Cultural Heritage in a Spatial Context – Towards an Integrative, Interoperable, and Participatory Data and Information Management

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Abstract. The authors discuss a concept for a comprehensive three dimensional cultural heritage (CH) information architecture including a time component that takes geographic space as the dominant organizing, presentation and exploration principle. Activities concerning a complex, decentralized information architecture with a cooperative component have only recently gained full relevance since they rely on new achievements. We name three such achievements: fast and user-friendly 3D reconstruction technologies, web-based 3D visualization within standard browsers, and emerging maturity and usage of volunteered geo-content, which is built from vector data, photo collections and 3D models. Achieving more than academic ephemera requires overcoming key problems associated with interoperation, spatial disparities of knowledge, object referencing, data volumes, abstraction, or object lifetime, to name only a few. Reliable and comprehensive solutions will perform well as upcoming business models. Full accounts of the state of the art of all mentioned key issues cannot be given (each of them justifies its own paper). Nor can fully developed solutions or approaches be offered in all cases. At least, a structured compilation of ideas on versatile and practical CH management architecture may provide incentives for future developments.

Keywords: Cultural heritage · Information management concept · Data integration · Virtual globe · Geo-data visualization · User-generated content · Time handling

1 Introduction

It has frequently been stated that present day access to data is unprecedented and the volume of available information is constantly growing [1]. In contrast, there is currently comparatively poor access to *structured information* stemming from skilled data organization, analysis and dissemination. This is despite the fact that structured information would obviously contribute more strongly to cognizance and – on a more general level – to knowledge when compared to uncontrolled data streams [2]. This statement applies pretty well to the informational context of cultural heritage (CH) sites and objects.

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Awareness and cognition related to CH may be seen in the cultural context where *virtual geographic space* progressively forms a gateway to a wide range of spatial [3], and (indirectly) non-spatial information (i.e. *geobrowsing*). This goes along with a pictorial turn [4], a tendency to augment or even replace lingual knowledge representation by *visual models*. There can be little doubt that virtual 3D landscapes will assume a central role in many affairs related to CH [5], be it with a scientific, an educational, an administrative or a marketing background.

The last decade has shown that sustainable information architecture has to be dynamic and open for volunteered contributions and shared content. Herein, volunteered geographic information (VGI) is one major component. The online community Historypin can be named as a showpiece of a crowd-sourced, digital multi-media collection, which allows geographic query and content retrieval [6]. The most popular volunteered geographic data source, OpenStreetMap (OSM), has established CH offshoots, too, as documented by close to 500,000 objects with the data tag "historic" [7] and a specialized "historic place" subproject [8]. Explicit authorities will continue to be important players but may also be faced with the task of filtering, evaluating and approving external input of various types. If one agrees that spatial context matters, then geo-information – including paradata and metadata [9] – can and should be widely exchanged and integrated into digital CH documentation whilst avoiding redundancy and consistency problems.

This article takes up findings, ideas, and open questions that have emerged within application projects guided by the authors: (1) The Turkic name *Uch Enmek* (which is also the project name) relates to a mountain in the Russian Altai Mountains, which overlooks an important archaeological site of primarily Scythian origin. In cooperation with archaeologists from Ghent University, a prototype of an interactive landscape model was created and presented based on the OpenWebGlobe framework [10]. This imbeds archaeological information into the rural 3D environment of an archaeological conservation area [11]. (2) A second project is called GEPAM, an acronym formed from German and Czech words for commemoration [12]. Dedicated to a virtual memorial, the web application comprehensively introduces places of Jewish persecution during the "Third Reich" within the towns of Dresden and Terezin in a perceivable spatial context. Both a historical and a present representation of each urban space have been included [13] along with detailed context information referring to places of interest (POI), the focal points of Jewish history from 1933–1945. The application was based on Google Earth technology. (3) A third project focuses on combined 3D reconstruction and textual treatment of the historically important elements of Freiberg Cathedral (Saxony, Germany). The main practical outcome of this cross-disciplinary educational project is a smartphone app that serves as an interactive church guide [14].

Moreover, we imbed theory extracted from studies dealing with principal issues of research cooperation and scientific structures. This type of research primarily uses methods from scientometrics, management studies and social sciences [15, 16].

This article continues with a brief look at some integral parts of a technical environment relevant for digital information management (Sect. 2). Section 3 proposes a geo-centered integrative concept as one possible solution in the CH context. This has consequences for modes of data structuring, analysis, and visual presentation. If on-demand (geo-)integration of indexed and authored model components can be developed, 3D models and context information will improve significantly. Section 4 sheds some light on selected key issues related to the establishment of comprehensive CH information handling. Due to space limitations, this article will concentrate on highlighting important concepts and promising facets of an integrative solution.

2 Key Achievements as the Necessary Basis

Both tangible and intangible CH can certainly profit from virtual counterparts. The latter can support internal and external conservation tasks, and also facilitate analysis, dissemination and scientific dialogue, mainly by connecting CH models to web facilities. By focusing on CH assets in their spatial context, we are fortunately able to build upon recent generic achievements.

One major breakthrough was the introduction of user-friendly *3D reconstruction technologies* delivering metric results. Quick and accurate 3D content is appreciated as for its superior analytic potential and attractiveness in comparison to 2D sketches and photographs. Vergauwen and van Gool [17] published a modular concept, implementation strategies and results of a CH-related photogrammetric 3D reconstruction web service nearly 10 years ago. With greatly increased computing power, typically distributed via a cloud, 3D reconstruction services have meanwhile become a well-staffed service (e.g., Pix4D). Terrestrial laser scanners (TLS) have been known as a strong alternative model source for more than ten years [18]. The complementary use of dense matching and TLS is possible and has been tested [19]. Vrubel et al. [20] describe the transformation of range and color images into accurate textured 3D models in detail. Roosevelt et al. [21] recently published on synergetic digital recording in archaeology and cite reference projects dealing with the “third dimension in archaeological recording” (p. 326f.). Processing techniques influence geometric reliability, especially in photogrammetric solutions, whilst equipment type and costs are more critical with TLS. Skill and experience remain crucial factors in any case.

A second trigger for the development of three-dimensional virtualization is a *standardized visualization technology*. Originating from proprietary specialized software and data formats, 3D visualization is becoming a more ubiquitous experience almost regardless of the operating system, specific software or hardware. Increasing developer response to Web3D consortium standards, in particular WebGL and HTML5, makes it possible to show and manipulate 3D models without any difference between desktop and web applications, with a JavaScript code running in the browser window [22]. Greater simplicity in provision (interoperable 3D assets) and interaction with 3D models will drive 3D applications in the CH context. The VR (virtual reality) model of Siena Cathedral makes a persuasive case. This complex model generation dates back 15 years [23], but can now be explored by everyone using advanced web and browser technology [24].

Another influence originates from new players in geo-data capture and distribution. The result has been termed *volunteered geoinformation*. The starting point is the general spatial context in the sense of topographic references. In this domain OpenStreetMap (OSM) has gained spatial coverage [25] and a level of detail that has even attracted numerous commercial users. Especially in first world urban environments, active OSM communities provide data upon which detailed 3D townscape/landscape models can be built [26]. Schemes have been published to even extend them to interior spaces [27]. At least a rough landscape context of a CH site can be modeled with moderate effort in most cases. Categorized geo-data as OSM can further be augmented by free pictorial content from photo collections like Flickr® and Panoramio®. Their potential may be demonstrated by a figure taken from Pippig et al. [28]: 32,984 geo-tagged photos have been found and extracted for the town center of Dresden alone. Even missing localization can be mitigated within a web community: Historypin aims to reference pictorial information to places [6]. Alternative web-based geotagging activities can, for instance, be taken from Bourn [29]. Localized images assist interpretation and manual modeling, or – in combination with powerful cloud-based photogrammetry – even feed automated workflows for extensive 3D model creation. Concepts and related technology can be examined on the BigSFM project website [30]. The last category of relevant user-generated content consists of digital 3D models. There is no easy accessible information on volume and typical quality, but their general potential and modes of future incorporation are worth considering.

We agree with Chiabrando and Spano that "an integration of […] models into Web-GIS for a global management of spatial information concerning built heritage is under great attention" [31, p. 67]. As more and more heterogeneous sources become available (including survey results, digital archive and user-generated data) integration becomes the bottleneck. The OGC's (Open Geospatial Consortium) efforts towards *interoperable geo-data* have been successful, but the present situation is still not ideal. The assumption may hold that primarily geographic content from GIS-like environments can potentially semantically and spatially cooperate, the latter through coordinates and unambiguously defined spatial reference systems. Yet this will not work in the short term with user-generated 3D content, since common 3D data (X3D, COLLADA, etc.) do not feature semantic or absolute positional information [32]. In a model assembly process drawing on numerous web resources, manageable models are impossible to achieve without major human effort in controlling, editing, harmonizing and streamlining (e.g., down-sizing) assets, a challenge that is discussed further below.

3 Challenges

3.1 An Integrative Access to Relevant Content

Modeling and presenting individual CH objects in various selections, scales, and details have become easier and more effective, and further progress is still to come. Comparable advance could be achieved by a concerted effort to concentrate on the best-possible use and dissemination of these achievements and their digital results. We understand use in a broad sense which encompasses the documentation, exploration, scientific transformation and analysis, maintenance, surveillance, reconstruction, presentation and marketing of CH. The CARARE project is one related and impressive European initiative. All collected CH content bears an explicit spatial reference. Thus, 2D references provide information about "what is where" as shown on a web map. Methods of access to 3D/VR content still need to be studied and formalized [33].

3D is still mostly “ad hoc, redundant, not efficient, and not exploiting its full potential” [34, p. 14]. Thus, new effort might be directed into a convenient and strongly *computer-assisted integration of numerous object- or profession-centered information components* under one umbrella. Ideally, requests could be served by a single architecture which relies on decentralized cooperative resources. The allegory of an umbrella is used for a flexibly shaped and scaled information architecture, with some degree of standardization and well-designed workflows (offline or as services). Standards foster interoperability and stimulate software development, but acceptance criteria should not be overly restrictive. *Minimum standard compliancy* is a prerequisite to smooth support of elementary processes such as data query and evaluation, editorial selection and content structuring including hyper-linking resources, geographic integration and joint visualization from multiple sources, interchange of addressable contents for scientific and administrative use, and smooth front end presentation.

3.2 Geo-Access as a Versatile, Integrative Solution

Such an umbrella could flexibly span geographic space as the proposed primary access mode. Without excluding different organization principles, geo-centered access is suitable for the vast majority of sites and artefacts tagged as CH. A 2D case can already be realized with the help of well-established IT components like Content Management Systems, WebGIS, and dynamic HTML technology. The success of the geo-approach in information retrieval is documented by ubiquitous and every-day products like Google Maps, Google Earth, Bing Maps, or MapQuest. This type of product (*virtual globes*) is part of the average person’s information environment, and usability is therefore highly facilitated by existing experience. This also seems to address the *ludic drive* of human beings; it has become a prerequisite of commercial success for many types of computer games to present a well-made and interesting landscape (typically a 3D representation) to the gamer community. A third emerging geo-application is a branch of *augmented reality* (AR), where a known viewpoint and view direction reported by a mobile device can be used to blend a physically existing section of the environment with further digital context in various presentation and interaction modes (pictorial, textual, audible, etc.). Web-based interaction with 2D worlds is nowadays operational.

Upgrading to versatile digital 3D portrayal of CH in a geo-context suggests itself. At the composite level the concept seems fresh but various ideas and technical solutions have a longer history, as illustrated by selected references from archaeology in the next section.

3.3 Selected Contributions to Geo-Access and Integration

Digital 3D visualization was already being evaluated in the late 1980s for archaeological purpose [35]. A demand for improved *spatial analytics* comprising 3D topology and queries, which amount to a 3D GIS (“what is next to”, “what surrounds”, “what is above, below, to the side of”, “what is the value of the object at this location”, and “what are the relationships between this feature to surrounding features”, [36, p. 309]) dates back to the 1990s, but this is still not sufficiently supported by standard software. As the context extends from site to landscape level and computing power increases, 3D reconstructions in a wider geographic context emerge. The Appia Antica Project [37] may serve as an example. A high degree of *immersion* (VR) is seen as research stimulant, since an "impartial observer becomes an active participant" [38]. The most immersive technical environment may, however, not automatically perform better at problem solving compared to more abstract depictions [39]. *Integrative 3D visualization* imbeds 3D CH content into a landscape representation and uses a browser as the front end [40], whilst implementations relying on open source software components are preferred [41].

Integration of decentralized 2D and 3D content on demand through web-based services, meaning without tedious manual model augmentation and harmonization, is obviously a key factor. It may determine the future success and dispersion of such context-oriented concepts, which presents a big challenge. On one hand, this relates to *ontology*. A wide spatial and, even more so, thematic integration greatly complicates the taxonomies, which are typically developed in parallel, each serving a specific professional domain [42]. An all-encompassing Cultural Heritage Markup Language – CHML - has been proposed [43], but this is neither fully elaborated nor accepted. On the other hand, domain-specific 3D components have to be technically assembled [44] for a joint visualization, once the relevant assets have been identified. 3D interoperation standards, especially CityGML [45], are seen as one promising solution [46]. A CityGML adaption to CH, however, cannot follow a predetermined path; its provenance as a model of functionally defined topographic reference objects [47] calls for amendments prior to utilization, for example in an archaeological site. Moreover, a plethora of non-standard-compliant models cannot be toughened for full cooperation without major interactive modification. Therefore, a more straight-forward 3D model fusion, disregarding all complex relations in terms of attribute space and topology, might still coexist in the medium term. Structured geo-database storage of 3D objects and on-demand export to a X3D representation for subsequent exploration in a browser without plug-ins has been tested prototypically for a UNESCO heritage site [48]. In developing user-driven 3D assemblies further, we can fortunately rely on strong technical progress in client-based 3D rendering. The X3DOM framework, a JavaScript library, has proved capable of handling massive models if applied in connection with recent HTML and browser technology [49].

The uses of CH 3D landscapes are also worth a closer look. Recent projects have also shown virtual 3D environments as a stage for (educative and entertaining) storytelling [50]. This will most often imply adapting the model to various temporal states. The MayaArch3D Project [51] already bundles and implements many of the ideas cited in this section. The theme of the project is Maya architecture in Copan, Honduras [52]. Using the technical tool QueryArch3D [53], 2D and 3D landscape objects have been integrated by means of a geo-database to allow individual geographic navigation and exploration of architectural objects along with context information. In interfacing software from different domains QueryArch3D tries to connect the visual and explorative capabilities of 3D scenes and the analytical capacities of 2D GIS.

4 Identified Core Aspects

4.1 Object Identifiers

Three-dimensional reconstruction projects accumulate digital entities such as digital objects, part or even full-scale models, metadata and paradata. Identification, exchange and referencing would be facilitated by a comprehensive declaration scheme. Europeana projects have addressed the problem, for example through classification, linking and long-term availability strategies [54]. An alternative can be found in the digital object identifier (DOI) scheme [55]. It identifies and guides the handling of digital objects, and is already established for digital publications. The Uniform Resource Identifiers (URI) system provides identifiers for worldwide use including a database hosting basic metadata on classification and external references. No central repositories are needed, and providers can define access conditions. Along with auxiliary technologies [56] it provides registration and checks for the uniqueness of both entities and identifier.

4.2 Scale Restrictions

Scale and scope adjustments in an interaction with a model have been described as non-linear processes essentially connected to the individual appropriation of a modeled reality and to creative work on and revision of the model. This has been stated for the field of architecture [57], but seems equally applicable to 3D CH models in other disciplines. Scale and scope are opposites. Since, in any pragmatic solution, the spatial contextualization of CH may impact on the dominant research questions and identified causal chains, the extent of the phenomena involved may steer scope and scale as well.

It is, however, questionable whether data and model integration can seriously aim at the full range of spatial dimension, from a global view to extreme close-ups. The provenience may require tracing on a global or continental level, whilst conservation of a particular artefact may concentrate on structures in the millimeter range. The wider a possible scale range is defined, the more complicated class hierarchies and class relations will become. The same goes for visibilities and LOD (Level of Detail) representations. A composite (graphic) model may only jointly exhibit data that share comparable properties in terms of reliability and granularity. Otherwise, fidelity will be lost. A conceptual zoom limit is reached when cognition becomes too scattered or selective to form a complete image. “A researcher must assess how far the uncertainties in analytical results are due to the information loss associated with the data […] or the model employed (Goodchild 2011).” [58, p. 11].

Consequently, a preliminary *scale restriction* makes sense: At maximum zoom we find a historic site including all exterior components, and at the wide angle end we arrive at a highly generalized, wide geographic scope. Frequently, some inconsistency in the level of (known) detail or scale will be inevitable. In these cases, different graphic levels of abstraction (compare 4.4 below) can help in avoiding misinterpretations. If indoor, underground environments and much of the inventory (e.g., of a museum) are realistically beyond the scope of the concept, sensible interface nodes for the detail level should nevertheless be provided.

4.3 Cultural Heritage Within Different Thematic Spaces

Geospatial context can potentially free CH objects and domains from a museum-like (more or less displaced) arrangement. Geographic space in holistic terms, including history, perception and scale, may even be the proper focus of CH research, as in landscape archaeology: “The Historic Landscape Character method of landscape archaeology is distinguished by a concern for how the past and its remains contribute to people’s contemporary perception of landscape at a variety of scales and to a variety of degrees (depending on knowledge, understanding and interest of the individual beholder).” [59, p. 137]. Also in cases where research is centered on precisely localized CH objects and sites, a major range of associated topics will relate to a much broader context. The postulated geospatial anchor point of information retrieval and presentation can be exemplified by some geospatial units associated with CH. These units will come with more or less clearly defined outlines and with a wide range of geographical and time scales.

In zooming out, we may encounter units such as an ethnic or cultural space, a stylistic space (e.g., the spread of perpendicular architecture from the Île-de-France over a certain time), a space spanned by trade links, or a political space (territorial division at a certain time). In zooming in, we can eventually delineate a space from which the building material originates. A detectable geomorphic setting may then reflect strategic importance or determine the spiritual meaning of a site (e.g., pre-historic burial sites). At even closer quarters, the internal layout and all patterns of the material components of a site can be explored.

As each theme occupies its own geographic space, comprehension requires specific fields of view and presentations, which react within the technical and perceptive limits associated with scale. Whenever a broad spatial context has to be shown, “full” 3D is not essential. Systematic considerations regarding the visual interplay of the dimension of the geo-reference and the corresponding thematic content [60] provide initial orientation in a choice of visualization options. Such options, including dimensionality and LOD, can be further optimized by evaluating the diverse interrelations between geographic setting and all the themes portrayed.

While it is clear that not all desirable thematic content can be made accessible, and some of it not even in the medium term, a concept should nevertheless provide structures for these spaces and the context information.

4.4 Abstraction in 3D Presentations

An interactive model of the geographic environment has to adapt to the user’s field of view and the associated scale variation. The field of view controls the number of visible objects. Total data volume restrictions and acceptable rendering times now demand strict rules on object visibility and suitable LOD. Three-dimensional content is anyway only justified once a shape can be perceived as a 3D object. Below this level a 2D overlay suffices.

An elaborate concept of abstraction goes far beyond LOD and scale-dependent visibility. It includes *schematization* "to maximize task-adequacy while minimizing non-functional detail" [61, p. 301]. Schematic 3D content can improve 3D visualization (compare [47]). Like prototype objects and textures, it does not claim to copy reality as photo-textures do. The idea that photography is an accurate representation has been challenged for a long time. Gombrich's 1960 book *Art and Illusion* "shows how heavily abstracted a photograph actually is through exposing the many artifices employed: the micro-instant frozen forever, the limited angle of view, and the arbitrariness of photographic processing" [62, p. 29]. Photography can only get close to historical reality as it captures a visual appearance determined by momentary environmental factors (e.g. illumination), when the data is taken, that is, in the past. Excluding photographic portrayal frees a complex model from unwanted content, and will divert the user's attention less. If combined with a series of digital graphic techniques (e.g., edge enhancement, reduced color spaces), non-photorealistic (NPR) depictions [63] can be even more expressive, and thus convey specific contents more efficiently than photographic ones. For the geo-context, Semmo et al. [64] have presented inspiring NPR solutions, using an object context to decide on a level of abstraction. By applying multiple texturing techniques, this approach even circumvents a hard choice between realism and abstraction.

Schematic content is directly creatable from standard geo-data sources through automated workflows, whereas a categorical class is - in combination with visually relevant properties - translated into a prototype object. This strategy has been tested already and, as Fanini and Ferdani state, the biggest challenge has been in the "different typologies […] needed to reproduce a reliable virtual copy" [65, p. 111]. A schematic model requires less storage space. It also improves rendering performance, due to less different geometric and textural content. Furthermore, prototype contents facilitate scale transformation (zoom); transitions between prototypes can be stored explicitly (e.g., objects of type A, B, C will be amalgamated to a new object of type D), and surface properties can be optimized for smooth transitions. Defined graphic parameters make visual transitions predictable, instead of necessitating a switch between different images.

Despite these advantages, users might criticize that such models express a professional, filtered view, since all objects are solely shaped by the underlying conceptual data model and prototype design. If only instances of a limited number of primary objects exist, some degree of unrealistic uniformity might be bemoaned. This can be mitigated, but not eliminated, for instance by applying random modifiers to graphic parameters.

Reflections on realism versus schematization in 3D models also matter in an educational context. Visual experience, high authenticity, simple feedback between model and real world are arguments for the first option, whilst a stronger visual focus and higher demand for reflected perception favor the second. Preferences in one or the other direction can only be substantiated if a usage scenario is given [66]. A compromise between purist solutions could often achieve the best effect. To give one simple example, high realism (photorealism) through detailed explicit 3D modeling including photo-textured exterior shapes might be reserved for the focus objects which are obviously located within the CH sites and contain their prominent objects. The other parts of the environment could then be depicted in a more abstract, schematic way as outlined above.

4.5 The Role of Time

Undisputedly temporal relations are highly critical in the field of CH. The tension between time and space is currently a matter of intense debate and was the theme of the Computer Applications and Quantitative Methods in Archaeology (CAA) Conference 2013: "Across Space and Time". The key issues in time handling are discussed below.

Time-related question types were compiled and discussed back in 2007 by Constantinidis [67, p. 409]: "[…] a spatio-temporal GIS could respond to the following queries: Where and when did change occur? What types of change occurred? What is the rate of change? What is the periodicity of change?" Time as an independent dimension has not been introduced to complement standard GIS entities since 2007. It is true that time stamps can be assigned, and a pair of them can indicate a lifetime. In general, however, the lifetime of a geometric entity is very unlikely to be prime concept for use in CH. Take the example of a building. How does a standard model express a situation after a fire, where one part has been fully reconstructed, another demolished, and a third rebuilt on the remaining ground floor, whereas extensive reuse of building material has taken place? *Transformations*, a very common historical process, do not fit into a standard GIS concept, even less so if this process is lingering, like the gradual decay of a disused structure. Toughening up historical geo-data for the limited potential of current models would not only require shaping entities according to structural, functional or other thematic criteria, but also subdividing them into smaller entities thought to have a homogeneous transformation history. This seems impractical.

A second issue is *imperfect knowledge*. The further we go back in time, the more imprecise time references will normally become; time stamps have to be supplemented by uncertainty measures. A further related theme concerns relative time assessments, or models allowing for time relations to external events. A further complicated problem is missing synchronicity of knowledge about a geographic space, in particular an issue when CH is linked to a landscape context. Whilst prominent objects (e.g. a mansion) are often reasonably well documented, average objects (e.g., a farmstead) have sparser and very different reported timelines, if any are available at all. Promising proposals have been made for reassessing time in GIS. These include introducing a triangular time space model (time versus duration) along with the rough set theory, which nicely accounts for imperfect knowledge in defining temporal memberships as "definitely in", "definitely not in", and "possibly in" [68]. Such features are by no means part of standard software, however.

On the user side, dynamic landscape model visualizations will hardly ever allow a free choice of time, but only offer predetermined pseudo-snapshots along a limited timeline. Consequently, there is an urgent need for graphic coding of vagueness, which should be associative and reduce the risk of drawing false conclusions due to unquestioned perception.

4.6 Handling User-Generated Content

Volunteered (geo-)information has been tremendously successful, making it necessary to open up an integrative architecture to this sort of input. Sylaiou et al. [69] name examples of VGI input to CH research: Besides their established role in data collection, volunteers may also act as research assistants in scanning and interpreting large open data sets (e.g., archaeological site detection).

A data-oriented scheme may show the following modes of volunteered contribution:

1. Comments and corrections on an existing published status of information;
2. New links to or submission of recent and historic textual documents;
3. New links to or submission of recent and historic pictorial documents.
4. Contribution of prefab 3D content (SketchUp's 3D Warehouse, the most popular source, calls itself the world's biggest model repository [70]).

Whilst the first three contributions might be treated like internal documents, a 3D model merge (4) involves much more than drag and drop. Either complete geo-coordinates plus spatial reference complement a model, or – more likely – an anchor point plus inner orientation directs an initial geometric integration. Especially in dealing with a multitude of models, transformations and modifications prior to integration will be necessary. On a very generic level, the *object formation* inherent to a model has to be questioned and eventually modified. Other researchers have suggested that 3D (re-)constructions might become self-evident subjects of expert discourse and academic negotiations [71]. Consequently, addressing objects will only be possible if a minimum set of mandatory *object classes* reliably exists, which has to be proved. It is also doubtful that a broad integration of geometries will not generate conflicts (e.g., by overlaps or gaps). Three-dimensional topology testing is demanding [72], and requires automation, which links back to defined object classes. Beyond geometry, *object appearance,* that is its surface and environment properties, will definitely not match well if set by different model providers. As in the case of geometry, modifications may be inevitable. With respect to OpenStreetMap, rigid modeling guidelines might be omitted for the sake of greater attractiveness within the community of contributors, but ambiguities and redundancies have to be tackled by those in charge of the integration. If the right software resources are available, subject to the condition that fine front end applications might eventually gain popularity, it is likely that even complete 3D models can be composed from volunteered sources.

4.7 Remarks on the Database

The above discussion makes it clear that the key components of successful data information management are a well-designed database model and a powerful management system. The following subtasks must be performed to support this, although the list is far from being complete:

1. Ingestions or linking of primary documents;
2. Ingestion of documents to be published (authorized documents);
3. Geospatial hierarchies and their visual representations;
4. Administration of authorship;
5. Handling of temporal events;
6. Tagging of uncertainty levels;

7. Identification of missing constituents (in relation to output to be published);
8. Versioning;
9. Links between documents and associated formats and standards.

These subtasks have already been largely incorporated into published database schemes. Other sources refer to metadata [73], database architectures [74], usage schemes and their practical application [54].

5 Summary

If integration is a priority, standards are essential right from the beginning. It seems sensible to identify practical rules that can serve as a *broker* between various modeling standards associated with potential input. The integration initiatives applied to official European topographic references are a good example. A 3D modeling standard, CityGML [45], has been developed to meet the challenge of interoperation. It has already catered for various circumstances: It is flexible for semantic augmentations, different LODs, and visual properties. It is best suited to a GIS modeler, however, and not necessarily to the volunteer offering a fully textured stand-alone 3D asset. Tedious efforts to transform heterogeneous input into *one uniform binding standard* are best avoided, but then metadata has to show what part of the information relevant for integration exists and what is missing. Even if complete harmonization remains impossible in the short and medium term, multi-source model assemblies might work at a higher generalization level.

We propose directing research efforts into an *open framework*. The goal would be integrative, interoperable, and participatory geospatial information transfer related to CH. In the context of the present application, CH will be reduced to extant or historic built structures, whilst the geospatial context will rely on a comprehensive concept of the associated landscape, augmented with information on territorial patterns, trade links, sites of major historical events, and so on. Both experts and the interested public will have access to information, including modes of participation. Visibility management, transparent authorship, and versioning can prevent unintended seepage of internal or uncertified information components. Geospatial objects will carry scale-dependent 3D and 2D representations to allow them to cooperate within different spatial configurations (from continental to local). Cooperation between individual objects within a 3D scene depends on numerous prerequisites. Crucial parameters include the quality of the modeling reference, LOD, compliance to standards, geometric consistency, and unambiguous spatial referencing. For shared and distributed resources to work, a catalogue system must allow for searching, querying and identifying geospatial contents. Therefore we propose that the DOI approach be extended to the class of 3D geospatial objects.

Clearly, interoperability and smooth support by automated workflows are key factors in a framework becoming widely accepted and practically used. Neither the practitioners within the field of CH management nor the majority of exterior participants will have an in-depth expertise in geo-informatics or database management systems. Workflow development has to identify flaws and bottlenecks in close cooperation with users. Existing bottlenecks have already been located here: They include quality control of geospatial objects, the automation of 2D-3D upgrade of landscape data, clever data volume reduction as a prerequisite of a manageable cooperation, handling time, topological model adaption reacting on new elements, the categorization and systematization of new geo-objects, and the management of volunteered contributions, including requests for augmentation or corrections.

References

1. Gantz, J., Reinsel, D.: The digital universe in 2020: big data, bigger digital shadows, and biggest growth in the far east. In: IDC iView, December 2012. http://www.emc.com/collateral/analyst-reports/idc-the-digital-universe-in-2020.pdf. Accessed 30 Sept 2016
2. Hasler Roumois, U.: Studienbuch Wissensmanagement: Grundlagen der Wissensarbeit in Wirtschafts-, Non-profit- und Public-Organisationen. Orell Füssli, Zürich (2007)
3. Blower, J.D., Gemmell, A.L., Haines, K., Kirsch, P., Cunningham, N., Fleming, A., Lowry, R.: Sharing and visualizing environmental data using virtual globes. In: UK e-Science All Hands Meeting 2007, 10–13 September 2007, Nottingham, UK, pp. 102–109 (2007)
4. Mitchell, W.J.T.: Picture Theory. University Press, Chicago (1994)
5. Brovelli, M.A., Hogan, P., Minghini, M., Zamboni, G.: The power of virtual globes for valorising cultural heritage and enabling sustainable tourism: NASA world wind applications. In: International Archives of the Photogrammetry, Remote Sensing and Spatial Information Science, vol. XL-4/W2, pp. 115–120 (2013)
6. Historypin. http://www.historypin.org. Accessed 30 Sept 2015
7. Taginfo. http://taginfo.openstreetmap.org/. Accessed 30 Sept 2015
8. Historic Place. http://gk.historic.place/. Accessed 30 Sept 2015
9. Bentkowska-Kafel, A., Denard, H., Baker, D.: Paradata and Transparency in Virtual Heritage. Ashgate, Farnham (2012)
10. Loesch, B., Christen, M., Nebiker, S.: OpenWebGlobe – Ein quelloffenes Software Development Kit zur Entwicklung virtueller Globen auf Basis von HTML5 und WebGL. In: Seifert, E. (ed.) Erdblicke – Perspektiven für die Geowissenschaften, Publ. der DGPF 21, pp. 275–283. DGPF, Potsdam (2012)
11. Prechtel, N., Münster, S., Kröber, C., Schubert, C., Sebastian, S.: Presenting cultural heritage landscapes – from GIS via 3D models to interactive presentation frameworks. In: ISPRS Annals of the Photogrammetry, Remote Sensing and Spatial Information Sciences (XXIV International CIPA Symposium), vol. XL-5/W2, pp. 253–258 (2013)
12. Brödner, J., Kröber, C.: GEPAM – Eine interaktive Informationsplattform zur "Landschaft des Gedenkens". In: Koch, M., Butz, A., Schlichter, J. (eds.) Mensch & Computer 2014 – Workshopband Fachübergreifende Konferenz für Interaktive und Kooperative Medien – Interaktiv unterwegs – Freiräume gestalten, vol. 14, pp. 21–23. De Gruyter Oldenburg, Berlin (2014)
13. Jedlička, K., Čada, V., Fiala, R., Hájek, P., Janečka, K., Ježek, J., Strejcová, J., Vichrová, M., Roubínek, J.: Techniques used for optimizing 3D geovisualization of terezín memorial. In: Digital Proceedings of ICC 2013, "Cartography from Pole to Pole", paper 281 (2013). http://icaci.org/files/documents/ICC_proceedings/ICC2013/_extendedAbstract/281_proceeding.pdf. Accessed 15 June 2016
14. Kröber, C., Münster, S.: An app for the cathedral in Freiberg – an interdisciplinary project seminar. In: Sampson, D.G., Spector, J.M., Ifenthaler, D., Isaias, P. (eds.) Proceedings of the 11th International Conference on Cognition and Exploratory Learning in Digital Age 2014 (CELDA), pp. 270–274 (2014)

15. Münster, S.: Researching scientific structures via joint authorships – the case of virtual 3D modelling in humanities. In: International Conference on Infrastructures and Cooperation in E-Science and E-Humanities (forthcoming)
16. Münster, S.: workflows and the role of images for a virtual 3D reconstruction of no longer extant historic objects. In: ISPRS Annals of Photogrammetry, Remote Sensing Spatial Information Science, vol. II-5/W1, pp. 197–202 (2013)
17. Vergauwen, M., Van Gool, L.: Web-based 3D reconstruction service. Mach. Vis. Appl. **17**, 411–426 (2006)
18. Boehler, W., Heinz, G., Marbs, A.: The potential of non-contact close range laser scanners for cultural heritage recording. In: Albertz, J. (ed.) Surveying and Documentation of Historic Buildings – Monuments – Sites. Traditional and Modern Methods. Proceedings of the XVIII. International Symposium CIPA 2001, pp. 430–436. CIPA, Berlin (2001)
19. Bastonero, P., Donadio, E., Chiabrando, F., Spanò, A.: Fusion of 3D models derived from TLS and image-based techniques for CH enhanced documentation. ISPRS Ann. Photogramm. Remote Sens. Spat. Inf. Sci. **II-5**, 73–80 (2014)
20. Vrubel, A., Bellon, O., Silva, L.: A 3D reconstruction pipeline for digital preservation. In: IEEE Conference on Computer Vision and Pattern Recognition 2009, pp. 2687–2694 (2009)
21. Roosevelt, C.H., Cobb, P., Moss, E., Olson, B.R., Ünlüsoy, S.: Excavation is digitization: advances in archaeological practice. J. Field Archaeol. **40**(3), 325–346 (2015)
22. Sawicki, B., Chaber, B.: Efficient visualization of 3D models by web browser. Computing **95**(8), 661–673 (2013)
23. Behr, J., Fröhlich, T., Knöpfle, C., Kresse, W., Lutz, B., Reiners, D., Schöffel, F.: The digital Cathedral of Siena – innovative concepts for interactive and immersive presentation of cultural heritage sites. In: Bearman, D. (ed.) ICHIM 2001, International Cultural Heritage Informatics Meeting. Full papers, Cultural Heritage and Technologies in the Third Millennium, vol. 1, pp. 57–71. ICHIM, Milan (2001)
24. Web3D Consortium: X3D - large model high quality rendering: Cathedral at Siena, Italy. Example provided by Fraunhofer, IGD, VCST (2014) http://examples.x3dom.org/Demos/Siena/siena.html. Accessed 15 June 2016
25. Neis, P., Zielstra, D., Zipf, A.: Comparison of volunteered geographic information data contributions and community development for selected world regions. Future Internet **5**(2), 282–300 (2013)
26. OSM2World, http://osm2world.org/. Accessed 30 Sept 2015
27. Goetz, M.: Towards generating highly detailed 3D CityGML models from OpenStreetMap. Int. J. Geograph. Inf. Sci. **27**, 845–865 (2013)
28. Pippig, K., Burghardt, D., Prechtel, N.: Semantic similarity analysis of user-generated content for theme-based route planning. J. Location Based Serv. **7**, 223–245 (2013)
29. Bourn, D.: Geotagging: Using Maps to Organize Historic Images. http://usingsfhistory.com/2011/09/17/using-maps-to-organize-historic-images/. Accessed 30 Sept 2015
30. BigSFM: Reconstructing the World from Internet Photos. http://www.cs.cornell.edu/projects/bigsfm/. Accessed 15 Sept 2016
31. Chiabrando, F., Spanò, A.: Points clouds generation using TLS and dense-matching techniques. A test on approachable accuracies of different tools. ISPRS Ann. Photogram. Remote Sens. Spat. Inf. Sci. **II-5/W1**, 67–72 (2013)
32. Zlatanova, S., Stoter, J., Isikdag, U.: Standards for exchange and storage of 3D information: challenges and opportunities for emergency response. In: Bandrova, T., Konecny, M., Zhelezov, G. (eds.) 4th International Conference on Cartography and GIS, vol. 2, pp. 17–28. Bulgarian Cartographic Association, Sofia (2012)

33. Fernie, K.: CARARE – D1.8 – Final Report, http://www.carare.eu/eng/content/download/8733/74310/file/D1_8%20Final%20Report.pdf
34. Stoter, J.: 3D Modelling in the Netherlands. Presentation Slides at Geospatial World Forum, 5 May 2012. http://www.geospatialworldforum.org/2012/gwf_PDF/Jantien.pdf
35. Harris, T.M.: Digital terrain modelling and three-dimensional surface graphics for landscape and site analysis in archaeology and regional planning. In: Ruggles, C., Rahtz, S. (eds.) CAA 87. Computer and Quantitative Methods in Archaeology 1987. BAR International Series, vol. 393, pp. 160–170. B.A.R, Oxford (1988)
36. Harris, T.M., Lock, G.R.: Multi-dimensional GIS: exploratory approaches to spatial and temporal relationships within archaeological stratigraphy. In: Kamermans, H., Fennema, K. (eds.) Interfacing the Past. Computer Applications and Quantitative Methods in Archaeology CAA95, vol. II. Analecta Praehistorica Leidensia, vol. 28, pp. 307–316. Institute of Prehistory, University of Leiden, Leiden (1996)
37. Forte, M., Pescarin, S., Pietroni, E.: The Appia Antica Project. In: Forte, M. (ed.) The Reconstruction of Archaeological Landscapes Through Digital Technologies. Proceedings of the 2nd Italy-United States Workshop. BAR International Series, vol. 1379, pp. 79–95. Archaeopress, Oxford (2005)
38. Rouse, J.: You had to be there: landscape archaeology using GIS and VR (1994). http://www.wvgis.wvu.edu/Conference2004/ppt/session4/rouse.ppt. Accessed 30 Sept 2015
39. Bennett, R., Zielinski, D.J., Kopper, R.: Comparison of interactive environments for the archaeological exploration of 3D landscape data. In: 3DVis (3DVis), IEEE International Workshop on 3DVis (3DVis), pp. 67–71. IEEE, Piscataway (2014)
40. Pescarin, S., Calori, L., Camporesi, C., Forte, M.: Interactive landscapes reconstruction: a web 2D and 3D opensource solution. In: Mudge, M., Ryan, N., Scopigno, N. (eds.) The 6th International Symposium on Virtual Reality, Archaeology and Cultural Heritage VAST Short Presentations, pp. 33–38. Ed. Star, Pisa (2005)
41. Scianna, A., Ammoscato, A.: 3D GIS data model using open source software. In: International Archives of the Photogrammery, Remote Sensing and Spatial Information Sciences. Part 4-8-2-W9, vol. 38, pp. 120–125 (2010)
42. Bittner, T., Donnelly, M., Winter, S.: Ontology and semantic interoperability. In: Prosperi, D., Zlatanova, S. (eds.) Large-Scale 3D Data Integration: Problems and Challenges, pp. 139–160. CRCpress (2005)
43. Kuroczinsky, P.: Digital reconstruction and virtual research environments – a question of documentation standards. In: Access and Understanding – Networking in the Digital Era, Proceedings of the Annual Conference of CIDOC, Dresden, Germany (2014)
44. Nebiker, S., Schütz, S., Wüst, T.: Geo-roaming: model-driven content management for web-based 3D geoinformation services. In: XXII International Cartographic Conference (ICC2005), La Coruna, Spain (2005)
45. Gröger, G., Kolbe, T.H., Nagel, C., Häfele, K.-H. (eds): OGC City Geography Markup Language (CityGML) Encoding Standard. Version 2.0.0, OGC Doc No. 12 019, Open Geospatial Consortium, published 04 April 2012, 344 p. (2012)
46. D'Andrea, A., Lorenzini, M., Milanese, M.: A novel approach to 3D documentation and description of archaeological features. In: Contreras, F., Melero, J. (eds.) CAA'2010 Fusion of Cultures – Proceedings of the 38th Conference on Computer Applications and Quantitative Methods in Archaeology (2010)
47. Prechtel, N.: On strategies and automation in upgrading 2D to 3D landscape representations. CaGIS **42**(3), 244–258 (2015)
48. Hanitzsch, J.: Konzeption, Datenhaltung und – synthese für die 3D-Präsentation der Wörlitzer Anlagen. Diploma thesis TU Dresden, Inst. f. Cartography, 115 p. (2014)

49. Stein, C., Limper, M., Kuijper, A.: Spatial data structures for accelerated 3D visibility computation to enable large model visualization on the web. In: Web3D 2014 – Proceedings of the 19th International ACM Conference on 3D Web Technologies. ACM, New York, pp. 53–61 (2014)
50. Liestøl, G.: Along the appian way. storytelling and memory across time and space in mobile augmented reality. In: Ioannides, M., Magnenat-Thalmann, N., Fink, E., Žarnić, R., Yen, A.-Y., Quak, E. (eds.) EuroMed 2014. LNCS, vol. 8740, pp. 248–257. Springer, Heidelberg (2014). doi:10.1007/978-3-319-13695-0_24
51. MayaArch3D. http://www.mayaarch3d.org/language/en/sample-page/. Accessed 30 Sept 2015
52. von Schwerin, J., Richards-Rissetto, H., Agugiaro, R.F.G.: The MayaArch3D project: a 3D WebGIS for analyzing ancient architecture and landscapes. Literary Linguist. Comput. **28**(4), 736–753 (2013). The MayaArch3D Project: A 3D WebGIS for Analyzing Ancient Architecture and Landscapes
53. Agugiaro, G., Remondino, F., Girardi, G., von Schwerin, J., Richards-Rissetto, H., de Amicis, R.: QueryArch3D: querying and visualising 3D models of a maya archaeological site in a web-based interface. Geoinf. FCE CTU **6**(2011), 10–17 (2011)
54. Pletinckx, D.: Europeana and 3D. In: ISPRS Archives vol. XXXVIII-5/W16, pp. 483–490 (2011)
55. International DOI Foundation Inc.: The DOI Handbook (2005)
56. Reilly, S., Tupelo-Schneck, R.: Digital object repository server: a component of the digital object architecture. D-Lib Mag. **16**(1/2), 8 (2010)
57. Yaneva, A.: Scaling up and down. extraction trials in architectural design. Soc. Stud. Sci. **35**, 867–894 (2005)
58. Lloyd, C.D.: Exploring Spatial Scale in Geography. Wiley, Hoboken (2014). 272 p.
59. Turner, S., Fairclough, G.: Common culture: the archaeology of landscape character in Europe. In: Hicks, D., McAtackney, L., Fairclough, G. (eds.) Envisioning Landscape: Situations and Standpoints in Archaeology and Heritage. One World Archaeology, 52, Left Coast Press, vol. 52, pp. 120–145 (2007)
60. Dubel, S., Rohlig, M., Schumann, H., Trapp, M.: 2D and 3D presentation of spatial data: a systematic review. In: 3DVis (3DVis), IEEE International Workshop on 3DVis (3DVis), pp. 11–18 (2014)
61. Mackaness, W., Reimer, A.: Generalisation in the context of schematised maps. In: Burghardt, D., Duchêne, C., Mackaness, W. (eds.) Abstracting Geographic Information in a Data Rich World, pp. 299–328. Springer, Cham (2014)
62. Landsdown, J., Schofield, S.: Expressive rendering: a review of nonphotorealistic techniques. IEEE Comput. Graph. Appl. **1995**, 29–37 (1995)
63. Sayeed, R., Howard, T.: State of the art non-photorealistic rendering (NPR) techniques. In: McDerby, M., Lever, L. (eds.) EG UK Theory and Practice of Computer Graphics, pp. 1–10 (2006)
64. Semmo, A., Trapp, M., Kyprianidis, J.E., Döllner, J.: Interactive visualization of generalized virtual 3D city models using level-of-abstraction transitions. In: Eurographics Conference on Visualization (EuroVis) 2012, Computer Graphics Forum, vol. 31, pp. 885–894 (2012)
65. Fanini, F., Ferdani, D.: A new approach from 3D modelling and scanning of archaeological data to realtime online exploration. In: Zhou, M., Romanowska, I., Wu, Z., Xu, P., Verhagen, P. (eds.) Revive the Past. Computer Applications and Quantitative Methods in Archaeology (CAA). Proceedings of the 39th International Conference, Beijing, 12–16 April 2011, pp. 107–115. Pallas Publications, Amsterdam (2011)

66. Schwan, S., Buder, J.: Virtuelle Realität und E-Learning. Portalbereich Didaktisches Design, 20 p. (2006). http://www.e-teaching.org/didaktik/gestaltung/vr/vr.pdf. Accessed 15 Sept 2015
67. Constantinidis, D.: TIME to look for a temporal GIS. In: Figueiredo, A., Velho, G.L. (eds.) The World is in Your Eyes. CAA2005. Computer Applications and Quantitative Methods in Archaeology. Proceedings of the 33rd Conference, Tomar (Portugal), March 2005, pp. 407–411 (2007)
68. Qiang, Y., Delafontaine, M., Neutens, T., Stichelbaut, B., Tré, G., De Mayer, P., van de Weghe, N.: Analysing imperfect temporal information in GIS using the triangular model. Cartograph. J. **49**, 265–280 (2012)
69. Sylaiou, S., Basiouka, S., Patias, P., Stylianidis, E.: The volunteered geographic information in archaeology. ISPRS Ann. Photogrammetry Remote Sensing Spat. Inf. Sci. **II-5/W1**, 301–306 (2013)
70. https://3dwarehouse.sketchup.com/. Accessed 26 Sept 2015
71. Münster, S., Prechtel, N.: Beyond software. Design implications for virtual libraries and platforms for cultural heritage from practical findings. In: Ioannides, M., Magnenat-Thalmann, N., Fink, E., Žarnić, R., Yen, A.-Y., Quak, E. (eds.) EuroMed 2014. LNCS, vol. 8740, pp. 131–145. Springer, Heidelberg (2014). doi:10.1007/978-3-319-13695-0_13
72. Xu, D., Zlatanova, S.: An approach to develop 3D Geo-DBMS topological operators by re-using existing 2D operators. In: ISPRS Annals on the Photogrammery, Remote Sensing and Spatial Information Sciences II-2/W1, 8th 3DGeoInfo Conference & WGII/2 Workshop, 27 – 29 November 2013, Istanbul (Turkey), pp. 291–297 (2013)
73. Ronzino, P., Amico, N., Niccolucci, F.: Assessment and comparison of metadata schemas for architectural heritage. In: XXIII CIPA Symposium – Proceedings (2011)
74. Märker, M., Uleberg, E.: Databases on cultural heritage and their geographic visualization. Session at CAA 2013 conference. http://caa2013.org/drupal/sessions. Accessed 30 Sept 2014