TOWARDS THE LONG-TERM PRESERVATION OF BUILDING INFORMATION MODELS

Jakob Beetz, j.beetz@tue.nl
Department of the Built Environment, Eindhoven University of Technology, Eindhoven, The Netherlands

Stefan Dietze, dietze@l3s.de
L3S Research Center, Leibniz University Hannover, Germany

René Berndt, rene.berndt@fraunhofer.at
Fraunhofer Austria Research GmbH, Graz, Austria

Martin Tamke, martin.tamke@kadk.dk
Centre for IT and Architecture (CITA), Royal Academy of Fine Arts, Schools of Architecture, Design and Conservation, Copenhagen, Denmark

ABSTRACT

Long-term preservation of information about artifacts of the built environment is crucial to provide the ability to retrofit legacy buildings, to preserve cultural heritage, to ensure security precautions, to enable knowledge-reuse of design and engineering solutions and to guarantee the legal liabilities of all stakeholders (e.g. designer, engineers). Efforts for the digital preservation of information have come a long way and a number of mature methods, frameworks, guidelines and software systems are at the disposal of librarians and archivists. However, the focus of these developments has primarily been on textual and audio-visual media types. With the recent paradigm shift in architecture and construction from analog 2D plans and scale models to digital 3D information models of buildings, long-term preservation efforts must turn their attention to this new type of data. Currently, no existing approach is able to provide a secure and efficient long-term preservation solution covering the broad spectrum of 3D architectural data, while at the same time taking into account the demands of institutional collectors like architecture libraries and archives as well as those of the private sector including building industry SMEs, owners, operators and public stakeholders.

In this paper, an overview of the challenges of the multi-faceted domain of digital preservation in the built environment is provided. As a contribution to possible solutions to these challenges, the roadmap of the FP7 ICT-2011-9 project "DURAARK - Durable Architectural Knowledge" is presented. Initial preliminary results of the interdisciplinary working groups within this project ranging from the ingest and storage of voluminous sets of low-level point-cloud data from laser scans to semantically consistent descriptions of heterogeneous building products and their long-term preservation are introduced and discussed.

Keywords: digital preservation, BIM, point clouds, semantic web

1. INTRODUCTION

The overall goal of the DURRAARK project is the development of method for sustainable long-term preservation of architectural 3D data. In the project, a number of prototypical tools will be produced that allow the ingestion, storage and retrieval of architectural data compliant to the Open Information Archival System (OAIS) standard. Such data ranges from low-level point cloud scans of buildings up to highly enriched Building Information Models (BIM).

A broad range of use-cases for the archival of architectural and other engineering information concerning buildings can be identified. Many different stakeholders have a genuine interest in preserving and retrieving information about buildings. In order to appropriately address the needs, an investigation of use case scenarios and their requirements is conducted in the context of the DURAARK project, which determines the necessary research and developments. In this section, these scenarios are introduced and discussed.

1.1 Preservation scenarios and use cases

From a scientific perspective, buildings information is used for research purposes dealing with questions of cultural heritage, buildings as a manifestation of sociological conditions, providing the setting of historic events or to study the development of different design styles and building technologies and engineering approaches.

The ability to store and retrieve architectural and engineering knowledge in an information archive is also valuable to practitioners who want to enhance their efficiency and productivity by re-using the captured knowledge by e.g. investigating design patterns and solutions in re-occurring design problems and requirements. The large stock of legacy buildings (in Europe approx. 40 % pre-1960, 42 % 1960-1990, 18% post 1990, according to (Economidou et al., 2011)) and the enormous potential of energy savings in a short-term period that has been identified (European Commission, 2002) also makes the access to building information crucial in retro-fitting scenarios: In a preliminary stage, the potential impact with regard to the increase of energy efficiency of individual buildings, neighborhoods and urban areas can be evaluated using general information such as building data, construction method, material usage and global shape and orientation. In concrete planning stages detailed information of the existing construction and its condition are essential to execute the retrofitting activities. Information desirable includes data about space usage, spatial configuration of individual zones and structural components, as well as the detailed properties of individual building elements (wall and roof insulation, glazing, specification of technical equipment such as heating and air conditioning units etc.).

The preservation of building information is also relevant to Facility Management and liability issues of the various stakeholders that are involved in the building lifecycle. For the management of individual buildings or whole portfolios of e.g. private and public housing corporations the ability to store, retrieve and update past and current as-built and as-planned information is essential for increasing the efficiency. In many legal settings, the accountability and legal liability of designers, engineers, construction companies and manufactures of buildings and their components often persists for decades, making strategies for the reliable long time access to all information crucial. On top of the information about the work results and artifacts themselves, process-relevant information such as contracts, communication logs and daily construction records captured in various formal and informal documents make out an essential part of legal arguments and must therefore be also considered for long time archival.

Advances in the registration of building substance by means of 3d scanning technology give a further use case for building information stored in the prospective long-term archive. Here practitioners, as well as authorities will want to compare the current state of a building through a scan with the one described in the storage. The detection of differences between two or more states will provide the ability to track changes, their position and degree, whether it is a missing or misplaced element, the addition or the subtle movement of a whole building. This use case uses the secure storage of data in very different time scales as while a building is erected, circulating around events that take place temporarily, as through neighboring building work that might affect the foundation of a structure or the long-term shift and changes to buildings and building elements that answers history related questions.

The reliable and prompt access to building information also is essential in security related scenarios such as fire, hazards or crime. Escape routes, fire water outlets and security system architectures and implementations are among the data items that have to be retrieved with high urgency and accurate levels of details.

1.2 Digital preservation requirements

At present, information management in the above scenarios is mostly conducted using analogue, paper-based media. Implicit to this medium are the severe limitations regarding their machine readability and therefore its limited potential for support by automated systems. Even though the low-level digitalization of information on a per-document basis such as scans of the paper documents already increase the accessibility compared to mere analog archival, content-based indexing, searching and retrieval of the desired information will dramatically increase the usefulness of such archival systems. In the realm of textual information preservation crucial enhancements have been made over the last decades that allow full-text searches through tremendous amounts of information on institutional and consumer levels. For non-textual information such as engineering drawings, that are the predominant carrier of information and knowledge in the building and construction industry, past efforts for their automated interpretation have not reached mature levels with desirable applicability in practice (Yin et al., 2009). With the current shift in the industry away from 2D based analog drawings to object-oriented working processes that include the multi-dimensional representation of interconnected artifacts in Building Information Models (BIM) such machine-readable information becomes available at large scales. In future, these models will play an increasingly important role in creation, maintenance and access of various sorts information required in the use case scenarios illustrated above.

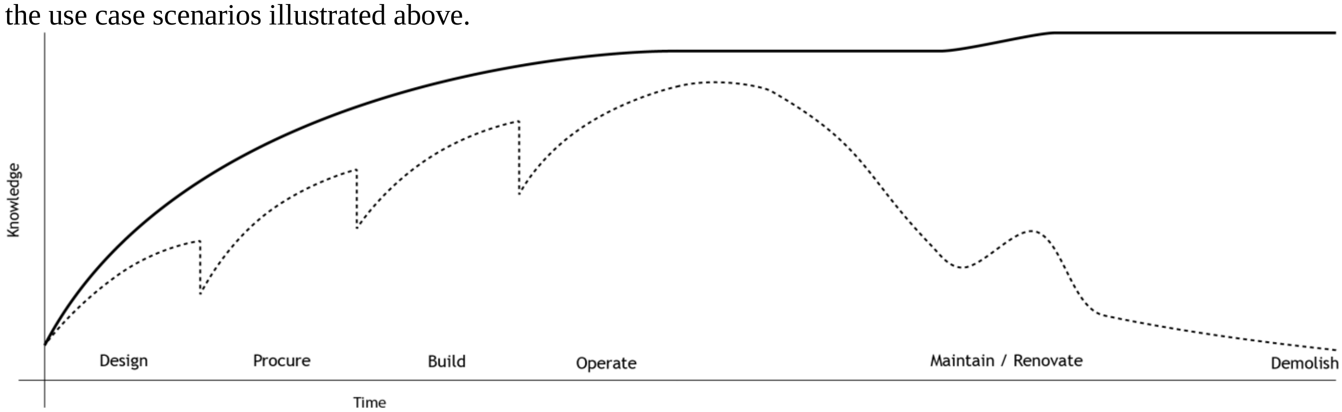

Figure 1: Adapted version of the saw tooth cure of knowledge loss in building and construction incorporating the decay over long periods of time. The dotted line represents the current state, the solid line the idealized preservation situation

However, a number of new questions and problems arise from this paradigm shift: The purely digital nature of such BIMs make new strategies for the analogue ‘hard-copy’ of a current state of a building in its life cycle necessary. The decrease of knowledge during information hand-over between the various stakeholders involved in the lifecycle of a building information model is a well-understood problem in the research community and is best depicted by the ‘saw tooth curve’ which has been adapted to cover long-term preservation issues in Figure 1. In long term digital preservation scenarios an additional dimension to these issues is focused: Apart from issues of information decay on a physical level caused by e.g. hardware failures (‘bit-rot’ etc.) which is addressed in other research domains, a particular problem within engineering is the broad scope of engineering disciplines and their respective individual software tools and formats that result in the well-understood ‘interoperability dilemma’. The general notion of the ‘islands of automation’ applies mainly to the exchange of information between different tools in the particular time frame of a specific collaborative building project. Digital preservation has also to consider the incompatibility of different versions of a single tool and its required context such as operating systems, hardware architectures etc. A piece of information generated in a particular contemporary tool might be impossible to access in 50 years from now.

Another concern of digital preservation is the generation of appropriate meta-data that enables the systematic storage, search and retrieval of artifacts stored in archives. Even for generic data items such as authorship, provenance, ownership and creation date, the particular case of BIMs as the result and/or by-product of collaborative efforts engineered in highly heterogeneous and volatile contexts some of the current approaches to capture such information has to be extended and adapted. In addition to these generic information types, domain-specific information has to be considered that have to be tailored to the requirements of the different stakeholders involved in the scenarios described earlier. Examples include the global shape, location, orientation and spatial organization of buildings, the construction principles and materials used in their realization as well as their intended use, as-planned performance indicators (e.g. energy usage) down to the metrics of of-the shelf component products in use. While some of these meta-data can be extracted from explicit information already present in the BIM or its related documents, other data is implicit and has to be added manually or through automated procedures by the curator of the archive. In contemporary networked structured, this process, referred to as semantic enrichment also includes the reference of external information resources stemming e.g. from building regulations, classification systems, or product data. Since many of these information structures are temporary themselves and are subject to constant change and evolvement, digital preservation also needs to address the capturing of this volatile data.

However, the explicit, manual crafting of elaborate models is not always feasible or affordable. The state of buildings in a particular moment in time often has no or only minimal documentation. For example, information of important historic buildings might not available at all, their physically decay occurring slowly due to environmental influences goes formally unnoticed and subtle modifications of the original as-planned design of a building such as the removal or addition of partition walls, dormers, balconies or coloring happens without the incorporation into a model. To this end, the increasing availability and affordability of capturing and measurement technologies such as photogrammetry and laser scans facilitates the documentation of buildings at a bulk levels. The automated generation of informed models from these data sources e.g. by means of object and feature recognition technologies is a promising source of information management for archival purposes. Yet, strategies to capture, process and preserve the vast amount of raw data associated with these capturing approaches have to be developed to be efficiently archived and exposed to the various users.

2. EXISTING WORK FOR THE PRESERVATION OF ARCHITECTURAL AND ENGINEERING DATA

Addressing many of the scenarios illustrated in section 1, several research efforts have been conducted in the field of digital preservation of architectural and engineering data. In the MIT project “Future-proofing Architectural Computer-Aided Design” (FACADE) (Smith, 2009) carried out between 2006 and 2009 a number of approaches for the archival of architectural data have been suggested that included an archival framework on project levels. Even though the prototypical system implementations were focused on proprietary data models and formats such Autodesk Revit or Bentley Microstation, open interoperability standards such as IGES, STEP and IFC have been identified as the most feasible approach to guarantee sustainable long-term use of data. Three-dimensional architectural models have also been a substantial part of the German PROBADO (2006-2011) (Berndt et al., 2010) project, that focused on the automated ingest and retrieval of a variety of 3D formats, but left the incorporation of semantically rich BIMs to futures research. The EU-project “Metadata for Architectural Contents in Europe” (MACE) (Stefaner et al., 2007; Wolpers et al., 2009) focused on educational purposes of architectural data and developed a rich set of meta-data and resource integration approaches. However, it did not consider 3D data. Preservation has also been researched in other engineering disciplines outside of building and construction. (Brunsmann et al., 2012) provide comprehensive overview of past and ongoing efforts including initiatives in the automobile sector (VDA, 2006), aerospace and defense (prEN 9300-003:2005, 2005) and Memory Institutions, Design and Engineering, and e-Science in the EU IP project SHAMAN (Antunes et al., 2012).

3. RESEARCH DIRECTIONS IN DURAARK

As a result of preliminary investigations of the needs and requirements introduced in section 1 and the gaps of state-of-the art research and developments documented in section 2, a number of research questions and topics have been identified which are addressed in the context of the DURAARK project. These topics are introduced in this section. They are grouped into three main topical categories which cover a wide range of research areas: Semantic enrichment of meta data, Documenting the changing state of built architecture including the recognition of meaningful structures and shapes and domain-specific strategies for their long-term preservation.

3.1 Semantic enrichment of meta data

In order to store, search and retrieve information efficiently, the vast amount of available raw data has to be made accessible on higher levels of abstraction and enriched with related knowledge and data. For these purposes, DURAARK follows a Linked Data-based strategy, where all higher level metadata and knowledge is exposed as RDF and accessible according to Linked Data principles (Bizer et al, 2009). The overall aim is to enable interoperability of all extracted data for data consumers, but also, to facilitate the wider interlinking of DURAARK data and models with related Web knowledge, such as geodata, architectural relevant policies, environmental or energy-efficiency data. Interlinking techniques (Nunes et al 2013) will be deployed to (a) automatically identify correlated Web data and knowledge for given data and models and (b) use these for identification of links between different DURAARK models or model elements. This information will be stored alongside the original raw data in the archival system and is the main reference for search and retrieval operations. In the context of buildings, such information covers many facets. The wide spectrum of proprietary data models and formats capturing the information produced and processed in building projects makes the development of custom preservation strategies on a per-domain level impossible. Also the maintenance of all different native file formats associated with the respective tools is impossible. As identified in previous work, this dilemma can only be addressed by vendor-independent models and persistency approaches that are able to integrate the various sub-disciplines in building and construction into a common, open model that facilitates information preservation independently from temporary implementations. In the building and construction domain the only widely accepted, standardized model fulfilling these requirements are the Industry Foundation Classes (IFC). The DURAARK project thus focuses its efforts on the use of this model. To address the requirements illustrated in section 1, many important data items can already be found in the semantically rich IFC model. These include provenance data such as authorship, creation date and stakeholder roles captured for all instances descending from the IfcRoot class, explicit information of individual components such as material and configuration properties (often documented in standardized PropertySets) as well as the spatial layout and intended use of rooms. The identification, extraction and exposure of information present explicitly in the model that is considered relevant to archival scenarios is a first step in the generation of meta data. Although the detailed commonly agreed-upon, re-occurring facets are encoded in more than 600 classes of the model, much desirable information is out of scope of the standardized information schema. To address this shortcoming a number of extension mechanisms have been built into the IFC model architecture that allow capturing of additional information. For example, product-specific information of door knobs as a part of the description of doors can be included in a number of ways: Custom specifications can be captured in freely definable properties associated to an object in an ad-hoc manner through the definition of IfcPropertys contained in IfcPropertySets on-the-fly. This powerful meta-modeling and extension mechanism however has the disadvantage of resulting in several descriptions for the same concept. While one generator may decide to call the property of an object “width” and assign the data type “REAL” to it, another generating software might label the same property “OverallWidth” and give a different data type (e.g. “DOUBLE”). To address this issues, properties can also be assigned using external references, e.g. to a library. The International Framework for Dictionaries (IFD) also governed by the buildingSMART is addressing this issue. A concrete reference implementation, the “buildingSMART Data Dictionary” (bsDD) provides an extensive library of concepts including building components that can used for uniform references. However, such vocabularies are constantly evolving. This constitutes an additional challenge for archival scenarios, where states of information must be preserved in such a manner that they can be restored to its original state. The DURAARK project addresses this by developing strategies to create snapshots of the referenced information.

While the development of archival strategies for the most widely used domain-specific information standards in building and construction will be tailored to the particular technological parameters (i.e. STEP technologies) the archival of linked data sets also imposes challenges to a much wider audience. In the context of the semantic web initiative, and in particularly Linked Open Data (LOD) (Auer et al., 2007; Bizer et al., 2008) , preservation requires the archival of partially interconnected yet distributed data sets. As these kinds of data sets are expected to play an increasingly important role, the DURAARK project also investigates required preservation strategies of such data. In the context of the semantic web initiative, and in particularly in the Linked Open Data (LOD) framework, needs to preserve interconnected data sets has also been postulated by numerous authors (Bechhofer et al., 2013; Moreau et al., 2011; Sanderson and Van de Sompel, 2010). As these kinds of data sets are expected to play an increasingly important role in future, the DURAARK project also investigates the inclusion of such data into the archives..

Unlike the existing STEP technology stack currently predominant in building and construction, the semantic web initiative consists of a rich set of technologies, data formats and conceptual frameworks that has been designed for heterogeneous networked information infrastructures from the ground up. In the particular case of linking additional information to building data, using the mechanism built into the buildingSMART standards (see above) can be achieved in a much more straightforward way using e.g. the Resource Description Framework (RDF) (Brickley and Guha, 2004). Following the semantic web principle "Anyone can say Anything about Anything" (AAA) additional arbitrary links between disparate data resources can be created if the resources can be identified by an URI. In contrast to STEP, this does not require elaborate changes in the schema but is inherent to all RDF data sets. The semantic enrichment framework in the DURAARK project facilitates this link between different data sets and includes them into the archival packages. A number of approaches are under investigation to achieve this goals, including the transformation STEP IFC models into RDF (Beetz et al., 2009; Pauwels et al., 2011).

This RDF conversion of IFC datasets also makes out an essential part of for the exposure of building relevant information as LOD. While earlier work has mostly been focused on IFC to RDF conversion an essential part of this effort tackled by the DURAARK project consists of creating a sustainable framework for domain-specific concept libraries. While these developments can profit from earlier developments in similar directions (Beetz and de Vries, 2009) the focus will be on archiving, versioning and distribution of such concept repositories.

3.2 Capturing the changing state of the built environment

In order to document the changing state of building artifacts, it is desirable to make use of technologies that allow capturing building data on large scales with high accuracies and yet are affordable. The increasing availability of laser scanning and other surveying technologies are a suitable starting point to address these needs. With these technologies interior and exterior scans of complete buildings can be achieved at relatively low cost. However, a manual effort has to be spent in order to make the resulting large point cloud data sets useful in any of the use case scenarios. Usually these processes include the cleaning of raw data, the generation of overall models from partial scans and finally the creation of semantically enriched geometric models which can be archived in a neutral, data format. The DURAARK project investigates the acceleration of such processes on a number of different levels.

Where models with explicit semantics are already present, for example as the result of an information handover at the end of a design and construction process, this as-planned data can be used to compare it with as-built information from point cloud scans. The explicit geometry from the BIM functions as an underlay and can be used to associate individual points and point cloud volumes with corresponding building elements. This segmentation and semantic enrichment requires novel algorithms and data structures that are developed in the DURAARK project.

In other scenarios, no such elaborate models are available beforehand and the point cloud datasets serve as the initial source that is semantically enhanced. Feature and object recognition approaches that have been successfully applied in other industry domains can be used to assist or (partially) automate this enrichment process. A number of machine learning approaches are investigated and the sample datasets of building models collected and processed throughout the DURAARK project will serve as training, test and validation data.

A further issue to facilitate the archival of architectural information based on point cloud datasets is the integration of such datasets into the building information model. The decision to base the archival efforts of the DURAARK project on the IFC model implies, that this new sort of data has to be incorporated into the model. On a schematic level this can be achieved in a number of ways, e.g. an additional ENTITYs for IfcShapeRepresentations or in the IFCGEOMETRYRESOURCE and/or IFCGEOMETRICMODELRESOURCE levels. Another issue connected to such integration is the typical size of datasets which often contain several million points even for simple buildings. Although extensive building models such as the HITOS project (Statsbygg, 2006) contain a million entity instances, scalability and performance issues are likely to arise and will be addressed by investigating compression algorithms and binary serialization formats of STEP data such as HDF5 (Folk et al., 2011)

3.3 Domain-specific strategies for long-term preservation

Past research efforts in the domain of long-term digital preservation have led to the widely accepted framework Open Information Archival System (OAIS) (CCSDS, 2012). This has served as a reference model for several commercial implementations that are in use in many large institutions such as libraries and archives. However, due to their complexity such system are hardly used by SMEs which make out the majority of the building and construction sector (Eurostat, 2009). In the context of the project investigations are conducted how such systems can also be made available to companies in the building sector.

At present, archival efforts are mostly focused on black-box approaches that archive information artifacts on a mere bit stream level and enhance these data sets with meta-data about the file formats, the software tools used for production and authorship etc. However, in many scenarios more fine-grained search and retrieval on an object-level is desirable which is investigated in the project.

4. PROJECT ROADMAP

The DURAARK project consortium is composed of researchers from multiple disciplines that include library sciences, computer graphics, information systems, software engineering, architecture and construction informatics. Industry involvement is realized by the Norwegian company Catenda AS who is the developer of the reference implementation of ISO 12006-3 based concept libraries bsDD for the buildingSMART organization. Furthermore, the development, integration and evaluation of business-relevant applications of research results is realized by the collaboration with libraries, archives, SMEs from the building industry and standardization bodies carried out in workshops, questionnaires and field tests of prototypical implementations of software tools.

While the majority of deliverables consists of research reports, a number of prototypical implementations of the envisaged systems will also be made publically available. These prototype modules that are integrated in an overall software framework will include meta-data extraction from building models and linked information resources, a semantic concept archive, semi-automated registrations of point clouds in BIMs and the semantic annotation of point cloud datasets, object recognition and feature detection prototypes and point cloud integrations into the IFC model.

5. SUMMARY AND OUTLOOK

In this paper we have provided a general overview of the research aims and objectives envisaged in the EU FP7 project “DURAARK – Durable Architectural Knowledge”. We have illustrated the three main research topics of semantic enrichment of building information meta-data, point cloud-based as-built state documentation of buildings including the automated detection and annotation of objects and features, and domain-specific approaches to the long-term preservation of digital architectural models based on open standards.

Although no tangible results can be reported at this very early stage of the project, we can already contribute the identification of a number of specific short-comings in the current state-of-the-art research and provide preliminary directions to address these issues.

Future work will be focusing on the individual topics and first tangible results will be reported in early 2014.

ACKNOWLEDGMENTS

The research efforts documented in this paper are financed by the European Union through the grant 600908 in the context of the ICT-2011.4.3: Digital Preservation call of the Seventh Framework Programme.

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