Cultural Heritage Markup Language

How to Record and Preserve 3D Assets of Digital Reconstruction

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Abstract: The digital 3D reconstruction of destroyed or never existing cultural heritage is a relatively well known and established visualisation method, in particular of art and architecture. Although there exist guidelines for computer-based visualisation – such as LONDON CHARTER (2009) –, there are no commonly applied standards for documentation and visualisation of 3D data available until now.
In the light of the semantic web technologies occur innovative and promising methods for the documentation of the data created in the process of 3D reconstruction ensuring interoperability and long-term persistence at the same time. The development of a metadata schema, the use of controlled vocabularies and authority files are the groundwork for the implementation within an application ontology for 3D reconstruction to reach the next level of the semantic web layer cake. The paper introduces the design of Cultural Heritage Markup Language (CHML), a metadata schema used in an ongoing digital 3D reconstruction project as a basis for developing the first application ontology for this kind of scientific research projects, referenced to the CIDOC-CRM ISO-standard. The design of CHML takes under consideration the whole process chain of the 3D reconstruction and is based on customised concepts as Semantic 3D Modelling and Semantic Level of Detail. The development can be followed and joined at http://chml.foundation.

Keywords: Computer-visualisation; digital 3D reconstruction, semantic 3D modelling, metadata schema, ontologies

Introduction

The 3D reconstruction of tangible Cultural Heritage (CH) experiences a renaissance thanks to the rapid development of the laser, structure-light scanning and photogrammetry. In result the amount of 3D data sets exponentially increases and confronts us with questions how to ensure a long-term availability of the geometry and – not less important – it's meaning. In light of the proclaimed Semantic Web the Linked Data technologies play a major role in bringing new insights for the documentation and dissemination of the knowledge. Technologies like RDF, OWL, SKOS and SPARQL establish the framework for Virtual Research Environments (VRE) where machine-readable data can be queried and inferences can be drawn. In the CH sector the CIDOC-CRM (ISO 21127:2014) prevails as a reference ontology defining the main classes and properties of cultural assets. With regard to the scholarly processing of the kinds of 3D data sets mentioned above, several attempts have been made to establish metadata schemata for e-documentation; currently represented by CARARE 2.0 (D'ANDREA and FERNIE 2013).

However in case of laser scanning or structure from motion campaigns we should distinguish between a 3D documentation of still existing artefacts in their present condition and, on the contrary, a 3D reconstruction of no more/or never existing object of interest, resulting in hand-made 3D born-digital model. In general the disparity consists of a technical-driven and human-driven data processing. The data acquisition e.g. from laser scanner relies mainly on the set up of parameters, the software and hardware and the positioning on site. The data process of 3D reconstruction however depends primarily on the source coverage and the interpretation in the scientist's mind's eye; technical aspects play a minor role. In short, the 3D reconstruction is based on hypothetical expression of space and materials referring to heterogeneous sources.

The methodical disparity explains the necessity of a data schema subsequently implemented in a domain ontology dedicated to the computer-based 3D reconstruction. The human-driven data processing reveals a strong relation to Digital Humanities, beyond the reconstructed item and content. Although applied for decades, the 3D reconstruction lacks in documentation and therefore still does not fulfil the scholarly standards. General guidelines, like the London Charter for the computer-based visualisation (DENARD 2012), are still not implemented in applied research, although the charter puts in an evident claim: 'Documentation of the evaluative, analytical, deductive, interpretative and creative decisions made in the course of computer-based visualisation should be disseminated in such a way that the relationship between research sources, implicit knowledge, explicit reasoning, and visualisation-based outcomes can be understood.' (LONDON CHARTER 2.1, 2009, 4.6) Further, the current state-of-the-art in the discipline of 3D reconstruction does not withstand the requirements of upcoming linked data technologies. To find a solution to the important scientific issues and to withstand the technological challenges we introduce the semantic 3D modelling corresponding to the Cultural Heritage Markup Language – a metadata schema for scientific purposes of 3D reconstruction further developed for an ongoing Leibniz Association project (KUROCZYŃSKI et al. 2015).

Semantic 3D Modelling

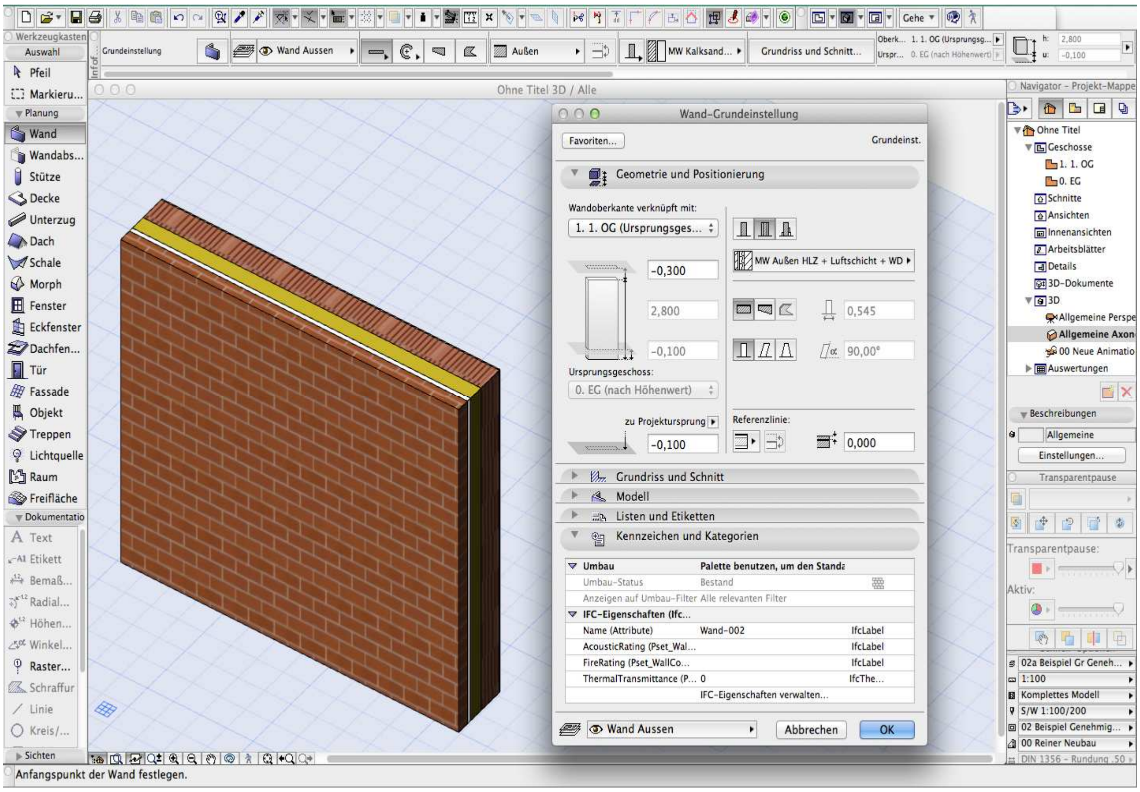

Fig. 1 – Semantic architectural modelling for planning purposes: A wall with attributes in ArchiCAD 17 (screenshot).

Computer Aided Design (CAD) software primarily focused on creating two-dimensional digital drawings. The only meaningful concept in these software packages was to organise the drawn lines by so-called layers that could be turned visible or not. While the field of prospective architectural 3D models experienced a continuous development to meaningful parametric model parts (Fig. 1) – starting with Graphisoft's ”Virtual Building“ concept for the first version of the ArchiCAD software in 1987 and leading to present-day Building Information Modelling (BIM) systems –, the field of descriptive 3D models for visualisation tasks mostly practised for reconstructions remained rather "meaningless" until today (Fig. 2) (Cf. BLÜMEL 2013 for distinguishing between prospective (for planning tasks) and descriptive architectural 3D models). There are actual ambitions on developing BIM-like features for the 3D modelling software products Rhino and FormZ[1]. There are no reports on such attempts for more common modelling and visualisation products like Maya, 3D StudioMAX, Cinema 4d or the open source software Blender. Stephen Wittkopf differentiated between "geometric modelling" and "semantic modelling" meaning BIM concepts (WITTKOPF 2001, pp. 77). For reasons of disambiguation with the same term used for data modelling in information technology, we prefer to call the object-oriented meaningful approach in 3D modelling Semantic 3D Modelling (HAUCK 2014).

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[1] Cf for FormZ: URL: http://architosh.com/2014/06/in-depth-the-new-and-dynamic-formz-8/3/ (accessed on July 25th 2014) and Rhino: URL: http://rhinobim.com (accessed on January 25th 2015).

The object-oriented approach of contemporary BIM models only allows the input of geometric objects when meaningful attributes are added. E. g. the walls forming a room can only be created adding attributes about the wall surface material. When the software creates a book of finishings room by room, the wall's surface information is collected for each room – all automatically. This simple example shows the large benefit of semantic modelling for planning purposes.

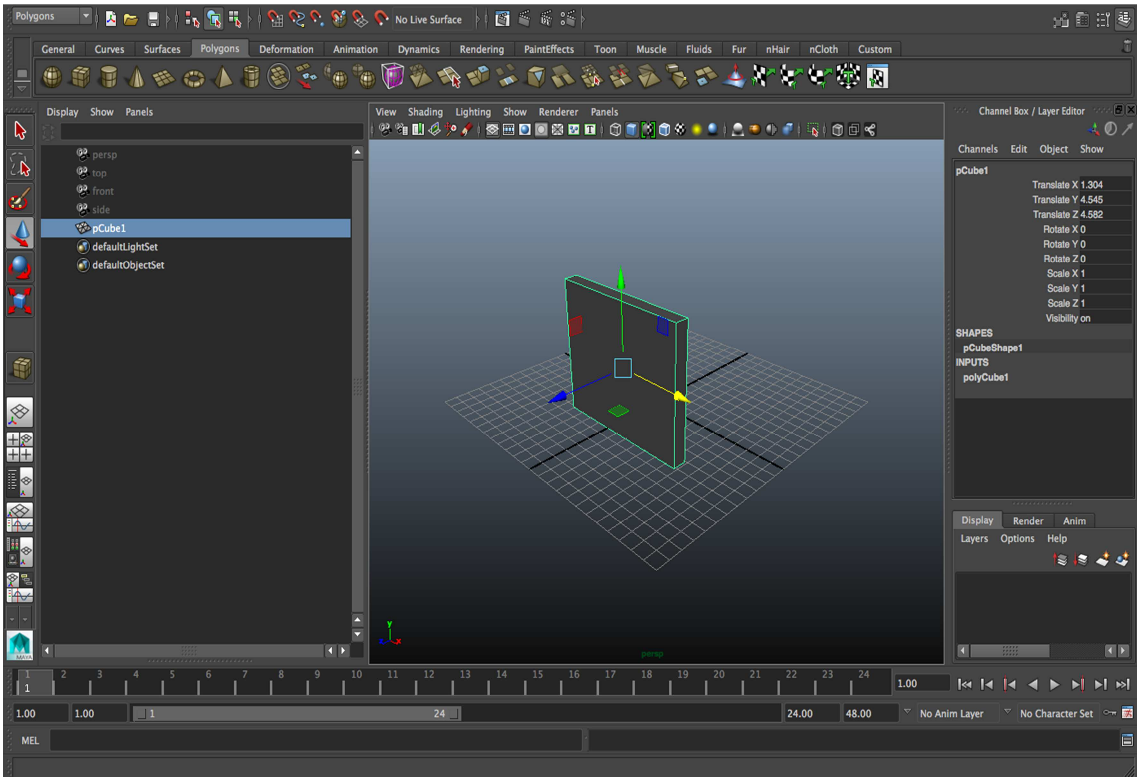

Fig. 2 – A cuboid in Maya without any meaning representing the same wall geometry as the example in Fig. 1 (screenshot).

Linking 3D model parts representing real building parts or other items of interest (so-called objects) with the sources for their 3D reconstruction also requires a meaningful approach: If the sources describe for example a wall with a fireplace, it is necessary to attach the information to the 3D objects in the 3D model representing these terms. Defining an object in the model is not a question of technical visualisation requirements any more, but it is a question of scientific topics with a special focus on the reconstruction's sources.

We model what we are talking and thinking about. Thus we define the 3D objects in the model by the architectural technical terms used in the descriptions (sources) and during the discussions of the 3D reconstruction process. This is also the reason why actual BIM software products can't be used for reconstruction purposes: as contemporary BIM models describe contemporary architecture with the technical terms of our times, it is very difficult to describe premodern architectural building parts with their corresponding terms and also terms from other disciplines than architecture with the products on the market. Another reason for not using BIM software for digital 3D reconstruction is the reconstruction's focus on visual communication: even if it comes to the visualisation of BIM models using state-of-the-art rendering software, the data set is trimmed to containing only information about the geometry and the visual appearance of the surfaces to be rendered. All other information behind the rendered pixels gets lost. This is one important reason why this information is generally not documented in 3D reconstructions solely published by imagery: all efforts of documentation are worthless if there is no means of publishing. Thus the call for scientific documentation of digital 3D reconstructions is in fact the call for virtual research environments (VRE) that bring the research the reconstruction is based on together with semantic 3D models telling the story of their own creation. Cultural Heritage Markup Language (CHML) is designed to describe the processes of 3D reconstructions and builds the foundation for a VRE in this field.

The Reconstruction Point of View

Existing markup languages in the field of CH deal with collection objects and monuments or describe meta data for digital 3D models and point clouds, as result of their digitalisation. A language for digital 3D reconstruction has to deal with both and – even worse – with the absence of both: starting a reconstruction project, there is no 3D model, because it is the goal of the process to create/digitally restore it and – in addition to that – in many cases, there exist no physical objects any more to relate to.

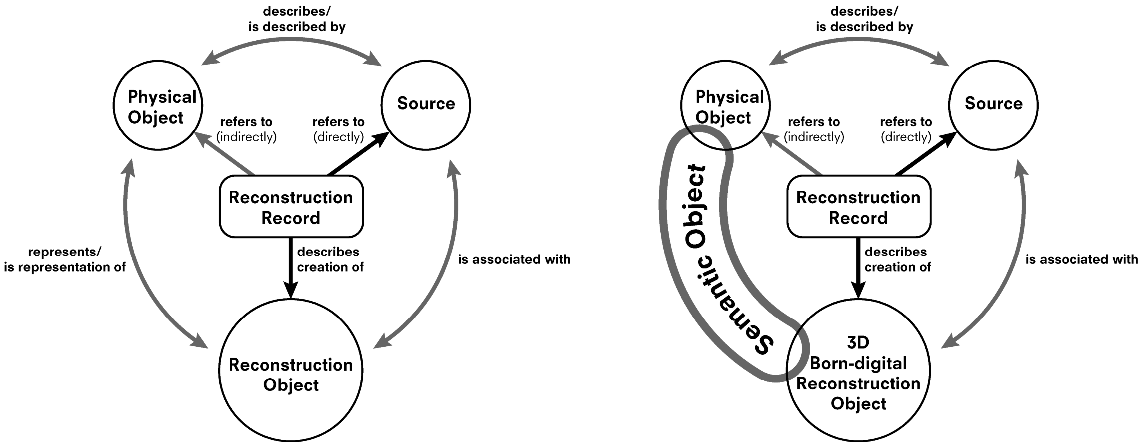

Fig. 3 – The relation between physical object, sources and 3D reconstruction model bounded together by the reconstruction activity. If physical object and reconstruction object are missing, there are only sources to refer to. The solution is the semantic object, which can be addressed any time.

Even if the physical object to be reconstructed is still existing, the modeller does not refer to it in a direct way. If a modeller sits actually with his computer in front of the object, he will need a measuring activity to enter the coordinates of the digital model's geometry. The 3D reconstruction will always refer indirectly to the physical objects to be reconstructed by referring to sources describing it – whether text, image, plan or point cloud (Fig. 3). This makes it is possible to reconstruct non-existing objects even without any indication (SVENSHON and GRELLERT 2010).

At an early stage of a reconstruction project, the reconstruction record has to describe objects that do not exist, nor physically neither as 3D models. In the majority of cases, reconstruction projects start with an evaluation of sources which sometimes even do not relate directly to the object to be reconstructed. Human language makes it possible to think and speak about these things. Scientists and modellers are talking about these non-existing things and CHML has to deal with this phenomenon. We call it Semantic Objects. Semantic objects are the glue that connects the physical objects and the 3D reconstruction objects representing them. Semantic objects are also the reference of the scientific discussions that don't care about the existence of physical objects and digital 3D models. The semantic object is used as the target for all references meaning the same thing when human language is used for thinking and speaking about architecture and artefacts.

From the 3D reconstruction point of view, primary sources can be defined by three aspects: they should be close to the object of interest and – in addition to that – either close to the time referred by the reconstruction or created by an investigation or research activity with the goal of the object's documentation. Hence it can be concluded that a source can only be a primary source for the reconstruction if it can be located close to the object of interest. All other sources are considered as secondary sources. Some examples on behalf of the reconstruction of Justinian's Hagia Sophia in Istanbul (STICHEL et al. 2011): the text of Paul the Silentary (VEH 1977) on the occasion of the inauguration of the building in the 6th century and the 20th century survey plans by Robert Van Nice (VAN NICE 1965) are primary sources for the reconstruction as well as the 19th century survey drawings by Wilhelm Salzenberg (SALZENBERG 1854). On the contrary, the text of Anthemios (one of Saint Sophia's architects) about elliptic geometry (HUXLEY 1959), the 19th century renovation concept drawings by Gaspare Fossati and the 20th century monograph by Rowland Mainstone (MAINSTONE 1988) are designated as secondary sources. It is important to differentiate between these two kinds of sources, because a reconstruction without any primary source should be seen as an entirely hypothetical construct.

Using semantic objects allows people who do not have 3D modelling skills to prepare the 3D reconstruction model. During the first steps of source evaluation, the objects of interest can already be defined and later referred to by the 3D model parts. One of the most important decisions being taken at the beginning of the modelling stage is the definition of what 3D objects are. Semantic 3D modelling allows to take this decision out of the scope of the modeller and to bind the definition of objects to the scientific discussion of the reconstruction.

Fig. 4 shows the underlying methodological structure of CHML: activities create and describe sources that are used by the 3D modeler to create the 3D born-digital reconstruction model. The semantic object can be referenced constantly throughout the whole process although there is neither a physical object nor a digital 3D object.

The semantic core of CHML is a simple attribute called type. The type gives everything a meaning. It is a required attribute for every object, source, activity and actor. It consists of a four letter code for example CEIL for ceiling. The type is a non-ambiguous categorisation that can be linked to authority files, controlled vocabularies, thesauri and wikipedia (via DBpedia). The type system can be used for creating project's glossaries and for the translation of technical terms. The type system can be seen as the basis for a controlled vocabulary and even a thesaurus for 3D reconstructions. Every type has hierarchical relations with other types: a "window", for example is a narrower term than "opening", "tracery window" is a narrower term than "window". But there are also other, more complex relations expressed by certain rules: an architectural survey as a type for activities for example creates always primary sources for the reconstruction. A window or a niche is always part of a wall (according to ISO 6707-1:1989). In addition to that, types can be correlated with certain traditional architectural scales or levels of detail.

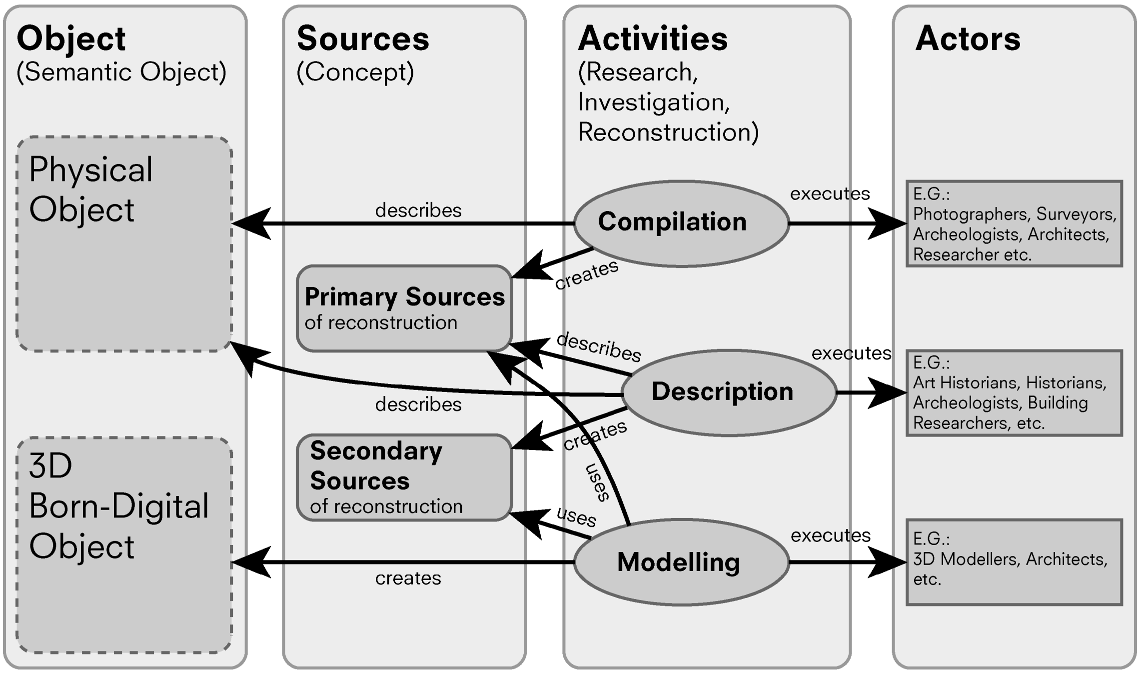

Fig. 4 – The relation of sources, physical and 3D reconstruction objects as well as actors bounded together by the research/investigation and reconstruction activity.

Semantic Level of Detail

Ever since the dawn of architecture in human civilisation, there is a tradition of architectural models as well as of geometric abstraction in architectural plans. These traditional plans and models differ from actual computer-based models by a certain degree of abstraction that can be tied to a certain scale. Digital 3D models have no scale. They are always thought to be a 1:1 representation of the objects. Nevertheless there is a concept of different degrees of abstraction in digital 3D models which is called Level of Detail (LoD). This concept originates from the need to reduce render time: „Discrete level of detail, the traditional approach creates LoD for each of the object separately in a pre-process. At run-time, it picks each object's LoD according to the particular selection criterions“ (TAN and DAUT 2013). Version 2.0 of CityGML (KOLBE 2009) – a geographic markup language describing 3D city models – includes rules for the representation of buildings in five different levels of detail which are strongly connected to the semantics of that language: „In CityGML, all object classes are associated to the LODs with respect to the proposed minimum acquisition criteria for each LOD (…) An object can be represented simultaneously in different LODs by providing distinct geometries for the corresponding LODs.“ (GRÖGER et al. 2012) According to Tan and Daut this is a concept of discrete LoDs enriched by semantic rules for the use of these LoDs: „For example, a building may be assigned a solid geometry in LOD2. If the building is further decomposed into thematic surfaces like WallSurface, RoofSurface etc. their associated geometries should refer to those surface geometry objects which are part of the outer shell of the building's solid geometry.“ (GRÖGER et al.

2012) This is a promising idea for semantic 3D reconstruction models which is further developed for CHML. We call this semantic LoD (HAUCK 2014).

The semantic LoD stands for a strong connection between building parts/model components and their CHML type. Architectural terms in general imply a certain scale or LoD: if someone talks about a palace this includes everything inside the building like storeys, rooms, ceilings, doors, paintings etc. This means that the term "building" implies a lower LoD than the term "room" which implies a lower LoD than the term "wainscot". Thus these terms can be linked to traditional architectural scales: a 1:100 section plan does not show details like baseboards, but a 1:20 wall elevation plan does. We suggest nine different LoDs for CHML without strict rules for which CHML type has to be modelled in which LoD. We recommend to decide this on the basis of the project's requirements following one rule: broader types should have a lower than or the same LoD as narrower types and the modelling of one object/type in more than one LoD is to be avoided.

In other words: the semantic LoD can be connected to traditional plan and model scales. Thus the information granularity of sources can be expressed in a similar way called „level of information" (LoI). Concerning plans with scales it appears quite obvious, but also images and even text mentions can relate to scales using the semantic LoD: if an image shows objects that would be shown by plans at a certain scale, the image is consistent with the same scale and LoD/LoI (Tab.1). This leads to a convenient way of expressing the hypothetical aspect („level of hypothesis" LoH) of a 3D reconstruction model: LoD - LoI = LoH.

Level of Hypothesis (LoH = LoD - LoI)		**Level of Information (LoI)**		**Traditional Scale**	**Level of Detail (LoD)**	
Compliant to source (Also if LoH is negative)	0	Known existence	1	N.A.	Symbolic geometry	1
Feasible assumptions	1	Locatable	2	1:5000	Emblematic geometry	2
	2	General information about appearance	3	1:500	Diagrammatic geometry	3
	3	Freehand drawings, paintings, photographs	4	1:200	Reduced geometry	4
	4	Survey drawings, close-up photographs	5	1:100	Simplified geometry	5
	5	Detailed drawings, photogrammetry	6	1:50	Detailed geometry	6
	6	Detailed drawings, photogrammetry	7	1:10	Highly detailed geometry	7
	7	Highly detailed drawings	8	1:5	Compliant to building parts	8
Completely speculative	8	Point clouds from 3D scan	9	1:1	Geometry with all distortions	9

Tab. 1 – The resulting "Level of" matrix (HAUCK 2014)

CHML – Cultural Heritage Markup Language

An early approach of semantic 3D modelling – avant la lettre – has been the „Akropolis 4D“ project (HAUCK et al. 2002) where 3D building parts of the Athenian Acropolis' Propylaea have been linked with the sources used for the 3D reconstruction (e. g. BOHN 1882). The conclusions that have been taken from this project lead to the idea of creating an XML-based language for describing 3D reconstructions called Cultural Heritage Markup Language (CHML) which has been presented primarily at TU Darmstadt’s CeBIT booth in 2003 (HAUCK and NOBACK 2003). A first following step was the creation of RadianceML to describe geometric models for the radiance light simulation package by an XML language (GROBE 2004).
The workflow diagram shown in Fig. 4 builds the framework for the four main topics of CHML: objects, sources, activities and actors. There are some other auxiliary topics like places, historic events, materials, light sources, camera settings, object’s behavior, and scenes – some of them still to be developed. Objects are seen as semantic objects with child elements for physical objects and 3D born-digital reconstruction models. Sources are seen separately from the information carrier object – just like bibliographic references commonly link to the content of a book (ISBN) without taking into consideration the single book in the shelf of a library (library signature). The information carrier object of a source can be part of the model. For example a painting in a palace shows the palace in the background. The scan or photography of that painting is described as a source, the painting itself is modelled as a part of the 3D reconstruction and thus also described as an object.
This special relation of source and object is described by the informationCarrier element. The usual semantic link between sources and objects are the (source) coverage and (object/event/actor) isShownBy element.

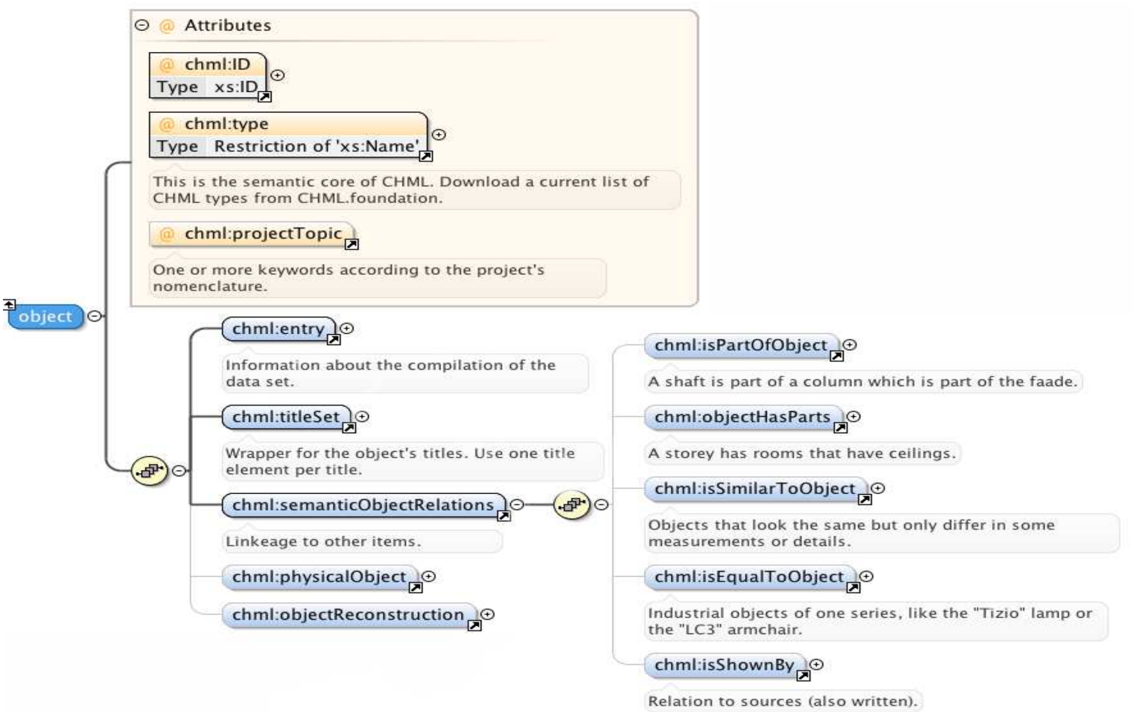

Fig. 5 – The main branches of the object element's tree in CHML. The semantic object relations can be used independently from the physical object or 3D models representing it

In other existing CH languages, the difference between an event and an activity is the activity having a certain goal. The building of a castle is an activity, the destruction of the roof by a lightning strike would be an event. From the 3D reconstruction point of view, the building of the castle is also a historic event. CHML thus distinct between „historic events“ and „research activities“ defining research activities as either an activity creating a source for the reconstruction or being the digital 3D reconstruct itself.

As shown in Fig. 5, the object record in CHML can be used without information about the physical object (physicalObject element) and the 3D model (objectReconstruction element). The most important feature is the need of defining at least one semantic Relation (semanticObjectRelations element): it can be a „part of“ or „has part“ relation as well as a „shown by“ relation that links to a source covering the object. (Fig. 5)

The different features for the physical object's description are very close to other CH XML languages like LIDO, MIDAS Heritage and CARARE Schema. The objectReconstruction element contains all information about the 3D born-digital reconstruction object (Fig. 6). The model provenance branch can contain copyright information if the 3D model comes from outside the project and the model description branch can include a general description of the model and the reasoning about different possible model variations if applicable.

The most important branch starts with the modelHistory element. It contains all 3D models representing the physical object. There is a modelVariation element for each variation having a variationNumber attribute and containing a modelVersion element for each version and a protocol element for describing the version history if there is more than one model version. The difference between variations and versions is that versions are for refinement and development in time; variations differ by concept: they should be seen as alternatives of the reconstruction. Each modelVersion element has three attributes: one for the version number, one for the LoD and one for the LoH. The modelGeometry element contains information about the 3D model's insertion point and bounding box coordinates as well as the possibility to either link external files with the model geometry or to contain embedded inline geometry code, e.g. COLLADA DAE, obj, X3D, dxf, json, radiance, etc.

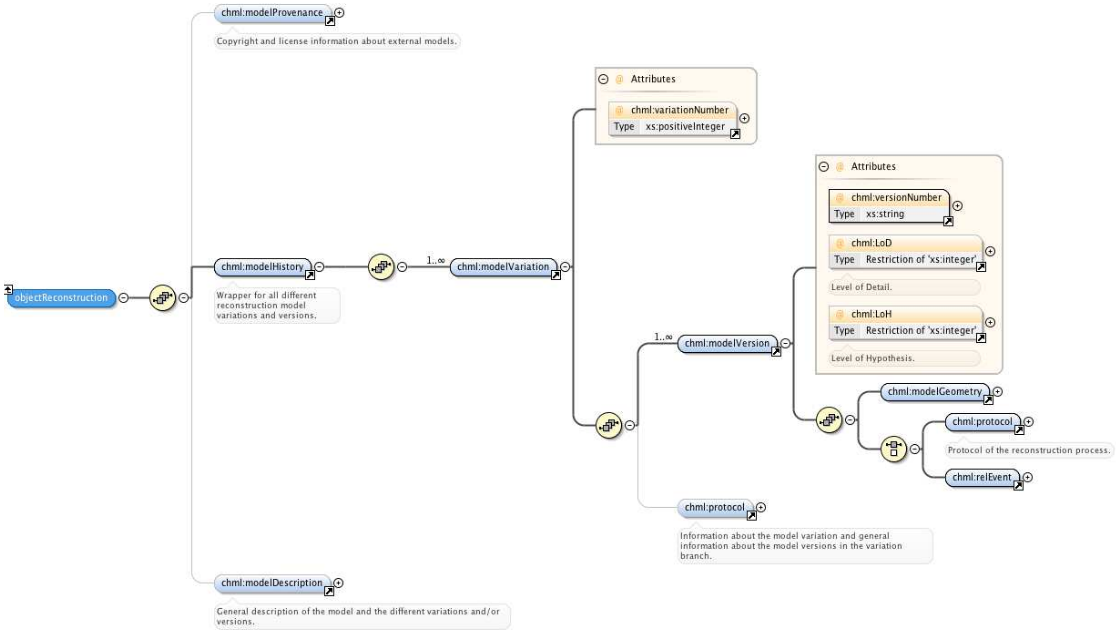

Fig. 6 – The object Reconstruction element tree.

The reasoning about the model creation can either be linked to a reconstruction modelling activity (which is the preferred way) or it can be included by a protocol element.

Conclusion

The CHML based domain ontology is the groundwork for a Virtual Research Environment with 3D content and responds to the scientific issue of adequate documentation, scholarly standards and dissemination. It faces the requirements of Linked Data and Semantic Web technologies and brings new findings into the question on how to record and present 3D data sets for research purposes (KUROCZYŃSKI et al. 2014). But it also reveals further unsolved challenges, like failing and missing authority files and controlled vocabularies to represent the whole spectrum of heterogeneous terms in Art and Architecture. The lack of relevant thesauri for scholarly 3D reconstructions leads to the own solution of CHML types, which enable a labelling with existing Linked Data thesauri, like Getty Art & Architecture Thesaurus (AAT) or DBpedia.

CHML can embed 3D data using COLLADA DAE – a promising new standard for xml-based description of 3D models not only containing information about the model's geometry and surface materials, but also about object's behaviour in time, physical material definitions, camera settings and so-called scenes. The possibility of describing physical material properties does not mean that the information already exists. Particularly values for historic materials and light sources are not provided by contemporary manufacturers. There is a lot of research to do measuring and describing physical material and light source properties for different render applications. The same is true for controlled vocabularies and thesauri in the field of 3D reconstruction.

If computer-based 3D reconstruction instead is seen as a holistic instrument of describing, recording and disseminating objects of cultural heritage (KUROCZYŃSKI 2012), it could be an alternative method to achieve new findings and to come to new conclusions: 3D reconstruction models could be used as a spatial information model telling the story by annotated context. Imagery then is only a by-product of such a semantically enriched 3D model that has to be published in a new way, preferably in a semantic web environment.

The design of CHML is the underlying schema for the implementation of a domain ontology for the 3D reconstruction within Web Ontology Language (OWL). The approved Scientific Communication Infrastructure WissKI integrates CHML in a RDF-Triple-Store based on Erlangen-CRM – currently the only applied OWL-DL implementation of the CIDOC-CRM. Reflecting the whole process chain and emerging relations from the event-centric point of view CHML correspond to the reference ontology CIDOC-CRM (SCHOLZ and GOERZ 2012). Introducing the semantic object however causes the need to extend current CIDOC-CRM classes.

In the light of the prospectives and challenges mentioned above we would like to encourage establishing a research field dedicated to digital 3D reconstruction promoting international collaboration and quality of continuously growing digital 3D data sets in CH.

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