# A five-level LoD concept for modelling of Buddhist statues in 3D with semantic information

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**Keywords:** Buddhist statue, Semantic modelling, Level of Detail, CityGML ADE, Cultural heritage.

## Abstract

The concept of Levels of Detail (LoDs) plays a critical role in 3D semantic modelling by balancing geometric and semantic complexity with application needs. In our earlier work, we proposed a four-level LoD framework tailored to Buddhist statues, ranging from symbolic representation to detailed geometry, aiming to fulfil the needs for about 60 applications. However, when implementing this concept to applications in the cultural heritage domain, it is suggested to introduce an intermediate LoD between LoD2 and LoD3 because some applications need geometries coarser than the LoD3 but more detail than LoD2. In this paper, we present the analysis of these requirements and propose a new LoD for the 3D modelling of Buddhist statues. To verify the updated concept, we conducted a questionnaire among experts in geomatics and archaeology. Feedback from 170 participants confirmed that the five-level LoD concept is more appropriate and the revised framework provides a more comprehensive alignment with tasks in archaeology, conservation, museum exhibition, and risk management, and demonstrates strong potential for standardization within CityGML ADE.

## 1. Introduction

The notion of Levels of Detail (LoDs) was first introduced in 3D modelling to manage geometric complexity by providing multiple representations of the same object (Kolbe, 2009; Gröger and Plümer, 2012). In general, two types of LoDs can be distinguished: those developed for visualization and data transmission purposes, where simplified models accelerate rendering and data streaming (Biljecki et al., 2014), and those designed for application purposes, where different granularities of geometric and semantic information are required in tasks such as conservation, analysis, or risk management (Luo et al., 2025). Recent study have emphasized the importance of coupling LoD (geometric detail) with LoI (Levels of Information), thereby enabling cross-scale representations that support surveying, analysis, and exhibition within a single adaptive framework (Abualdenien and Borrmann, 2022; Kutzner et al., 2020).

At the standards level, CityGML has advanced a clear decoupling of semantic and geometric LoDs, while OGC 3D Tiles and I3S provide engineering pathways for scalable data streaming and attribute queries (OGC, 2023). Meanwhile, project practices such as the EU 5DCulture initiative have validated the reuse value of enriched multi-LOD assets in education, tourism, and creative industries (Corns et al., 2024). Novel approaches including neural multi-resolution rendering have further expanded possibilities for ultra-detailed visualization (Kuznetsov, 2021). In parallel, HBIM research has demonstrated the growing role of semantic-rich modelling in heritage conservation, integrating risk assessment, digital twins, and sustainability perspectives (Fattore et al., 2025; Penjor et al., 2024). Beyond technological frameworks and project implementations, international and national guidelines such as the London Charter (Denard, 2012), CIPA 3×3 rules (Waldhäusl and Ogleby, 1994), and Chinese standard WW/T 0115-2023 (Huang, 2024) emphasise that 3D digitisation quality should be purpose-driven, and that different application scenarios require different levels of geometric accuracy, documentation depth, and data deliverables. By following this principle, the five-level LoD concept proposed in this study seeks to align modelling granularity and semantic structuring of Buddhist statues, providing a domain-specific refinement consistent with existing normative guidance.

Within cultural heritage, representation of artifacts and monuments in virtual environments has increasingly relied on structured LoD approaches. Previous work has explored LoDs for buildings and other urban infrastructure (Arroyo Ohori et al., 2018), but heritage objects such as statues require frameworks adapted to their semantic and morphological specificity. To close this gap, our earlier study (Pan et al., 2025) published in Geo-Spatial Information Science proposed the first LoD framework specifically for Buddhist statues. Unlike visualization-oriented schemes, this framework was explicitly application-driven: it followed a four-step procedure (application inventory → geometric requirements → number of LoDs → definition of geometric expressions) and introduced a four-level system (LoD1–LoD4), enriched with semantic decomposition.

As the application-driven concept of LoD, the framework identified five domains of application: (i) archaeological and digital heritage analysis, (ii) museum and exhibition design, (iii) conservation and restoration, (iv) transportation and storage management, and (v) emergency and disaster management.

Following this publication, we promoted the framework to museums, archaeological departments, and conservation agencies in the cultural heritage field. Although the concept had already been discussed with experts during its development, broader dissemination brought renewed and consistent feedback. Specialists acknowledged the value of the framework but pointed out a critical limitation: the gap between LoD2 (convex hull) and LoD3 (main semantic components) was too large. Several tasks in applications—such as exhibition support design, transport cushioning assessment, and low-cost structural analysis—required an intermediate representation that neither a simple convex hull nor a fully decomposed semantic model could adequately provide.

To address these issues, we refined the framework into an updated five-level LoD concept, which introduces a new intermediate level and specifies geometric precision and semantic alignment rules for each stage. This revision closes the LoD2–LoD3 gap and provides stronger alignment with the five application domains originally identified in the GSIS study, ensuring broader usability across archaeology, conservation, museum practice, transport, and disaster management.

The remainder of this paper is organized as follows: Section 2 will present the process of introducing the new LoD into the existing four-level LoD concept for the 3D modelling of Buddhist statues, followed by elaborating the question designs in a questionnaire to verify the updated LoD concept, Section 3 will demonstrate examples of the five-level LoD models for several Buddhist statues, finally, Section 4 will have discussions for the presented work and conclude the whole paper.

## 2. Methodology

This section includes two parts: the need for introducing a new LoD and the design of a questionnaire for the purpose of verification.

### 2.1 The need for a new LoD

In Pan et al. (2025), 60 applications were listed in which 3D models of Buddhist statues are used based on the advice of several archaeological experts and an intensive literature study. These 60 applications are classified into 5 categories: archaeological and digital heritage analysis, museum and exhibition design, conservation and restoration, transportation and storage management, and emergency and disaster management. By analysing the geometrical requirements of these applications, four LoDs were suggested whereas LoD1 is defined as 2D symbols, LoD2 as convex hull geometry, LoD3 as coarse solid boundary representation, and LoD4 with detailed geometries for every small component, as depicted in Figure 1.

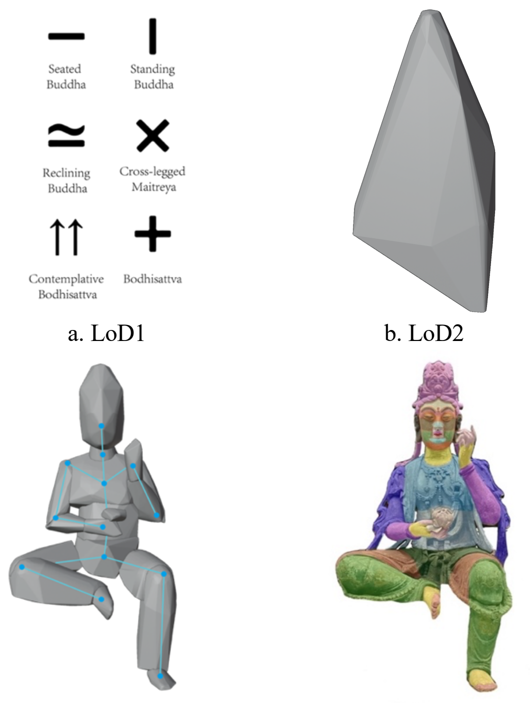



Figure 1. Four LoD models for 3D semantic modelling of Buddhist statues (Pan et al., 2025).

However, when promoting and implementing this concept to a number of museums and institutes of grotto research in China, we had opportunities to ask for opinions from technicians and colleagues who are working directly with many of the 60 applications. Based on their experience, they pointed out that the following applications require 3D models of Buddhist statues with geometries coarser than the current LoD3 and finer than LoD2.

- Digital Archaeology
- Furnishing and Furniture
- Exhibition Planning
- Digital Twins of Displayed Artifacts
- Structural Analysis
- Material-Specific Linked Data Analysis
- Marking for CRP(close range photogrammetry)
- Heating and Lighting
- Cross-Cave Material Source Inference
- Spatial Analysis in Conservation
- Protection Shell Design
- Simulation of Sun Protection
- Artifact Transport

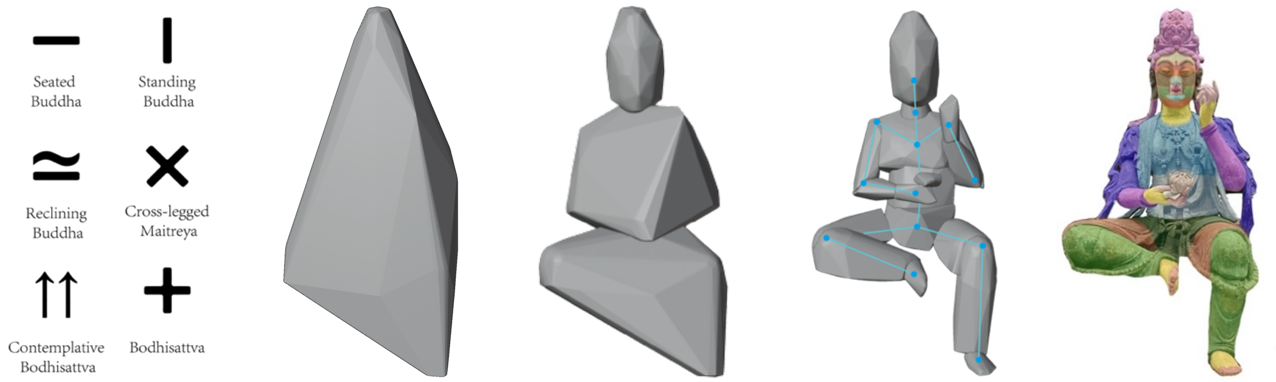
In some of the scenarios of the above listed applications, we need 3D models which reveal the body-like geometry and contain semantic information of at least three main components, namely, head and neck, upper body and lower body. The division of the statue also corresponds to established anthropometric segmentation principles (Li and Zhang, 2019). For instance, (ISO 7250-1, 2017) defines human body measurements based on standardized anatomical landmarks and major body segments such as head, torso and lower body. Although originally developed for ergonomic purposes, such structured body-level segmentation provides a consistent reference for describing human-like geometry. The proposed intermediate LoD therefore follows a logically grounded, body-based geometric abstraction rather than an arbitrary simplification. For example, in the application of digital archaeology, sometimes, people need to analyze the constellations of Buddhist statues and other objects within a large grotto. In this case, there is no need to include details such as arms, legs and other small components. Instead, it is required to know the approximate shape, size and position of the main components such as head, upper body and lower body, so that archaeologists can calculate and discover how the statues were arranged to avoid sight and light occlusion. Another example is the geometric need in artifact transport. For better planning of the loading of Buddhist statues alongside other artifacts in trucks, ships or airplane, it is crucial to know the position of head, upper body and lower body inside of the protection suitcase, in order to optimize the space of shipment and guarantee the safety at the same time.

### 2.2 The Updated concept of LoDs

Based on the requirement analysis in Section 2.1, an intermediate LoD between LoD2 and LoD3 in Figure 1 needs to be introduced. It should be a 3D model that contains semantic information of head and neck, upper body and lower body and represents the geometry of these three components with approximate shape and size. In the practice, a LoD3 model of a Buddhist statue can be represented as a three-part combination of the convex-hull of the three main component, namely, the convex-hull of the head part in the upper side, the convex-hull of the upper body in the middle and the convex-hull of the lower body in the downside, as one can see in Figure 2(c).


https://doi.org/10.5194/isprs-archives-XLIX-B4-2026-767-2026 |  

As suggested by Pan et al. (2025), Buddhist statues can be modeled in 3D with rich semantic information by using a CityGML ADE (Application Domain Extension). With CityGML grammar and specification, the 3D Buddhist statues at LoD2, LoD3 and LoD4 will use solid in the form of Closed Boundary Representation using polygons for the geometric modelling of individual component, while TIN surface will be used for undetachable components to describe their detailed geometric characteristics. And for detachable components, solid geometry is used in the form of Closed Boundary Representation using TIN surfaces of their child components. Table 1. denotes the requirements of the five LoDs as the guideline for 3D data production.




a. LoD1 b. LoD2 c.LoD3 d. LoD4 e. LoD5

Figure 2. The updated LoD system for semantic modelling of Buddhist statues.

Table 1. Requirements of the updated LoDs for Buddhist statues

| Model Scale Description | Accuracy (Position/Geometry) | Level of Generalization | Facial and Body Features | Surface Texture and Color |
|---|---|---|---|---|
| LoD1 | Symbolic representation | Position accuracy 2 m | Maximum generalization | None |
| LoD2 | Overall convex hull boundary | Geometric accuracy 5–15 cm | Approximate object shape | None |
| LoD3 | Sectional structural representation | Geometric accuracy 5–10 cm | Representation of main sections | None |
| LoD4 | Skeleton lines and key features | Geometric accuracy 3–5 cm | Structured outline of components | None |
| LoD5 | High-precision detailed model | Geometric accuracy 2–3 mm | Clear geometric details of components | Fine features |

### 2.3 Expert Survey: Purpose and Design

To validate the updated five-level LoD framework for Buddhist statues, we designed an interdisciplinary expert questionnaire. The design is inspired by the principles of Delphi method, namely collecting convergent judgments from a group of experts to ensure stability and scientific reliability of the results. To balance quantitative comparability with qualitative depth, the questionnaire adopted a hybrid format: Likert five-point scales were combined with open-ended questions.

In the questionnaire, four questions were designed to collect opinions related to the concept of LoD. Among others, there are two questions about LoD suitability and precision requirements. Respondents evaluated the appropriateness of the five LoDs, including the new intermediate LoD, and assessed whether the stated precision thresholds (e.g., 2–3 mm accuracy for LoD5) struck a reasonable balance between modelling cost, archaeological research, and exhibition needs. In addition, there are two questions about the rationality of LoD design, and the wide application scope, respectively.

## 3. LoD Demonstration and Validation

### 3.1 Demonstration of 3D models for six typical types of Buddhist statues

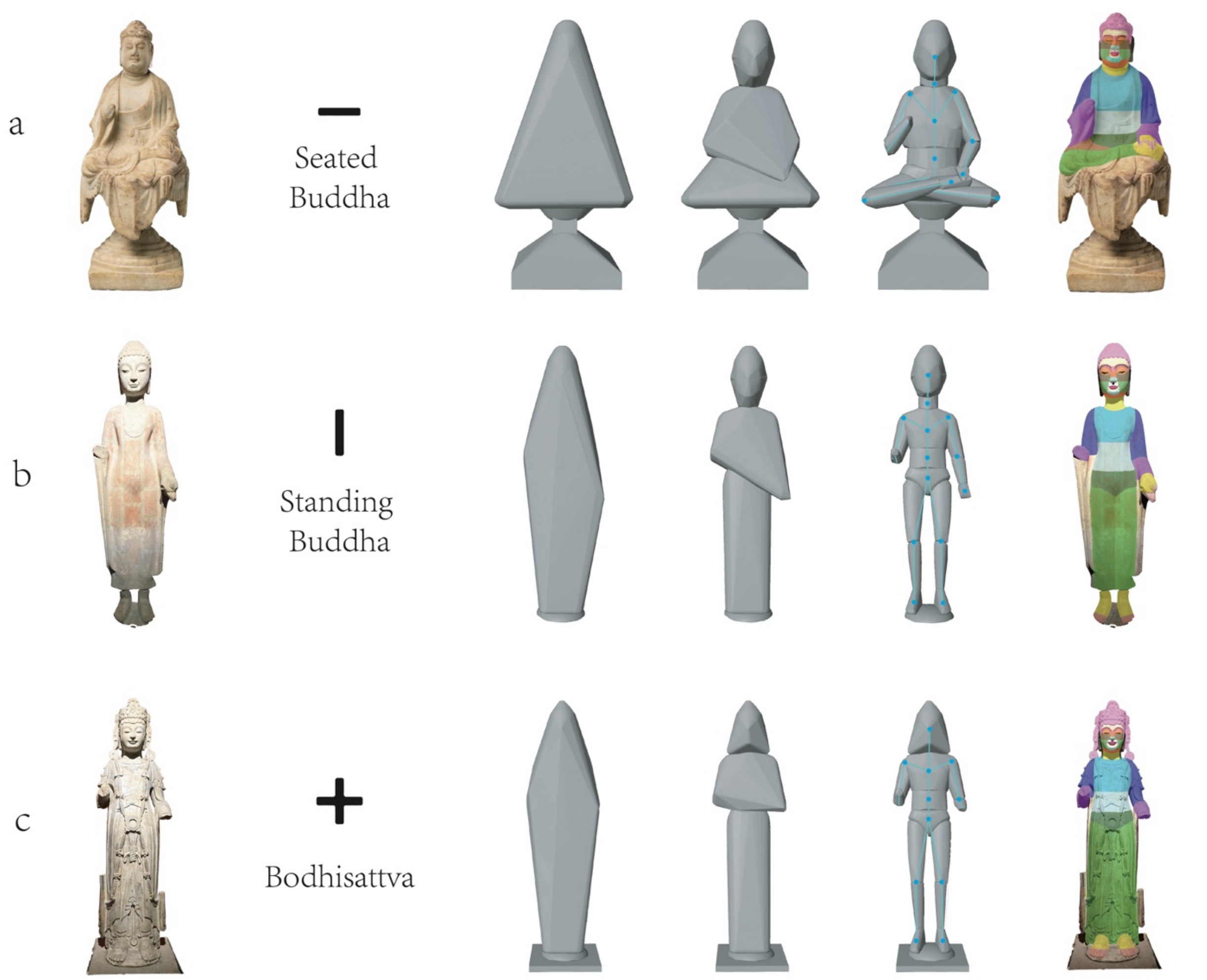
In order to demonstrate examples of 3D models for the updated concept in Section 2.2, we present 3D models of six types of Buddhist statues at their five LoDs in 3. Comparing with the selected Buddhist statues for demonstration in Pan et al. (2025), the difference of the demonstration in this paper reveals in two aspects. On the one hand, a new LoD is added for each type of Buddhist statue. On the other hand, we use different Buddhist statues for four types (namely, seated Buddha, standing Buddha, Bodhisattva, and contemplative Bodhisattva) while keeping another two types (Reclining Buddha and cross-legged Maitreya) unchanged. As we can see on Figure 3(a), 3(b), 3(c), and 3(f)., 3D models at LoD2, LoD3, LoD4 and LoD5 are generated for the four different types of Buddhist statues, respectively, according to the concept of the LoD models. For the reclining Buddha and cross-legged Maitreya, the 3D models at LoD3 are made by using the combination of the convex-hull models of the main body parts which are head and neck, upper body, lower body and seat installation in these cases. A comparison of all LoD models in Figure 3 shows that the transitions between the neighboring LoDs appear smoother and more gradual. Most importantly, the 3D models in the updated LoD system can better fulfil the requirements of different applications in a more precise manner.

### 3.2 Feedback from the questionnaire

The questionnaire survey was implemented in two ways: online (via digital platforms) and offline (paper and pen). Since April 2025, all questions were distributed through the Wenjuanxing platform (https://www.wjx.cn/vm/h6dAG8O.aspx#), with dissemination mainly through four channels: (i) WeChat working groups of research institutes and museums specializing in grottoes such as Yungang, Dazu, and Anyue in China; (ii) social media promotion by doctoral supervisors and collaborating experts in the fields of cultural heritage and geomatics; (iii) WeChat groups of research teams in surveying and geomatics departments at more than ten Chinese universities; and (iv) direct invitations to relevant experts and professors. By September 15, 2025, a total of 170 valid responses were collected.

Respondents represented three principal disciplinary backgrounds: 3D modelling and digitization (56.47%), computer science/semantic modelling (16.47%), and cultural heritage conservation (9.41%). This distribution indicates that the survey reached both technical and humanities-related domains. Regarding years of professional experience, 58.82% of respondents had 1–5 years of practice, 22.35% had 11–20 years, and 6.47% had more than 20 years, ensuring a balance between emerging perspectives and senior expertise.

The feedback show that, 91.76% of respondents judged the defined LoDs to be suitable for Buddhist statue modelling, and 91.18% agreed with the proposed millimeter-level accuracy of LoD5. Nevertheless, constructive critiques emerged: some experts suggested LoD1 should use 2D projected images analogous to building footprints. Furthermore, some participants proposed splitting LoD5 into “geometric detail” and “geometry plus ornaments and color.” In summary, the expert survey demonstrated that the LoD design is comprehensive and reasonable.



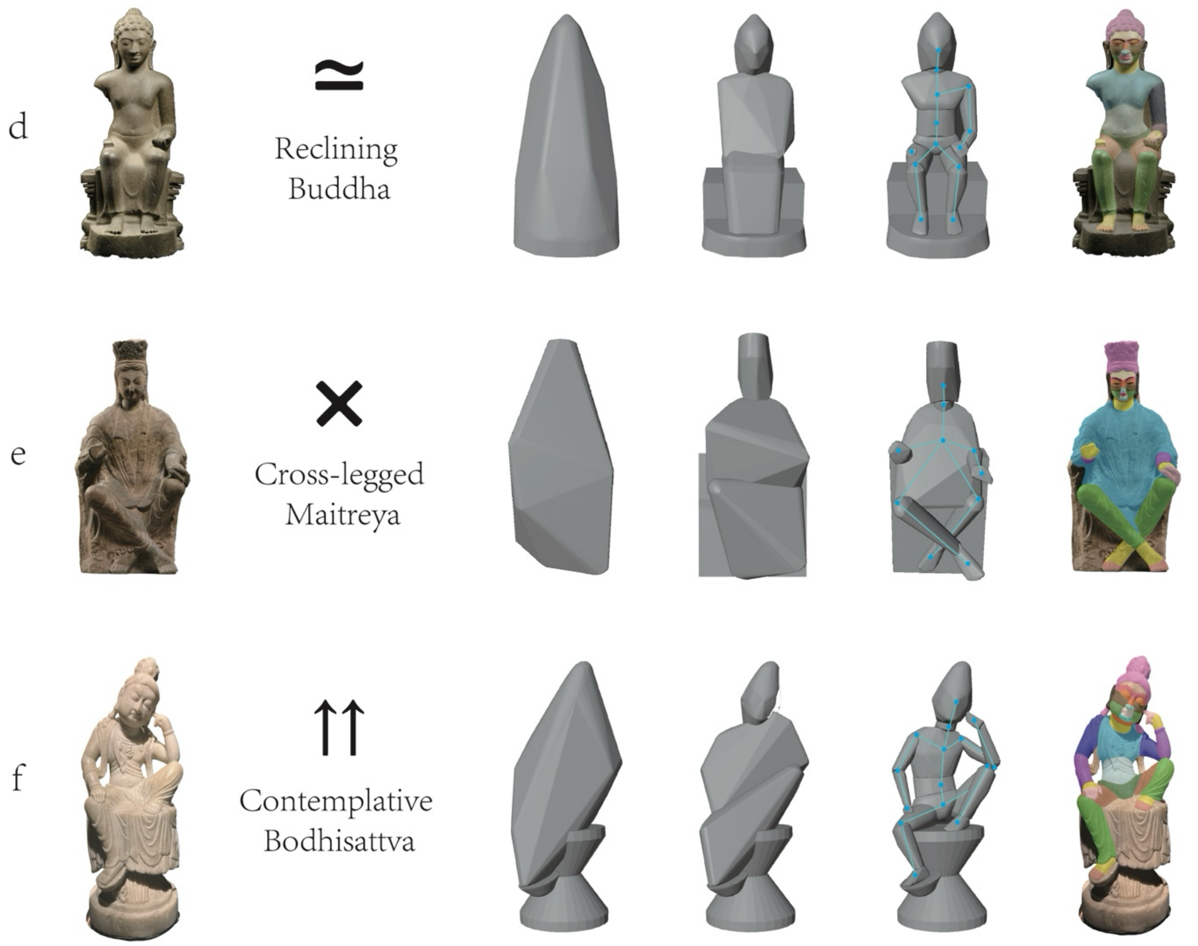



Figure 3. Typologies of six different Buddhist statues and their corresponding LoDs.
Source: the Metropolitan Museum of Art, Poly Art Museum

## 4. Discussion

A LoD1 model in this study is defined as a 2D symbolic representation rather than a 3D geometry. The reason to include it in the LoD system is two-fold. First, in archaeology and museum practice, such symbols have long been used by earlier generations of scholars to map the distribution of cliff-face Buddhist statues. From an iconographic perspective, these marks capture the first layer of meaning and thus resonate with the idea of “semantics” in semantic modelling. While alternative features—such as clothing, crowns, backlights, or pedestals—could also serve as bases for classification, the traditional symbolic system offers a holistic entry point that connects naturally with component-based attributes and provides stronger analytical support. In retrospect, this symbolic classification shows considerable scholarly insight. Second, this symbolic level also parallels the logic of LoDs in CityGML, where 2D footprints are used as LoD0 of 3D building modelling. By maintaining this transitional representation, the framework ensures continuity between iconographic traditions and contemporary semantic modelling.

Comparing the two sets of LoDs in Figure and Figure 2, it is evident that the leaps among the 3D models in the neighboring LoDs in the updated version look gentler and smoother, both in terms of geometric representation and in terms of semantic information. Most importantly, the new version of the LoD models can meet the requirements of different applications more precisely.

The term of accuracy in Table 1. might cause confusion in some cases and is clarified as follows. For LoD1, the accuracy means positional accuracy while for the rest LoDs, the accuracy means geometry accuracy (type of resolution in terms of geometry). In other words, it means the size of the smallest part we need to model. In this work, LoD2 models are defined for applications such as spatial layout, transportation, and storage planning where broad shape and size are required. For these tasks, an accuracy of 5–15 cm is required. The new LoD3 models are designed for applications like digital archaeological and artifact transportation which need know the approximate geometries of main components (head, upper body and lower body). Therefore, an accuracy of 5-10 cm is required.

LoD4 models are used for applications like conservation, restoration, and pose analysis. We do not need to have the details of hand, arm and head. For example, to calculate the size of the material (stone or wood) for a replicative Buddhist head for restoration purpose, it is not necessary to model components such as nose, mouth, eyes in 3D. Details of components around 3-5cm in size can be omitted in the 3D modelling. Therefore, the accuracy is set at 3-5cm. LoD5 models have to offer the highest level of detail for research and study in the domain of archaeology, history, museum, art, etc. For example, people are looking at the details of the accessories (i.e. ornament) to identify the impact of the local culture on the development of the Buddhist statues or other cultural meanings. Therefore, it is necessary to model the smallest detail even with 2-3mm.

## 5. Conclusion and Future Work

Based on several rounds of intensive discussions with colleagues in museums and institutes of grotto research in China, we found 13 applications that require 3D models of Buddhist statues with more detailed information than the convex hull model but less than the skeleton models defined in Pan et al. (2025). For this reason, in this study, we introduced a new LoD for the 3D modelling of Buddhist statues with semantic information, in order to more accurately fulfil the requirements of geometric and semantical information in the applications where 3D models of Buddhist statues are needed.

The new LoD is designed to contain main semantic components like head, upper body and lower body and be geometrically represented by using the combination of the convex hull of these semantic components. With this new LoD, the concept of Pan et al. (2025) is updated to a five-levels of detail system. In order to verify the updated version of LoD, a questionnaire has been conducted. Up to now, 170 valid responses were received, showing that more than 85% of participants agreed with the updating.

In the future, this updated LoD concept will be integrated into the newly developed CityGML ADE for modelling Buddhist Statues in 3D with semantic information (Pan et al. 2025b). At the same time, a set of algorithms will be developed to derive coarser 3D models at coarser LoDs from the most detailed LoD models. Furthermore, the ADE including LoD concept will be applied for practical projects in museums and institutes of grotto research in China. In addition, discussions at a more broad level will be carried out to extend this concept for the 3D modelling of sculptures in Western cultures for various applications.

## Acknowledgements

This research is funded by the project "Digitalization for Culture Heritage" (Project No. UTF-2024/10124), funded by the Norwegian Directorate for Higher Education and Skills, and the project "Interpreting the Value and Emergency Craft Restoration of Diancui Artifacts in the Collection of the Palace Museum" (Project No. 24VJXG034). The authors would also like to express their gratitude to the experts from various research institutes for their valuable feedback during the development of the LoD framework.

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