and is deduced from the archaeological report.

"Wall 2" is the missing part of the wall, whose position is deduced from the remains, as well as the texture. The dimension and shape are found in drawings and reconstructions made starting from the archaeological report. The historical period is also indicated in texts connected to the archaeological excavations. Therefore, all the five parameters belong to the uncertainty level "3-deduction".

"Window 1 (bifora)" is the type of window that we can see in the eastern and western façade. There are four windows of this type and two of them are preserved in the SchPIRA Museum. Thus, in this case we can be sure about their morphology, dimension and texture, but also about their position: the original ones were replaced by copies that occupy the same position. The historical period is deduced from written texts.

"Window 2 (circular)" is still existing, therefore we can be sure about

FIG. 91: Evaluation of uncertainty based on five parameters: morphology, position, dimensions, texture, historical period. Author's visualisation.



morphology, dimension and position. The texture can be deduced from some traces, the historical period from written texts.

"Window 3 (single opening)" is quite hypothetical. The position and historical period can be inferred by analogy from written texts concerning similar buildings, the texture is assumed to be similar to the one of the other windows, but dimension and shape are highly hypothetical: we have some written descriptions that mention the presence of windows on the northern and southern façade, but we don't know them in detail and it is believed that originally they could also have been circular such as "window 2". A variant of the model has been made in order to consider this hypothesis.

"Portal" has been reconstructed starting from images of morphologically similar structures, which have been also used to try to reproduce the texture. The historical period has been retrieved from written texts connected to these examples used for analogies. We don't know its position and dimension in detail: we can try to guess them starting from the archaeological findings, but this remains a hypothesis.

"Floor" and "Ceiling" have been reconstructed with similar operations. We can deduce their position and dimensions in relation to the other elements of the building and their morphology from images of analogous structures, whereas the other features remain hypothetical, as confirmed by the written texts we have.

"Roof" is completely hypothetical for its morphology, texture and dimensions, especially its height. The (hypothetical) sketches and images from the previous reconstruction projects have nonetheless been considered to reconstruct it. Its position is derived from the other elements of the building. The historical period is attributed in analogy with similar structures.

"Aron Hakodesh" can be deduced from foundations and traces on the eastern façade, at least as far as its dimensions and position are concerned. Its morphology and texture is derived from images of similar structures and the historical period from written texts about them, as far as possible.

“Cornice” and “Plynth” still exist in large part and the reconstruction process is analogous to the one described for “Wall 1” and “Window 2 (circular).

The only parameter that remains excluded from the 4-parameter matrix that we have presented is the evaluation of quality according to Thomson et al. (2005). The evaluation, in this case, has been performed separately and applied to the single elements. Four of them, belonging to different uncertainty categories (still existing, by inference, etc.) have been selected and compared in **FIG. 92**.

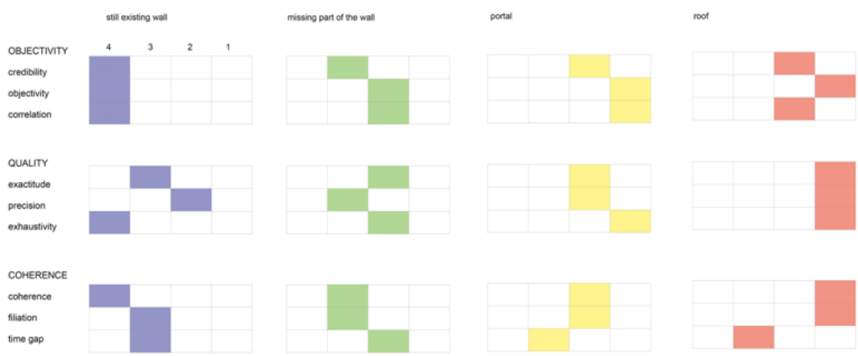


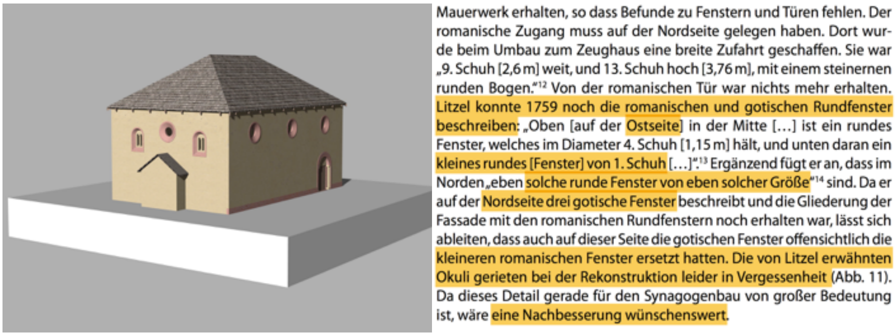
FIG. 92: Uncertainty evaluation based on the assessment of objectivity, quality and coherence parameters, according to Thomson et al. (2005). This evaluation has been performed on four elements belonging to different categories: “still existing”, “reconstructed by inference based on direct sources”, “reconstructed by analogy”, “reconstructed by hypothesis”. Author's visualisation.

D.2.
Second Romanesque phase: a variant with circular windows

A variant with circular windows is proposed to fill the information gap observed by Pia Heberer (2012):

> «The Romanesque entrance must have been on the northern side. A wide driveway was created there during the conversion to the armory. It was «9 feet [2.6 m] wide, and 13 feet high [3.76 m], with a round stone arch». Nothing remains of the Romanesque door. Litzel was able to describe the Romanesque and Gothic round windows in 1759: «Up [on the eastern side] in the middle [...] there is a round window, which has a diameter of 4 feet [1.15 m], and, below it, a small round [window] measuring 1 feet [...]». He also adds that in the north [on the northern façade] there are «exactly such round windows of exactly such size». Since he describes three Gothic windows on the northern side and the structure of the façade with the Romanesque round windows was still preserved, it can be deduced that the Gothic windows had obviously replaced the smaller Romanesque windows on this side as well. Unfortunately, the oculi mentioned by Litzel were forgotten during the reconstruction [by Architectura Virtualis]. Since this detail is of great importance for the synagogue construction, an improvement would be desirable».

This model has also been uploaded to the DFG Repository as a variant of the previous one. It has also been imported into SketchUp, so that a City GML file with uncertainty information could be created. The same has been done for all the structural variants of the synagogue here presented.



Mauerwerk erhalten, so dass Befunde zu Fenstern und Türen fehlen. Der romanische Zugang muss auf der Nordseite gelegen haben. Dort wurde beim Umbau zum Zeughaus eine breite Zufahrt geschaffen. Sie war „9. Schuh [2,6 m] weit, und 13. Schuh hoch [3,76 m], mit einem steinernen runden Bogen."[12] Von der romanischen Tür war nichts mehr erhalten. Litzel konnte 1759 noch die romanischen und gotischen Rundfenster beschreiben: „Oben [auf der Ostseite] in der Mitte [...] ist ein rundes Fenster, welches im Diameter 4. Schuh [1,15 m] hält, und unten daran ein kleines rundes [Fenster] von 1. Schuh [...]".[13] Ergänzend fügt er an, dass im Norden „eben solche runde Fenster von eben solcher Größe"[14] sind. Da er auf der Nordseite drei gotische Fenster beschreibt und die Gliederung der Fassade mit den romanischen Rundfenstern noch erhalten war, lässt sich ableiten, dass auch auf dieser Seite die gotischen Fenster offensichtlich die kleineren romanischen Fenster ersetzt hatten. Die von Litzel erwähnten Okuli gerieten bei der Rekonstruktion leider in Vergessenheit (Abb. 11). Da dieses Detail gerade für den Synagogenbau von großer Bedeutung ist, wäre eine Nachbesserung wünschenswert.

FIG. 93: Variant of the Speyer synagogue with circular windows. Author's visualisation.

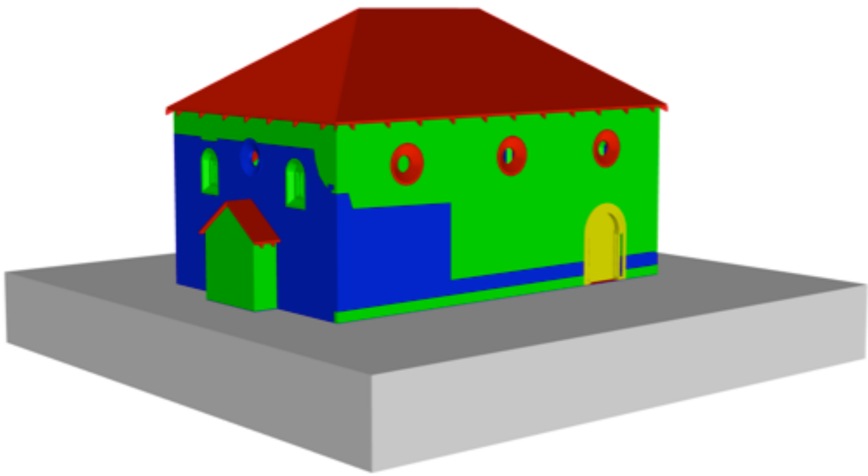


FIG. 94: Variant with circular windows: levels of uncertainty applied using Rhinoceros. The levels of uncertainty are still the same; just the shape of the windows has been changed. Author's visualisation.

D.3.
Gothic phase: the synagogue in 1350

During the Gothic phase, the Frauensynagoge (women's synagogue) was added and connected to the southern façade of the Romanesque building; a lower construction had also been added on the northern façade, where the entrance was supposed to be located.

The roof also had probably changed its shape. This model (**FIG. 95**), uploaded into the DFG Repository, was elaborated with SketchUp, from which the CityGML file was created.

In the SketchUp file the colours to indicate uncertainty have also been included (**FIG. 96**).

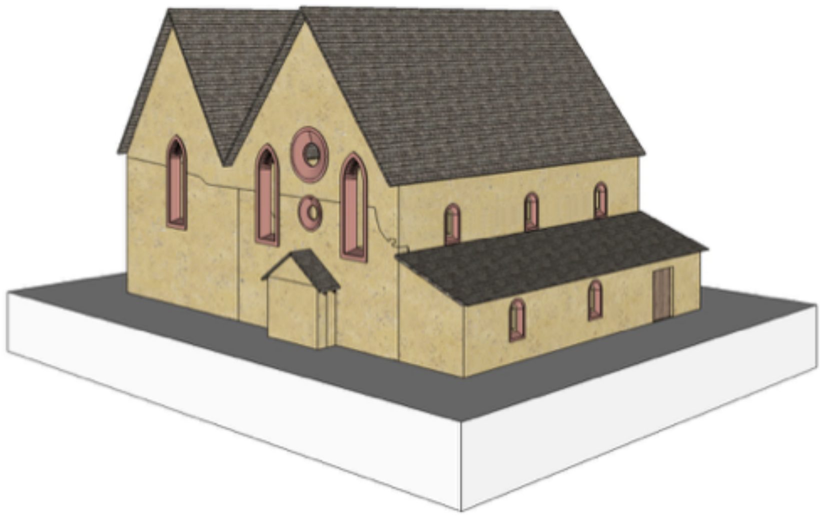


FIG. 95: Variant of the synagogue in its Gothic phase (around 1350). Author's visualisation.

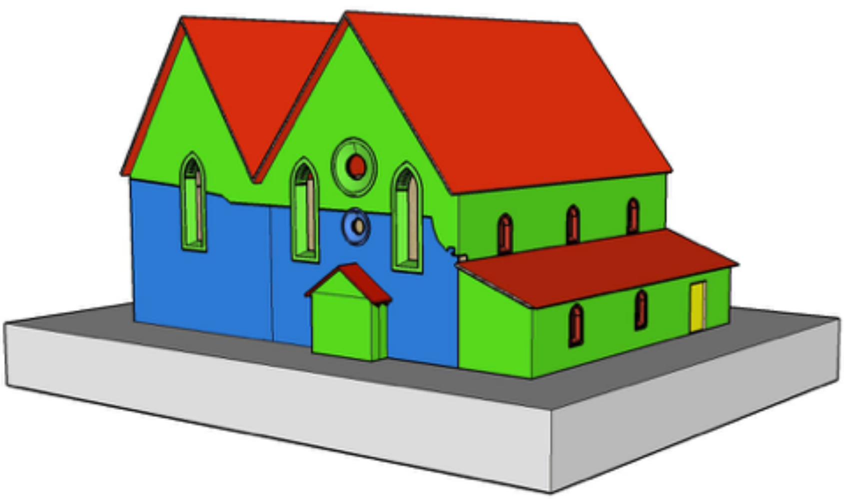
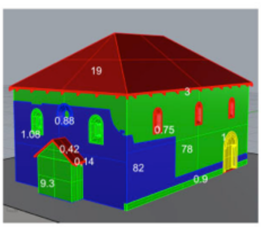


FIG. 96: The uncertainty scale applied to the 1350 Gothic variant using SketchUp. Author's visualisation.

E.
UNCERTAINTY AND LEVEL OF DETAIL

The calculation of the average uncertainty of the model has been performed (**FIG. 97**): this means that at another level of detail (**FIG. 98**) – imagining of putting it into a larger model of the city of Speyer where buildings are reconstructed at LOD 1 or 2, without closures – its average uncertainty would be 3.

This is why we should also consider the level of uncertainty in relation to the LOD. According to the semantic segmentation of the model, we can apply the parameter of uncertainty at different levels, also to a more detailed one, even though the portal here below (**FIG. 99**) is just an example and we don't have accurate sources that allow us to work at this level: from a scientific point of view, this would be a nonsense.



HYPOTHESIS
(19+0.42+3+0.14+0.75*6)*1 = 27.06

ANALOGY
1*2 = 2

DEDUCTION
(78+9.3+0.9+1.08*2)*3 = 271.08

STILL EXISTING
(82+0.88*2+1.08*2)*4 = 343.68

hypothesis + analogy + deduction + still existing = 643.82

total volume = 204.34 m^3

weighted average = 643.82 / 204.34 = **3.15**

FIG. 97: Calculation of the average uncertainty for the model of the Speyer synagogue. Author's visualisation.

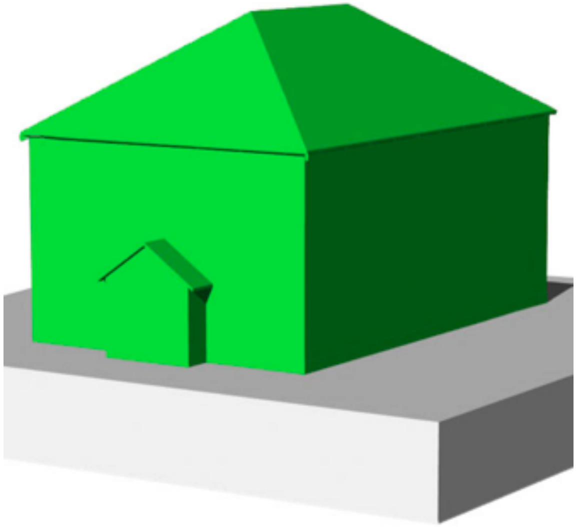


FIG. 98: At LOD 1 or 2, we would consider the (average) uncertainty level of the entire building, without differentiating it according to its elements. In this case, the average uncertainty level would be 3. Author's visualisation.

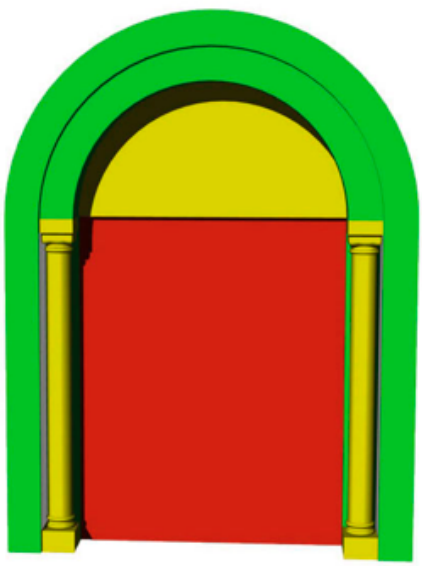


FIG. 99: If we imagine working at the detail of the single element, in this case the portal, a further subdivision into parts is probably necessary: in this case, we would indicate the level of uncertainty of each single sub-element. This visualisation is a pure example: the sources that we have to reconstruct the portal don't allow reasoning at this level. Author's visualisation.

F.
UNCERTAINTY VISUALISATION VARIANTS

In the previous part of the study we have focused on the visualisation scheme that seems to be the most effective one to graphically keep track of uncertainty; here we take into account a number of visual variants, sometimes to prove that the chosen scale works better, sometimes to propose alternatives that may be useful on particular occasions.

F.1.
Recognisability of the used colours

In the handout for the SpSya1250 reconstruction, we defined precise RGB colours in order to avoid misunderstandings; however, the scale should remain, to some extents, flexible and allow variations in colours, always enabling their recognisability. Here below, the model on the right has been coloured according to the scale by Apollonio et al. (2021); still we can recognise red, yellow, green and blue and we can say that the scale is almost analogous to the one used for the model on the left.

F.2.
A colourblind-safe variant

The colour scheme previously found on the ColourBrewer has been used here to generate a visualisation variant for colourblind people. Among the colourblind-safe schemes, this was the closest one to the scale we have proposed.

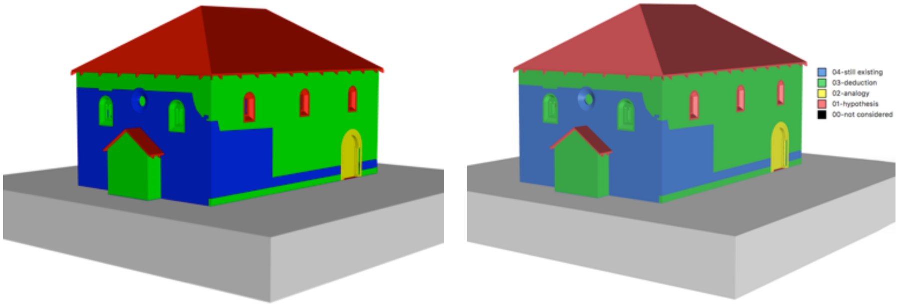


FIG. 100: On the left: the model with the “pure” RGB colours identified in the handout. Variations, however, may be possible. In the model on the right, the colours are still perceived as blue-green-yellow-red. These have been taken from the colour scale by Apollonio et al. (2021). Author's visualisations.

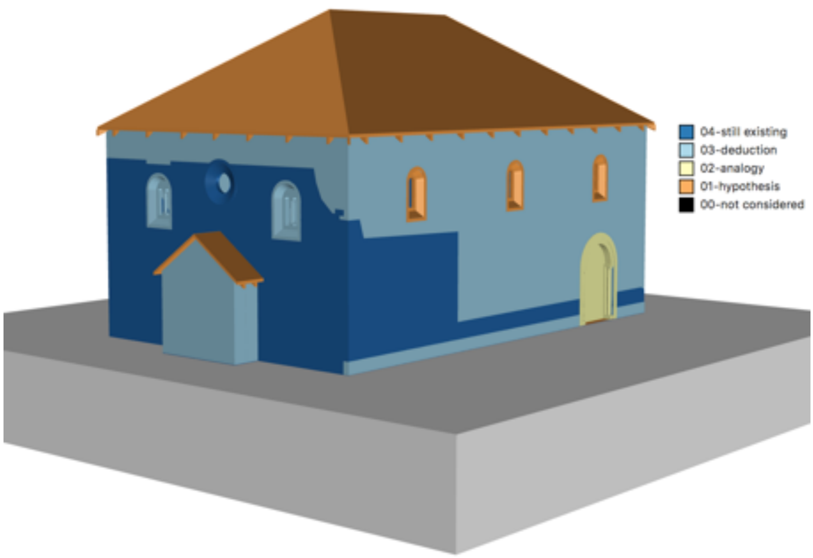


FIG. 101: A colourblind-safe uncertainty scale according to the ColorBrewer by Cynthia Brewer. Here the four colours used in the previous visualisations have been replaced by the series “blue”, “light blue”, “yellow”, “orange”. Author's visualisation.

F.3. Different degrees of lightness

Greyscale may be used, as an example, in all the cases in which colour printing is not available. However, shading generates the problems that we can clearly observe on the roof: according to the orientation, two different shades of grey are perceived.

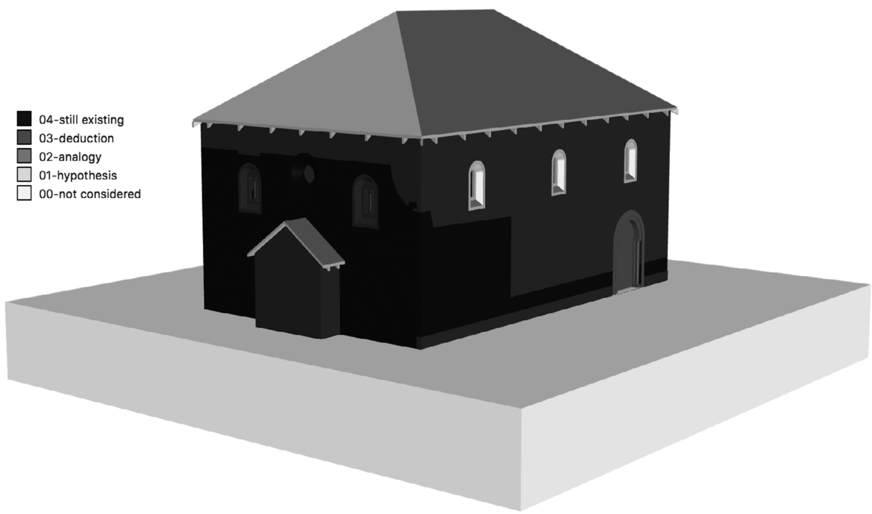


FIG. 102: Adoption of a scale based on the variation in lightness from black to white. Author's visualisation.

F.4. Use of textures

Textures (in this case stripes and dots) together with simple plain colours as black and white can be can already define a four-level scale that may be used, for instance, by people who don't properly perceive colour.

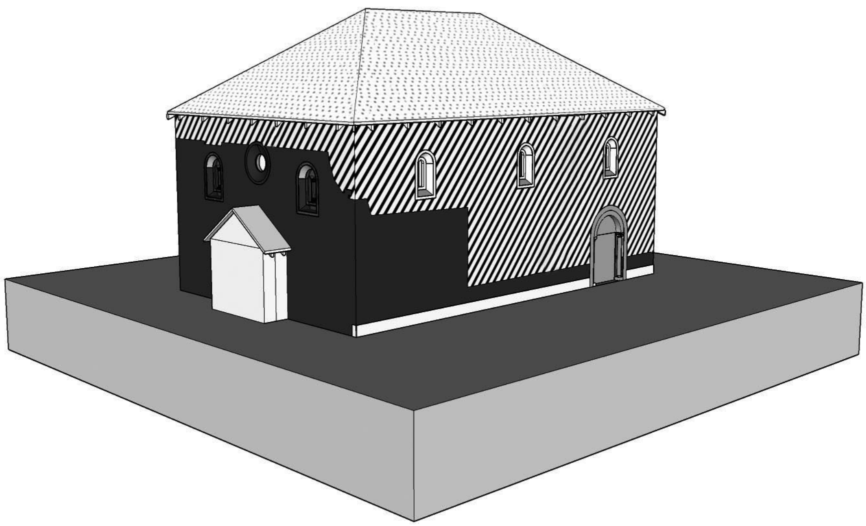


FIG. 103: The application of textures (stripes and dots) besides plain colours may define all the levels of the scale. Author's visualisation.

F.5.
Colours with different lightness

Different shades of red, green and blue may be used. Even in these cases, the problems of the black and white scale are still visible, especially in the difficult distinction between levels 01 and 02.

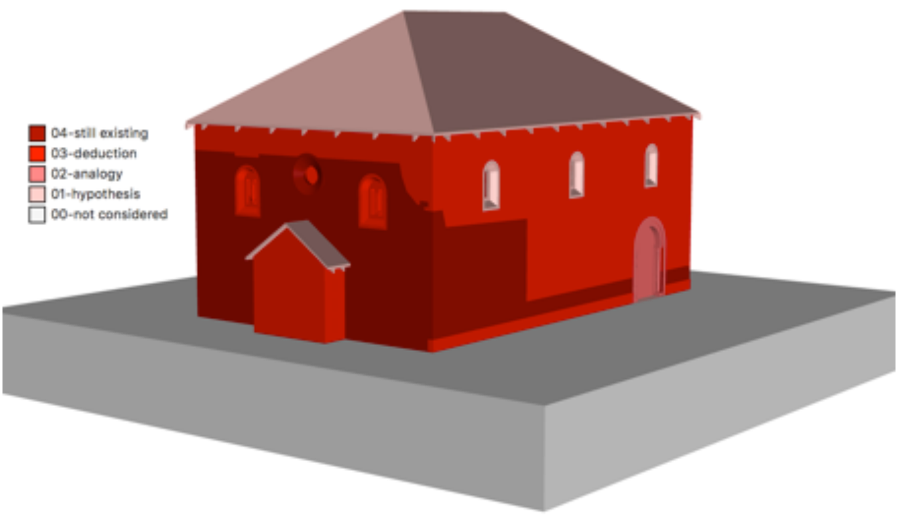


FIG. 104: Adoption of a scale based on the variation in lightness from red to white. Author's visualisation.

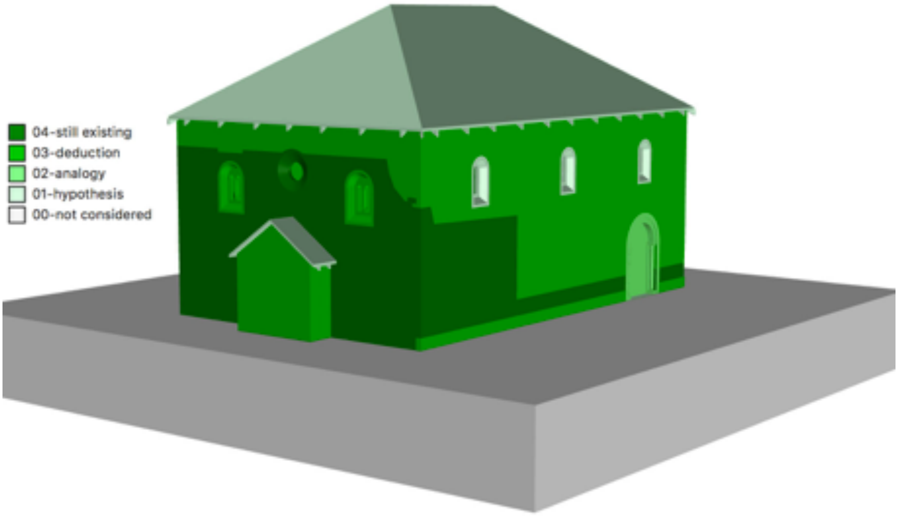


FIG. 105: Adoption of a scale based on the variation in lightness from green to white. Author's visualisation.

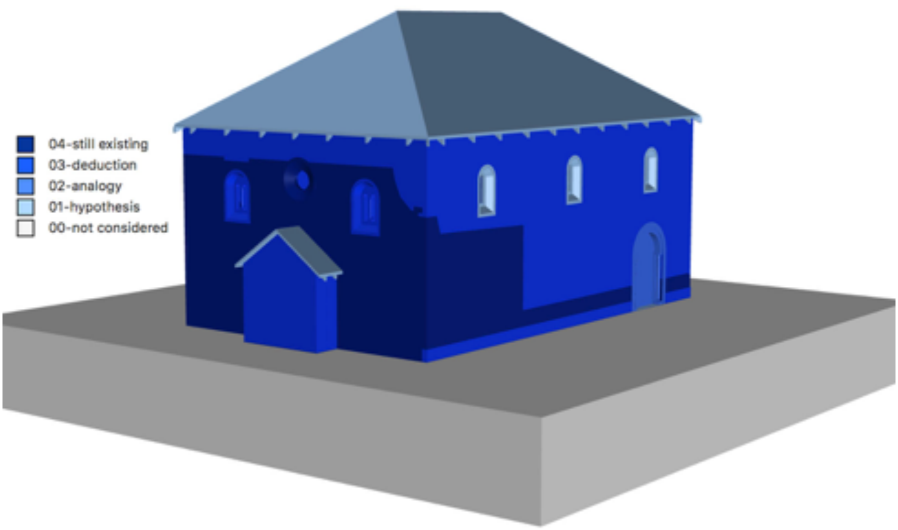


FIG. 106: Adoption of a scale based on the variation in lightness from blue to white. Author's visualisation.

F.6.
Different degrees of transparency

An alternative may also be the use of transparency, but this technique is especially employed when we have to simply distinguish what is reality-based and what is source-based, since we hardly perceive multiple variations in transparency.

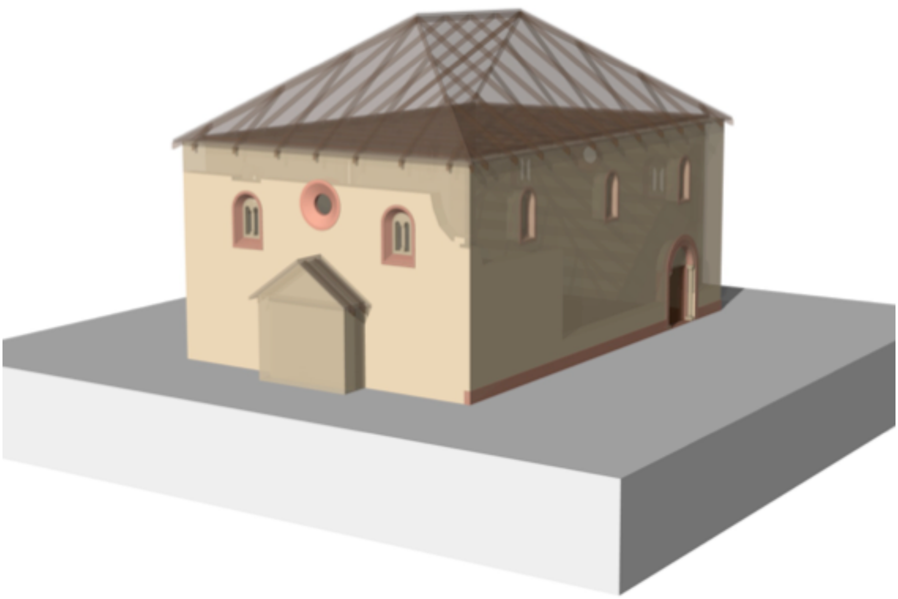


FIG. 107: Uncertainty expressed through different degrees of transparency – as far as they can be distinguished. Author's visualisation.

F.7. Wireframe and transparency

Therefore, if we want to visualise more variations, a combination of different techniques may also be considered.

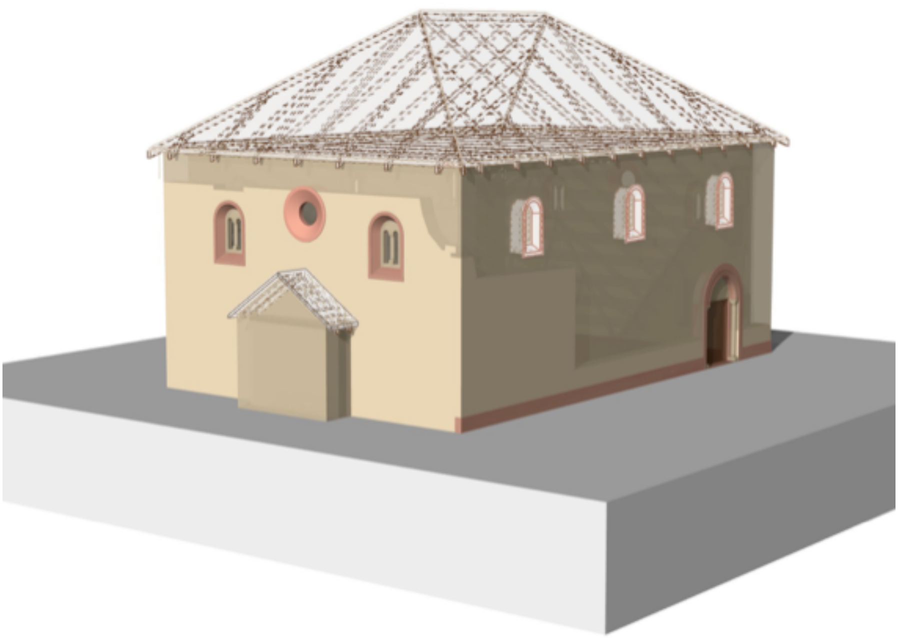


FIG. 108: Combination of opacity, transparency and wireframe to visualise more uncertainty levels. Author's visualisation.

F.8.
Use of a mesh to represent the still existing parts of the building

If we just want to distinguish what is still on site and what has been reconstructed starting from archival sources, a solution would be replacing the still existing elements with their actual (reality-based) mesh obtained by survey.

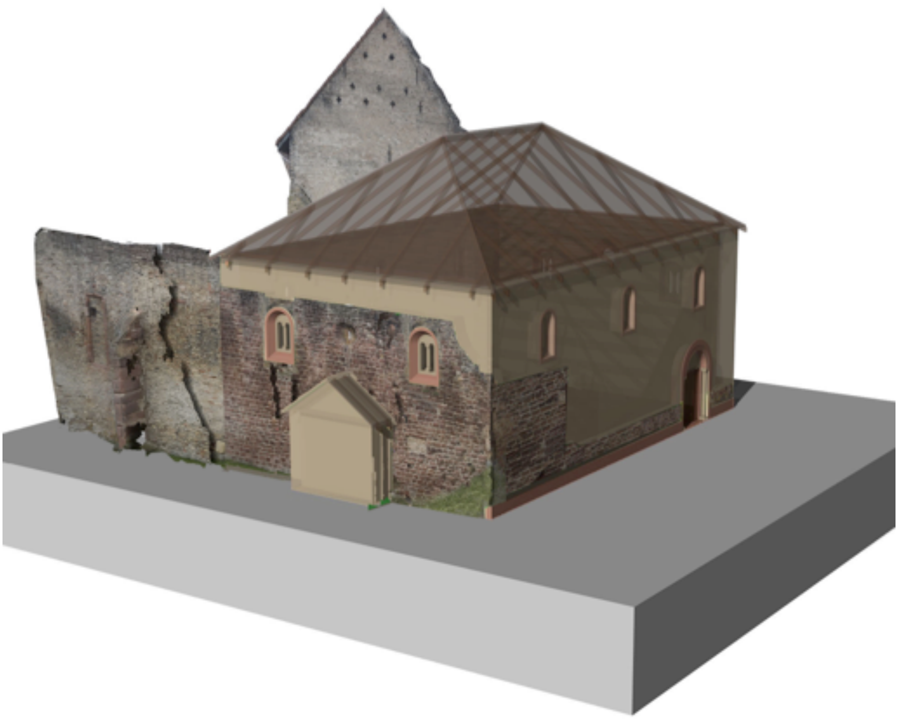


FIG. 109: Mesh produced by prof. Sander Münster and elaborated by the author. The pictures taken by the author have been initially used.

F.9.
Combination of the mesh with the levels of uncertainty

The levels of uncertainty, for the source-based part of the model, can still be indicated by using colours or a combination of the techniques described before.

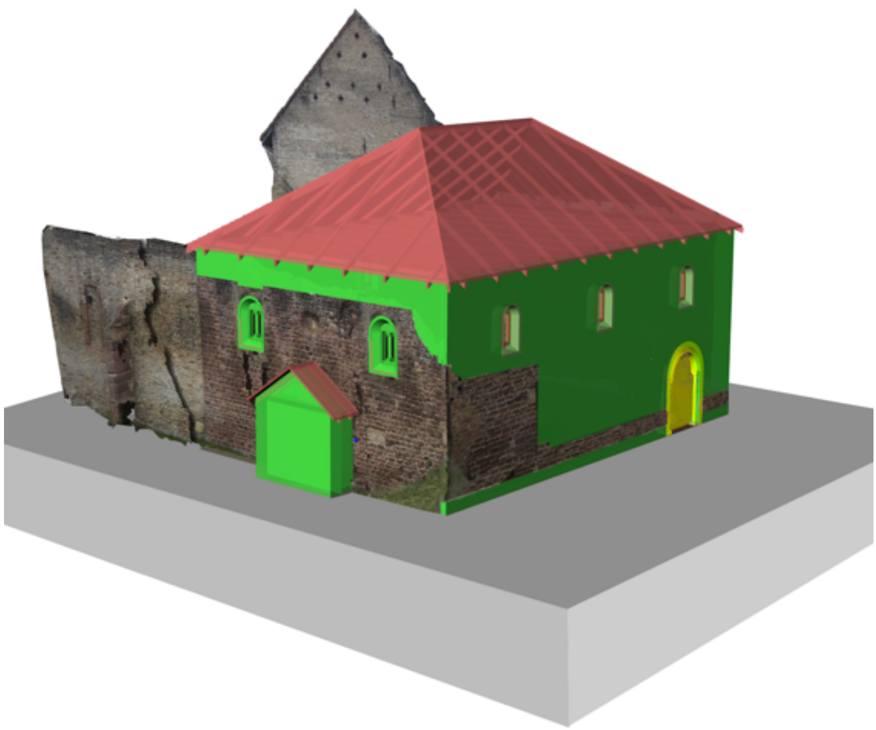


FIG. 110: In this case, the mesh has been used to visualise the still existing parts of the building, whereas a non-photorealistic model with colours indicating the different degrees of uncertainty (according to the scale seen before) represent all the source-based reconstructed elements. Author's visualisation based on the previous figure.

G.
MAKING UNCERTAINTY DATA INTEROPERABLE

We have two problems at this point:

(1) How do we share data about uncertainty? They are only visible in a particular version of Rhinoceros;
(2) Is it possible to share uncertainty data at different levels of detail?

Interoperability is allowed by using standard exchange formats such as IFC (for constructive solid geometry software) or CityGML (for boundary representation software): it is therefore necessary to focus on these standards.

(1) City GML: the model has been imported in SketchUp, so that it was possible to work with the City Editor extension. The uncertainty values were applied at two levels: the entire model and its single parts. At the end, the GML file was saved. When opened with FZK Viewer (free viewer for IFC and City GML files) we see that the information about uncertainty remains at both levels.
(2) IFC: the same can be done starting from Archicad. The work has been done by Igor Bajena in the framework of the SpSya1250 reconstruction project. He added uncertainty values according to the scale here discussed and saved the file in IFC format. Even in this case, when the file is opened with Open IFC Viewer, we can see that uncertainty data remain.

Here is an example of workflow that can be applied to SketchUp using the extension City Editor, allowing to add attributes and to export the file in .gml format.

The screenshots of the operations made on the various elements are shown in the next pages.

G.1.
Romanesque synagogue (1250)

We start the process by attributing, for all the walls, the boundary surface type “wall surface”.

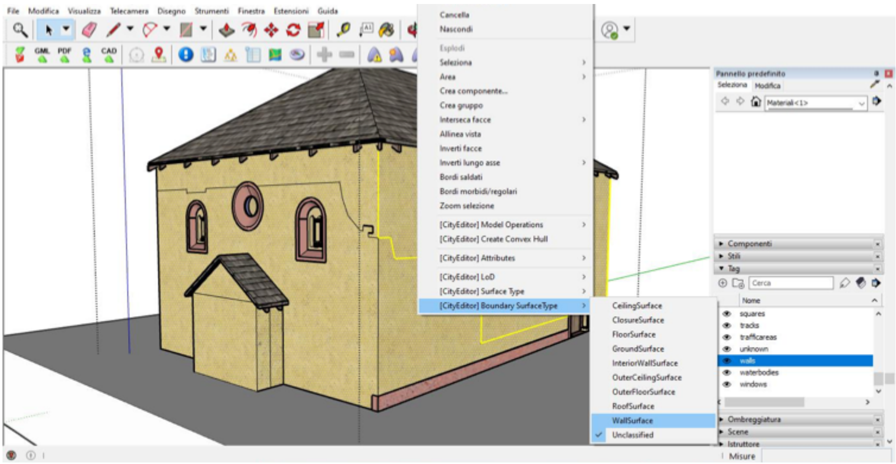


FIG. 111: Attribution of “wall surface” as boundary surface type. Author's visualisation.

Wall 1, which is the still existing part of the wall, has been then specifically identified. The standard attributes “id”, “name”, “date” are added, as well as a generic attribute called “uncertainty level”.

In the field “value”, a value in the range 0-4, according to our uncertainty scale, is entered. In the case of this wall, it corresponds to “4-still existing”.

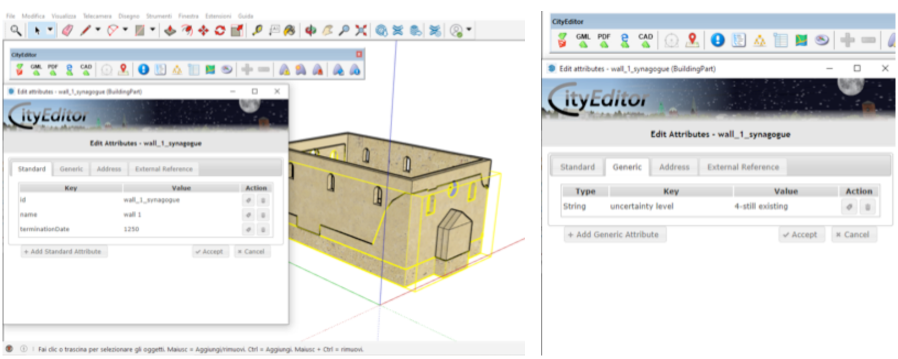


FIG. 112: The attributes related to the still existing part of the wall are added; as a generic attribute, the uncertainty level is also included. Author's visualisation.

The same has been done for all the other elements. Here we can see *Wall 2*, which is the part of the wall that no longer exists. In this case, the uncertainty value is “3-deduction”.

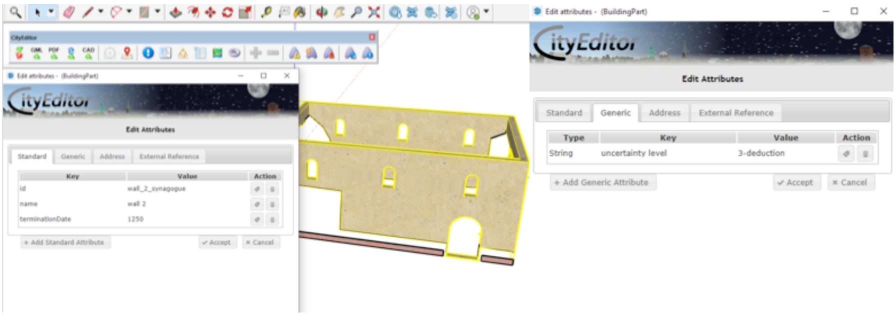


FIG. 113: The same has been done for Wall 2, whose uncertainty level is 3-deduction. Author's visualisation.

The element Roof, as the first thing, was assigned to the boundary surface type “Roof surface”. Then, the usual attributes were added. The uncertainty level is “1-hypothesis”.

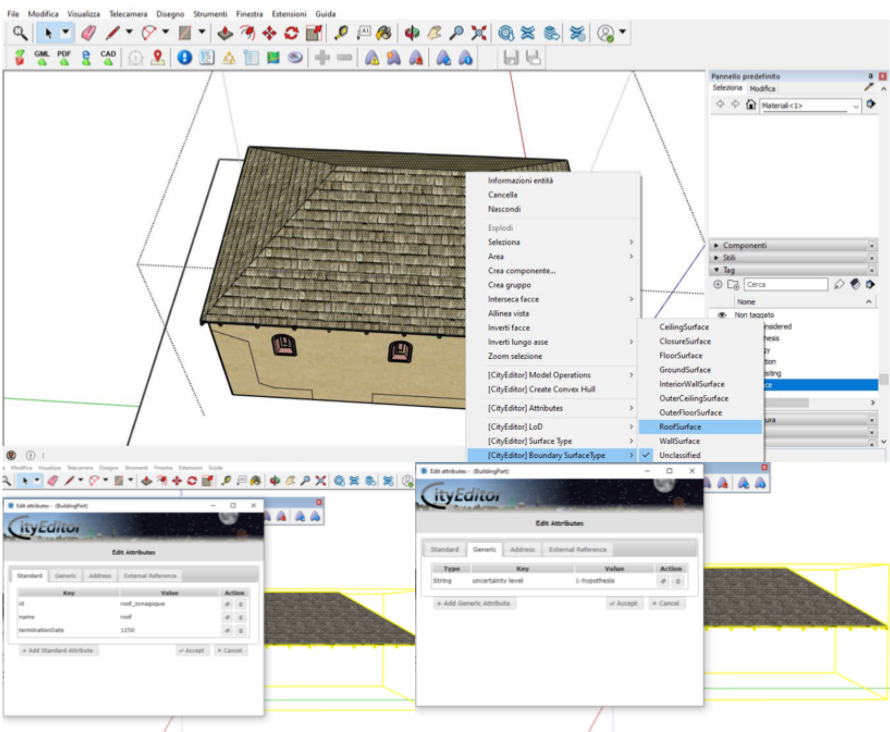


FIG. 114: Attributes were added to the roof in the same way. Here the uncertainty level is “1-hypothesis”. Author's visualisation.

The *windows*, together with the portal, have been selected and identified as “closure surface”. The attributes were then added. Here the uncertainty levels are multiple: “4-still existing” for the oculi, “3-deduction” for the windows on the eastern and western façades, “2-analogy” for the portal, “1-hypothesis” for the windows on the northern and southern façades. For all the other elements of the reconstruction the process has been repeated. We show here just some other examples.

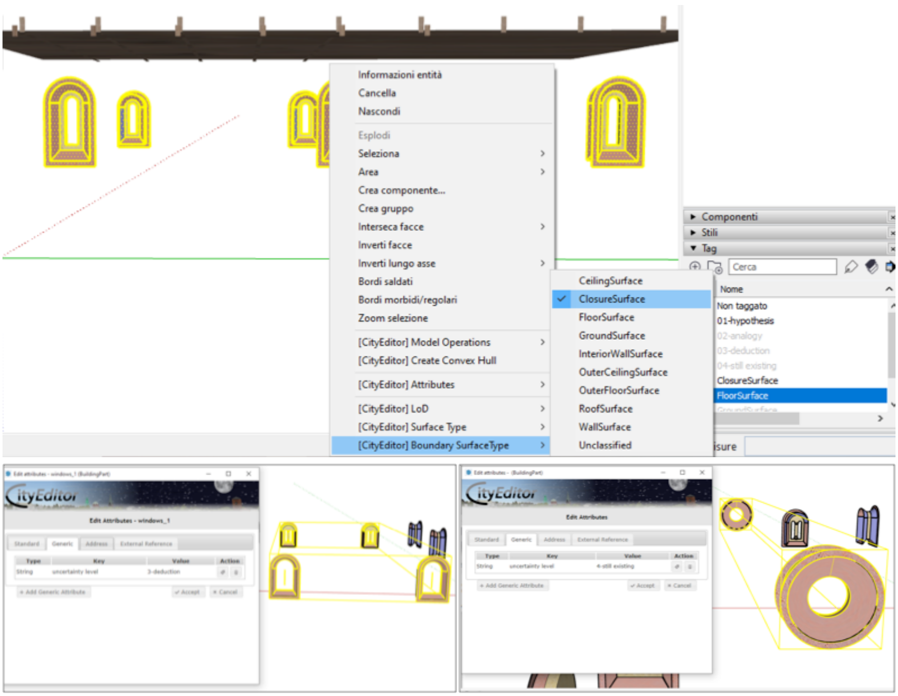


FIG. 115: Attributes are added to closure surfaces. Author's visualisation.

The same operations have also been performed on the variant with circular windows. The type of window is the same as the two oculi in the eastern and western façades.

The land on which the building is situated has been identified and the uncertainty level “0-not considered” has been attributed to it.

At the end, the entire model has been identified as a “building” (the elements seen before were indicated as “building parts”).

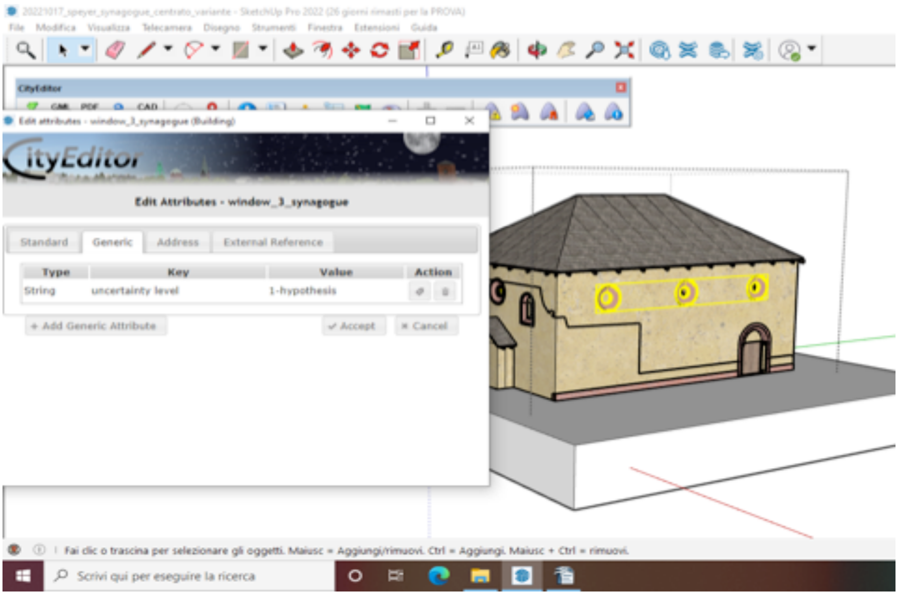


FIG. 116: Attributes are added to the variant with circular windows. Author's visualisation.

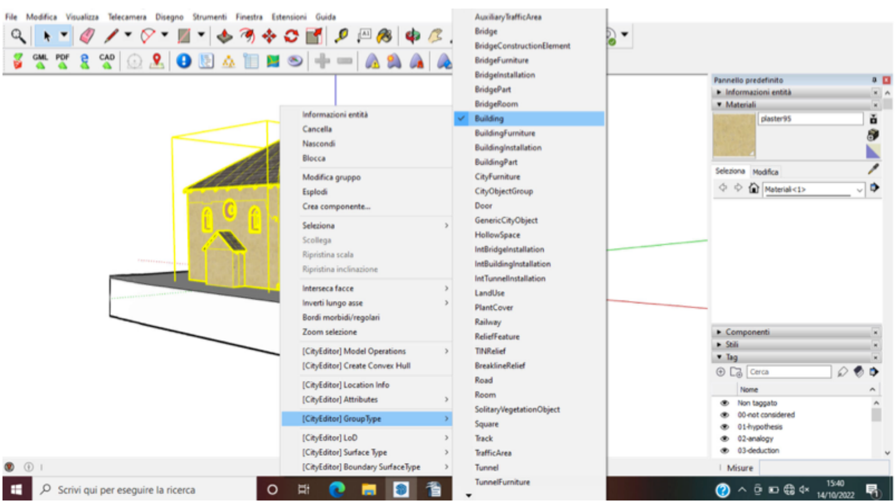


FIG. 117: The attributes are applied to the entire building, at another level of the hierarchy. Author's visualisation.

Similarly to building parts, standard attributes have been added to the whole building.

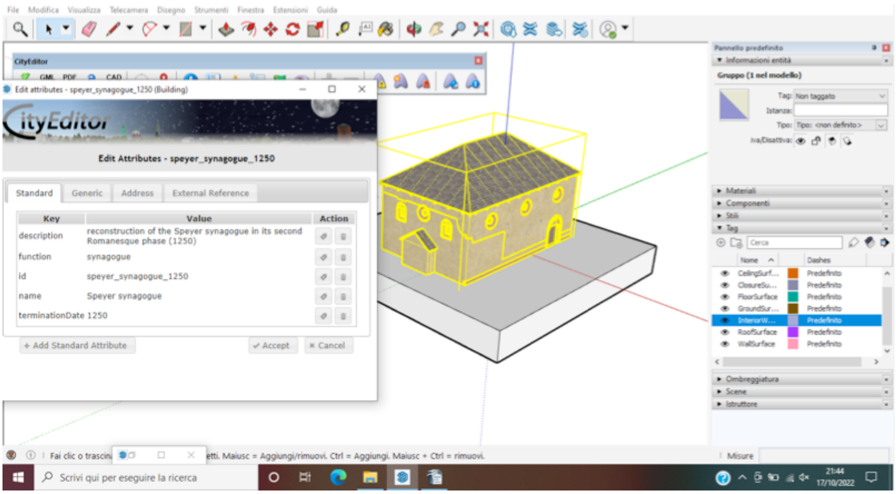


FIG. 118: The attributes are applied to the entire building, at another level of the hierarchy. Author's visualisation.

The average uncertainty level referring to the entire building has been added too, thus we have the information about uncertainty at two levels of the hierarchy.

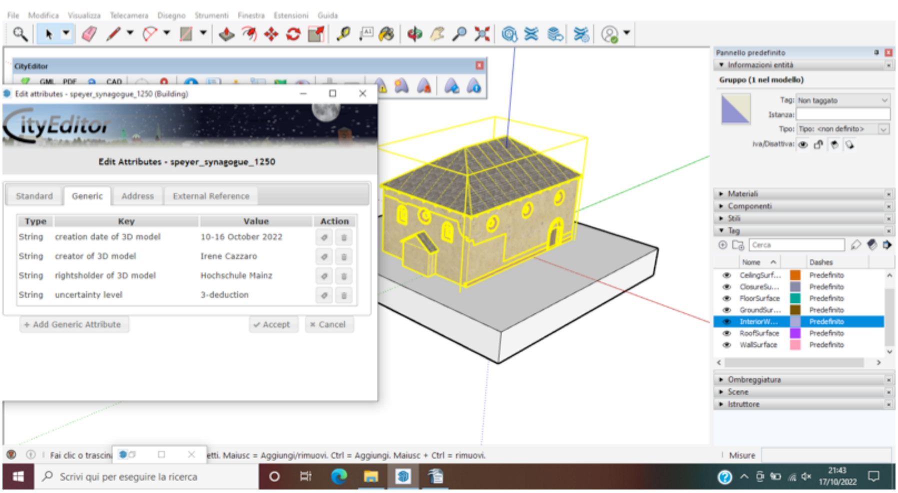


FIG. 119: The attributes are applied to the entire building, at another level of the hierarchy. Author's visualisation.

The model has been finally exported in CityGML format.

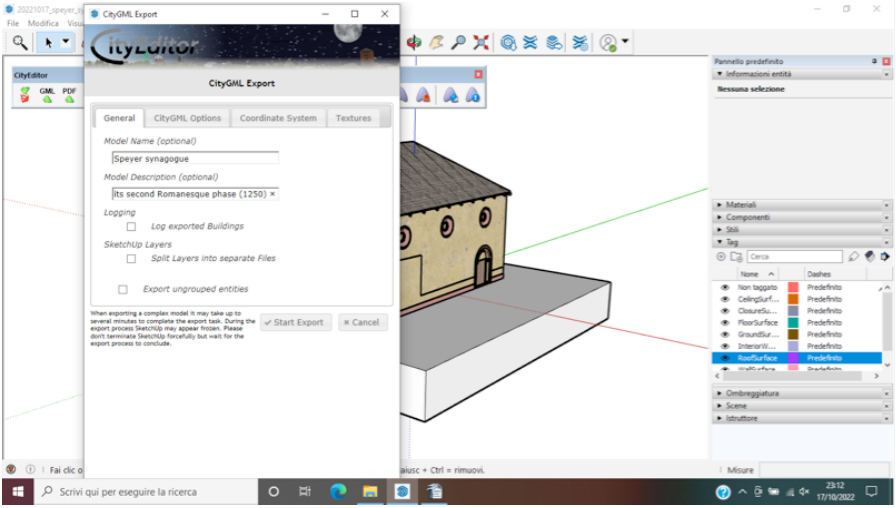


FIG. 120: The CityGML export. Author's visualisation.

When opened with FZK Viewer, a free viewer for IFC and CityGML files, we can observe that all the added properties are preserved, at both levels of the hierarchy: the entire building and the single elements. Some examples are shown here below.

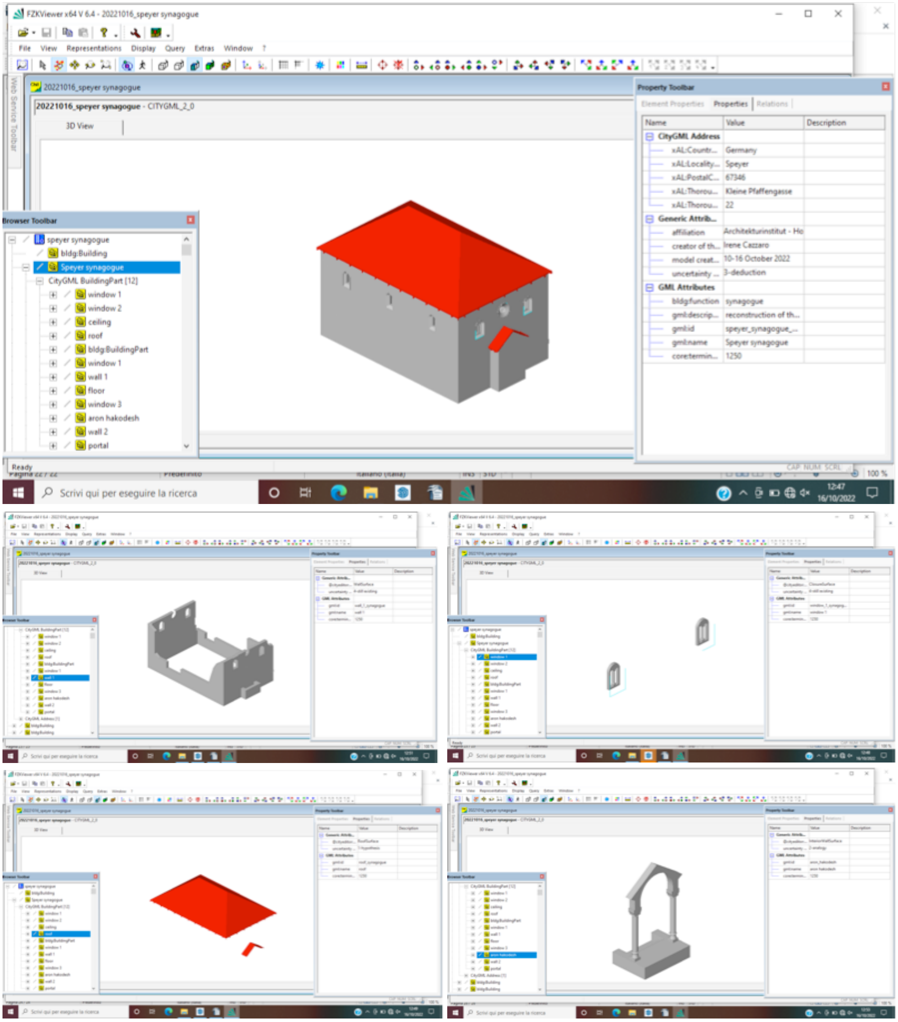


FIG. 121: Visualisation of the model and of some elements that compose it, together with the assigned attributes, in FZK Viewer. Author's visualisation.

The variant with circular windows has also been saved in GML format and opened with FZK Viewer, confirming that all the data added with CityEditor are accessible.

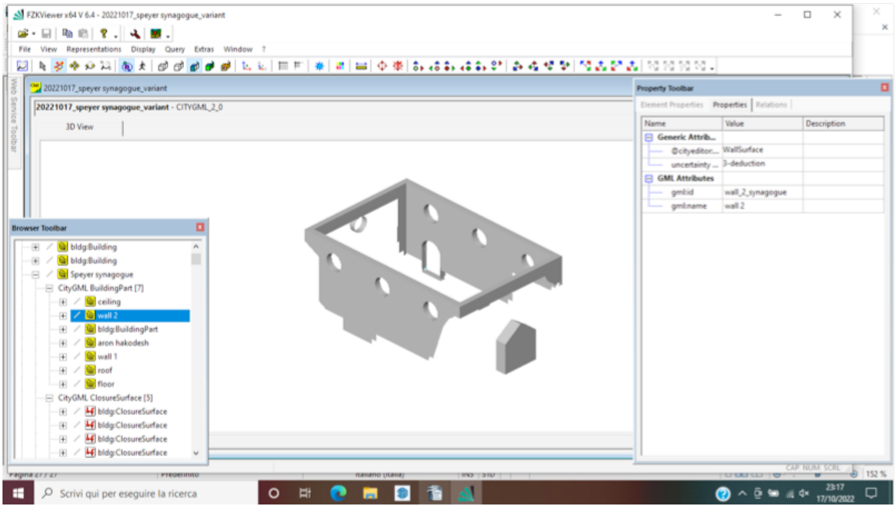


FIG. 122: Visualisation of the variant with circular windows and its related attributes in FZK Viewer: the deduced wall. Author's visualisation.

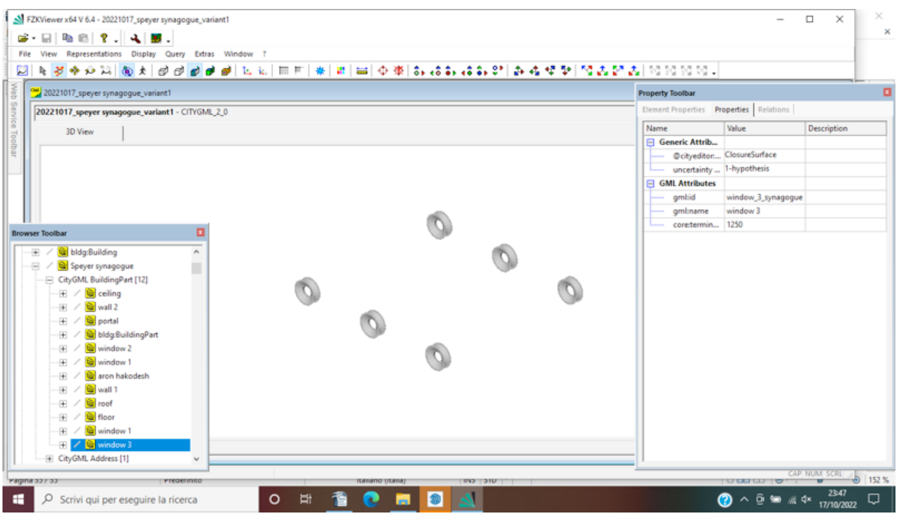


FIG. 123: Visualisation of the variant with circular windows and its related attributes in FZK Viewer: the circular windows. Author's visualisation.

G.2. Gothic synagogue (1350)

The same process has also been applied to the Gothic variant of the synagogue. A new type of window – *Window 5-Gothic* – has been created, with level of uncertainty "3-deduction" since the structure is partly visible on the eastern façade.

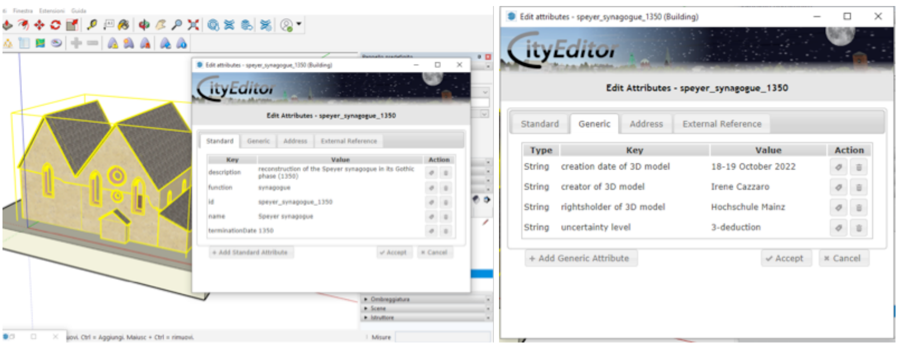


FIG. 124: Gothic variant: the attributes are added to the entire building. Author's visualisation.

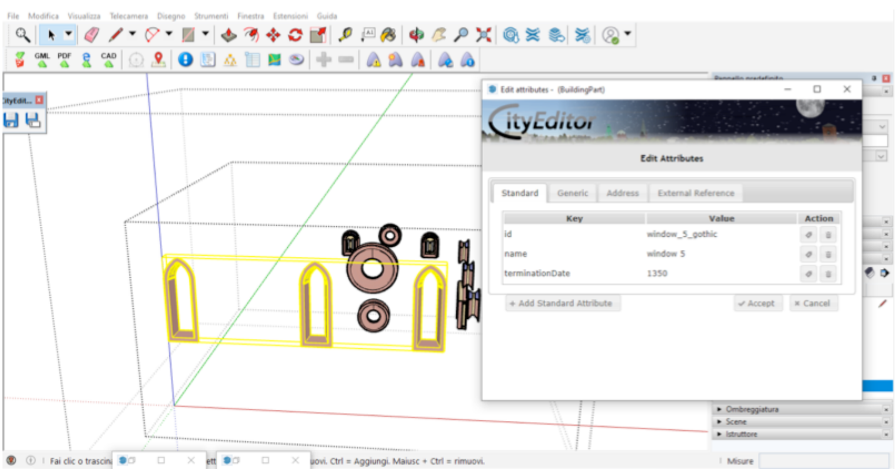


FIG. 125: Gothic variant: the attributes are added to every single element. This is only an example concerning the windows that have been transformed in the passage from the Romanesque to the Gothic synagogue. Author's visualisation.

The structure of the model can be navigated with the "model explorer" tool of CityEditor to check that everything is correct.

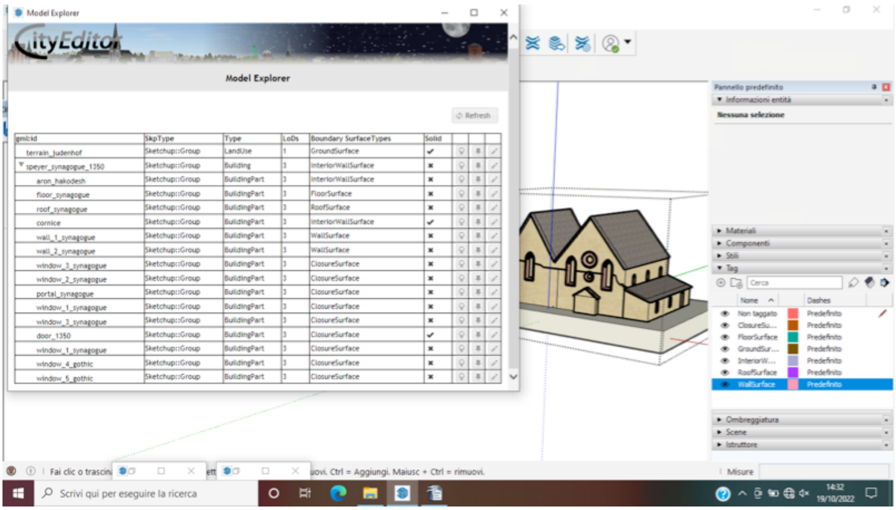


FIG. 126: The structure of the model in CityEditor. Author's visualisation.

Again, the model was saved in CityGML and opened with FZK Viewer, showing all the entered properties.

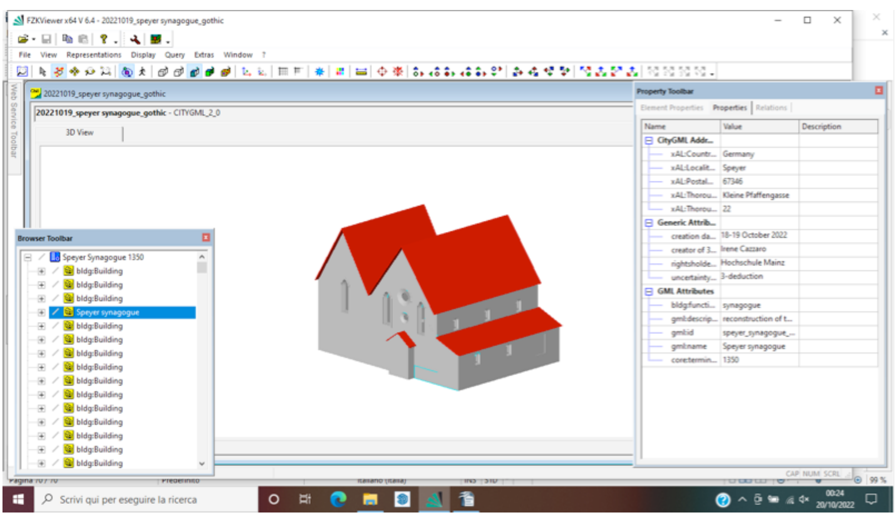


FIG. 127: The visualisation of the Gothic variant and its attributes in FZK Viewer: here the entire building can be seen. Author's visualisation.

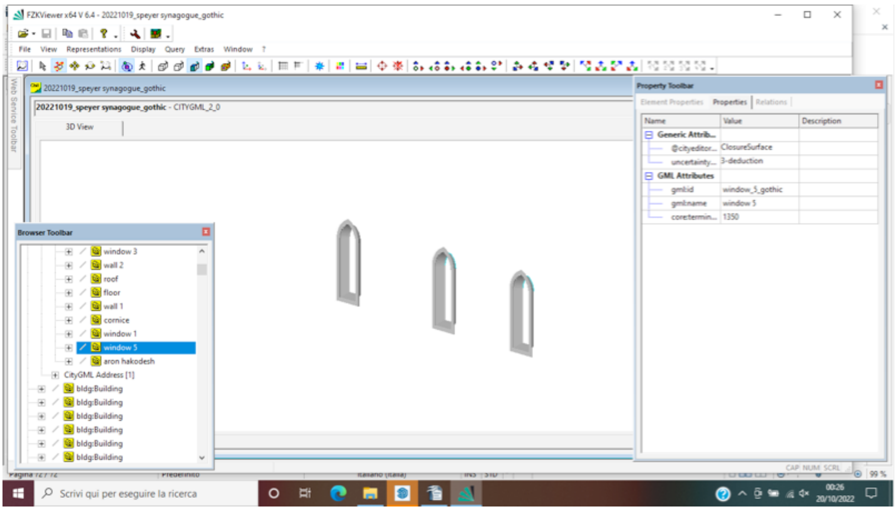


FIG. 128: The visualisation of the Gothic variant and its attributes in FZK Viewer: Gothic windows. Author's visualisation.

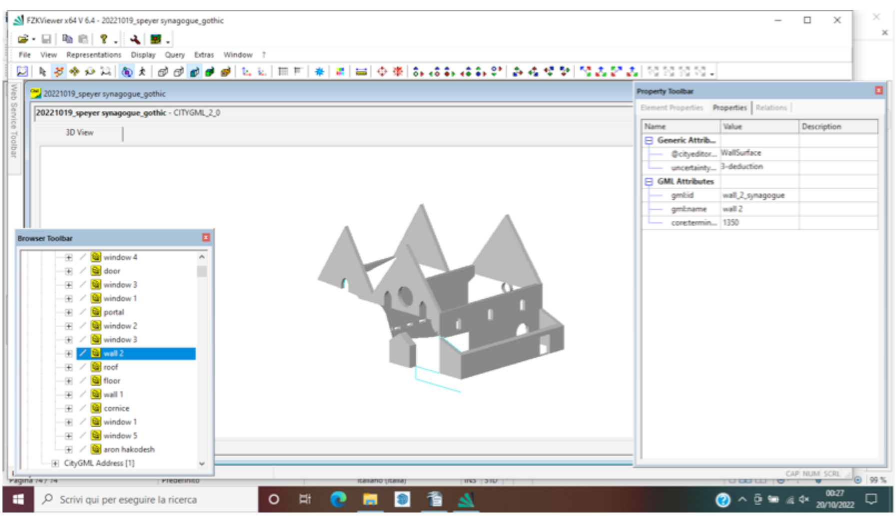


FIG. 129: The visualisation of the Gothic variant and its attributes in FZK Viewer: deduced part of the wall. Author's visualisation.

G.3. Using Archicad / exporting in IFC format

Of particular interest, still in the context of the SpSya1250 project, is the model made by Igor Bajena using Archicad.

In this case, it could be exported in IFC format and opened with Open IFC Viewer: here, as well, we can see that all the properties, also the ones related to uncertainty documentation, are preserved. The steps are illustrated here below.

A new parameter, which can be potentially attributed to all the objects, is added by means of the Property Manager tool.

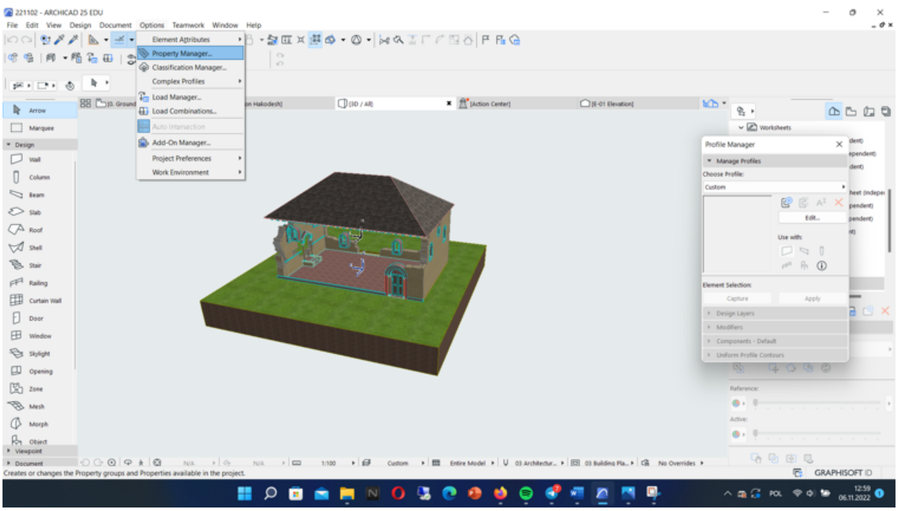


FIG. 130: Adding the uncertainty property in Archicad. Step 1. Visualisation by Igor Bajena.

This is actually a group or properties called “Uncertainty”, to which the property “Level” is associated. In this way, a level, with the desired value, can be assigned to uncertainty.

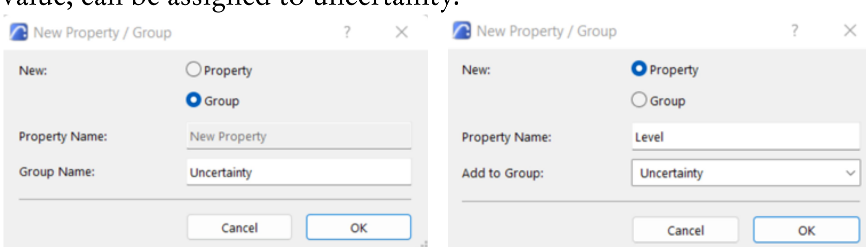


FIG. 131: Adding the uncertainty property in Archicad. Step 2. Visualisation by Igor Bajena.

Once created the new group and property, a description of the parameter is entered. "Option set" is selected as the data type: at this point, the list of the possible values is added. The value for each element will be selected from this list.

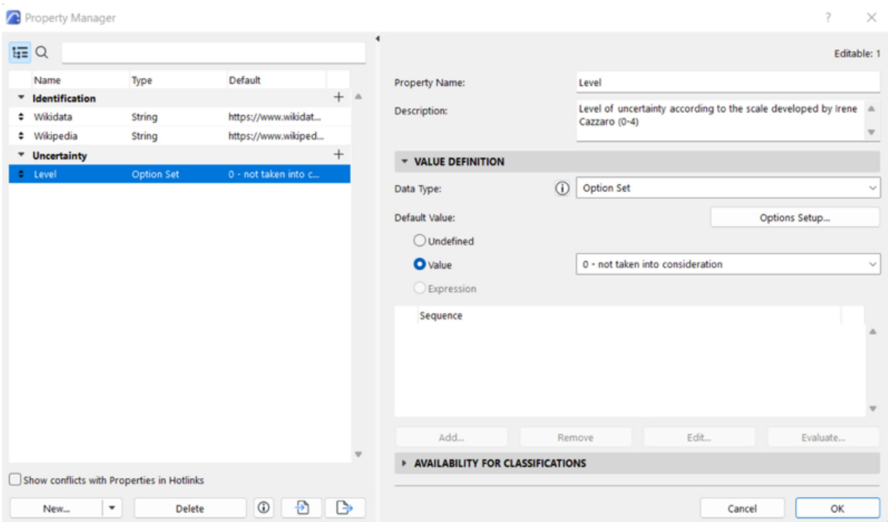


FIG. 132: Adding the uncertainty property in Archicad. Step 3. Visualisation by Igor Bajena.

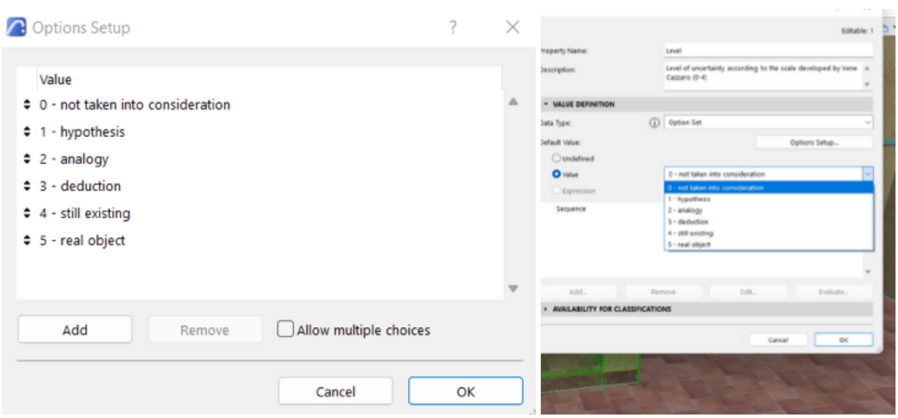


FIG. 133: Adding the uncertainty property in Archicad. Step 4. Visualisation by Igor Bajena.

Complex objects are created by connecting several components and saving them as a single object in the internal project library.

Only for the wall the division between still existing parts and missing ones has been kept.

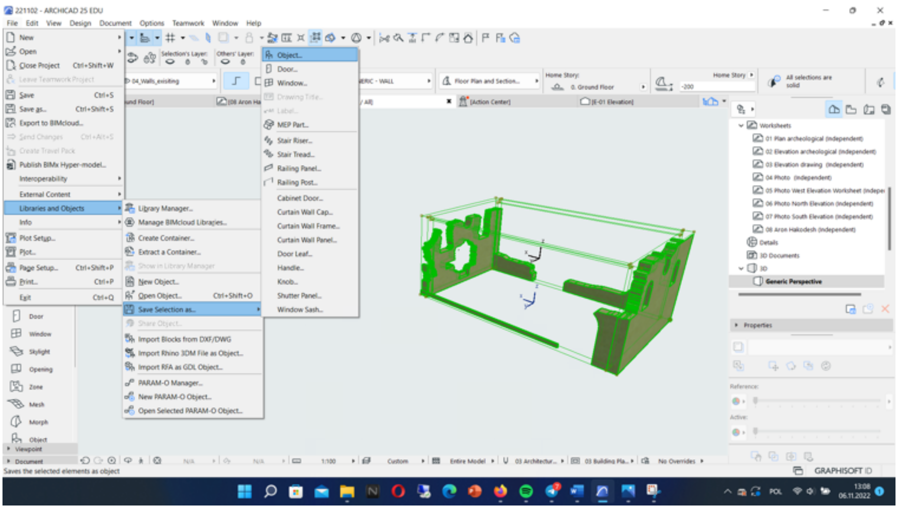


FIG. 134: Adding the uncertainty property in Archicad. Step 5. Visualisation by Igor Bajena.

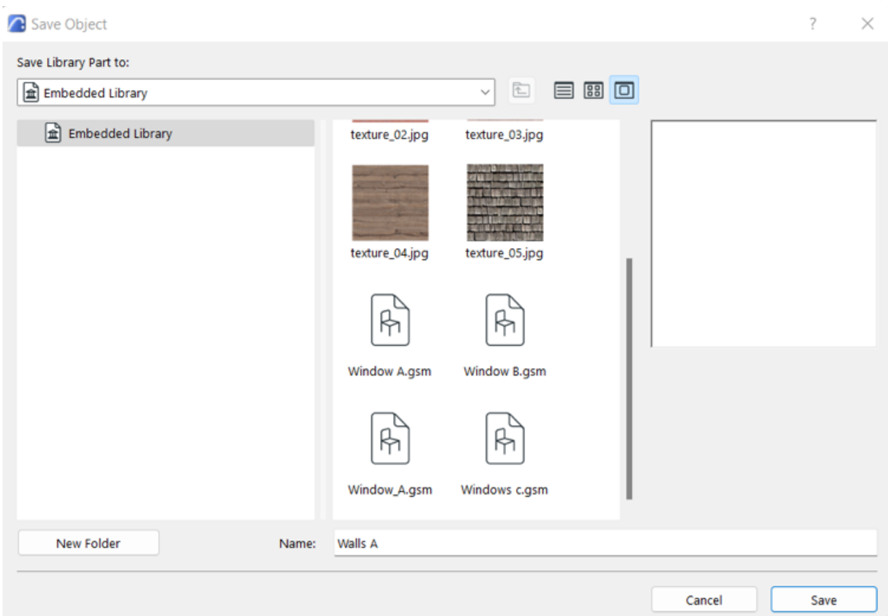


FIG. 135: Adding the uncertainty property in Archicad. Step 6. Visualisation by Igor Bajena.

The still existing wall (Wall 1) is selected and its properties are adjusted in the Object Selection Settings. Under the "classification and properties" section, the hierarchy prepared for the project "SpSya1250" is picked, as well as the class "wall".

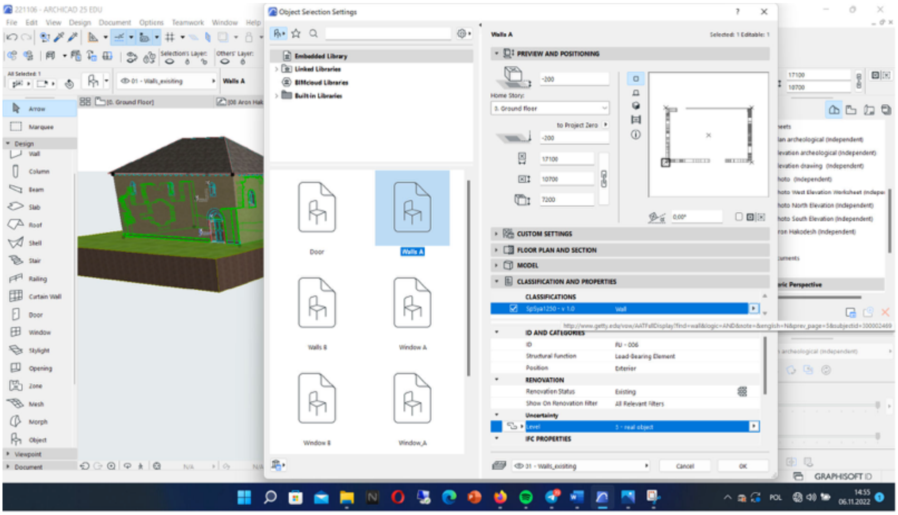


FIG. 136: Adding the uncertainty property in Archicad. Step 7. Visualisation by Igor Bajena.

Then, in the “uncertainty” section, the corresponding level is chosen (in this case, level “4-still existing”).

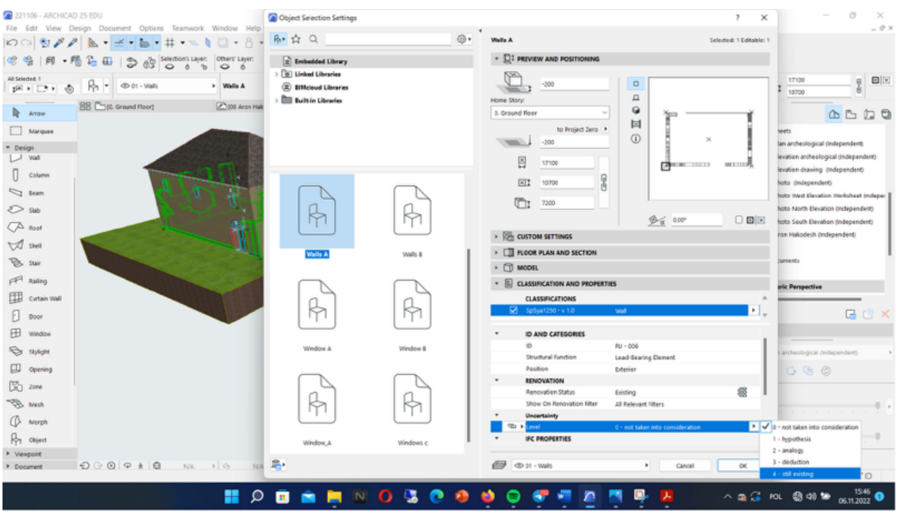


FIG. 137: Adding the uncertainty property in Archicad. Step 8. Visualisation by Igor Bajena.

The IFC export information has been adjusted in the “IFC properties” section by changing the “name” attribute to “Wall 1” and the “tag” attribute to “4 – still existing”.

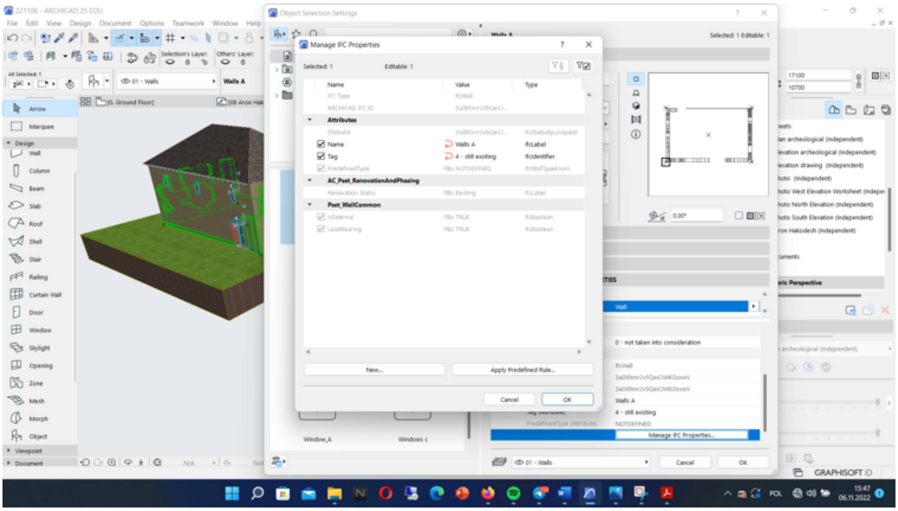


FIG. 138: Adding the uncertainty property in Archicad. Step 9. Visualisation by Igor Bajena.

After opening the IFC export in Open IFC Viewer, we can see that the uncertainty parameter is still accessible.

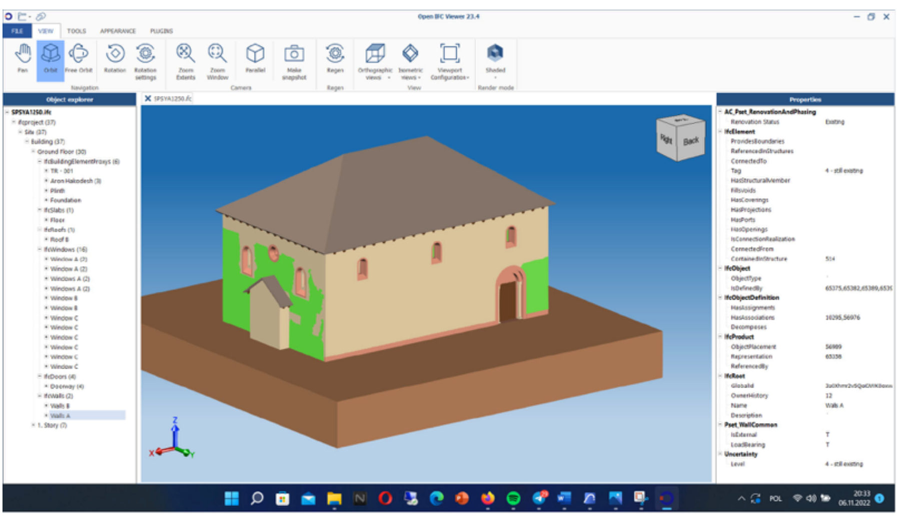


FIG. 139: Adding the uncertainty property in Archicad. Step 10. Visualisation by Igor Bajena.

H.
APPLYING THE SCALE TO OTHER MODELS

The same uncertainty scale should be applied to other reconstructions in order to be validated.

First of all, since our scale comes, to a large extent, from previous studies and applications, such as the one on Villa Pisani in Bagnolo by Andrea Palladio (Apollonio, Fallavollita, and Foschi 2021), the models shown here are actually a confirmation and validation of processes already presented, discussed[12] and in use, with the aim of standardising them and making them interoperable as far as possible.

The uncertainty scale will continue to be tested in upcoming projects; by now, we know that it has been applied in some reconstructions. In this regard, we show here the model of the Wołpa synagogue (Poland), elaborated by Katarzyna Prokopiuk, student at the University of Warsaw, who has attached the documentation of the choices she made and the uncertainty level of all the elements according to the handout for the digital 3D reconstructions that we provided.

The model was uploaded to the DFG Viewer.

By downloading it and consulting the related documentation, the uncertainty data could be integrated to the Sketchup model by means of the CityEditor extension, similarly to the previous cases, and then exported in CityGML format.

12 Especially during *DFG* and *CoVHer* international meetings.

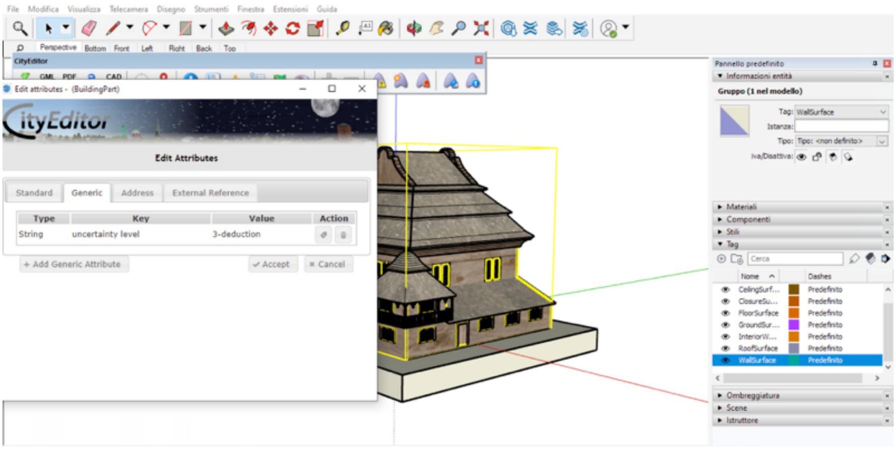


FIG. 140: Application of the average uncertainty level “3-deduction” to the entire building. Author's visualisation based on the model by Katarzyna Prokopiuk.

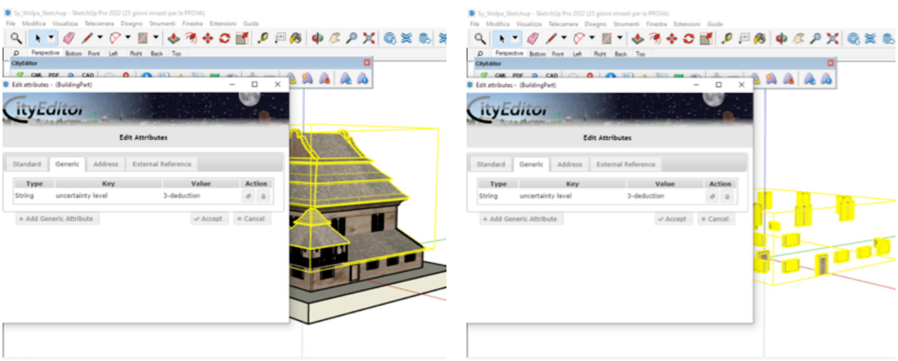


FIG. 141: Application of the uncertainty level “3-deduction” to walls, doors and windows. Author's visualisation based on the model by Katarzyna Prokopiuk.

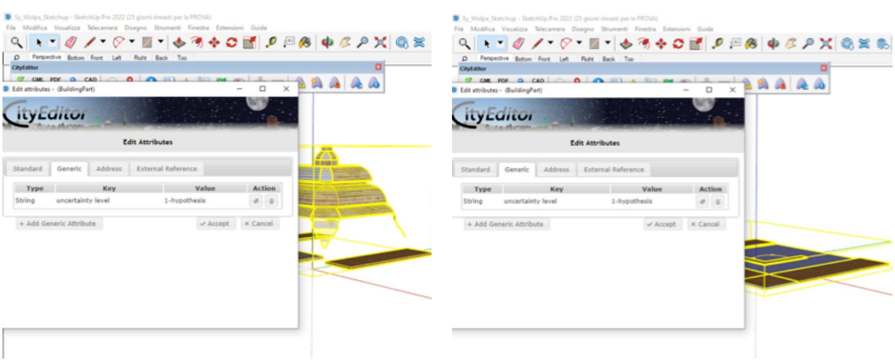


FIG. 142: Application of the uncertainty level “1-hypothesis” to the ceiling and the floor. Author's visualisation based on the model by Katarzyna Prokopiuk.

Once again, when exported in CityGML format and opened with FZK Viewer, the information about uncertainty is still accessible.

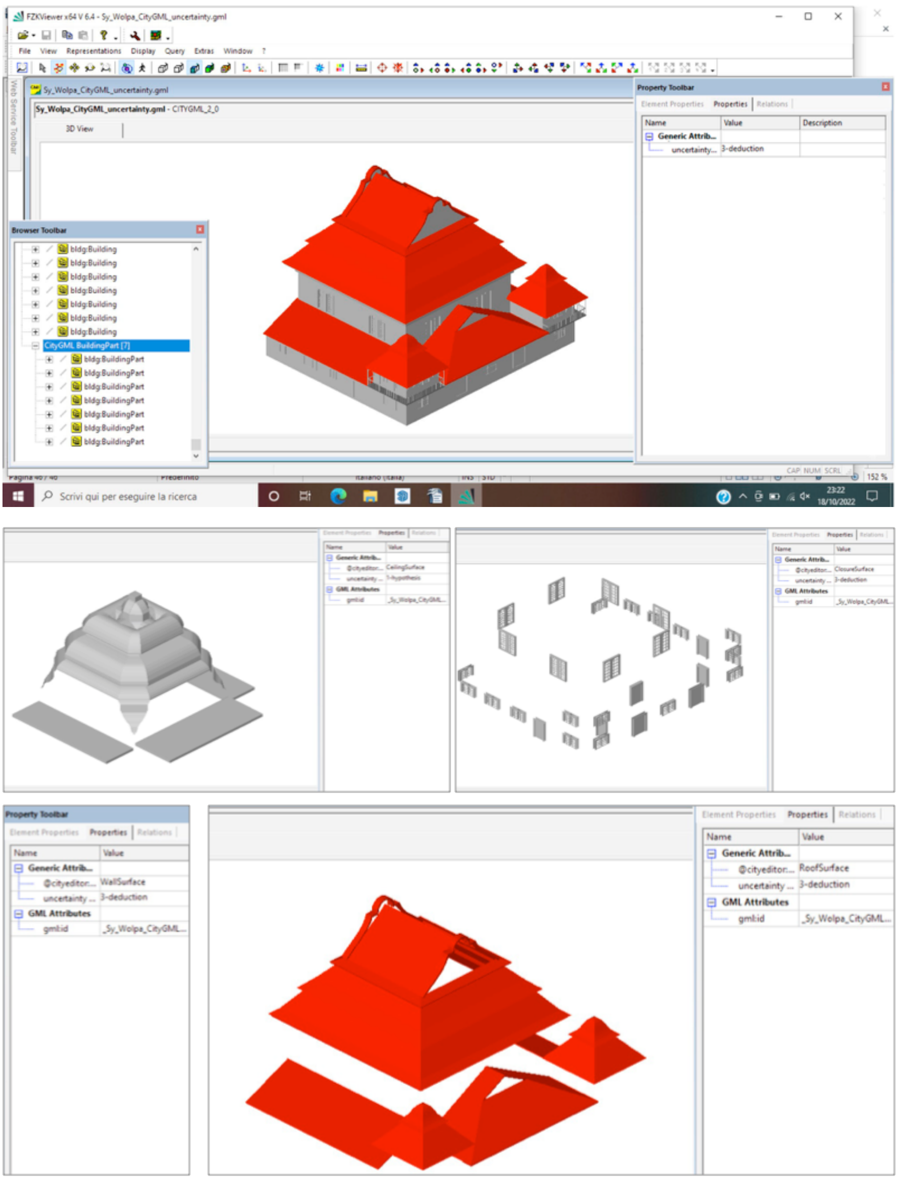


FIG. 143: The uncertainty parameter is still accessible once the CityGML file has been exported and opened with FZK Viewer. Author's visualisation based on the model by Katarzyna Prokopiuk.