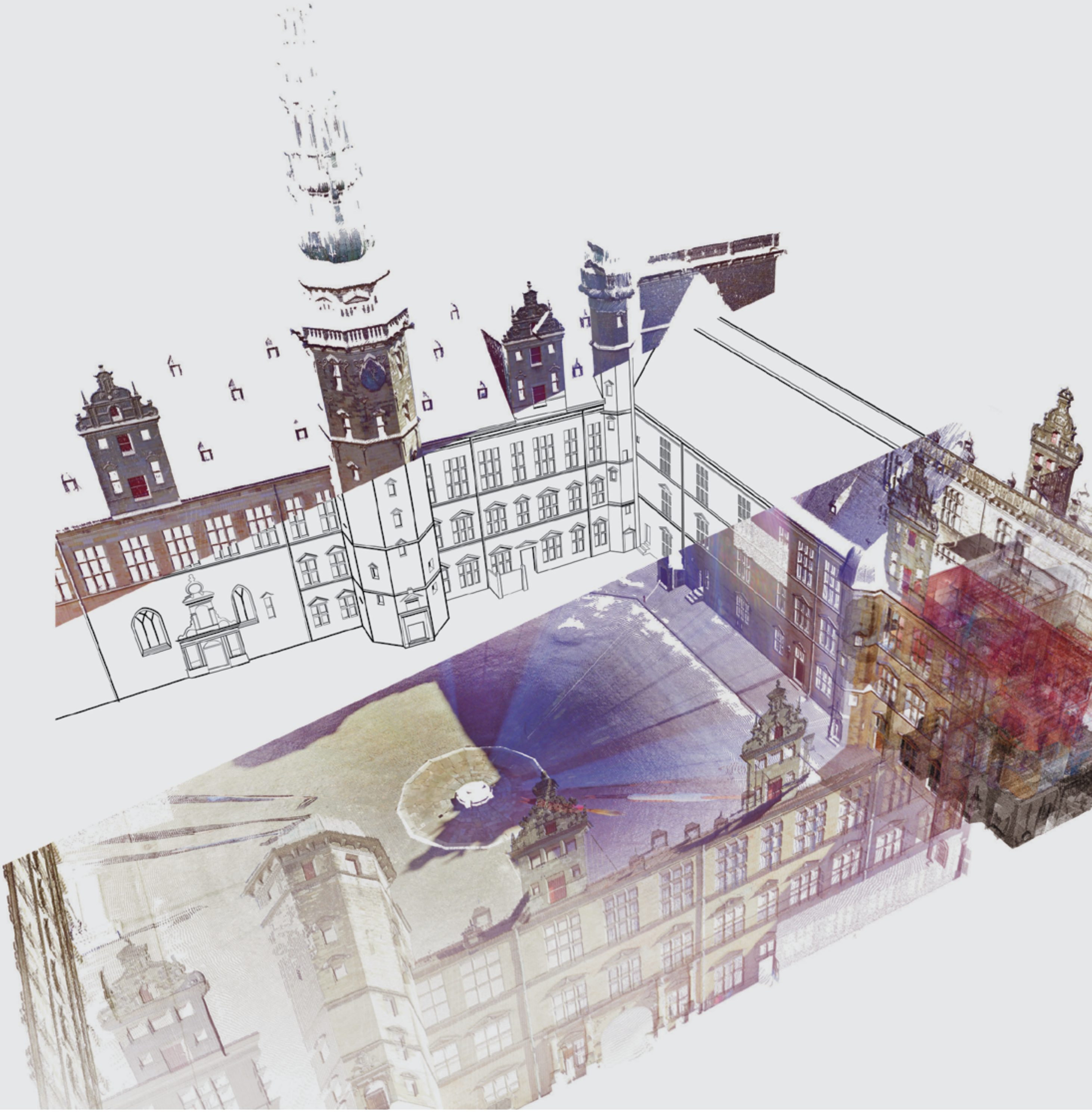
Deliverable 7.7.1:

Current State of 3D Object Processing in Architectural Research and Practice



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D7.7.1 Current state of 3D object processing in architectural research and practice

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Executive Summary

The Deliverable 7.7.1 reports on the ongoing changes within the building profession linked to the introduction of 3D object processing – namely that of Building Information Modelling (BIM) and 3D point cloud. A focus is set on stakeholders from Scandinavia. A region which has a long and successful track record in the introduction of 3D object and BIM processes in all building related areas.

General investigations, interviews with stakeholders and examinations on a rich dataset of more than **190 3D objects from the stakeholders practice**, show that a shift in the understanding and processing of 3D objects has occurred. Where related processes were initially understood by the stakeholders as "working with 3D geometries", they have become more and more aware of the potential that the information attached to these objects offer.

A practice emerges in which **3D object processing becomes information modelling.** Data becomes a resource for the stakeholders, which is enriched within an information chain: Architects, engineers and land surveyors and other stakeholder contribute to a shared model. This provides the necessary information for fabricators as well as for the administration on the side of clients or building municipalities. This chain does not end with the completion of a building but continues into the operation of a building.

BIM provides a common digital platform that allows for a **lifecycle model of 3D objects**. The benefits of this are however not equally distributed among the stakeholders. We identified especially building owners and secondly cultural heritage intuitions as the stakeholders with the most vested interest and biggest potential benefits.

Today's practice does not point at the establishment of a common digital model that is enriched throughout the process. Instead a practice emerges, where **one physical object is described through multiple digital objects**. These undergo different **periods of active use, conservation and enrichment**. We observe here that each of the existing models is specific to a stakeholders needs. And while they are not necessarily dependent on each other they are often semantically linked. These linkages are not bound to static data and geometries, but can as well take place through **dynamic links to external simulation models or references to external libraries or dictionaries of standards.**

3D object processing becomes the base of business practice for experienced and new stakeholders, as these observe a gain in efficiency, as new business opportunities. And while the role and demands of stakeholders concerning 3D object processing are shifting, we find that especially external **3D objects are generally met with little trust**. The potential of the digital chain is hence not utilized as **trusted institutions or vested control mechanisms for the quality and consistency of 3D objects** do not exist.

This goes along with a generally **low maturity of the tools** in use by the stakeholders. Progress is necessary on a technical level of software, that often lack good 3D modelling capacities, but also on a conceptual level. Here it is especially the high level of abstraction that current tools demand. This among other factors, results in the **lack of BIM tools to support planning processes within existing building stock**.

The stakeholders hence welcome the slow but steady integration of more adequate 3D object types as point clouds into building related processes.

However the legacy of the current tools in the CAD era seems to be prejudicial to the introduction of means to query and filter 3D object data and hence to **access the benefits that semantically rich 3D objects offer**. The stakeholders under investigation see the ongoing change from 3D object to information modelling as decisive and the benefits of this transformation, even if they are unevenly distributed, are undisputed among them.

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1. Introduction

The deliverable 7.7.1 ” Current state of 3D object processing in architectural research and practice” reports on the processes in the building profession that create and handle the 3D objects under investigation within the DURAARK project –IFC files and 3D point cloud. In the building profession these processes are only emerging. To understanding these and their impact on the level of content and quality can guide the development within the research project and make sure that the DURAARK research output is relevant to present and future developments within the profession.

1.1. Motivation

Fig.: 1 3D Scan, BIM, Images – The types of data under investigation in the DURAARK project

The types of media used by architects are seemingly expanding. Where previous generations of architects had a limited range of techniques to communicate the intended architecture and organize the work, as texts, spreadsheets, diagrams and scaled two dimensional drawings the ongoing shift to digital media comes with a plethora of new architectural representations, each able to describe a special aspect of intended and realized architecture (Fig.: 1). These new means of representation are for the first time in architectural history able to describe and overlay aspects that deal directly with architectures three-dimensionality as well as the processes that constitute architecture with respect to time and the interaction of people involved in planning, building and use.

With Building Information Modelling becoming the predominant approach towards architectural production a set of 3D-objects is entering the field that is conceptually able to include the whole range of architectural representations and hence introduces a new depth, width and length to it:

- Depth – describing all scales of architecture simultaneously
- Width – connecting the stakeholders and fields of knowledge in a building simultaneously
- Length – linking descriptions of all stages of architectural production and use from the registration of the existing to the design and simulation of the future

An information centred architectural approach is emerging in the field of building practice that allows for new collaborations and changes architectural design, planning and building processes fundamentally. The question is to which extent these potentials are met within the building industry of today and which direction future developments will take with respect to the anticipated lifecycle of 3D objects by DURAARK.

1.2. Aim of the Deliverable

To give insights in the underlying base, the state, drivers and directions of the ongoing changes in the building profession and how this affects the internal and external processes of stakeholders is the focus of this deliverable. The processes presented in this deliverable will help to guide the finer grain aspects of long-term archiving and the data processing approaches under development in DURAARK towards current and future needs.

The investigation concentrates hence on the processes of the stakeholders related to 3D objects that are used within the DURAARK project, as described in deliverable 2.1.

The deliverable provides at first in chapter *2. Potentials for 3D Object processing* insights into the basis and potentials of 3D object processing in the domain of building profession. The developments on technological and conceptual level in research and legislation are described with respect to the processes of the stakeholders under investigation. The subchapters 2.1.2 and 2.1.3 identify furthermore Scandinavia as the focus area of this deliverable. Digital information technologies in the building profession have in Scandinavia not only a long history but as well a strong propagation among all stakeholders. The practice of all stakeholders relevant to DURAARK is described in chapter *3, Stakeholders and Processes*. Here the investigations in the processes of each group of stakeholders are summarized and exemplified with exemplary companies or institutions. The findings are set into perspective in the final chapter *4. Outlook - a shared Vision for 3D objects?*

1.3. Approach

The deliverable is based on publicly available knowledge and with respect to the stakeholders especially on interviews with companies and institutions. As processes centring on the 3D datasets of stakeholders are in the focus of DURAARK these are under special adherence of this deliverable. Where available, datasets from stakeholders were collected. A complete overview of these can be found in *3.1 Overview of collected set of sample data from stakeholders*. The evaluation of this datasets is a part of the assessment of the stakeholder's processes. This as the operations executed by the stakeholders should be readable in the data and indicate the quality and steps of the processes as the underlying aims and quality of the data. The investigation of the data allows as well an alternative perspective on the narrative of the stakeholders and provides as well methods and tool for the batch extraction of information from 3D files that can be of direct benefit in other parts of the DURAARK project.

The chapter *3 Stakeholders and Processes* provides here summaries of the investigations of the datasets of each stakeholder. The approaches that extract and analyse the parameters within the 3D objects are described in the appendix in chapter *7 Appendix: Practice of 3D object processing – An Evaluation,* where as well the full analysis of the datsets can be found, divided in IFC (7.3) and 3D scan laser (7.2) scan related data.

2. Potentials for 3D Object processing

This chapter describes the development towards the current state of 3D Object processing seen from a process and stakeholder centric view. This approach acknowledges the fragmented and diverse nature of the processes and respective professions related to architecture in a wider sense.

All partners in the building industry have their own agenda in regard to 3D objects. The following chapters describe the currently available frameworks for 3D processes, their development and their current implementation in the profession. Where the current 3D modelling approaches in BIM are well described (Underwood, 2009) we describe in Chapter 2 shortly the development that lead to its current state (2.1.1) and its implementation in Scandinavia as pre-runner of the digitalisation (2.1.2, 2.1.3). Chapter 2.2 focuses on the, in an architectural context, relatively new 3D documentation technologies and their implications.

An Outset

Although architecture is inherently three dimensional its design, planning and communication within took for the most time place in the abstracted space of the two dimensional drawing (Evans, 1995). These drawings can take on a symbolic level, communicating through codes rather than descriptive line drawings. Where one might assume that working in a two dimensional representation took place due to technical limitations, it is obvious that the communication through two dimensional abstractions holds efficiency in regards to its production and communication.

However the building industry is facing an increasing complexity linked to their processes. This requires architectural design to become performance driven (Kolarevic, 2005) and hence better predictable on qualitative and quantitative level. Today architectural design has to give early on relative precise answers towards needed resources on financial, time and material level, both for the production as the operation of the building. The building industry realizes that a better control of their processes is needed to meet these expectations and to handle the increased complexity. With advances in digital technology networked approaches and the modelling of buildings in 3D became achievable. This movement and the potential gain in efficiency are similar to that in other industries, as aeronautic, automotive and shipbuilding. Industries that building industry is often compared with.

But similar to the other industries it becomes obvious that the step from two dimensional to three-dimensional or even to 3D object oriented planning processes means in the end a total change of business processes. A transformation is taking place in the building industry, where individual stakeholders are redefining their work processes through the processing of data in order to gain efficiency. Building partners have here expectations that the digital chain (Migayrou, 2003) integrates external data seamlessly with their own processes and aims.

2.1. Architectural 3D Object processing - BIM

The building industry is divided in many partners in loose and changing collaborations (Underwood, 2009) and hence conflicts arise towards the content, structure and level of detail of data. And where partners in the building industry usually see the benefit of collaboration and ease of exchange their common double faced appearance as receiver and dispatcher of data creates awkward situations - especially on level of contracts, responsibility and the time perspective of their needs.

It was only in 2002 that Jerry Laiserin (Laiserin, 2002) coined the term of Building Information modelling to describe the information centric chain that takes place in building related processes that include analysis, design as well as management tasks. Over the following years these originally distinct areas have been chained and visualized in “BIM Wheels” (Fig.: 2) which emphasise the linked but especially cyclic nature that building related processes undergo. The understanding of a building as being in a constant cycle of planning, building and maintenance relates to the raising awareness of sustainability and its similar emphasis on cyclical processes. These wheels might be seen as counterpoint to the reality of the building industry – that is often critics as being made of self-centric partners (van Nederveen, 2009)

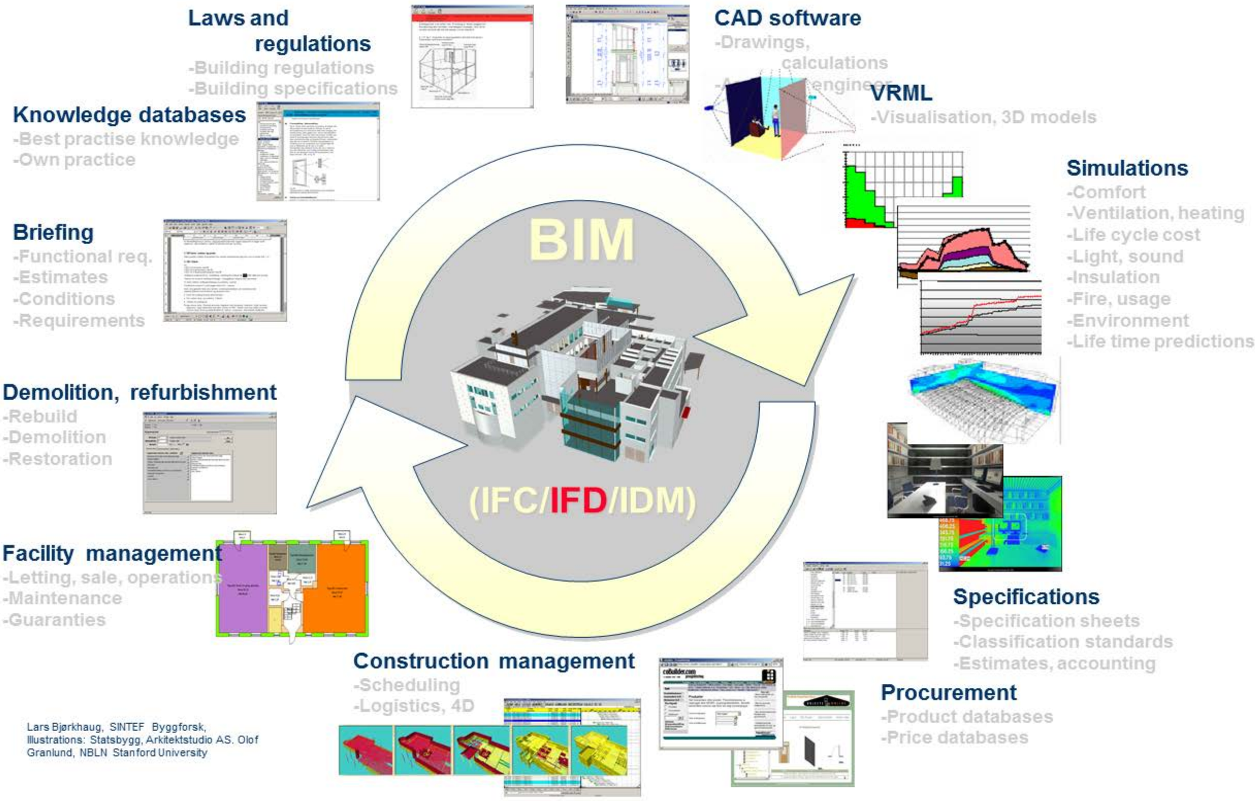

Fig.: 2 A BIM Wheel showing a potential lifecycle of a building using BIM tools. (Bell, Bjørkhaug 2003) [1]

However the cycle described in the BIM wheel does not reflect the efforts spend on the making of the BIM model or models nor the time that each step in the process takes. Here it is the planning phase of a building - characterized by a very short cycle of information and rapid exchange between many partners with very different views on models (van Nederveen, 2013) – that contrasts with the operation and maintenance phase of buildings usually conducted by a single owner.

The need to coordinate and the obvious benefits that come with collaborative 3D object processing lead today to the emergence of new processes that are hybrids of data exchange and networked collaboration on digital models. Building Information Modelling is becoming the core of the industries' processes, especially in countries that are at the forefront of the general digitalisation. The Scandinavian countries are here a prominent example in Europe, as they saw early the potential of a digitalised building practice[2] and had as well the administrative and legislative means to enforce the introduction of Building Information Modelling across the heterogeneous building industry[3]. Though BIM is often perceived and marketed as a tool - a quasi 3D extension of the former drafting tools (CADD Computer Aided Design and Drafting) (Laiserin, 2002[4]) - the policy makers are usually emphasizing the role as a communication platform that eases exchange and provides better means to keep overview and manage the seemingly more complex building projects.

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[1] http://catenda.no/2008/02/29/free-bim-presentations-from-us-to-you/?lang=en

[2] http://bips.dk/v%C3%A6rkt%C3%B8jsomr%C3%A5de/det%20digitale%20byggeri#0

[3] http://www.bygst.dk/viden-om/digitalt-byggeri/ikt-bekendtgoerelsen/

[4] http://www.laiserin.com/features/issue15/feature01.php

The motivation for the introduction of more advanced information tools is here to increase productivity through easier and less flawed exchange. The view on digital processing tools is here biased towards aspects of communication and interfacing. This notion and the focus on the production phase of buildings characterize the historic and current trajectories in the development of BIM. This contrasts with the emphasis of models as means of representation – the usual understanding in academic and cultural communities (Evans, 1995). This difference in views is fundamental and explains partially why questions of archiving and documentation or even questions that are linked to an understanding of architectural documentation as knowledge are hardly present in the current development of 3D object processing. To understand this view it is interesting to look at the development of information modelling in architecture.

2.1.1. Building Information Modelling: Historical and technical development

BIM - Building Information Modelling has become an increasingly popular term in recent years. However, The history of Building Information Modelling can be traced to its roots in seminal works of object-oriented computer aided design such as Sutherland's Sketchpad (Sutherland, 1963) and Eastman's BDS (Eastman, et al., 1974). Up to then the various kinds of information were traditionally communicated predominantly by technical drawings - two-dimensional projections of future artefacts such as buildings(Ferguson 1977; Ackerman, 2002). With the advent of ICT and CAD in particular, the need to structure information about buildings became apparent. A crucial notion from the early days onwards was the idea of parametric components that incorporate behaviour and other attributes, only a part of which is visible in the form of geometric representations. Many early systems followed such object based parametric approaches and excelled in particular domains solution addressing specific design and engineering tasks. Many research efforts focused on the creation of conceptual frameworks and domain models for the building industry as a whole and the architectural domain in particular (Gielingh, 1988; Björk, 1994; Augenbroe, 1994). However, the interoperability among the different tools remained a pressing issue in an industry that depends on the collaboration and integration of a large spectrum of sub-disciplines. In other engineering domains, the standardization of domain models for the exchange of information booked significant successes under the roof of the Technical Committee 184 ISO 184/SC4 of International Standardization Organization which resulted in a series of the ISO 10303 standards, more commonly referred to as the STEP Standard for the Exchange of Product model data) initiative (Pratt, 2001). The several hundred parts of these standards share a common stack of technological foundations such as the EXPRESS modelling language (Schenck, et al., 1994) for schema definitions, clear-text and XML serializations (ISO10303-11:1994 1994; ISO10303-28:2007 2007) or shared representation description models (ISO10303-42:1994 1994). However, due to the inert and laborious standardization procedures of ISO, the development of the building domain model was not going fast enough for many stakeholders (Eastman, 1994). It was decided to found an independent organization by industry stakeholders such as large software vendors.

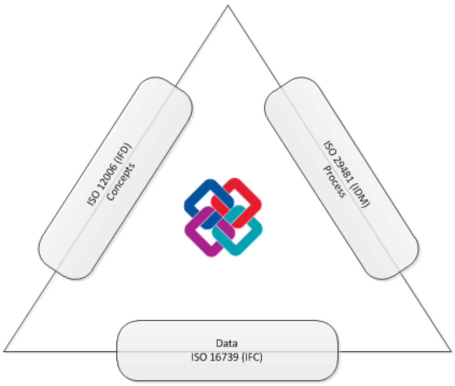

Fig.: 3 The three main standards governed by the buidlingSMART organization

This newly found International Alliance for Interoperability (IAI), later rebranded under the name of buildingSMART (Fig.: 3) released a first version of the domain model for building – called the Industry Foundation Classes (IFC) - in 1997 and has released a number of schema model revisions since. In contrast to the ISO standards, all specifications under the roof of buildingSMART are freely available and can be implemented without royalty fees or other costs. This led to a quick uptake of implementations by software developers. Despite the complexity of the model and other thresholds, today's Industry Foundation Classes core model is supported by more than 150 software tools[5] and is widely recognized as the most important de

tation/implementations

facto and de jure standard in the building industry. Although the IFC model is the most important standard by far, a number of other frameworks and model specifications are governed by the buildingSMART organization:

- IFC (ISO 16739) The semantically rich core data model for the vendor neutral exchange of building information including geometry
- IFD / bSDD (ISO 12006) The "International Framework for Dictionaries" / buildingSMART Data Dictionary, an extensible meta structure for the storage of concepts and facets along with multi-lingual names and descriptions. Its main purpose is the uniform persistence of classifications from different sources. A reference implementation filled with currently more than 30,000 concepts is available at ifd-library.org .
- IDM (ISO 29481) The Information Delivery Manual is a process-oriented standard for the structured exchange of information among actors. It is based on the concepts of:
  - Process Maps (PM) that are a structured way to design and document information hand over processes among different stakeholders in various stages of the building lifecycle. They are based on the Business Process Modeling Language BPML.
  - Exchange Requirements (ER) that detail what kind of information have to be provided at information handover events identified in the PMs. They are independent of any specific data model.
  - Functional Parts (FP) which implement ERs based on subsets of the IFC data model.

2.1.2. A Nordic perspective: Norway

The Nordic countries can be seen as the Europeans' site of experimentation for the introduction of digital technologies in the building sector. Due to the relative small size and homogenous societies they were able to push the digitalization of the building sector. Where this push from the side of the state might have left a footprint on the way information technology is used in the Scandinavian building sector, the developments are however well suited to serve as a blueprint for future developments in other countries.

This chapter describes how Norway introduces digital processes in the building sector.

Building Information Modelling and here especially the participation in the international buildingSMART organisation has a strong standing in the Nordic countries, especially in Norway. There are several reasons for this institutional support. The most important one is probably that large governmentally owned building property companies (Statsbygg[6] and Forsvarsbygg[7]) have taken a very clear position in being positive to the open buildingSMART standards. This is may partly be because they see that they have much to gain in the shape of lower costs and higher quality, if the industry improves the tools it uses for communication. In the end it is the building owners that pay when there are inefficiencies in the building processes. In addition the Norwegian government has taken a clear position to support opens standards.

In May 2007 Statsbygg stated that as a main rule BIM would be used in all of their projects and building processes from 2010 onwards. They have developed a BIM-handbook[8], and the purpose of this is stating what information they expect to find in the IFC file.

Another indication of the strong position buildingSMART holds in Norway is that the largest construction research organisation in Norway (SINTEF Byggforsk) has had a separate group working exclusively on this

[6] http://www.statsbygg.no/

[7] http://www.forsvarsbygg.no/

[8] http://www.statsbygg.no/FilSystem/files/prosjekter/BIM/StatsbyggBIMmanualV1-2Eng2011-10-24.pdf

topic (this turned into the spin-off company Catenda; a DURAARK partner). Other important organisations for the industry have also strongly supported more integrated communications using IFC, and here “Boligprodusentenes forening” (the organisation for the companies producing homes) should be mentioned.

All in all it seems that the reason for the strong position for buildingSMART in Norway is a result of two facts: The first is that the government has been positive to open standards, and the other is that in a small country a few large and strong-headed organisations can lead the whole industry (but things still take time). Today it is not unusual that even an architect working on his own knows about and uses IFC, and the technical & content quality of the IFC file is much higher today than it was just a few years ago.

2.1.3. A Nordic perspective: Denmark

Allready in the period of 1988-95 a Danish government initiative was initiated that should support the standardization of data exchange in the building sector. It focused on common descriptions of building parts. Through the merge of three interest groups from the building sector in 2003 a common organisation was founded to further a digitalized building process. Operating under the acronym bips [9] the independent organisation aims to develop publications, online tools, paradigms, standards and system files in order to streamline the design and building process and raise the quality from building program to facility management. Bips also developed “The Digital Foundation” covering Danish building classification, 3D working method, logistics and process[10].

The move towards BIM was majorly pushed by the government in 2003 through the initiative: Det Digitale Byggeri[11] (Digital Construction), whose results were developed and implemented from 2004-2006. It was coordinated by the Agency for Commerce and Construction[12]. Det Digitale Byggeri was developed by 5 consortia consisting of actors from the AEC industry and academic institutions. It dealt with 5 areas of activities:

1. Project web
2. 3D models
3. Digital procurement
4. Digital hand-over
5. Best-in-construction cases resulting in a line of owner/developer demands.

The essence of Det Digitale Byggeri was, on the side of legislation, to have state-owned building developers/owners to make demands on using the digital information processes in order to drive the technological development in the rest of the AEC industry. The vision was to be able to reuse the accumulated data from the digital building process and to have all participants contribute to the total set of information generated in a building case, all the way from idea, building, managing to taking down a building. The intention was to make the industry aware of the advantages, have it take over initiative and implement Det Digitale Byggeri as an industry standard.

In 2007 laws were decreed that forced Danish building owners to make demands in Information and Communication Technology[13] (IKT). Digital Construction Methods (=BIM) had to be used for all state-owned

[9] http://bips.dk

[10] http://bips.dk/files/bips.dk/article_files/bipsnyt2-2004.pdf

[11] http://bips.dk/v%C3%A6rkt%C3%B8jsomr%C3%A5de/det%20digitale%20byggeri#0

[12] http://erhvervsstyrelsen.dk/file/3771/detdigitalebyggeri.pdf

[13] http://www.bygst.dk/viden-om/digitalt-byggeri/ikt-bekendtgoerelsen/

building cases of more than 3 million Danish kroner volume. A ripple down effect of BIM processes to all levels of the AEC industry was expected, benefitting all through increased productivity, reduced costs and errors.

Throughout the hole process of digitalisation it was met critically by all groups of Stakeholders. In part as they have to invest due to the partially state driven efforts, but especially as the shifts in information processing forces them to shift work- and business concepts. This had to happen “on the run” and with little precedence. This caused costs and frustrations as obviously not propositions worked as expected. An example is the Danish concept of Information Levels (informationsniveau). This is a way of describing the level of details in 3D models. In the Danish context levels are described between 0-6, where 6 is the most detailed as-built model. The intention was that the level 6 model should be used as facility management (FM) model. As shown in the chapter on stakeholders that are actually using 3D data for FM modelling (Chapter 3.6.3and 3.7.2), it turns out that level 2 or 3 models are actually the only ones used in practice.

Despite this type of shortcomings, BIM related tools and practices proliferated from their initial administrative level throughout the building industry. The exchange and collaboration with information technology and especially 3D data has become an everyday practice in Denmark. Legal and process related questions are today defined within so called IKT-specifications (Information Technology Specification), as agreement on the use of digital methods (i.e. software, formats, schedule) between the building partners prior to the design and building process.

Overlooking the development it can be stated that the Danish AEC is a precursor in regards to the implementation of Digital Construction and BIM. More detailed information on the practical consequences of this are given in the stakeholder specific chapters (3 Stakeholders and Processes).

2.2. Architectural 3D Object Processing – 3D scanning

The introduction of processes that handle 3D objects changes the professions totally. Where 3D object processing is often synonymously understood with BIM this cuts too short. BIM tools are based on the common practice of design and planning which is today predominantly based on polygons and attributes. What if this practice changes?

We observe a change of practice through the introduction of 3D scanning. This challenges the traditional planning process. Where most stakeholders described in chapter 3 are used to work with very abstract models, 3D point clouds not only have a high level of precision but especially a low level of abstraction. This does not fit naturally into the process of decision making within the current practice. This is generally characterized by an overwhelming amount of information and parameters to be considered. The reduction of options is hence key and the geometry of spaces is in a planning stage simply one of many parameters in need of condensation. Within the current design paradigm point clouds threaten to overload early stages of planning with information, while later processes might actually need the precision obtained by 3D scanning techniques.

The stakeholders in chapter 3 see 3D scanning as an essential technology of their future. This chapter describes the current and emerging approaches to capture the complexity of the build environment with 3D documentation and deduces potentials for all stages of architectural practice.

2.2.1. 3D documentation techniques

Architectural 3D documentation deals with the recording of position, dimension and shape of architectural features and objects in three-dimensional space. (Barber, et al., 2011) Several techniques are available today to generate this three-dimensional survey information. Even though the DURAARK project focuses on terrestrial 3D laser scanning, the spectre of these approaches will be briefly described to deliver a common understanding of this field.

Approaches for 3D documentation range from hand measurements to satellite remote sensing, and these are usefully characterised by the scale at which they might be used and the complexity of objects that can be recorded. Fig.: 4 depict these different approaches for 3D documentation. On the scale of buildings common techniques are Hand Measurement, Terrestrial Survey, Terrestrial Photogrammetry and Terrestrial Laser Scanning.

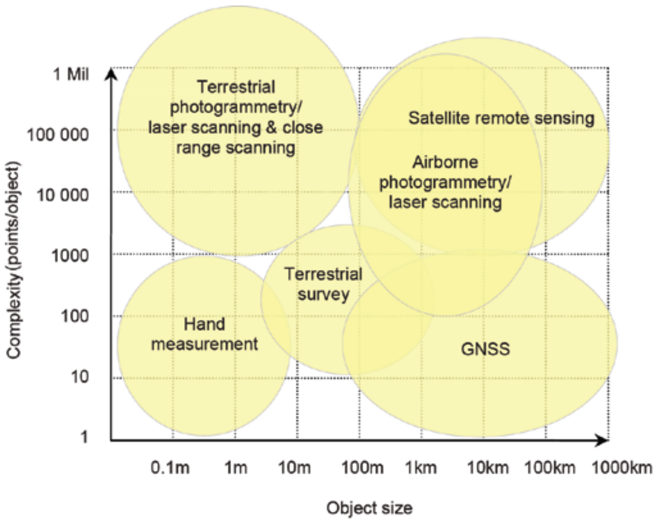

Fig.: 4 Three-dimensional survey techniques characterized by scale and object size (derived from Böhler presentation CIPA symposium 2001, Potsdam). (Barber et al., 2011)

2.2.1.1. *Hand Measurement*

The interviews with architectural companies conducted for this deliverable suggest that Hand Measurements is still very common in the architectural field. It provides dimensions of objects and spaces up to a few metres in size. It is impractical to extend this to larger objects and the collection of many measurements, e.g. 1.000 measurements (Barber, et al., 2011).

2.2.1.2. *Terrestrial Survey*

Terrestrial Survey constitutes of traditional survey methods such as the optical telescopic sight and measuring system for angular direction of sight. It is among the interviewed land surveyors still the most used technique for 3D documentation. The results of this method are high in precision, but require substantial on-site work in order to record significant attributes of the measured structure and facilitate its post-treatment. This method is time consuming and becomes tedious with complex environment to be measured. (Deveau, 2006)

2.2.1.3. *Terrestrial Photogrammetry*

Terrestrial Photogrammetry uses photographs taken from different points of view and stitches them together to build a 3D restitution of the desired environment. The output is a point cloud. Its resolution is based on the amount of pixels in the images. (Guarnieri, et al., 2004) (Grussenmeyer, et al., 2001)

2.2.1.4. *Terrestrial Laser Scanning*

A generic definition of a laser scanner adapted from (Böhler, et al., 2002) is ‘any device that collects 3D coordinates of a given region of an object’s surface automatically and in a systematic pattern at a high rate achieving the results in near real time’. (Böhler, et al., 2002)

This process can be undertaken from a static position or from a moving platform on the ground or in the air. As DURAARK has a focus on static terrestrial 3D scanning (from here on referred to as 3D scanning) we will focus on this type of laser scanning. 3D scanning scans a near spherical ‘image’ of the environment it is located. Separate scans produced are in the following post-processing put together into one scan project (Registration).

Laser scanning is the easiest and fastest of the 3D documentation techniques available today. (Fuchs, et al., 2004) Different kinds of scanners exist. They all deliver the same outcome, using three principal approaches:

Triangulation scanners generate the measurements by sending out a laser beam, which is reflected by the surface of the subject and focused onto a sensor by a lens. The location of the laser on the sensor and the known separation between it and the origin of the laser is combined to determine a point coordinate by triangulation. These systems have a limit of about 25 meters, but degradation in accuracy is to be expected at these ranges. Furthermore the technique performs badly in bright light. (Barber, et al., 2011)

Systems based on **time of flight** utilise the two-way travel time of a pulse of laser energy and the horizontal and vertical angles to calculate point coordinates. These systems typically offer accuracy between 3-6mm. They are appropriate for architectural documentation tasks in a longer range of typically 2-300m. With this technique collections of tens of thousands of points per minute are recorded. (Barber, et al., 2011)

The **phase comparison system** is very similar to the time of flight, and offers similar accuracies, but calculates the point coordinate by comparing the phase shift of the transmitted and received wave of the modulated signal (Marbs, et al., 2001). Registering millions of points per minute phase comparison systems have a much higher rate of data capture than time of flight systems (Barber, et al., 2011)

All three methods can be coupled with a spherical picture either taken by an internal or external camera. These can be projected onto the point cloud in the post- processing phase. Coloured 3D point clouds are the result.

All these scanning methods are fast and reliable and measure with millimetre precision. However they can only capture geometries within the line of sight (Fig.: 5). Hence every 3D scanning session has to be well planned in order to make sure all desired features are captured.

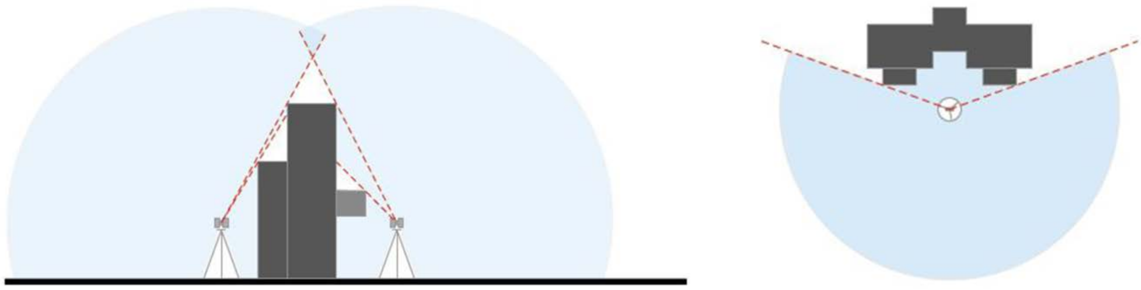

Fig.: 5 Range of scanner (Product of LE34)

To be able to register different scans into one point cloud a minimum of three markers are set up. These have to be within the line of sight of several scan positions. The local registration marks are often combined with traditional terrestrial surveying in order to position the final scan project in a global coordinate system.

2.2.2. Output of 3D scanning and post processing

The output from the 3D scanner is an unstructured point cloud from each scan position consisting of point position and intensity values reflecting the energy levels of the returned laser pulse.

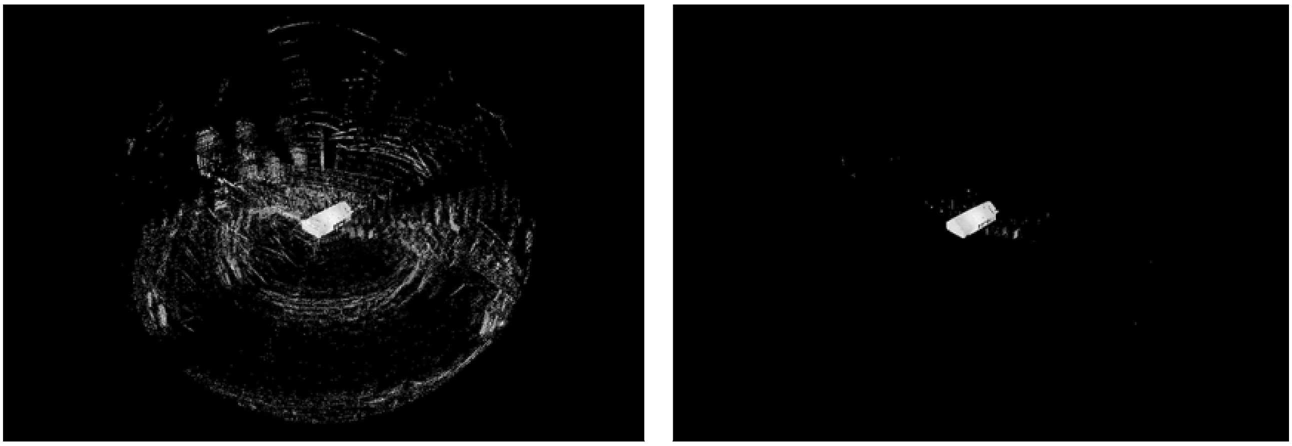

Fig.: 6 Standard cleaning filters of post-processing software

The 3D scanner records all information from returning laser pulses, as well those that have been hardly reflected, thus having a very low intensity value. The first step of any post-processing software (e.g. Faro Scene) is hence to clean (remove) point coordinates with poor information level (Fig.: 6).

The registration markers previously mentioned are then automatically or semi-automatically identified in the point clouds. Each point cloud is than translated according to positions where the corresponding markers overlap. In this step the point cloud is as well referenced to an eventually surveyed position in a global coordinate system.

2.2.3. Future of 3D scanning

3D scanning technologies are in constant evolution and increase constantly the point cloud quality, the density of points and speed, while reducing error margins and the amount of manual labour needed (Hichri, et al., 2013).

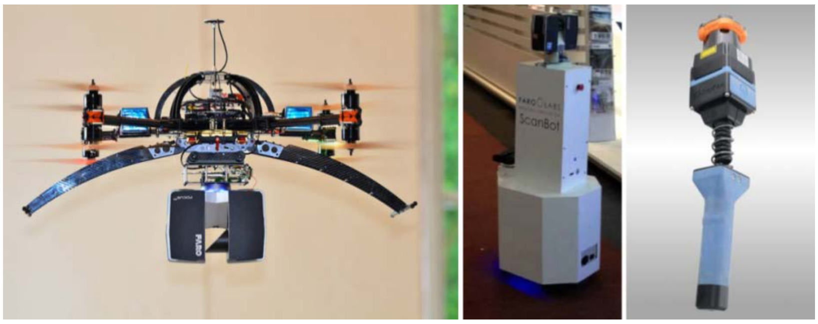

Fig.: 7 From Left to Right – Faro Labs ScanCoptor , Faro Labs ScanBot and CSIRO ZEB114

A growing trend of autonomy, speed and quality can be observed, where typical examples of current research in scanning hardware are the ScanCopter and 4D-IT by Faro, the ScanBot by Faro Labs and the ZEB1 developed by CSIRO Autonomous Systems Lab Examples of research done at the moment in the hardware of these scanners are e.g. the ScanCopter by Faro and 4D-IT, the ScanBot by Faro Labs and the ZEB1 developed by CSIRO Autonomous Systems Lab, which all show a growing trend of autonomy, speed and quality (Fig.: 7) [14]

2.2.3.1. *ScanCopter*

The ScanCopter is basically a Faro Focus scanner mounted on an octo-copter. The scanner scans while the copter is flying and the real time aggregation of the point cloud is automatically registered by combining it

[14] http://www.architectureanddesign.com.au/getmedia/00cb2e5b-c317-4692-8c02-bd453b8c68a9/130923_Zeb2.aspx

with a constant measurement of the precise position of the flying scanner. This is automatically done using a total station. This system allows to capture environments from angles that are out of scope from ground based scanning, while the speed of post-processing and registration is increased. Currently the ScanCopter is remote controlled, but an autonomous operation is envisioned.

2.2.3.2. *ScanBot*

The ScanBot is autonomously navigating in an unknown environment while 3D. It has a Microsoft Kinect attached to it, which it uses for the tracking of obstacles like furniture and people. The ScanBot moves first randomly around in an environment in order to draw a planar map of the environment. This serves him to calculate the optimal positions to capture the whole space in a second scanning run. According to FARO the ScanBot is in the last stages of development. Its deployment will reduce both on-site and off-site workloads, and it might serve the detection of build structures, as well as those that are still in building process.

2.2.3.3. *ZEB1*

The ZEB1 is a handheld mobile mapping system. It consist of a lightweight LiDAR (light detection and ranging) scanner with a 30 m range and an industrial grade MEMS IMU (inertial measurement unit) mounted on a simple spring mechanism. As the user is holding the device and moves through the environment, the scanner loosely oscillates on the spring. This generates a rotation that converts the LiDAR's 2D scanning plane into a local 3D field of view. An algorithm estimates the trajectory of the scanner on the spring from the available range and initial data. Given the trajectory estimate, the raw range measurements can then be projected into a globally consistent 3D point cloud. The hardware and software developed generate at the moment point clouds at centimetre precision.

As ZEB1 is a handheld device with the ability to simultaneously self-localise and map and the data processing is fully automated, it can access any space a human can with the speed of a human. Unlike wheeled mobile platforms, the scanner can hence operate on e.g. stairways and allows for seamless mapping between levels, interiors and exteriors and multiple buildings. This research points at a new class of small, light and fast devices for 3D documentation and has the potential to dramatically increase the use of 3D mapping (Hunter, 2013).

2.2.4. Architectural application of 3D scanning

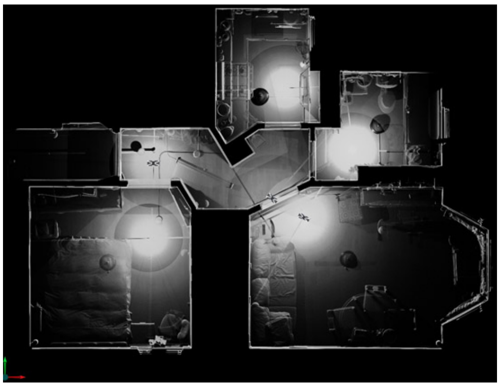

Fig.: 8 Orthographic section plan

3D scanning is today used in a wide spectre of scales from product manufacturing to infrastructures. The complexity of build architecture and the related computational power demanded to process huge point clouds has though been exceeding that available on the stakeholders computers. Recent developments are now allowing for mobile, fast and accurate indoor scanning (Hunter, 2013). And with the evolution of 3D object oriented design tools and related requirements from a governmental perspective the integration of 3D point cloud processing into architectural processes has seen a big push (Barber, et al., 2011).

Today 3D scanning is commonly used in the architectural field as a base for the generation of orthographic plans and sections (Fig.: 8) [15].

[15] http://www.aecbytes.com/viewpoint/2012/issue_66-images/fig3small.jpg

The guide for '3D Laser Scanning for Heritage – Advice and guidance to users on laser scanning in archaeology and architecture' developed in 2006 by the School of Civil Engineering and Geosciences at Newcastle University lists further appropriate uses for 3D scanning (Barber, et al., 2011):

- contributing to a record before renovation, which would help in the design process as well as contribute to the archive record
- structural or condition monitoring
- providing a digital geometric model of an object from which a replica can be generated as a replacement in a restoration scheme
- contributing to three-dimensional models, animations and illustrations for presentation in visitor centres, museums, through internet and media
- spatial analysis

2.2.4.1. *Use of 3D scanning in Facility management, Maintenance and Renovation*

In the planning phase of architecture 3D scanning and point clouds are commonly used for extensions or renovations of buildings. Here 3D CAD models are either modelled from underlying 2D orthographic representations or point cloud.

In order to establish awareness and a best practice in the Danish context the Danish Building & Property Agency (Byggestyrelsen) has conducted a survey of 3D documentation methods (Digital 3D Opmåling: Pilotprojekt på Syddansk Universitet), and developed a guideline for the digitalization of the build environment with a focus on the information- and communication technologies of BIM for facility management, maintenance and renovation projects (Birch, 2010).

This guideline recommends using 3D scanning for building survey. It is reasoned that the costs for this type of measurements are equal to those by traditional terrestrial surveying, while 3D scanning delivers more value for the following processes of design and execution.

The guideline states different classes for the measurement and digitalization of the build environment through 3D scanning (Birch, 2010). Though similar on first-hand the resulting level of detail and modelling is very different.

Class 1

3D scanning of the whole building and 3D modelling of the whole building **including** installations

To deliver:

- 3D scanning of whole building
- Point cloud in proprietary format
- 3D object oriented building model in information level 4. Proprietary and IFC format.
- Inconsistencies in building elements below 0,5 – 1% corrected to theoretical position
- Consistency control between point cloud and theoretical model to insure a tolerance of 0,5-1%
- Classification of objects in 3D model according to DBK
- Point cloud in server-based viewer solution
- Link between spaces in 3D model and scans in point cloud viewer

Class 2

3D scanning of the whole building and 3D modelling of the whole building **excluding** installations, but including installation shafts

To deliver:

- 3D scanning of whole building
- Point cloud in proprietary format

- 3D object oriented building model in information level 3. Proprietary and IFC format.
- Inconsistencies in building elements below 0,5 – 1% corrected to theoretical position
- Consistency control between point cloud and theoretical model to insure a tolerance of 0,5-1%
- Classification of objects in 3D model according to DBK
- Point cloud in viewer solution

2.2.4.2. *Monitoring of buildings using 3D scanning technology*

On the construction site 3D scanning provides means to achieve a holistic overview of the construction progress (Brandt 2012). Such methods concentrate typically on the comparative analysis of large point clouds to determine areas of concern.

Research shows how this information can be tied back into the planning phase and corrects here previous decisions. In a recent project a very complex concrete structure needs over 2.000 curtain wall units to be individually installed. Here a feedback loop from the 3D scanned as-built information to the planning environment was tested. The process of this integration of 3D scanning in a bi-directional design/build structure looked as followed:

1. The Building Information Model is created
2. The primary structure is built
3. The as-built connection locations are scanned
4. The iso-model parameter tree is updated with new locations
5. Anchors are fabricated/adjusted to fit existing conditions
6. Curtain wall units are erected

2.2.5. Working with point clouds

In order to initiate any work in a 3D planning environment utilising point clouds from 3D scanning one needs an understanding of the enormous amount of unstructured data which comes in form of the point cloud. This is done by a segmentation, classification and semantically enrichment of the point cloud prior to the integration of this into the BIM environment.

2.2.5.1. *Segmentation and Classification*

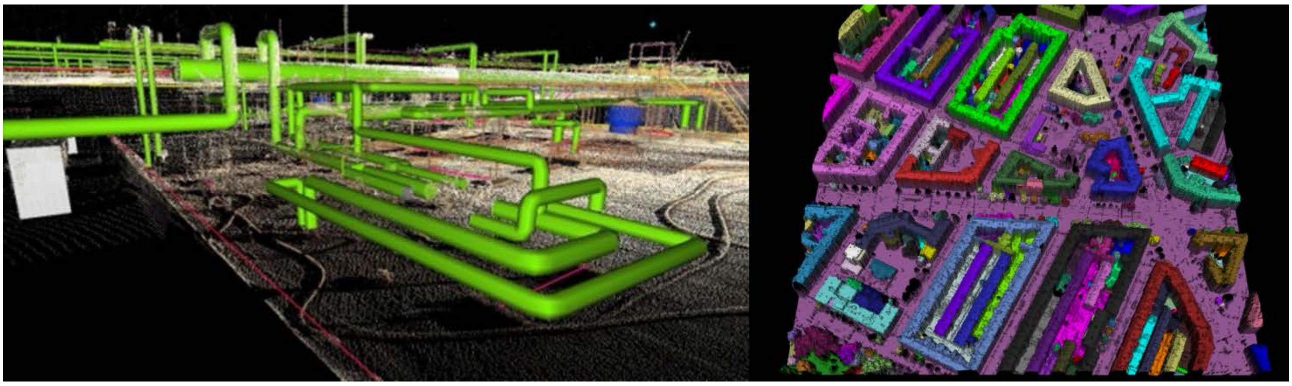

Fig.: 9 Segmenting and fitting geometric elements onto point cloud in piping and infrastructure

Algorithms for semi-automated point cloud segmentation and classification are available in the fields of infrastructure and piping (Fig.: 9) [16][17] but not readily available on an architectural scale. The groundwork for this is however done, as producers of architectural BIM software started to integrate point cloud engines into their environments and offer as well standalone applications for point cloud processing (such as ReCap[18] from Autodesk or Pointools[19] from Bentley). *(For more information about, see D4.4.1 Documenting the Changing State of Built Architecture; Chapter 5 Evaluation of suitable host application.)*

Integrated functions provide users with a better understanding and hence efficiency in working with 3D point clouds within BIM software. The segmentation and classification requires still a fair amount of manual work, as i.e. desired parts of the point cloud have to be selected manually in order to distribute them to a layer structure similar to those within CAD software like e.g. Autocad. Speed issues are tackled through partial loading of point clouds.

Other commercially available software (Bentley Descartes[20] and Pointtools) provide an extended set of algorithms for segmentation and classification, as classification by height and recognition of cylindrical or planar objects and faces. These are however as well applied semi-automatically (i.e. users select a group of points in a plane and an algorithm detects subsequently the points in the plane and its boundaries). These software packages have as well clash detection algorithms which indicate a clash between the point cloud and the planned CAD geometry. This is used the planning phase of retrofitting and reconstruction, where e.g. the refitting of HVAC is a major tasks.

Most available packages allow for a further level of semantic enrichment of point clouds through i.e. the application of labels, comments and measurement tags.

2.2.5.1.1. Research into automated feature extraction

In the field of computer science research in automated feature extraction algorithms is under constant development. Some methods that have been applied to the architectural field for shape recognition are:

Zhana et al., 2009: A method based on colour similarities and spatial proximities uses an algorithm based on region growing in order to find the nearest neighbour of each seed point creating regions which is being merged and refined on the basis of the colourimetrical and spatial relations.

Ning et el., 2010: A method based on shape detection adopts an algorithm of region growing and normal vectors to segment each planar region, and then architectural elements are extracted through an analysis of planar residuals.

Dorninger et al., 2007: Methods inspired from the 2.5D segmentation approach introduced by (Pottman, et al., 1999) based on a distance measured between planar faces are also applied in the architectural field. This method measures the distance in order to determine seed-clusters for which a region growing algorithm is performed, and an analysis of component connection is accomplished in the object space in order to merge similar seed-clusters.

Research conducted in the DURAARK project (Ochmann, et al., 2014) shows alternative ways of accessing architectural data. Besides geometrical descriptions of space a focus is set on the detection of spatial relationships between these. The DURAARK approach extracts for this room graphs showing the hierarchy of spaces from 3D point cloud scans.

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[16] http://www.tankonyvtar.hu/hu/tartalom/tamop425/0027_DAI4/ch01s03.html

[17] http://revisitortoday.blogspot.dk/2010/06/classification-of-lidar-point-cloud.html

[18] http://www.autodesk.com/products/recap/overview

[19] http://www.bentley.com/en-US/Promo/Pointools/pointools.htm?skid=CT_PRT_POINTOOLS_B

[20] http://www.bentley.com/en-US/Products/Bentley+Descartes/

2.2.5.2. *Scan to BIM*

The complexity of architecture demands a simplified representation for planning tasks. Here the concept of "as-built" BIM describes a process to obtain a semantically enriched 3D model, representing both physical and functional characteristics of a physical structure (Hichri, et al., 2013).

"As-built" BIM involves the description of the object shape (geometric representation), relations (positions and displacements of components) and attributes (characterizing objects in order to enrich the final 3D representation). The later includes information about e.g. materials, cost or state of construction or renovation. (Hichri, et al., 2013)

As stated in (Hichri, et al., 2013) 'the process of "as-built" BIM is mainly a manual process that can be tedious, intensive and subjective', and this is usually done by 3D modelling in a BIM software with the segmented and classified point cloud as an underlay or by plan- and section views.

In the previously mentioned guideline from Byggestyrelsen; Digital 3D Opmåling: Pilotprojekt på Syddansk Universitet, it is suggested to develop software for a more automatic extraction of abstracted 3D models from point clouds. These models should be suitable for planning practises and provide a more intuitive process through functions for parallel visualisation and handling of both point cloud and abstract model (or respective information from both) (Birch, 2010).

Commercial software products are though emerging that focus on a Scan to BIM process. Kubit VirtuSurv is a software program linking point clouds to many different BIM environments. BIM elements are modelled through selection of predefined element types and selection of points in the planar image produced by the 3D scanner.

2.2.5.2.1. Research in Scan to BIM

Research into Scan to BIM investigates approaches that utilize heuristics from the architectural field in the definition of discrete building component types.

Pu et al. developed an algorithm that allows for extraction of windows from building facades, among others. The first step of this algorithm is segmentation (Vosselman, et al., 2004), followed by constraint definition (position, size topology, direction etc.) and finally the recognition using a heuristic table. (Pu, et al., 2007)

Other modelling approaches based on similar heuristic logics use the relations between components. These algorithms detect planar patches by combining neighbour points using a region growing method. The patches are then classified according to their contextual relationships. (Xiong, et al., 2010)

The detection of differences between the "as built" (the point cloud) and the "as designed" (a BIM model) is used in a an "as-built" BIM modelling procedure. Here the modelling is reduced to the problem of matching entities of the BIM model and the point cloud. (Yue, et al., 2006)

A different approach uses ontologies. Inspired by the model of the semantic web, knowledge about objects and environments is extracted from databases, CAD drawings, GIS, technical reports or expert knowledge belonging to particular fields. This constitutes the basis of elective detection and recognition of objects in point clouds. (Hmida, et al., 2012)

The current research approaches might create satisfactory results in the recognition of geometries. However they lack the detection of semantics and attributes. Hichri et al. proposes hence in 2013 that parts of the semantically enrichment of point clouds takes part in the data acquisition phase.

3. Stakeholders and Processes

This chapter investigates and exemplifies how the above described processing of 3D objects is implemented among the group of stakeholders identified in the DURAARK deliverable 2.2.1. Through this detailed investigation we want to identify the processes that characterize the different steps in design and building processes. We aim for an understanding of the specific demands that the stakeholders have towards data they want to ingest into their working practice and how their output of data can be understood with respect to quality and exchange with collaborators. We are as well observing their position and role in the whole process connected to the build environment, looking at the creation, maintenance but as well operation and documentation of information. Identifying the stakeholders' needs provides crucial information to include them in an emerging information chain that includes the long-term archiving of their data.

The stakeholders were identified and investigated within the work of the DURAARK work package 7. Each chapter starts with remarks on the general tendencies observed, based on publicly available documents and interviews with stakeholders. 2-3 of these are described more detailed. Theses description are based on interviews with them and datasets provided by them and describe their processes, visions and challenges related to 3D object processing in the following subcategories:

- Description of stakeholders (company etc.), position in overall building process
- Typical process and lifecycle of data
- Interfaces, interaction and dependencies to partners
- Formats and software
- Storage / archival strategies
- Further emphasis was set on the exploration of the stakeholder's understanding of a vision for data exchange, how he understands a good process and interface and how this reflects in a good quality of data (i.e. Information Level, Modelling approach).
- If datasets are provided by the stakeholder a short evaluation of these is included. A detailed evaluation and a descriptions of the methods developed and used for this task can be found in the appendix of this deliverable.

3.1. Collected stakeholder dataset – overview and general remarks

Work package 7 of the DURAARK consortium has acquired a dataset from the most relevant stakeholders. As of January 2014, the dataset has a data volume of 500 GB. The dataset contains models of the two areas of concern:

	Building Information Modelling (IFC format)	3D documentation / Point clouds (E57)
Amount	109	83
Building types	15	11
Countries	6	9
Stakeholders	14	10
Data volume	2,4 GB	442 GB
Represented in IFC & E57	10	

A detailed list of the models collected until January 2014 can be found in Appendix 6.

A glance over the dataset of DURAARK shows that it differs from those that are provided i.e. by the buildingSMART consortium[21]. The main differences are:

- the complexity within the datasets is often higher
- the amount of metadata is lower
- the coherence within the datasets is generally lower.

The reasons for this might be the often pedagogical aims that motivate the publication of datasets for the public domain. This data shall often provide a best practice example, guide students or promote a certain way of modelling. Hence the data is often modelled in a quite homogenous way, from a single person and on generic examples that are not typical for building practice. The so far 109 datasets in IFC format and 83 point cloud scans, are coming from the stakeholders practice and give in so far a better perspective on the reality and constraints that are found in the processes of the diverse stakeholders.

We received until now models from all main stakeholders identified in deliverable 2.1:

- Data creators - Land Surveyors and 3D Scanning Companies
- Architects and Engineers
- Construction companies
- Researchers
- Building Owners and Real Estate Managers
- Public Administrations/ Public Planning / Policy Makers
- Cultural Heritage Institutions

We observe that the modelling approach taken in the creation of the 3D models is mainly driven by economic considerations of the stakeholders. This, as the creation of any of the files in the datasets demands an investment of paid labour ranging between approx. two hours for a single 3D scan and its off-site registration and post-processing (example file: 20131121_ScanPrecision_000_Res1_5-Qua3x.e57) to several years of interdisciplinary team effort to create the design and construction planning of the building for the headquarter of a major company (example file: PLH_DSV_Arch_Conf.IFC). The models given to the DURAARK consortium are hence carriers of a huge economic investment. They have as such still an economic value for their owners and the DURAARK consortium is glad to have found partners that are willing to provide the data on a non-cost basis anyway.

3.1.1. General Assessment of the stakeholder dataset

A detailed analysis of the stakeholder dataset on level of data as the description of the used methods and tools can be found in the appendix 7. On a general level we can summarize that the 3D scan data shows a level of information and quality of process that is appropriate to the processes the scans are made for. The data files are as well of consistent quality.

The IFC data in contrast shows a high degree of inhomogeneity in quantity and quality between, but as well within the data files. Apart from the possible influences of the immature tools used within the examination of the IFC data, the sometimes unexpected results, and generally low data content of the models, might stem from the stakeholders processes:

[21] http://www.IFCwiki.org/index.php/Examples

- Stakeholders do not use the IFC format in a consistent way. The usage is not prescribed by the IFC file standard; hence it is possible to make inconsistent models.
- Exports from proprietary formats are not always true to the IFC classes.
- Models can be built in a variety of ways, and some object types do not translate directly into the correct IFC property sets.
- The user's modelling skills are not always sufficient to create optimal IFCs.
- Later stage models from stakeholders not involved in the early stages are more precise.
- Stakeholders minimize the amount of attributes and metadata to their own needs and these requirements might change between and within areas of a model.
- some of the models are technical domain models and do for that reason does not contain the usual building components.

3.2. Data creators - Land Surveyors and 3D Scanning Companies

Land surveyors stood typically in the beginning of any planning process, whether related to new build or renovation. Their discipline is in its core related to the abstraction of the world complexity to understandable information for users that want to process this information. The surveying of architectural objects is here just a part of the discipline that stretches today from there to the creation of real-time digital orientation systems with famous examples such as GPS and Google maps. 3D scanning techniques are well introduced in the field and have all sorts of occurrences from stationary laser scanners to autonomous mobile and flying ones. They make surveying extremely fast, precise and as well cheap. And as the whole industry is shifting towards 3D the companies are trying to sell point clouds as a new product. They are facing however the problem that this product is not compatible with the processes of their direct clients in the building practices. Where researchers in the field of architecture and the cultural sciences have eventually tools (and the funding) to interpret the 3D data scanners create, architects and engineers are not willing to pay for a product they cannot use as directly as they could with the former 2D sections delivered by the stakeholders. Land surveying companies are hence investigating how to deliver 3D objects that are directly usable within their clients' processes. To create fitting data is in so far difficult as:

- multiple formats, and partly customized software platforms are used
- Projects work with individual levels of tolerances, concerning fit of measured geometry and created data
- Clients have an expectation that ordered 3D data objects should integrate seamless into their architectural planning process
- Clients demand customised metadata and setup of 3D objects.

To derive this data from 3D scans requires architectural knowledge, as the interpretation of the existing building is more akin to the processes of architects and engineers than land surveyors.

A new type of service providers are occurring, which are specialised in the quick scanning of buildings with the purpose to create tailored 2D and 3D data for architectural use. Direct to BIM measurement techniques like flexiJet[22] or 3D scanning and 3D modelling processes employ architecturally skilled persons that operate a BIM tool. The created data is directly usable by the clients 3D planning software, as it is tailored to the level of information and detailing needed. This approach differs in so far from the use of laser scanning for building

[22] http://www.flexijet.info/en/produkte/flexijet-3d/das-flexijet-3d/

documentation in i.e. cultural heritage studies and archaeology, where an almost standardised and homogenous, as well as high level of detail is expected. The data handed over to the clients here has in comparison a high degree of abstraction and differs in so far way more from the source data. This is often not part of the data package delivered to the clients and stays with the scanning companies, although the higher resolution of the original data might be interesting for later planning processes, as during or after the lifetime of the building

3.2.1. Plan3D

Fig.: 10 Scanning to BIM

Plan3D[23] is a Berlin based company founded in 2012 by three graduates of the faculty of architecture (Fig.: 10) [24]. The company has three partners and one employee, as well as additional staff in peak times, sourced among architectural students. Their business concept is the documentation of existing buildings with a FARO Focus 3D scanner and the following generation of 3D models using BIM software. These 3D models allow Plan3D to derive 2D sections and elevations which are sold to clients.

Plan3D aims to document besides residential buildings as well those from cultural heritage and complex technical installations. They claim to be able to create for buildings deformation analysis as well as marketing materials.

Their company was started with the scanning of a former hospital area in the north of Berlin. These scans funded the acquisition of a 3D scanner. The primary target of this job was the creation of a documentation of the building suitable for needs of real estate development. For this purpose Plan3D developed their initial scan to BIM technique.

Due to their background in architecture Plan3D claims to be able to judge and document what is inside the scanned structure and consider themselves as being better suited than land surveyors to create 3D models for use in architectural processes.

3.2.1.1. *Typical Process*

Upon discussions with the client about requested quality and quantity, Plan3D executes a scanning session in the building. This is planned and executed so that all building related objects (columns, corners, openings) are captured from all sides. A bigger amount of scans guarantees in their eyes a good fit of scans, as it minimises steep angles between laser beam and object.

The scans are usually executed without link to a world coordinate system. Reference marks as well as vertical connections (Staircases) are used to create references between rooms and levels. The possibility of the scanners inbuilt camera to create photo documentation and panoramas is not used, as it is typically not demanded by clients and elongates scanning time. A typical scan takes ca. 1,5 minutes. Plan3D creates on request photographic documentation of buildings using an external camera.

[23] http://plan3d-berlin.de/

[24] http://plan3d-berlin.de/#/projekte

Postproduction takes place offsite and includes registrations of scan and import into 3D BIM software. The export from Faro Scene is used to reduce the amount of points. Plan3D is not cleaning or separating scan data into i.e. building elements and furniture or storeys, but they use the point clouds directly as snapping guides for 3D modelling. The created 3D models describe the basic geometry of the building in a coherent way. Abstractions and architectural standardisation of the models, as the assumption of grid and axis lines, are both seen as auxiliary assistance to the modelling as to the later planning process.

In the next step 2D sections are created from the 3D models through the BIM software's sectioning planes. The 2D sections are if requested detailed, as in roof areas, where detailed scanning and modelling is too time intensive and clients typically don't demand precise measurements.

Plan3D estimates that 1 hour scanning time results in 5 hours of postproduction in their office. They claim that this is similar in other companies (land surveyors time) and estimate that the creation of fine detailed 3D models would result in a ratio of 1:10 and very rough models in 1:0,33.

3.2.1.2. *Interfaces to partners*

The typical clients of Plan3D are real estate companies that want an overview about their assets in from of sections in scale 1:100 and datasheets showing the area of spaces and on the other hand architects that need sections for planning. The clients do not work with 3D software but use 2D drawings. Definitions of accuracy are defined between the client and Plan3D and are not based on precise numbers (i.e. for tolerances), but through relatively loose agreements backed by Plan3D´s knowledge on needs of architectural planning and other building related processes.

3.2.1.3. *Formats and Software*

Plan3D uses FARO scene for the registration and processing of point clouds and Autodesk Revit for the creation of 3D models and sections. They use the software's proprietary formats and exchange with client typically in Autocad dwg format (version Autocad 2000).

3.2.1.4. *Storage / Archival Strategies*

Plan3D stores all files related to a project in their native formats and organizes these in folders on their server.

3.2.1.5. *Stakeholders Definition of good quality of data*

According to discussions with Plan3D a coherent and in so far complete 3D model of a scanned building structure is the main goal of their enterprise, as this allows for the good extraction of sections. Coherency means here a fitting abstraction from the data presented by the scan into 3D BIM models that are characterized i.e. through unified levels of storeys and heights of parapets and railings. Plan3D criticises the limited possibilities of current BIM software to model and represent geometries that deviate from the perpendicular (i.e. in tilted and conical walls).

Another challenge is for Plan3D situated in the step of abstraction from point cloud to BIM that is generally not a neutral act but case specific in its filtering. According to Plan3D a model commissioned by a company working on pipes would necessarily have a detailed model of pipes and the surrounding architectural elements as railing, where all other parts as openings etc. would only be modelled quite approximately.

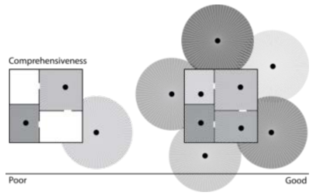
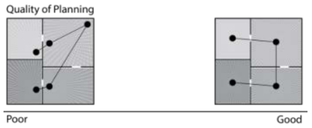
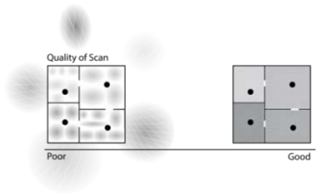
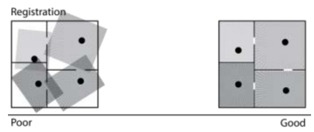
3.2.1.1. *Evaluation of dataset*

Plan3D has delivered two scan projects. The results of the statistical evaluation of one of these projects, Project House 30, is here shown as a prototypical example of the scanning procedures of Plan3D.

Project House30 is a large scan project by Plan3D consisting of 107 scans, both of interior and exterior scans.

The quality measurements show an exhaustive interior and exterior project, where only the roof is not scanned. The planning and the scanning of the project are above average. The cleaning of the scans is below average (only standard filters). The mean point to point distance is just below the recommended 30 mm for architectural recognition. The registration of the project is very well done with an average point distance error significant below 5mm for each floor segment. However the segments are not linked.

This depicts well the process described by the stakeholder. However the final registration of the floor segments together could improve their workflow.

Comprehensiveness	*Quality of Planning*	*Quality of Cleaning*	*Quality of Registration*
			
90 % Derived from Interior 100% Exterior 80%	**57,6%** Derived from SensorSensor Mean = 7,3 m SensorSensor StD = 5,4 m	**38,6%** Derived from Quality PointPoint: 8,3% Quality SensorPoint: 62,6% Quality PointPointRec: 45,0%	**Average point distance error:** 2,6 mm **Surveyed references:** 0 **Most used number of references:** 15

For more information on how this quality evaluation is conducted see *Appendix Chapter 7.2* Assessment of 3D objects with methods and tools developed in WP7

3.2.2. LE 34

Fig.: 11 3D Scanning by LE34

LE34[25] is a Danish land surveying company with about 160 employees distributed over 9 offices within Denmark. They deal with all areas within the field of surveying and 3D documentation ranging from large infrastructure project, and architecture to oilrigs. Over the last years they intensified the field of 3D scanning using Trimple's TX 5 3D scanner. LE34 has until now been delivering millimetre precise full 3D point clouds, clusters or enriched sections to clients, but they are in the process of extending their product portfolio to 3D BIM models extracted in-house from point clouds. They employ architects for the development of best practices in a Scan-to-BIM workflow.

[25] http://www.le34.dk

3.2.2.1. *Typical Process*

Discussions with a client allow LE34 to find the balance of quality, quantity, time, cost and used technology. In case of 3D documentation LE34 visits first the site and plans the scanning session. This is executed with their Trimple TX 5 scanner. LE34 prefers to scan the totality of a building, as a few extra scans are not expensive and the results allows later for an observation of initially not considered details Scans are almost always geo-referenced using a total station. Reference markers as well as vertical connections serve to register separate scans to one point cloud. In order to capture a structure as complete as possible LE34 uses the scanners in-built camera for capturing of colour. A scanning session is usually done with approximately 5-6 scans per hour.

The process of building documentation has changed for LE34 through the use of 3D scanning technology. Where traditionally land surveyor used to discuss with clients before 3D documentation which points had to be measured and why, the only information needed today is which areas are needed.

LE34 works within their scans with a tolerance that is defined by the point drift in-between their registration markers and/or geo-references. In 3D models they aim to have a tolerance of 5-6mm towards physical reality. In jobs for planning processes they aim for half of the construction tolerances at building site.

The post-processing of the raw scan data is conducted off site. The first step is always the registration in the software Trimple RealWorks and the cleaning of noise. A quality report from the software depicts the point drift of registration points. As they experienced that the quality report doesn't always give a clear image of the real registration quality LE34 also does a manual check of quality by zooming in and looking at the overlays of different scans in areas with planar surfaces. After this the scan data is cleaned through the application of a distance threshold in order to reduce overlay of points from different scans and avoid too steep angles between scan direction and surface as this, from their experience, reduces the quality of the scan. On request the point cloud is clustered into specified parts, as rooms or floors or according to a drawing grid, before delivery.

3.2.2.2. *Interfaces to partners*

LE34's clients are usually architects or engineers, whose CAD software can't handle large point cloud datasets. Hence sub-sampling, segmentation of point clouds is negotiated and delivered to the clients.

For façade renovations / retrofitting LE34 deliver usually only exterior scans - often with a colored registration of the facades deviation from. This helps clients to determine the necessary tolerances for the construction on site.

3.2.2.3. *Formats and Software*

LE 34 used to use Faro Scene for the registration and cleaning of the point clouds, but they are moving to Trimple RealWorks as this has more functionality build in, as deviation from plane and has a more versatile export option that fit the proprietary formats used by their clients.

3.2.2.4. *Storage / Archival Strategies*

LE34 stores all data of a project in their native and exported formats in a structured folder structure. They weekly back-up all data.

3.2.2.5. *Stakeholders Definition of good quality of data*

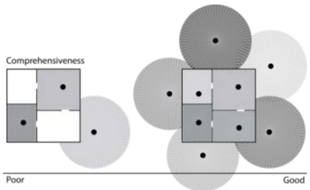
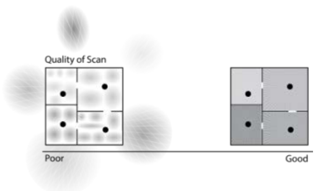
LE34 defines the main factor for good quality of their 3D scan data as of how exhaustive the amount of objects are captured and stored. This definition can however be overruled by project purposes. Sub parameters for their definition of quality are in the following order.

3.2.2.6. *Evaluation of dataset*

LE34 has contributed 4 scan projects and uses surveyed points for geo-referencing. The evaluation focuses on the project Vestergade 72, a large interior project consisting of 314 scans - a typical project by LE34.

The quality measurements show an exhaustive interior scan project, which has been very well planned and conducted. The cleaning of the point cloud is on average level, probably only done with standard filters. The average point to point distance is good and below the recommended threshold of 30 mm for visual recognition of architectural elements. The registration of the project is very well done with a low point distance error below 5 mm.

This depicts very well the processes described by the stakeholder.

Comprehensiveness	*Quality of Planning*	*Quality of Cleaning*	*Quality of Registration*
			
50 % Derived from Interior 100% Exterior 0%	**75,0%** Derived from SensorSensor Mean = 4,8 m SensorSensor StD = 2,7 m	**50,4%** Derived from Quality PointPoint: 10,0% Quality SensorPoint: 66,9% Quality PointPointRec: 74,4%	**Average point distance error:** 4,4 mm **Surveyed references:** 4 **Most used number of references:** 3

For more information on how this quality evaluation is conducted see *Appendix Chapter 7.2* Assessment of 3D objects with methods and tools developed in WP7

3.2.3. ScanLAB Projects

Fig.: 12 The House of Detention by ScanLAB

ScanLAB Projects[26] was started in 2010 by two freshly graduated from UCL/The Bartlett. They employ today around 5 people. The company is specialised in large scale 3D data capturing and creates in full colour millimetre precise 3D datasets in all scales from design objects to landscapes (Fig.: 12) [27]. The company pushes the boundary of what 3D scanning technology and where it can be applied. Besides working for clients such as architects, museums, theatres, TV channels and Greenpeace, they are actively involved in teaching and research at the Bartlett School of Architecture, University College of London and their work benefits in their eyes from their

[26] http://www.scanlabprojects.co.uk

[27] http://www.scanlabprojects.co.uk/projects/the-house-of-detention.html

background in architecture.

ScanLAB Projects provides services in three different areas:

Scan to Design – Architects are the dominant clients. A desired area is scanned and a 3D model (legacy 3D CAD models or 3D BIM models), 2D drawings (Autocad plan- and sections) or scaled orthographic images are generated from the scan data.

Scan to Make - ScanLAB Projects delivers 3D models direct for 3D printing, CNC machining and robotic fabrication. With this they can contribute to the design cycle of the building industry by delivering a novel level of precision for model making of existing conditions. The fabrication and construction industry can verify components before costly onsite installation.

Scan to Visualise - Full colour and millimetre precise orthographic images or video fly-throughs are the speciality of ScanLAB. These are based on in-house innovations in technique.

3.2.3.1. *Typical Process*

ScanLAB Projects use a Faro scanner for capturing of points coordinates, but instead of using the inbuilt camera, they use an external SLR camera for colour capturing. It’s better light sensibility is the base of their excellent Scan to Visualise service. Their scans are generally not linked to a global coordinate system. Registration markers help to connect different scans. Depending on the scale of the project resolution and quality settings differ a lot. (Architectural scale projects: medium resolution and quality, 7-8 min per scan. Capture of the spherical photo with SLR camera extra 5 min).

Scan to Design tasks uses FARO scene standard filters. From here they export the scans into the software that offers the formats required by the client and 3D model.

Scan to Make services employ a similar Faro scene initiated process. From here they export the data to Geomagic[28] for mesh generation for e.g. 3D printing.

Scan to Visualise jobs start with import of scans into Faro Scene with all filters turned off. Further post-process uses carefully filters with individual settings in order to achieve the desired visual result. From here the data is exported to Bentley Pointools, where e.g. a camera path is set up and an image sequence is exported. Special attention is turned to the transparent appearance of the point cloud. Finally a movie is compiled from the image sequence in the Adobe Suite[29].

3.2.3.2. *Interfaces to partners*

Through high quality drawings or 3D models ScanLAB Projects delivers a finale product in the proprietary formats needed by the clients. Raw point clouds are usually not given to clients.

3.2.3.3. *Formats and Software*

ScanLAB Projects uses Faro Scene for post, and move from here to a diverse set of other software packages. They use .pod files (proprietary format of Bentley Pointools), directly exported from Scene into Bentley Pointools for their jobs predominately situated within visualisation.

[28] http://www.geomagic.com/en/

[29] http://www.adobe.com/

3.2.3.4. *Storage / Archival Strategies*

ScanLAB Projects stores all related data (and a series of backups at specified steps of the post production process) in its native formats on a local server. They also store a raw set of data, plus they store a SD card per project with raw data from the scanner and camera as a last resort.

3.2.3.5. *Stakeholders Definition of good quality of data*

ScanLAB Projects tries to gather as much data as possible and avoids loosing information through i.e. import filters. As their projects range from architectural services to art, they often see the relevance of the noise produced by the scanner. An artefact is discarded by most other stakeholders.

3.3. Architects and Engineers

Architects and engineers are engaged with the modification of existing or the creation of new buildings. Traditionally they understand the physical reality through a set of models that help to describe structural behaviour, energy consumption, construction processes, finances or concepts and visions. These models can be developed separately in relation to time, disciplines and persons working on them, as well as in relation to abstraction levels. This separation of models has clear benefits, but as well the disadvantages of complex interfacing and coordination. These latter two aims to be solved with the introduction of 3D processing and here especially Building Information Modelling. As the related tools have their origin in the later stages of a building process, they are not well suited for the high level of abstraction and low level of information that distinguish the early design stages. The relatively high demand of specification needed for the modelling is seen as a limitation. 3D modelling itself has become a standard in the offices and is generally welcomed and seen as an essential part of the business and communication strategy. A new set of 3D based design tools, e.g. Sketchup[30], 3D parametric modelling tools, or fast 3D modelling tools stemming from the animation industry, provide architects with extra productivity and flexibility in the creation of the models.

3D parametric modelling (Davis, 2013; Woodbury, 2010) changes the foundations of the current modelling practice. Where the roots of the current generation of architectural CAD tools can be traced to drafting (Aish, 2013), parametric modelling is inherently linked to a programming practice and allows for flexible models that can adapt to feedback given from external sources as simulations or statistical tools. With the same ease, they can stream information in any format downstream to production. Today, large scale buildings are built with parametric technologies as these get more and more proliferated throughout the whole building profession. This high level of information exchange threatens to sideway the IFC format in a very project specific and yet less sustainable approach in terms of long time accessibility than BIM models.

As a profession, engineers are often consulting or taking over projects from the architects that envisioned them. Engineers are used to the toolsets and use them as well. Their profession has generally a longer tradition using 3D modelling, which is linked to very domain-specific investigations using proprietary simulation software. The engineering field put quite some effort into creating interfaces between BIM modelling approaches and their domain specific software packages such as Robot[31] that links to Revit or Tekla[32] creating an integrated BIM and structural solution that can deal with the bulk of engineering business cases in 3D. More specialised investigations into for instance building dynamics need however still custom-made 3D models and create corresponding economic and timely expenses.

While BIM is becoming the standard method of exchanging information, it is still plagued by interface problems that are sometimes based in lack of sight of user´s modelling skills or software but as well the principal incompatibility of processes. Accordingly, architects and engineers are in a learning phase of how to

[30] http://www.sketchup.com/

[31] http://www.autodesk.com/products/autodesk-simulation-family/features/robot-structural-analysis/all/gallery-view

[32] www.tekla.com

exchange information in a consistent manner. Tools for information management and quality control are just introduced and while their focus at the moment is on interdisciplinary control, their potential for in-process control is not fully realized.

All these processes, however, are related to the planning of new buildings. The planning of renovation related processes is still dominantly executed with 2D approaches due to the shortcomings of BIM tools and the structures of offices and architects that are concerned with renovation, which are often more traditionally oriented and / or in a later stage of their work life.

3.3.1. Schmidt Hammer Lassen (SHL)

Fig.: 13 Urban Media Space by SHL Architects, Aarhus, Denmark

SHL architects was founded in Aarhus, Denmark, in 1986 and employs today 140 staff, with offices located in Aarhus, Copenhagen, London and Shanghai. The practice has a track record as designers of cultural buildings, such as art galleries, educational complexes and libraries (Fig.: 13). Recent projects include the University of Aberdeen New Library in Scotland, The Crystal in Copenhagen, the City of Westminster College in London, and a number of projects and master plans in China and Eastern Europe, totalling approximately 2 mio sqm currently under development (2013). In Scandinavia, Schmidt Hammer Lassen architects is best known for the extension to the Royal Library – The Black Diamond, the ARoS Aarhus Museum of Art and the Cultural Centre of Greenland in Nuuk.[33]

3.3.1.1. *Typical Process*

Schmidt Hammer Lassen structures its internal design and planning processes almost exclusively with BIM related techniques. This means in practice that at every start-up of a new project, the design stage is initiated with a 3D BIM model in Revit. SHL argues to have through BIM a more efficient mode of both internal and external collaboration. The collaboration with partners follows a written BIM Execution Plan, which describes in detail how models should be built in order to ease exchange. The sketching phases are not initiated with BIM, but SHL tries to push the use of BIM/Revit to an ever earlier point in the process. At present, SHL has no experience with 3D scan data, but expresses a wish to use the technology to register especially pipes and cable trays in the future.

3.3.1.1. *Interfaces to partners*

Whenever possible, SHL uses the native Revit format for collaboration both internally and externally. Exchange is done via Revit Server. SHL receives 3D data from land surveyors, municipalities, architects and contractors. As for instance in a current hospital project SHL is working on, a model handover in IFC format is often imposed by clients and subsequently delivered via Dalux BIM checker by SHL.

[33] http://shl.dk/eng/#/home/about-us/

3.3.1.2. *Formats and Software*

In sketching phases SHL uses 2D Autocad (dwg) and 3D Sketchup (skp). They aim to replace Autocad with Revit as they observe a positive evolution of the program and their staff's experience in using it for sketching.

In the design phase Revit is the modelling tool for BIM. Revit Server is used for internal and external sharing of models. For model checking and validation, Navisworks (Autodesk) and Dalux Model Checker are used. For sustainability simulations, SHL uses Ecotect Analysis[34], Vasari[35] and Flow design[36] (all Autodesk). IFC is the format for model handover to clients and the file is produced by export from Revit. SHL reports that the Revit export has become less faulty in recent years. As their client´s knowledge and use of IFC models has risen they meet more often the demand to include basic meta-information in the IFC models, e.g. room information.

3.3.1.3. *Storage / Archival Strategies*

SHL has a digital storage of approximately one Petabyte in size. Every digital data that was created is stored, no discrimination is done. Dedicated IT staff has the responsibility for storage of data on managed backup servers located in Aarhus. Backup is performed constantly, from local servers and Revit Servers in all local SHL departments and partners internationally.

The studio does not have a strategy to search-and-retrieve within stored data, but express a strong need for it. Data has been archived since the dawn of CAD, but files are not checked for corruption or bit rot. Servers are replaced every 3 years. Paper documentation is stored separately.

3.3.1.4. *Stakeholders Definition of good quality of data*

SHL understands itself as provider of good architectural services to their clients and collaborators. Hence a lean and uncomplicated collaboration for the benefit of the client has priority. This defines as well the approach towards production of data, where they try to match firstly the demand of the client.

3.3.2. Erik Møller Architects

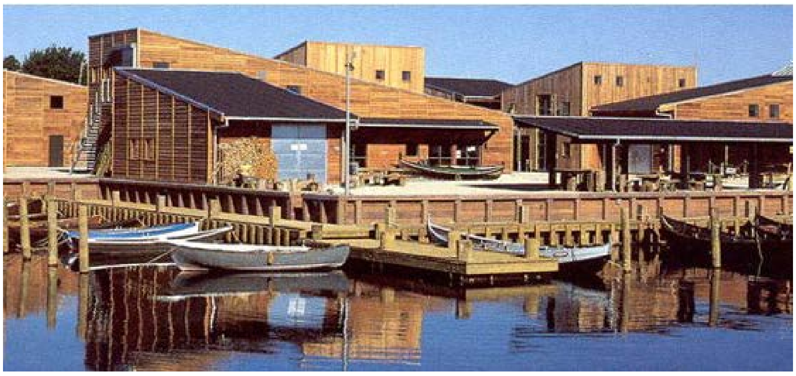


Fig.: 14 Viking Ship Museum by EMA, Roskilde, Denmark.

Erik Møller Architects is a Copenhagen based studio with 45 employees founded in 1935. Their main focus is cultural heritage, restoration, renovation and transformation of existing buildings (Fig.: 14). They have built up reputation and experience through many prestigious projects, among these the recent renovation of the residence of the Crown prince of Denmark.

[34] http://usa.autodesk.com/ecotect-analysis/

[35] http://autodeskvasari.com/

[36] http://www.autodesk.com/store/flow-design

3.3.2.1. *Typical Process*

Erik Møller Architects (EMA) start a restoration project with documenting the existing building in its present state through drawings. This process involves on-site measurements of the overall building dimensions as well as the 3D documentation of minute details in ornamentation etc. At present, EMA rely on manual methods for this. They see this as a time consuming but accurate method when performed by an experienced restoration architect. This measurement process is physically demanding as it often takes place outdoors and under bad seasonal and heating conditions. 2D cad drawings are produced from measured data and serve as a base for further planning. In regard to new buildings, Erik Møller Architects have the capacity to deliver 3D Revit models to meet client demands. EMA has established a 3D modelling/Revit team.

3.3.2.2. *Interfaces to partners*

Among others, EMA is an advisor to the Agency for Palaces and Cultural Properties and the retrofitting of the Castle of Kronborg is one of their projects. EMA´s role is to produce accurate 2D drawings (Autocad) of the existing conditions at Kronborg with an accuracy of 3 mm in every detail. CITA took the opportunity to 3D laser scan areas of the castle relevant to the retrofitting project. The aim was to determine the requirement for the quality of 3D scanning for retrofitting of building heritage. The result was that the laser scanning method is much faster, more precise and more convenient than the traditional tape and weight measuring method that EMA had performed.

EMA has previously received 3D scans performed by a scanning company to help build a 3D model (BIM) of an existing university complex (University of Southern Denmark). Although promoted by the client as a success[37], from the perspective of EMA, it was not a success because the precision of the BIM model that was commissioned to an external partner was much too low. A time consuming period of 6 months followed, where architects of EMA had to manually rebuild the 3D model.

3.3.2.3. *Formats and Software*

EMA uses 2D Autocad formats for all projects involved in cultural heritage, restoration, renovation and transformation of existing buildings. They do not yet use 3D laser scans in any of their workflows, but are determined to do so in the future. This depends on technological development that provides ways to incorporate data that represents the actual geometry of existing buildings in 3D BIM models and that their project teams get more experienced with 3D models.

For new buildings EMA uses 2D Autocad, when BIM is not required. Their BIM modelling group uses Autodesk Revit for projects where clients demand BIM and IFC.

3.3.2.4. *Storage / Archival Strategies*

Erik Møller Architects store their data internally and back up to externally hosted servers.

3.3.2.5. *Stakeholders Definition of good quality of data*

EMA is focused on high precision in measuring existing buildings. The threshold for good measuring and precision data is for them 3 mm tolerance.

[37] http://www.bygst.dk/viden-om/digitalt-byggeri/3d-laserscanning-paa-syddansk-universitet/

3.3.3. Christensen & Co Architects

Fig.: 15 Kristallen, Town House of Lund, Sweden.

Christensen & Co. (CCO) is an international practice, based in Copenhagen, Denmark, started by Michael Christensen in 2006 and employs today 45 staff. Their main focus is on projects for new buildings acquired through competitions. Concerning the use of BIM, CCO describe themselves as a pragmatic studio, they do not strive to be forerunners but aim at using the BIM method when it is economically viable (Fig.: 15)[38]. However in their practise any project or competition taken on will be done as a BIM project if it is officially required - otherwise not. This is mainly because employee's expertise and efficiency is still heavily tied to 2D CAD. CCO realizes that 3D Revit modelling is essential for future project collaborations, but not necessary for winning competitions.

3.3.3.1. *Typical Process*

At CCO a BIM project is usually started with a competition model done in 3D for visualization purposes 2D drawings describe the project in plan, section and elevation. The Revit model is built at the point of the design phase when collaboration with partners is mandatory, as for instance for a collision control through the merge of different 3D models. BIM models are used by CCO for information take off, i.e. areas, quantities, 2D drawing production, as well as for communication, simulation and visualization purposes. Visualizations are serving communication with clients. Daylight simulations are done in-house, acoustic simulations are done by external partners, both on the basis of a 3D model.

CCO does not yet use 3D point cloud data as an integral part for their workflows. They are very conscious of the technological development in the field and will adopt pragmatically.

3.3.3.2. *Interfaces to partners*

3D models are exchanged with partners on a case basis. 3D Revit models are used to exchange via project web (Byggeweb[39]) with other partners: engineers and entrepreneurs.

In projects where partners use Revit for structural, mechanical, engineering or plumbing models the exchange of files is done in an Autodesk software product (native format). In projects where partners use other proprietary software, the exchange is done via IFC export.

The validation of the final project is done at the handover through checking of an IFC model as described by Danish regulations for public building projects. For CCO it is typical practise that 3 IFC models are delivered during a building process: 1st model for project validation, 2nd as-built model, and 3rd model for facility management purposes.

CCO (as well as other studios) report that clients are often not very conscious of the purpose and usability of the BIM models they receive. The demand is mainly a lawful agreement and less an actual data source for facility management purposes.

[38] http://www.christensenco.dk/projekter/2/32

[39] http://www.byggeweb.dk/cms/dk/

3.3.3.3. *Formats and Software*

For 3D object processing, CCO uses Revit (rvt), Navisworks (nws), and Velux daylight visualizer. For the exchange of 3D BIM data proprietary Revit format is preferred, else IFC is used.

3.3.3.4. *Storage / Archival Strategies*

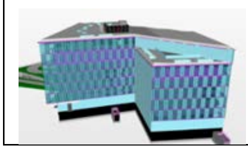
CCO stores all data on managed in-house servers. Exchanged data is also stored on project web (cloud based) which is managed by ByggeWeb and secured for 5 years or more.

3.3.3.5. *Stakeholders Definition of good quality of data*

CCO is very conscious of the IFC export which has been a particular challenge to perform with satisfactory accuracy. Most studios report that IFCs are often fault ridden in the form of missing or misplaced geometry. Therefore CCO is meticulous in checking the correctness of the IFC compared to the native model (Revit).

3.3.3.1. *Evaluation of dataset*

Kristallen is the new town hall of Lund, Sweden. The architectural domain model is geometrically highly detailed object data include acoustic properties, structural properties, material finish, and classification codes. This IFC file is the largest in the DURAARK IFC repository, both when it comes to data content, diversity and byte size.

	IFC model	Filesize	Elements (IFCproduct)	Rooms (IFCspace)	Beams (IFCbeam)	Walls (IFCwall)
	Kristallen	200 MB	11.000	485	40	1574

3.3.4. PLH

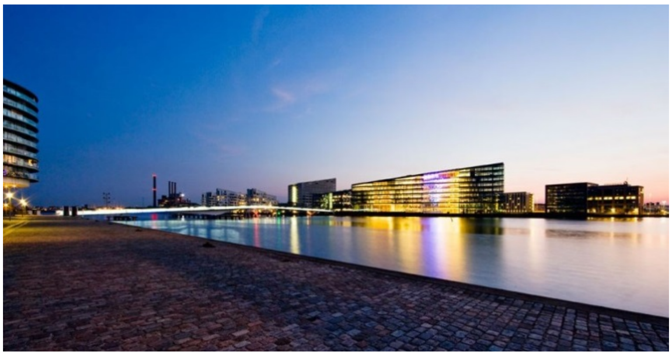


Fig.: 16 Aller Head Quarters by PLH, Copenhagen.

PLH was founded 30 years ago and employs 52 people in one office in Copenhagen. They work in city planning, building design as well as product design (Fig.: 16) [40]. PLH is one of the few Danish studios using CAD products from Bentley Systems. The studio is involved in the development of the standards and rule sets governing the mandatory implementation of BIM in Denmark. This includes the official Danish CAD manual of 2008 which became the Danish standard description of 3D model related services (ydelsesbeskrivelse[41]). Presently the studio is contributing to the newest classification system CCS in collaboration with CUNECO, the Centre for productivity in construction.

[40] http://www.plh.dk/projects/Allerhuset/

[41] http://www.danskeark.dk/Medlemsservice/Raadgiverjura/Aftalegrundlag/Ydelsesbeskrivelser/Byggeri-og-planlaegning.aspx

3.3.4.1. *Typical Process*

The typical work process at PLH is largely determined by client demands. An example is Novo Nordisk, a major client of PLH, which has precise demands on the data and drawing material they want to receive from the studio. This means for PLH to follow a standard which is not BIM or even 3D based, but matches Novo´s existing portfolio of building data and drawing standards.

Another client, DSV (transport and logistics company), has internal BIM processes. PLH plans their new head quarter, which was modelled and handed over as a 3D BIM project. The geometry of the project is built by PLH in Bentley Microstation (BIM program). IFC is used for handover and collaboration among partners in the building process.

3.3.4.2. *Interfaces to partners*

As a typical architectural studio, PLH interfaces with clients, public and private, project partners like engineers, entrepreneurs, and land surveyors. They are also heavily involved with developing official Danish toolsets for the Digital Construction initiative and very active in the Bentley User Group, aiming to strengthen the position of their preferred software tools in the Danish AEC industry. Through this, they interface with other domains like civil engineers, public planners, rail and road planners etc.

3.3.4.3. *Formats and Software*

The BIM department of PLH reports bad experiences with the export and exchange of IFC files that forces them to stick to proprietary file formats whenever slightly complex geometry is involved in the building design. The report on loss of information when exporting to IFC is in line with other studios’ experience.

PLH uses a variety of software including, but not limited to, Bentley Microstation, IFC, Solibri Model checker.

PLH would like to have the possibility to enrich created IFCs in later steps of a process. Their idea here is to split the IFC model in parts that can be updated or added separately. For example, models were outer wall/façade is separated from inner walls, so that they can be more easily updated when changes in layout occur during the lifetime of certain buildings.

In relation to the export and use of 3D models in facility management, PLH states, that IFC is the right format to use. They foresee problems with proprietary formats, as these will phase-out in the future. The studio doesn’t have direct experience with use of IFC models for FM.

PLH is heavily involved in the user forum of Bentley products and in this way up to date on the development of new technology. Their use of 3D laser scanning is limited to one retrofitting project where the CAD team used a 30.000 sqm scan, to model the buildings in 3D (Strandboulevarden). Their experience was that the point cloud was not very useable for the purpose, because their later planning required an abstracted polygon based geometry. The delivery of a 3D model rather than a point cloud would have been more beneficial for the project.

The DURAARK project seemed promising to them in so far as developed toolsets could aid in the transformation of cloud data to surface geometry.

3.3.4.4. *Storage / Archival Strategies*

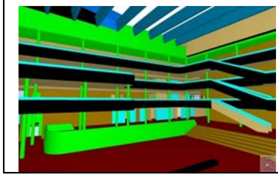
PLH store data on in-house servers that are maintained by dedicated IT staff. Back-Up is performed on external servers.

3.3.4.5. *Stakeholders Definition of good quality of data*

PLH adapts their information modelling strategy to the needs of the client and their data demands.

3.3.4.6. *Evaluation of dataset*

This IFC model is a headquarter project for the transport and logistics company DSV in Hedehusene, Denmark. The model has a medium level of detail with object data including naming, type, material finish and classification codes. This IFC is one of the few in the DURAARK repository which has been exported from Bentley Systems´s Microstation BIM modeller.

	IFC model	Filesize	Elements (IFCproduct)	Rooms (IFCspace)	Beams (IFCbeam)	Walls (IFCwall)
	DSV HQ	133 MB	8804	0	0	5307

3.4. Construction companies

The greatest deal of costs in the making of buildings is managed by construction companies (Liebchen, 2002). They are handling all parts of the realization of buildings including the related detailed steps in the planning process. Their responsibility is the accurate translation of the abstracted building intend into physical form. They are first in line when it comes to any problems within this part of the building process. Hence they have developed rigorous controls on all level of the process. The Nordic countries have seen a concentration process in construction and only a few big players are left that work all over Scandinavia. These are using information technology to gain higher efficiency in a highly competitive market. Building Information Modelling is the key technology and construction companies as NCC [42] try to solve the complexity of the building process with tools that manage a building in 3D and 4d, as the digital scheduling of the construction process is coined by software vendors.

Software tools as Tekla or Digital Project[43] are able to manage complex building projects and globally distributed interdisciplinary teams. The experiences that construction companies make in these big projects are rippling down to the bulk of projects. One of these is that 3D object processing is more efficient than other planning approaches and that a high level of detail in the 3D modelling, but especially the level of information that is attached to 3D objects, allows for more quality and hence efficiency in the building process. Every technology that can help to create more efficient processes is welcomed and will be tested for its use and place in the company's process. This applies for instance in the use of 3D documentation that is being introduced at different positions in the process for data acquisition, process monitoring as well as documentation with selected resolution of detail and quality.

Regulations and complexity of the building practice force construction companies to document their 3D object processes with great care and in a way that makes the data still accessible for the review and controls within the warranty of 5 years. Where the building process itself might take longer than this timespan, construction companies are afterwards hardly interested in the 3D objects, as the general innovation most probably outdated them and their knowledge is situated within the operational BIM libraries rather than old projects.

Construction companies are, due to their level of responsibility and size, however not fast movers and have to take a conservative look at innovations. Their position in the market allows them however to push developments. This is happening with BIM technologies in the Nordic countries, where their demands forces their partners in land surveying, architecture and engineering to change their business model to 3D object processing that follows the construction company's needs. The outsourcing of i.e. information enrichment of 3D objects does however not always bring the gain in efficiency that the companies expect as the received

[42] http://ncc.dk/da/Byggeri/

[43] http://www.gehrytechnologies.com/digital-project

quality might be lacking. And where the companies push for the standardisation of processes according to BIM standards and product libraries they are met by resistance of planners and authorities that emphasize the need for diversity in the build environment (Lauri, 2012).

3.4.1. NCC

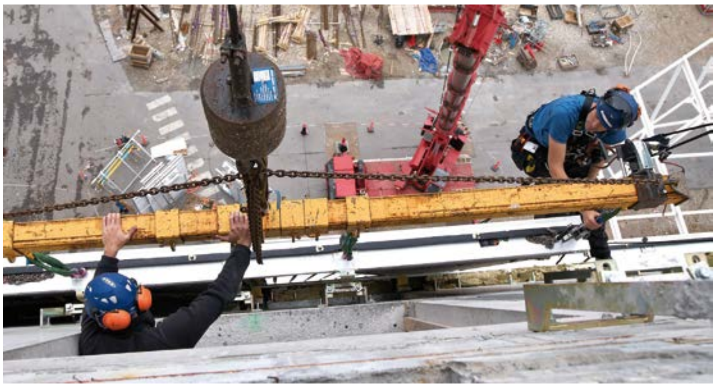


Fig.: 17 NCC Denmark at work.

NCC is one of the leading construction and property development companies in the Nordic and Baltic countries as well as Germany. The Group has approximately 17,000 employees, of which 2,000 are situated in Denmark. The company covers all areas of construction work for building and infrastructure (Fig.: 17) [44]. And while they are as well developing and running buildings, they are not designing and planning these. In this area they are collaborating with external experts, mainly architects and engineers.

NCC is a significant driver of BIM technologies and has been part of all coordinated efforts to develop the digitalisation in several disciplines. Their main objective in using BIM technology is to coordinate all of their building, construction and operational processes and use information for communication and instruction, as well as simulation and construction processes with an economic gain. Their vision is that information should be sourced from a central set of models rather than having it distributed over several places. NCC has an in-house “Virtual Design and Construction department (VDC)” that coordinates all building related IT services, gathers best practice knowledge and educates internally and externally to drive implementation of BIM technology.

3.4.1.1. *Typical Process*

As a major company in the building sector NCC is involved in almost all kinds of building projects between large scale urban, infrastructural, industrial and residential and all of these have specific IT processes using 3D objects. As the company is responsible for the actual making on site, they have to ensure the absolute correctness of all data, their fit to the physical reality and hence have to build in quality control mechanisms. These two aspects; the ensuring and verification of the correctness of data to provide them for further processes and the link of data with physical reality, are the processes within NCC that link the most to questions in the DURAARK project. NCC is here standing in the start of the chain as sponsor and contracting body of planning and design and at the end of it as building and operational company.

Documentation

All of NCCs projects start with an assessment and measurement of the existing structures which is done with the ordering of a survey at a land surveyor. The captured data is distributed among the project collaborators, a practice which becomes difficult with the shift to 3D as the data can be interpreted in more ways than 2D by surveyors and builders. E.g. a tilted wall within a restoration building implicates a shift in position of the low, top and midpoint of the wall when projected onto the ground level. And where this fact would usually be considered as too detailed for the architectural planning of concepts, it is of high importance for the actual planning and execution of the building work by NCC.

[44] http://danishresponsibility.dk/ncc-denmark

In order to resolve this complex issue NCC commissioned a quick modelling of a building using the Flexijet 3D technology[45]. The so created rough BIM model was given to the partners are responsible to adapt the data to their own needs. The process is seen as a success by NCC as it speeds up the planning and provides an equal basis to all partners. Point clouds have been tested at NCC as well. However, for their processes they prefer explicit data because the amount of points that are aggregated e.g. in a corner, introduces another decision making step in their process when they have to decide in-house which point represents the corner best. NCC is expecting to use the service of land surveyors less in the future as their working processes are not directly linked to BIM processes and create a man in the middle situation that needs to translate their into BIM data.

As-built documentation, control and warranty

NCC is the one party that is directly responsible for the delivered building work as well as providing as-built documentation and 1&5 year reviews for the building owner. NCC sees a big potential for more effective processes in these time consuming activities by moving the data collection from the building site to the 3D model. As until today, the Danish (and other Nordic) building laws see the 2D documentation as the legal base for all activities – there is little incentive at the moment to change the practice towards 3D, despite the advantages of a 3D documentation. Especially as the building owners until now hardly have implemented 3D objects in their own facility management processes. Sticking to 2D processes has as well the advantage of working on a greater abstraction level, and following with this, less responsibility, and today as well less work for all engaged parties. NCC sees however the advantage of 3D object processes especially in the as-built area – not at least as their own processes are to an increasing extent based on 3D drawings. And with more and more buildings being finished, based on BIM 3D, the company is preparing for the upcoming 1 and 5 year reviews in 3D.

3.4.1.2. *Interfaces to partners*

The coordinating and scheduling of processes is increasingly taking place in 4d planning tools, where 3D BIM data is structured around a time axis. Therefore, all of NCC´s processes are interfaced with partners and their respective software environments. The VDC of NCC is hence generally software and format agnostic and sees the data given to them as resource for their own processes, e.g. collision control, quantity determination etc. Generally, NCC´s partners exchange via open file formats, exported from software of their own choice.

NCC finds that all their partners in the building sector in Scandinavia today, are having in-house 3D processes. Engineers have a stronger tradition in working with a wide range of 3D tools - however with a limited view on 3D modelling due to the more refined area of work as for instance the planning of structures or HVAC. Architects are having a wide field of work and are in this respect challenged. They have as well often a limited amount of staff that is capable of professional 3D object processing, which often becomes the bottleneck in collaborations. NCC uses contracts (IKT aftale: Information and Communication Agreement[46]) to define the demands on the side of 3D objects and their exchange. The contracts have a focus on buildability, which sometimes requires different modelling strategies than in usual BIM models. The logics and timely steps of the building process come into play here and lead to another conception of a buildings segmentation than the predominant one that organises a building by stories.

The information heavy models can serve well as a base for models that can be used by partners situated downstream in the process. This can for instance be building owners as Copenhagen Properties (KEjd) who uses 3D models as base for their Facility Management processes. NCC has good experiences with this interface where they delivered FM data to KEjd, but hasn't met any building client though, that would request the same information density that is currently reflected in NCC´s models.

[45] http://www.flexijet.info/en/produkte/flexijet-3d/das-flexijet-3d/

[46] http://bips.dk/node/1810#0

3.4.1.3. *Formats and Software*

The preferred in-house BIM and CAD tool of NCC is ArchiCAD[47]. Besides this, they are using a variety of other software including Revit and TEKLA[48] for detailed construction planning in 3D. IFC is the company´s standard format for exchange between BIM platforms and NCC has observed an increase in quality of IFC due to improved exports, but as well better working practice with 3D objects through recent years. Naviswork[49] and Solibri[50] are tools that are commonly used to manage and compare received BIM files e.g. for collision of elements. In order to collect diverse 3D data NCC uses the Danish Byggeweb[51] and if this is not fitting to a project, as well internal BIM servers. For the planning of time based 3D processes NCC uses Synchro, a 4d planning tool by Synchro LTD[52]. 2D drawings are often used for the handover to clients and serve as legal documents. Preferred document formats are here dwg and standard pdf.

3.4.1.4. *Storage / Archival Strategies*

NCC has a centralized data centre near Stockholm that manages and distributes the terabytes of data of the company to the local branches. The centre is as well the central archive for all projects after their completion. The projects are packaged and stored in a way so that they can easily be accessed by other teams of NCC for the 1 and 5 year review with clients.

3.4.1.5. *Stakeholders Definition of good quality of data*

NCC considers information rich and consistent 3D models as a necessary resource for their activities. They emphasize, that the 3D models have to reflect buildability issues in the first place. In data heavy projects, the digital unit of NCC experienced that the enrichment of 3D objects with properties defined in detail with IKT contracts takes a considerable amount of time for the parties that are bound to deliver to NCC. And while these parties have no use for this additional information in their own processes, it consumes their time in model administration rather than actual planning. Where this statement might not reflect the official policy of NCC, it indicates that with a relatively constant honorarium for planning jobs, the productivity within the set of NCC partners has not grown sufficiently through 3D processes as it needs to absorb the extra work for model administration as well. Bad data (and bad planning) quality can be the result of this constellation and NCC is seeing the need for a principal change in the way honorariums are distributed, as well as who is enriching models with information. Concerning object data enrichment, their experience so far tells them, that it is better to let the collaborator who needs the data, enrich the objects when they need them, rather than making data rich objects from the beginning.

3.4.1.6. *Evaluation of dataset*

NCC supplied models from two stages of a building development: for the tender phase and a detailed architectural domain model for the construction phase. The exports to IFC were made by NCC from Revit Architecture. The project is an 8 storey mixed-use building.

The tender model is intended for information take off and calculation of quantities. It is fairly detailed and the data includes object types, materials, and Revit family source.

The detailed architectural model is double in size, has more detailed doors, windows, floors, suspended ceilings, acoustic panels, fire measures and contains data on how the elements are fitted.

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[47] http://www.graphisoft.com/archicad/

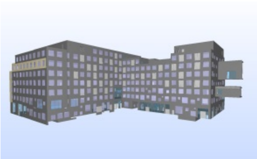
[48] http://www.tekla.com/uk

[49] http://www.autodesk.com/products/autodesk-navisworks-family/overview

[50] http://www.solibri.com/

[51] http://www.byggeweb.dk/cms/int/

[52] http://synchroltd.com/

	IFC model	Filesize	Elements (IFCproduct)	Rooms (IFCspace)	Beams (IFCbeam)	Walls (IFCwall)
	Carlsby Tender	27 MB	7768	346	0	1275
	Carlsby Detailed	72 MB	9807	505	22	3170

3.5. Researchers and Lawyers

The field of architectural and engineering research deals with all levels and flavours of 3D object processing. It is in the laboratory environments of architectural researchers that 3D object processing is covering the complete chain of architectural genesis from early design to fabrication and operation in a prototypical way. Different models are here interacting in a seamless manner, adapting to feedback from simulation and other means of measurements. The link to physical reality is created through digital fabrication and 3D documentation technology, eventually creating evaluation cycles and feedback to the design models through feature detection in point clouds or other tracking technologies. The projects are software, file format and domain agnostic, they establish interfaces to all kind of parallel (software) processes on and the lifetime of the generated data usually hardly exceeds the projects lifetime. And where the described projects are extensively modelling streams of information this notion of the projects is hardly conceptualised in this field of research that has is well known within the building profession but detached from the fields of building informatics.

Through its applied character this research practice can however be seen as a blueprint for an emerging architectural practice, where models are not representing in the first place geometric entities but relations between adaptable 3D objects. In these performance driven models, (Kolarevic, 2005). Adaptions can be triggered by internal as internal parameters, as updates on material properties on dimensions, functions due to forces, user needs, changes in program triggered by simulation results, (economic) calculations, discussion results or real time updates from physical reality. The concept of a persistent model (Ayres, 2012) emerges that is constantly updated and updating physical reality. Where some applications of this concept have emerged in practice (Brandt 2012, Ayres 2011), legislative as well as questions of restraint of responsibility are eventually limiting the direct application in the details of the building field. On a higher and longer term level, as among building owners, the idea of having a constantly updated digital model of the physical building are very present.

3.5.1. ICD Stuttgart

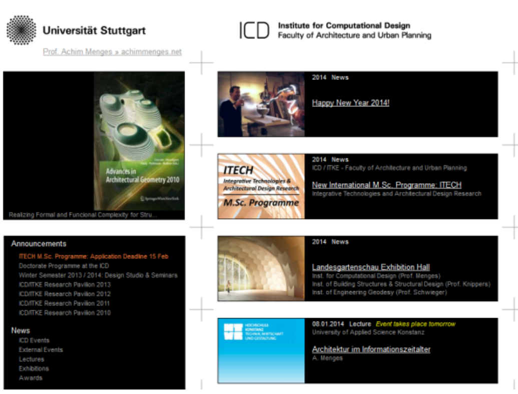


Fig.: 18 Webpage of ICD

The Institute for Computational Design (ICD) is dedicated to the teaching and research of computational design and computer-aided manufacturing processes in architecture.

Following its self-description (Fig.: 18)[53] ICD is following two primary research fields: the theoretical and practical development of generative computational design processes, and the integral use of computer-controlled manufacturing processes with a particular focus on robotic fabrication. These topics are examined through the development of computational methods and research which balance the reciprocities of form, material, structure and environment, and integrate technological advancements in manufacturing for the production of performative materials and building systems.

Observing their publications (Menges, 2011) the ICD has a seemingly linear process that iterates from a conceptual design level, through analysis to robotic fabrication. They use 3D scanning for the evaluation of the predicted material and structural behaviour.

3.5.1.1. *Typical Process*

The ICD is typically collaborating in their research with partners from engineering. These perform precise simulation of structures, where the ICD itself is responsible for concept, design, parametric 3D modelling, later digital fabrication and the overall project management (Fig.: 19).

Fig.: 19 A: Geometry model as the basis of fabrication; B: 3D laser scan model as the basis for vector-based deviation analysis; C: Vector-based deviation analysis.

3D Modelling and fabrication

The ICD and the ITKE (Institute of Building Structures and Structural Design) from the Stuttgart University, Faculty of Engineering have established a joint annual research led studio that designs and constructs research pavilions. While computational and material focuses are shifting a constant is the linkage of simulation and digital production. Several 3D models are created during the project, ranging from 3D sketches in Rhino, to parametric fabrication models using Rhino[54], Grasshopper [55]and their respective scripting environments[56]. Architects and engineering students and faculty share basic parametric models in the process and refine these for their own purposes, as the creation of fabrication data for prototypes or simulation of behaviour. The analysis is executed in the engineering software SOFISTIK[57], which allows the import of 3D data via dwg interface, the direct interfacing with Rhino (McNeel) or the generation of geometry within the program using modelling or scripted tools. As such the interfacing between partners can be adjusted to the project needs at each point in time.

The design process is relatively linear and employs one main parametric model that is enriched throughout the process with insights gained through analysis and finalised in a pavilion, as in 2011, when bespoke hexagonal modules of 6,5mm birch plywood (Schwinn, 2012) were assembled into a dome structure.

3D Scan

3D scans are used to detect the deflection of the build prototype and compare this with the various simulation models (design model, finite-element model, and fabrication model). Through this the ICD validates its related computational processes, and the evaluation of material behaviour over time in and after the development process (Krieg 2011).

[54] http://www.rhino3d.com/

[55] http://www.grasshopper3d.com/

[56] http://wiki.mcneel.com/developer/rhinocommon

[57] http://sofistik.de/

With a Faro Focus3D Scanner two complete 3D laser scans (12 individual scans) were performed within a three-month interval—the first scan just after completion of the project, the second scan just before the disassembly. Reference points on site were used for registration of the scans and to align the geometry model with the scan model. The point clouds are coloured using FARO Scene.

Measured differences are inspected by ICD and can be attributed to different origins ranging from inherent tolerances in surveying of the site and the laser scan, to fabrication (attachment of CNC robot to base <0.5 mm, deflection of cantilevering work pieces <1 mm, tolerances of the robot <0.2 mm), construction tolerances (levelness of the site, accuracy of base/foundation and compound tolerances during assembly). and material behaviour. This was predicted through FE to be up to 5.95mm nodal displacement under dead load) . With all tolerances added up, an accumulative tolerance of up to ±2.5 cm (±1 inch) was to be expected.

Comparison of scan and 3D model of simulation

The large quantity of available data required filtering processes. Only every 250th point within the bounding box of the pavilion is visualized yielding roughly 1,200,000 points. For the overall displacement analysis a first run was done on every 2,500th data point. The display of their distance to the reference model was used to identify zones of varying measurement deltas. Subsequently reference boxes allow the independent high-resolution analysis of identified quadrants of higher deviation. In high resolution and with ca. 600,000 points per quadrant displayed, deviations from the reference model become obvious.

Interpretation of data

The ICD concluded that the analysis of the distance values between measured points and reference geometry needed a good amount of interpretation in order to come to valuable insights (Fig.: 20). Their scans showed deviations in a range of 0 to 70 mm (Schwinn 2012). However, the average was only 15.76 mm, and more than 80 percent of the values lie within a range of ±25 mm and this refers to the compound deviation of the global geometry. The actual tolerances between the modules averaged around 6 mm, with the measured maximum being 14mm.

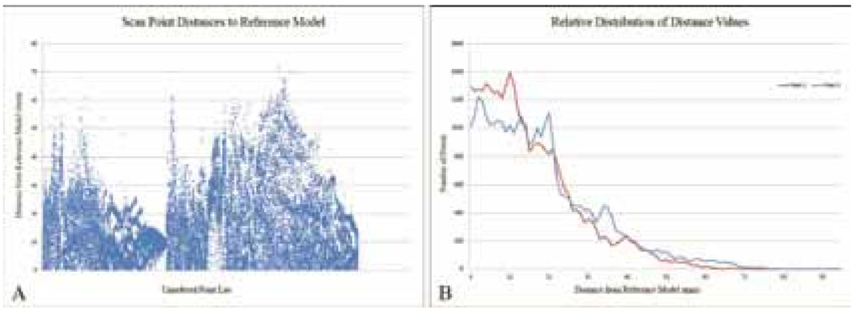


Fig.: 20 Scan data analysis. A: Chart showing the distribution of closest distance values for scan 1. B: The relative distributions of deviation values show that the number of points with a deviation larger than 60mm approaches zero.

The scan was crucial for the ICD to evaluate their process and product on a quantitative level as it fortified experiences made during the construction process. The analysis of a later second scan was helpful, as it allowed quantifying the increasing deviation over time. The few zones where deformation actually occurred over the lifespan of the project could be identified and it could be concluded that the prototype was extraordinarily stable (Schwinn 2012).

3.5.1.2. *Interfaces to partners*

The 3D scanning at ICD is carried out by partners from a neighbouring faculty for land surveying. These provide the scanning hardware and execute the scan, as they perform analysis and comparison between the simulation result and the 3D scan of the physical model. The feedback to ICD is taking place in diagrams showin i.e. mean deviation a swell as 3D models that highlight area of deviation.

3.5.1.3. *Formats and Software*

The ICD uses Rhino as standard CAD tool and the parametric plugin Grasshopper for generative models. This platform is shared with engineers, who work on the same platform and interface from here with their simulation software SOFISTIK, which allows the import of 3D data via dwg interface, the direct interfacing with Rhino (McNeel) or the generation of geometry within the program using modelling or scripted tools.

The point cloud data is generated in FARO scene the data from here are not shared with the architects.

3.5.1.4. *Storage / Archival Strategies*

The ICD conserves the final data at the end of the project on their server. Precautions for a long-term accessibility are not taken. Data is later usually accessed for presentation purposes.

3.5.1.5. *Stakeholders Definition of good quality of data*

The purpose of data for the ICD lies within the creation of models that reflect the physical reality of the build prototype (Schwinn 2012). Simulation and parametric models aim towards a convergence of the two. Data quality is hence defined by a clear internal organisation of the data throughout different models and a high interoperability between the instances of the data and software and fabrication machinery.

3.5.2. CITA

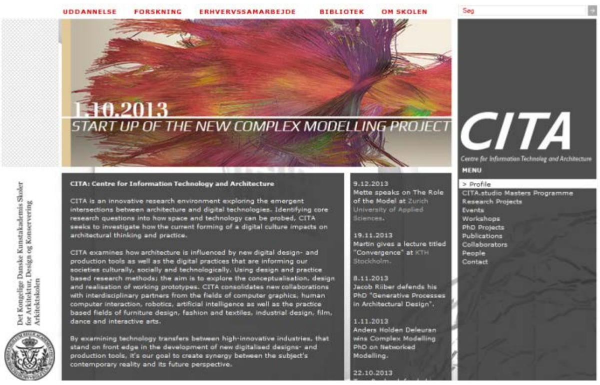


Fig.: 21 CITA webpage

CITA is a research centre at the Royal Academy of Fine Arts, Schools of Architecture, Design and Conservation in Copenhagen (Fig.: 21)[58]. Founded in 2006 it is using design and practice based research methods (Thomsen, 2009) for exploring the emergent intersections between architecture and digital technologies (Kolarevic, 2003). Key drivers for this move are situated within the field of simulation and digital fabrication. The field is here moving beyond a focus on sole geometric data (Hensel, 2006), as it is seemingly including the behaviour of elements in structures or buildings. The emerging inclusion of performative aspects in design (Kolarevic, 2005) necessitate the ability to predict the behaviour of architecture through simulation techniques. These depend today on the exact knowledge of all border conditions within an element, knowledge that is not at hand in early design stages. CITA is developing means to generate this knowledge early on and introduce it into the design environments. 3D documentation techniques and digital 3D models are here key components.

3.5.2.1. *Typical Process*

Though the modelling process at CITA is understood as an iteration between physical and digital 3D models (Thomsen, 2009) and the writing of CITA creates a theoretical framework where models for design and planning become persistent as and get enriched throughout their (Ayres, 2012), the reality of the modelling process is often more mundane and driven by project needs. Here processes like the one described for the ICD in section 3.5.1 are common. Generative and parametric models are capturing the requirements towards design and receive feedback from linked analysis tools. The role and benefits of integrated or sequenced modelling approaches for feedback is conceptualized and evaluated (Tamke, 2013).

[58] http://cita.karch.dk/

Here it is the consequent use of parametric and generative approaches, that can change according to events outside one digital design model as simulations or sensors , that challenges the current architectural practice that is today dominated by static 3D models.

3D Scanning

CITA uses 3D scanning in order to evaluate assumptions in the design models. These assumptions can be based on simulation or the aggregation of knowledge throughout the modelling process. A range of scanning techniques are employed by CITA.

Automated comparison of Scan and 3D model of simulation - Dermoid

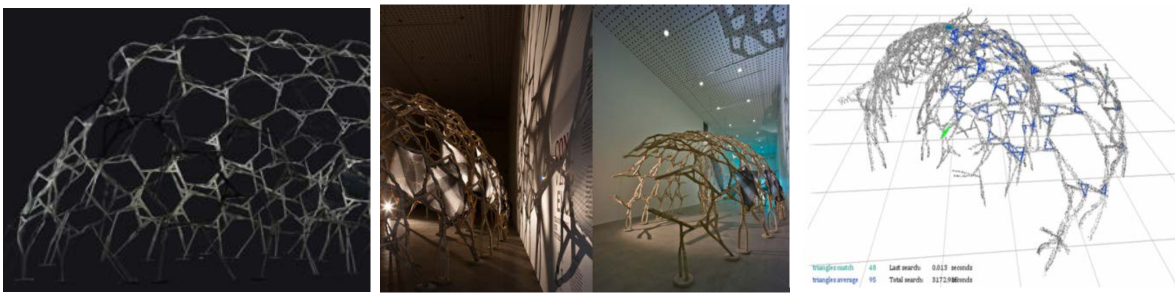


Fig.: 22 Left: DermoidIII 3D Scan, Mid: Dermoid III Pictures, right: algorithm detecting elemenst in point cloud.

The Dermoid structure (Hernandez, 2012), a grid shell made of 4mm Plywood, is designed to deform under self-weight (Fig.: 22). This deformation is predicted using a process similar to the one described in section 2.2.1.4.1. The build demonstrator is as scanned with a FARO Focus 3D scanner. During the post processing the point clouds are filtered in a Processing[59] environment by deleting 9 of 10 points. This process turned out to be sufficient in quality for the evaluation process in RhinoCAD and other tools at CITA and their partners from engineering.

Deviations between the point cloud and the build structure are taking place in an exact overlay of the two digital models using registration marks from the environment. Within the Dermoid project CITA was especially interested in the deviation of points in the nodes. These have a typical triangular shape, though in a bespoke non-repeating manner. The similarity of the nodes allowed CITA to program an algorithm in the processing programming environment (Processing[60]), that detects triangular structures within the point cloud and exports these as polylines. This allowed a good comparison of the over 100 nodes after the scanning session.

[59] http://processing.org/

[60] http://processing.org/

3D scan of dynamic processes - Persistent Model

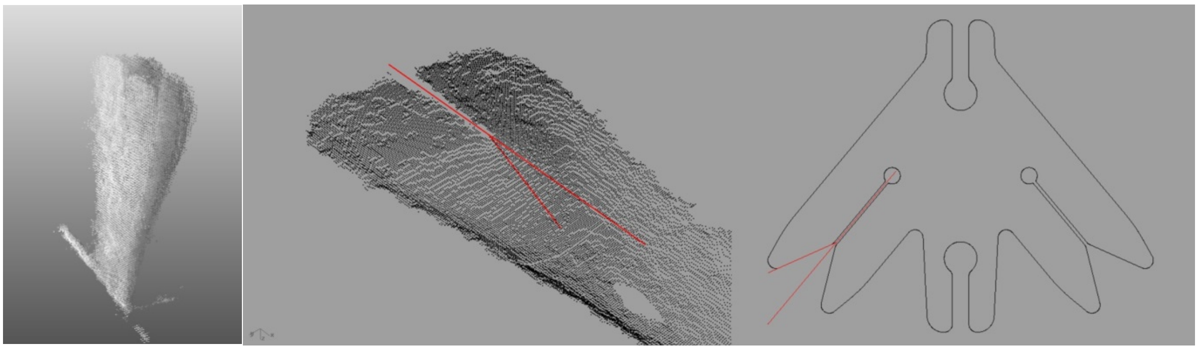


Fig.: 23 left: Dynamic scene capture. Changes in greyscale represent discreet scans at time intervals of approximately 1 second, right: Extraction of geometric data from connecting node to inform the design at inflation.

The 3D documentation approach for the Persistent Model project explores the continuous capture of point cloud data in order to determine change within a scene (Fig.: 23). In this context 'continuous' is to be understood as temporal increments of 0.1 – 1 second between scans. The project focuses upon the inflation of metal components as the scene to capture and the resultant point data was used to inform and calibrate simulation methods.

The Microsoft KINECT[61] is a proprietary scanning device designed specifically for continuous point cloud and image capture. The device was designed for the gaming market, yet offers a Windows Software development Kit and other third-party open source libraries for interfacing with the device.

The KINECT was chosen for its ability to stream depth sensing data, with a resolution of the streaming video in 640x480 pixels. It thereby captures the self-forming process of metal components undergoing inflation and provides through its 3 dimensional record a unique insight into geometric change over time. The scale of these components was suitable for close range scanning (distances of approximately 1.5 – 2m). As such the fixed cone of vision and lower capture resolution of the KINECT in comparison to industry scanning technologies available from producers such as FARO, was not an issue as the captured points were of sufficient density for interpolating geometry.

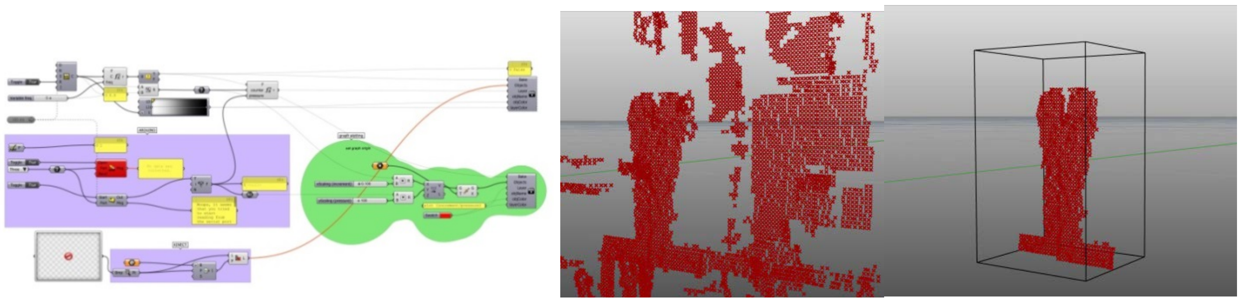


Fig.: 24 Left: The interface of the second capture tool using FIREFLY, GRASSHOPPER & RHINO, Mid: The full scene, Right: Real-time purging of irrelevant data

Two bespoke data-capture tools were developed that build upon open-source libraries allowing direct interface to the KINECT device. Employing a set of programmable development environments (Processing, Grasshopper) and tools and libraries (Thomas Diewald's dLibs_freenect Processing library[62], Firefly[63]) the tool create a direct link from the measurement to the design environment of a physical artifact. (Fig.: 24).

The research demonstrates the benefits of a discreet point import operation and how real-time 3D scene data can be operated on directly using standard CAD operations.

[61] http://www.microsoft.com/en-us/kinectforwindows/

[62] http://thomasdiewald.com/blog/?p=109

[63] http://fireflyexperiments.com/

3.5.2.2. *Interfaces to partners*

CITA's interfacing with partner is usually happening in a bilateral way, where data is send, but a swell received in a variety of formats, depending on purpose and nature of the project and collaboration.

On the level of point clouds the interfacing to other partners is done through exchange of point coordinate files with XYZ coordinates or native FARO scene format. The point clouds exchanged with partners are usually only representing the architectural object that is in the projects focus. Point cloud data that represents the environment is filtered out, as well as any obstructing elements.

Parametric Models are exchanged in native formats, as for instance Grasshopper (McNeel[64]) or Generative Components (Bentley Systems[65]). It is important for the involvement of other partners that the full relational logic of the parametric model is exchanged. This is only the case within the naïve formats. In cases where only geometric information has to be exchanged CITA is using formats that are fitting to the partner's needs, as dwg, dxf, 3Ds (Autodesk[66]) or Rhino file format (McNeel[67]).

Further collaboration with partners takes place on the level of code sharing, where GIT hub is at the moment a common platform.

3.5.2.3. *Formats and Software*

Standard tools for the creation of 3D Scans are Faro Scene for data coming from the CITA owned FARO Focus3D Scanner. Point clouds are exported into XYZ format. This allows for straight import into the Rhino CAD environment or parametric modeller (Grasshopper for Rhino[68]) or scripting environmnent (Processing[69]). All of these approaches are employed in parallel at CITA.

A Microsoft Kinect Scanner is employed for dynamic scans. Here a custom solution using Firefly and Rhino is used to interface scan and CAD environment.

3.5.2.4. *Storage / Archival Strategies*

All data is stored in native and processed formats on a server, hosted by the School of Architecture's IT unit. The server provides multiple backups at different station and is as well used for longterm storage. After finishing of a project, the respective folders are usually (but not always) cleaned, so that only original and the last working or processed version of a file is present.

No precautions for data conversion to updated formats are taken. Usually only processed files are reassessed, when similar projects appear at the Centre.

3.5.2.5. *Stakeholders Definition of good quality of data*

For CITA good quality of data is achieved when the model is following its extension. This varies between different uses and formats. Where point cloud data should be free of artefacts and of high precision, 3D polygon models in other formats should be as lean as possible and use i.e. subdivision surface modelling approaches in order to increase eventually the resolution of the models. The general intention of CITA is to use generative or parametric models. These are capturing the design intent within their programmed logic, are

[64] http://www.rhino3d.com/

[65] http://www.bentley.com

[66] http://www.autodesk.com/

[67] http://www.rhino3d.com/

[68] http://www.grasshopper3d.com/

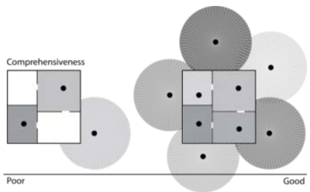
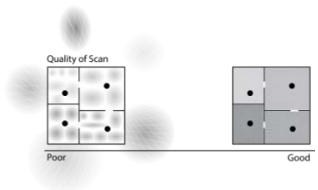
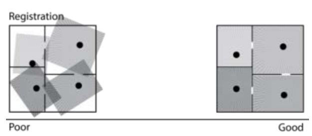
[69] http://processing.org/

usually adaptive and provide output channels to other software or fabrication machinery. Good quality models can capture changes in design and planning process without problems and generate eventually new valid versions of the desired output.

3.5.2.6. *Evaluation of dataset*

CITA has contributed with 11 scan projects and here are shown the statistical results of a typical project by the stakeholder, Project Dermoid III, which is consisting of 12 scans.

The quality measurements show an in-exhaustive scan project with only part of the interior, which follows the work from CITA by being object focussed. The planning and scanning session of the project is shown to be very well, which shows the desire to capture all angles of the object and a very well post-processing of cleaning to capture all details. And with a very good mean of point to point distances close to the recommended 10 mm for detailed architectural recognition. The registration of the project is also shown to be very well done, again because the focus in this is on the details of a smaller object. The quality evaluation is very much in line with what is described by the stakeholder.

Comprehensiveness	*Quality of Planning*	*Quality of Cleaning*	*Quality of Registration*
			
25 % Derived from Interior 50% Exterior 0%	**71,4%** Derived from SensorSensor Mean = 5,1 m SensorSensor StD = 3,4 m	**80,1%** Derived from Quality PointPoint: 82,0% Quality SensorPoint: 68,9% Quality PointPointRec: 89,5%	**Average point distance error:** 1,1 mm **Surveyed references:** 0 **Most used number of references:** 3

For more information on how this quality evaluation is conducted see *Appendix Chapter 7.2 Assessment of 3D objects with methods and tools developed in WP7*

3.6. Building Owners and Real Estate Managers

The interfacing of as build data from Building Information Modelling (BIM) with Facility Management (FM) – hence the transition of data from the domain of the construction industry to the building owner is usually considered as a important feature in an BIM approach (Gu, 2013) and the most essential part on the way to information lifecycle. Here the BIM model provides the building owner with all necessary information and becomes the operational Facility Management data that provides maintenance and similar data until the next construction cycle arises.

The investigation carried out here suggests however that related practices are only developing and is facing challenges on a process and a conceptual level.

3.6.1. Challenges on process level

In the current practice the creation of an 3D as build model is not only an expensive and time consuming step that is hence most of the time deferred by the building client. Usually only 3D BIM files from the latest planning stage of the building exists. The actually build may however deviate substantially from these. The necessary tools to create 3D as build BIM models through adoption of the 3D planning models do not exist. Research in the DURAARK work packages 4 and 5 might spur this development at least partially.

3.6.2. Challenges on conceptual level – a question of abstraction

The investigations conducted for the deliverable here show however that the data needed for the maintenance of a building differ substantially from the focus exposed in a building IFC model. These focus on the construction process and are determined by construction logics. Facility Management models are however concerned with the maintenance of a building and this takes, form the perspective of the stakeholders, in a predominant way on the mobile and surface related assets of a building. Their models require hence information about spaces and all parts that are exposed to users and other factors that induce wear and damage. They serve to trigger time based processes as maintenance or yearly inspections and provide a database to follow up on these tasks and consequential repair and other tasks. Some of these might actually lead to the change of the building substance itself. The FM model is hence an operational one that instructs personal about the location and specification of their tasks. This is today done on the base of digital 2D plan drawings that guides the personnel. Systems as the DaluxFM software provide this information even location based on mobile devices. And while the personnel might profit from a BIM based three dimensional view, for instance through augmented reality devices as research supported by Statsbyg Norway suggests (Liestøl, 2011), it is not obvious for the stakeholders what the efficiency of maintaining their FM related information in 3D is.

This points at the basic problem between an FM and an as build model, which delivers an overload of information for FM model. And while IFC models should be able to hold both views the investigation here shows that building owners today are transferring data hold in IFC models to their Facility Management programs and shelve the IFC files.

However the operation of a building is the single largest expense in a buildings lifecycle and all building owners that are included in this investigation work intensively on gaining efficiency through the use of information technology. A blueprint is found in Industrial applications such as Bentleys AssetWise an Information Management Services for Asset Lifecycle Management (Bentley, 2013), where information is combined and CAD tools are linked to the database, which is updated through these actions. These resource heavy applications scale however hardly to the economic realities of most building owners, where the margins are comparable low per asset in comparison to production industry. Alternative data management systems as the Dalux FM software [70]are hence developed that work on the base of IFC files from which the information for the FM system is derived. The stakeholders are hence starting to make digital records of all assets in their properties in 3D. These 3D models are tailored to the needs of Facility Management and have to be acquired in an efficient manner. Currently different approaches are test including surveying based systems as the Flexijet or 3D laser scan techniques.

3.6.3. Danmarks Tekniske Universitet (DTU)

[70] http://dalux.dk/flx/dk/produkter/daluxfm/

Fig.: 25 Main building of the Danish Technical University.

DTU, the Technical University of Denmark, is an almost 200 year old educational institution founded by the physicist H.C. Ørsted, the father of electromagnetism, in 1829.
DTU is ranked as one of the foremost technical universities in Europe, with 8000 students and 1500 researchers. DTU Campus Service is the facility managing department of the 600.000 square meters of buildings which are concentrated north of Copenhagen (Fig.: 25)[71]. DTU is forerunner in terms of public building owners combining 3D models with digital Facility Management. DTU is very well aware of the almost explorative nature of their work and understands this as part of their research activities. As such they are interested to share their developed knowledge on which information is needed and should be included in the 3D model at hand-over from the building to an operational stage of a building.

3.6.3.1. *Typical Process*

DTUs process of converting the received building data to facility management data is described as follows: Alongside the acquisition of new building models from entrepreneurs, Campus Service models their existing building portfolio in Revit for the purpose of FM. The level of detail in these is comparable to the KEjd practice, i.e. low, while the hand-over models have high level of detail.

Conditions for DTU Facility Management system

After hand-over, Campus Service, empties the models of information and stored it instead in an existing FM SQL database along with other FM information. At the present implementation stage, not very much information is actually retrieved from the models. The model geometry is stored separately, but he link between information an object geometry is still maintained via industry foundation classes which make it possible to mirror the information back into the model. FM is not done on the basis of the IFC model because a software program supporting 100% FM via IFC doesn't exist.

Never the less, DTU Campus Service is determined that BIM and IFC is the future of Facility Management and has a strict practise with handover of IFC as built and FM models from contactors in the cases of new buildings. They also demand the proprietary formats of the models because of the risk of error ridden IFC exports, often Revit. Current practice of transferring BIM models to DTU FM system

Entrepreneurs receive IKT-aftale (ICT-declaration) with very specific needs regarding FM information which should be included for Facility Management at DTU.

In the declaration DTU ask for all information to be put in the 3D models using the Danish former classification system Sfb and not the present new system called CCS. The use of the older classification system is due to implementation issues on the part of the new CCS system. The models are handed over in IFC, and also in Revit format if possible. DTU asks for all domain models as-built and FM models, but currently no entrepreneurs have been able to deliver FM models for other domains than architecture. As-built models are handed over in 3D when available.

When the FM model is received by DTU the information content is transferred to an in-house SQL database for actual storage.

[71] http://www.vinduesvidensystem.dk/billeder/DTU.jpg

The FM information is also required to be entered into a DTU Excel document by the entrepreneur. This document functions as the actual link between the 3D object model and the FM information stored in the SQL database. The excel document also links to external FM documents in pdf, word formats etc.

Presently DTU only has 10 small buildings which are managed exclusively via 3D models. The large majority is managed via the SQL database linked to Excel.

Migration from 2D legacy CAD to 3D BIM

DTU has a migration plan to convert their host of 2D Autocad and other legacy CAD format into 3D BIM model with embedded FM information on object level.

The buildings which are documented in single CAD files are readily able to be re-modelled in 3D Revit. Problems arise when CAD files contain externally referenced files (xrefs). The migration of this information and geometry is yet to be delt with.

Buildings design before the Autocad period is stored digitally in a legacy Cad format which is presently not readable. This is the exact problem that DURAARK is targeting and which is an area that DTU is especially interested in participating to solve for future workflow.

The Campus Service FM team has a very long list of information that they want included in the model for FM purposes. This is categorized in 7 parts: Ventilation, architecture (walls, windows, doors, ceilings, roofs), electric installations, automatics (sliding doors, access control installations), terrain (outside sewage system, chemical filtering plants), plumbing (indoor pipes and fixtures) and landscape (outside foliage, green roofs, green indoor walls).

DTU receive design models from all domains in high detail level geometry, low data content

They are archived to reflect the as-built stage for future reuse. Their Facility Management models are in low detail level geometrically but high in information content.

Future

DTU is developing a web based tool for digital handover of FM models called Dalux FM. This is a BIM checker designed for the DTU needs of FM information and will ensure that all the required information demanded in the IKT-aftale is actually present in the IFC model. It will save the DTU a lot of effort in returning incorrect IFC models from entrepreneurs.

More importantly the Dalux FM software will be the interface for daily facility management of the DTU building portfolio, used by campus service and maintenance workers on a daily basis.

Technically, the interface will be a 3D viewer of the IFC models with a direct link to display all stored FM data in DTUs local SQL database. The interface is browser based to ensure that maintenance workers can access all FM information from anywhere.

3.6.3.2. *Interfaces to partners*

As a building owner and client, DTU Campus Service interfaces to architects, entrepreneurs, contractors and the users of the buildings. They use extensive contracts to define the interfaces during the building processes, as well as for the handover of data to the operational services of DTU. These interfaces are new to all participants and cases exists, where DTU send retrieved data more than 13 ties back in order to have partners fullfill the set standards.

3.6.3.3. *Formats and Software*

DTU uses DaRufus software for FM information stored outside of the models. DaTia software keeps track of the object oriented model and DaluxFM software is used for document management. All model data is handed over in IFC. DTU models existing buildings in Revit file format. Additional file formats used include dwg, pdf, tiff and other legacy CAD formats.

3.6.3.4. *Storage / Archival Strategies*

At Campus Service all documents are scanned and stored digitally in an SQL database along with natively digital data. All building data is archived at the State Archive (Rigsarkivet) mainly in the tiff scan image format.

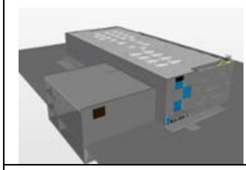
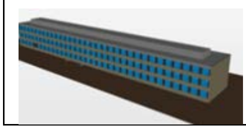
3.6.3.5. *Stakeholders Definition of good quality of data*

Campus Service is adamant to receiving correctly modelled IFCs according to the “IKT aftale”. No flaws are accepted and models are returned to sender up to 12 times for corrections. In reality no entrepreneurs are able to fulfil all demands to the level of information asked for in the 3D model. E.g. all domain model have not been delivered, so far only the architectural domain is received.

3.6.3.1. *Evaluation of dataset*

DTU has provided examples of both a facility management model and a handover domain model from a contractor.

The hand over IFC model is a new teaching facility by CCO architects in medium level geometrical detail containing the architectural, structural and HVAC domain models. The architectural model has object data on naming, types, material finishes including certain supplier information, DTU classification codes including location and thermal values for windows. This model is intended to continue to be used in DTUs facility management program. The structural and HVAC domain models are not intended for hand over but were used solely by the subcontractors in the building process. The structural model contain DTU descriptions, -classification, -location and basic structural-analytical parameters. The HVAC model has basic electrical installations as well as the main piping systems. Data include DTU location, -classification, -supply type, pressure values, and insolation parameters.

	IFC model	Filesize	Elements (IFCproduct)	Rooms (IFCspace)	Beams (IFCbeam)	Walls (IFCwall)
	DTU Building127	11 MB	2930	55	0	176
	DTU Building204	38 MB	3415	189	366	866

3.7. Public Administrations/ Public Planning / Policy Makers

A political agenda drives the use of 3D object processing among the investigated stakeholders that are related to the public domain. These are internally trying to create higher efficiency among the vast amount of assets they own and are here acting similar to building owners, on the other side they are using their legislative tools as well as the power that the public properties provides them in the market to push the development of building information modelling for the sake of the society on an economic as well as qualitative level. The taken steps are proactive and often taken in a speculative manner. This can be exemplified in the introduction of the need to use IFC format for building applications, where the stakeholder was aware that

- the others in the field are not yet able to produce 3D objects in an sufficient way
- itself had no sufficent methods to access the data received.

This situation is changing and the public administrations have today developed tools and demands concerning 3D objects they receive and are actively supporting the further development of these through support of standardisation organisation, as the CUNECO [72]organisation in Denmark or buildingSMART Norway [73]in Norway. The investigated public administration sees itself as an integral part of the building industry and acknowledges that they are themselves undergoing a learning process (Carstad, 2011). Within this they are realizing the value and the application of the information stored within the property layers of 3D objects and that automated tools can help the stakeholder to give an objective view on the performance and implication of the 3D objects in the physical world.

The public domain shares this knowledge through reports and best practice examples, for instance a swell on the integration of BIM and 3D Scanning (Birch, 2010). Their own experiences and needs with 3D object processing induce as well research projects that are tailored to push for an understanding of better integration of the 3D objects in the lifecycle of Building Information Models, as the Norwegian projects “Scanning of Cultural heritage objects) and “BIM & BAS”, that develops methods to link Building Information Models with the operation of buildings.

3.7.1. Bygningsstyrelsen - Danish Building & Property Agency

Fig.: 26 Part of project portfolio

The Danish Building & Property Agency (Fig.: 26)[74] is a part of the Danish Ministry of Climate, Energy and Building and was created by the formation of the government on 3 October 2011 through a merger of parts of the Danish Palace and Properties Agency, the Danish University and Property Agency and the Danish Enterprises and Construction Authority.

The Danish Building & Property Agency is the state's property enterprise and developer. They have the responsibility to create modern, functional and cost-effective frameworks for the country's most important government institutions, as the universities, the police, the courts and the government departments. With a total property portfolio of approximately 4 million m^2 - of this about 1 million private leases and PPP-projects - and more than 1,600 leases and with current and planned construction projects for a total of approximately DKK 14 billion, the Danish Building & Property Agency is one of Denmark's largest public property enterprises and developers.

The Danish Building & Property Agency understands their large portfolio as an opportunity for systematically keepings the costs down for the state and making use of economies of scale. They understand themselves as

[72] http://cuneco.dk/

[73] http://www.buildingsmart.no/

[74] http://www.bygst.dk

well as a political body that has the mandate to create synergy and coherence in government construction and property transactions and create development in the construction industry. The agency is hence pushing the Danish sector as it is connected on an international level with a focus on the Nordic countries. The agency is for instance a member of The Nordic Committee on Governmental Buildings, where working groups concerning cultural properties, energy optimization and BIM exist, that share knowledge and try to harmonize the steps within the countries on an informal base.

One of these steps has been the enforcement of digital processes in the building industry in Denmark, as chapter 2.1.1.3 described.

3.7.1.1. *Typical Process*

The Byggestyrelsen is involved through its different branches in political, administrative, legislative and operational activities concerning buildings. It is however not planning or constructing buildings, but hires specialized companies for these tasks. The tool for the selection of these is competitions. And it is this tool that the agency used to enforce the use of 3D object processing in the building industry. From 2007 onwards they were demanding that competition entries had to include IFC files that followed the at that time valid Danish BIM standards (BIPS). Where the agency admits today that they did not know how to use these files beyond visualization purposes and that they even were not successful in using this (Carstad, 2011), the pure demand of IFC files pushed the building sector. The agency was aware that the other stakeholders were not completely ready to fulfil the demands and were as such indulgent but persistent in keeping the general demands up. The agency underwent together with the other stakeholder groups a learning process in how to define the demands for IFC models and tried on the way as well other formats, such as 3D pdf for visualization purposes, however with little success.

Throughout the process the learned that despite the three dimensionality the “real value of the models are the properties that are built within these” (Carstad, 2011). The agency is using the properties stored in the IFC models for the assessment of economy in relation to area, volumes and energy using the BIM checker from the Danish company Dalux. This tool is a swell available for the partaking stakeholders in order to allow them to check the quality and conformity of their IFC file themselves. IFC files that are not conforming are rejected and the responsible stakeholders disqualified from the process. The delivered IFC files are as well used to do shadows analysis and a check of fit into urban context.

The assessment done by the agency is giving the agency another indication of the quality and efficiency of the competition proposal that is used for the final decisions, which includes usually a jury of experts.

3.7.1.2. *Formats and Software*

The Danish Building & Property Agency is using IFC for all building related data. They are pushing open standards. Internally they are using a variety of programs in order to organize their administrative duties. They are commissioning the development of software themselves, if these are not existing. The IFC inspection tool Dalux BIM Checker[75] is such an example, where the agency paid for the development. The use of the resulting online service for file quality control is today demanded from all stakeholders that want to deliver IFC files to the agency. The tool checks here for consistency of the file and whether the contemporary Danish BIM standard CCS (Cuneco Classification System) is met in the file as it does a basic assessment of the energy performance of the building proposal based on the BE10 calculation developed by the Danish Institute for Building Research .

Data exchange practice and vision

Today the agency has clearly described demands on the quality of IFC files and created with the Dalux BIM checker a tool that enforces this. The agency demands IFC file with low but consistent information level

[75] http://dalux.dk/flx/dk/produkter/dalux_bim_checker_kvalitetssikring_af_bim_og_IFC/

instead of highly detailed 3D models. These models shall contain a 3D basic building geometry with included properties that describe the objects use of energy, volume and material according to the CCS standard.

The agency is well aware and calculates with economies of scale where the practices that are now employed on bigger projects will ripple down into smaller projects as well as onto other levels as urban master planning. Rather than a sole tool of increased efficiency they perceive BIM as an entry into a better level of information about the build environment and a better environment itself. Accordingly they state that "spaces and buildings have a great influence on learning, efficiency and job satisfaction. The frameworks that we create …contribute to the development of society."

3.7.2. Københavns Ejendomme – Department for Development and Management

Fig.: 27 The third largest property administrator in Denmark

The property portfolio of Copenhagen Municipality (Københavns Kommune)[76] is developed and maintained by Københavns Ejendomme (KEjd)(Fig.: 27) [77] . KEjd is the third largest property administrator in Denmark. The portfolio include administration buildings, town hall, culture centres, libraries, institutions, nursing homes, schools and sports facilities, totalling appr. 3 mio sqm of buildings.[78] KEjd maintains an up-to date database of building information and is in the process of converting the database to include building information models. Apart from the Danish State, KEjd is one of the main driving forces in the implementation of Digital Construction in Denmark. As a public building owner KEjd is required by Danish law (the ICT-declaration) [79] to demand digital workflow in the building process, digital building documentation and IFC models from contractors and developers at building handover. The demand is to ensure an effective collaboration in the building process as well as an intention to reuse the produced information for facility management purposes and future retrofitting/renovation projects.

In 2012, 150 building projects were completed. This year, 2013, 3 day-care centres are completed every month. All new and existing buildings (95%) in the portfolio are to be modelled in 3D object based software (Revit).

3.7.2.1. *Typical Process*

The main task of KEjd is to maintain a database of the portfolio and continuously add 3D models in order to create a BIM database. Technically, this means that existing and future facility management information will be stored via objects in the 3D models. KEjd needs to always be able to search and retrieve information on any building in the portfolio via the database. To support this, the system is flexible and makes it possible to change classification system in an automated way. The Danish classification system is in a transition phase

[76] http://kejd.dk

[77] http://kejd.dk/om-kejd

[78] http://kejd.dk/om-kejd/mal-og-strategier

[79] http://bips.dk/v%C3%A6rkt%C3%B8jsemne/byggeriets-ikt-specifikationer#0

from a recent version, DBK (Danish Building Classification) [80], which turned out to be hard to use, to the new version CCS (Cuneco Classification System) [81].

Existing buildings in the portfolio are modelled in-house by KEjd. These models are low LOD (level of development) Revit models comparable to informationsniveau 2. Certain domain models will be higher LOD (600) than the rest for project-specific reasons. Objects are classified using CCS in Revit. Rooms are classified in DaluxFM[82]. At present, the models are geometry only, no information or metadata is stored in them.

At new building handover, KEjd receives a medium to highly detailed Revit model at information niveau 4-6 instead of IFC, according to their ICT-declaration. For renovation projects level they see a level 2 model as sufficient. Their experience is that IFC is not suited for KEjds purposes because of potential data loss during export/import. The demand is that the received model should be readable in Revit 2014 without loss of data or geometry. All relevant building FM information is stored in databases separated from the digital models: Ejendomsportalen, KKorg (administration and tenants), Redo, and Caretaker. The connecting system is called Hive.

Future developments

Along with other public building owners and administration, KEjd is developing a model based FM system in collaboration with the company Dalux.[83]

The new system will import the models and establish links between objects and relevant FM information which is stored in other databases.

The information will be accessible in a 3D interface displaying the geometry of the building and linking to the required information.

From the month of march 2014, the process of reviewing new buildings (bygningssyn) will be done via 3D models. At present stage only the dimensional sizes of windows, doors, outer walls, etc. are registered via the model, but later, much more detailed information will be registered on object level in the models.

When it comes to 3D scanning, the idea of being able to go back in time via 3D models and have information stored on the development of buildings via 3D scans, seems to KEjd to be an interesting facility management strategy for the future. As all other stakeholders, KEjd is limited to strategies that are economically viable and will only apply workflows that are efficient in their existing work methods. In this respect, 3D scanning can most likely be used to document listed/protected buildings.

KEjd is adopting the international concept of LOD (level of development) which is in the process of being described by the danish entrepreneur MT Højgaard for use in the Danish AEC industry[84]. This new concept will replace the Danish concept of informationsniveau 0-6.

3.7.2.2. *Interfaces to partners*

KEjd interfaces with the political system of the municipality, maintaining existing buildings as well as effectuating new building plans according to the political decisions of the public administration.

As a building developer, KEjd interfaces with entrepreneurs and contractors of the Danish and international AEC industry.

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[80] http://bips.dk/v%C3%A6rkt%C3%B8jsemne/klassifikation-dbk#0

[81] http://cuneco.dk/artikel/projects

[82] http://www.dalux.dk/flx/dk/produkter/daluxfm/

[83] http://www.dalux.dk/flx/dk/produkter/daluxfm/

[84] http://mth.dk/~/media/Files/dk/Bim-bygningsdelkatalog/Bygningsdelkatalog_MTHojgaard.ashx

In building maintenance, which is the bulk part of KEjds tasks (90%), the interface is with cleaning personnel and other maintenance crew.

3.7.2.3. *Formats and Software*

Revit is the only 3D modelling tool used. For exchange with DaluxFM, a plug-in is used for Revit. For collision controls Solibri is presently being implemented and in this workflow IFC is used. Autocad is still used for reading in the few cases where drawings are still stored in dwg format. DaluxFM being implemented for FM. Presently the main database is CaretakerFM. ByggeWeb is used for project web communication between collaborators.

3.7.2.4. *Storage / Archival Strategies*

KEjds FM software is CaretakerFM by COWI (Danish consulting company). [85] Project managers and building owners are expected to journalize building projects in a system called E-doc. The managing of the digital archives is performed by a company called Koncern Service. Other public institutions that use same strategies and software include Styrelsen for Slotte og Ejendomme and Teknik og Miljøforvaltningen.

3.7.2.5. *Stakeholders Definition of good quality of data*

As the administrator and facility manager of a very large portfolio of public buildings, KEjds main focus is on keeping information up to date at all times. For the FM database, geometry is not the key focus, but the searchability of relevant information on the buildings is paramount.

One particular issue in maintaining the large database is to ensure consistency and uniformity in the available information kept on every project, e.g. info about the objects, naming convention of drawings. Good data is rigid in the sense of not to be open to errors. The purpose is to be able to retrieve all information in a uniform fashion.

It’s a challenge that systems at present are not readily interchangeable. Ways of journalizing have not been clear. Guidelines of hand-over and classification have been unclear in the past.

On the side of hand-over of data from entrepreneurs, good quality of data is in compliance with the IKT agreement that KEjd has formulated. In model terms, this means receiving IFC and Revit design models in level of detail corresponding with Informationsniveau 5, which is the level just below as-built model. On the side of the building database, good quality of data is keeping not too much but enough information on object level which is needed for facility management.

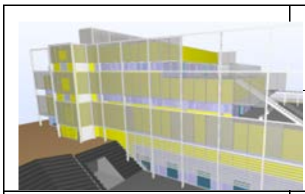
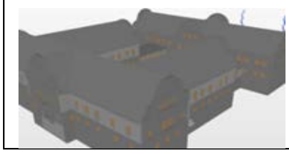
3.7.2.1. *Evaluation of dataset*

KEjd supplied examples of a facility management model and a handover model from a contractor.

The handover model is a geometrically highly detailed architectural domain model. It is a kinder garden in 4 storeys by Dorte Mandrup Architects and the first (and so far only) project KEjd has received from a contractor in 3D BIM. Objects contain a minimum of information limited to naming, type, geometrical information, and basic structural data.

The FM model is modelled by KEjd in low geometrical detail with few object types. Data is mostly generic and include DBK classification codes.

[85] http://caretaker.dk/

	IFC model	Filesize	Elements (IFCproduct)	Rooms (IFCspace)	Beams (IFCbeam)	Walls (IFCwall)
	Haveje Kindergarden	50 MB	4331	96	92	307
	Kastelsvej	25 MB	1988	319	0	855

3.8. Cultural Heritage Institutions

Cultural Heritage Institutions are highly aware of 3D modelling approaches and see the benefits as well as the challenges in 3D object processing. They developed for their own domain applications for 3D documentation that documents building and object from the cultural heritage. The introduced standards are here very high and informed initially the practice of land surveyors. Where the precision achieved in the best practice examples (Barber, et al., 2011) is exemplary the related costs with respect to time and finances needed are prohibitive for the direct application in building practice. Advances in technology make 3D documentation campaigns however more probable and public institutions that have the mandate to take care of their own cultural heritage , as the Danish Styrelsen for Slotte og Kulturejendomme or the Norwegian Statsbyg, are beginning this process.

These institutions are however hardly capable of using this data themselves on an operational basis or that they have concepts to integrate this data in a productive process themselves. They have direct influence on other stakeholders and create processes that force these to use the 3D objects for the benefit of the cultural heritage. This will enforce change of the internal processes within the collaborating stakeholders in order to fulfil the demands that the cultural heritage institutions set.

Cultural Heritage Institutions have however as well the mandate to preserve the 3D objects that are created within the architectural processes as these are part of the cultural heritage in themselves. Flagship institutions as the TIB in Hannover are conducting active research in this area. It seems that the bulk of institutions that have a defined mandate to preserve representations of the build environment have little capacities to develop or introduce processes that would allow an instant or long-term access of 3D objects and the stored information. In order to anyhow fulfil their mandate they demand 2D representations in image formats. The Danish State Archives[86] demands here for instance in their definition for the digital archiving of files created within or for the public domain[87]: the delivery of “one section in horizontal and vertical direction” of the CAD file of the building[88] .

3.8.1. TIB – Hannover

The TIB (Technische Informationsbibliothek) is the German National Library of Science and Technology. It focuses on all areas of engineering as well as architecture, chemistry, information technology, physics and mathematics. Located in Hannover, it was founded on the recommendation of the German Research

[86] http://www.sa.dk/content/us/

[87] http://www.sa.dk/content/dk/forskning_og_udvikling/digital_arkivering

[88] http://www.sa.dk/media%284156,1030%29/Informationer_og_systemer_i_den_offentlige_forvaltning.pdf

Foundation (DFG) in 1959. As an integral part of the national research infrastructure, the library has been jointly funded by the federal states of Germany (70%) and the German federal government (30%) since 1977. It is furthermore a member of the Leibniz organisation and conducts applied research and development in relevant areas of information science such as data visualization or digital preservation.

The TIB is a specialist library, collecting materials of the respective subject areas regardless of language and publication type and fulfils the role of an information and literature provider for research and industry worldwide. With an overall holding size of 8.9 million objects, the TIB is the world's largest specialised library for science and technology. Besides standard media types like books and journals, the library specializes in the collection of "gray literature" – a term used to describe information which is published informally and therefore hard to allocate and obtain, such as patents, conference proceedings and research reports.

Recognizing the importance of research data early on, the TIB became the world's first Digital Object Identifier (DOI) registration agency for primary data in 2005 and is currently the managing agent of DataCite.[89] Other current research and development activities in the field of primary data include participation in the DFG funded national infrastructure project "RADAR – Research Data Repositorium".[90]

With architecture being one of TIB's central subject areas, this naturally includes architectural primary data. In the analogue holdings, the "Albrecht Haupt Collection" consists of approximately 6.800 items from the year 1500 to the middle of the 19th century.[91] Between 2006 And 2011 the TIB partnered with the University of Bonn, the Technical University of Graz and the Technical University of Darmstadt in the DFG funded PROBADO3D project, which developed a platform for content and metadata based search and presentation mechanisms for architectural 3D data. [92]

As a national subject library, TIB has an archival mandate including the long-term stewardship for a growing digital collection. To meet the digital preservation needs, the library is active in national and international digital preservation networks like nestor[93] and the OPF[94] and has staff and budget dedicated specifically for digital preservation tasks. This staff is also responsible for hosting and administrating the Goportis[95] Digital Preservation System – an archival system used by TIB as well as by two other German national subject libraries.

3.8.1.1. *Typical Process*

The general tasks of libraries include collecting, sorting and making material available to a defined user group. Archival libraries, such as the TIB, furthermore have the task of archiving their holdings.

In the case of the TIB material typically enters the collection via an active selection process. Material can enter this selection process in two ways: (a) it is pulled into the process from available sources like publishing information, diverse gray literature sources or non-textual material sources like repositories (b) it is pushed into the selection process through legal deposit, user requests, donations or archival requests.

Both processes are in use for non-textual material such as 3D. 3D objects may be pulled from available TIB services such as PROBADO3D or they may be pushed through TIB's competence centre for non-textual materials (KNM)[96].

Post selection process, material is made available through services like the TIB catalogue, the GetInfo search

[89] http://www.datacite.org/

[90] http://www.tib-hannover.de/en/research-and-development/projects/radar-research-data-repositorium/

[91] http://www.tib-hannover.de/en/spezialsammlungen/albrecht-haupt-collection/

[92] http://www.probado.de/en_3d.html

[93] http://www.langzeitarchivierung.de

[94] http://openplanetsfoundation.org/

[95] Goportis is the Leibniz Library Network for Research Information: http://www.goportis.de/en/home.html

[96] http://www.tib-hannover.de/en/services/competence-centre-for-non-textual-materials/

portal[97] , PROBADO3D or tools and services being developed by the KNM. Furthermore, the objects are passed to the digital preservation system through fully automated, semi-automated or manual workflows – depending on the need of the respective collection.

3.8.1.2. *Interfaces to partners*

Main interfaces to partners in regards to 3D are currently the aforementioned portals GetInfo and PROBADO3D. The TIB catalogue (TIBKAT) as well as subject relevant parts of the DataCite metadata collection for primary data are included in the GetInfo search portal. While the contents of PROBADO3D are searchable through GetInfo, GetInfo does not yet support all search functionality that PROBADO3D does. However, extending GetInfo search capabilities is ongoing work.

3.8.1.3. *Formats and Software*

Depending on the collection and workflow, TIB may only accept data in specific formats. Two factors determine format recommendations: (1) usability, i.e. the target user's expectations and capabilities to render the information and use it meaningfully in the intended way (2) archival capabilities, i.e. the adherence of the format to general sustainability factors such as openness, degree of adoption or tool support. Proprietary, closed formats highly limit both usage and archival capabilities alike. In the case of 3D data open formats like STEP family file formats such as IFC or E57 for point cloud scans are preferred.

3.8.1.4. *Storage / Archival Strategies*

TIB maintains a digital preservation system. On a bit-level archival storage is implemented through multiple copies on spinning disk, additional backup procedures and error detection e.g., through integrity checks. On a logical-level objects are characterized during the ingest procedure, meaning the format is identified and technical characteristics are extracted and captured. This enables detailed data management and preservation planning processes on a format-based risk level.

The archival strategies are further supported through organizational procedures such as monitoring the designated community – i.e., the users – for changing expectations in target formats or monitoring changing technology.

3.8.1.5. *Stakeholders Definition of good quality of data*

Good quality data supports the two processes mentioned before: (1) usability and (2) archival capabilities. As such, data needs to support the identified usage scenarios and fulfil the needs of TIB's stakeholders. Data in open and well-adopted formats usually cover usability and archival needs as well. The expectations may differ e.g., when it comes to data size. While the user may expect compressed data which can easily be transferred through networks, archival expectations require data in an uncompressed state. In such cases multiple representations of an object are kept: a high quality uncompressed archival master as well as a compressed access copy which fulfils the user's needs.

In the context of an information provider and long-term data steward, data can only be considered good when the accompanying metadata lives to the same standards. Accompanying metadata is descriptive, technical and administrative metadata which supports the full information lifecycle processes and captures provenance, bibliographic, rights/legal and preservation information about an object. Metadata needs to be complete and available in a standardized form.

[97] https://getinfo.de/app?&lang=en

3.8.2. Styrelsen for Slotte og Kulturejendomme (SLKE)

Styrelsen for Slotte og Kulturejendomme (The Agency for Palaces and Cultural Properties) (Fig.: 28)[98] is a property management company, which principal function is to preserve, manage and maintain palaces/castles, gardens and other cultural properties in the Danish State, and to optimize their use. It is a constitution under the Ministry of Culture and got established in 2011. It has the responsibility of maintaining and development of approx. 30 properties with total square meters of 300.000, plus the facility management of the properties of the Ministry of Culture of approx. 400.000 square meters.

Fig.: 28 Part of the SLKE building portfolio

3.8.2.1. *Typical Process*

Since SLKE deals cultural heritage buildings they usually deal with 2D plan and section drawings, purely because that is what is available in the old drawing materials. They see the benefits in building information modelling, but haven’t found an appropriate way of constructing BIM models on the required as build level model in an economic level of time and expenses. In some rare occasions low information level 3D models were used for visualizations purposes in order to inform the public about plans for renovations of cultural heritage buildings.

They are though using 3D scanning as a means of recording the state of a building. This is conducted by subcontractors with guidance from SLKE of what is required. It is usually used for smaller artefacts, like sculptures and relics, to digitally preserve their state for a later production of a replica, if the artefact deteriorates or for archival of the state for historical reasons. This was usually done by casting but they have moved to 3D scanning because of the speed and accuracy, and the fact that 3D scanning doesn’t degrade the artefact.

3.8.2.2. *Formats and Software*

SLKE do not have an operational use for the files they inherit. Hence they are open to any software format.

3.8.2.3. *Interfaces to partners*

SLKE usually works in collaboration with architects or land surveyors in order to plan or register their cultural heritage buildings. They rarely develop their own 3D data besides in collaboration with architects they develop 3D models for visualization purposes.

For their documentation of buildings they use land surveying companies to do terrestrial surveying or 3D scanning in close conversations with them about what data is required.

[98] http://www.slke.dk

3.8.2.4. *Storage / Archival Strategies*

SLKE archives all data relevant for reuse or historical reasons on server maintained by the state, which is backed up daily.

3.8.2.5. *Stakeholders Definition of good quality of data*

For point cloud data SLKE aims for getting data with millimetre precisions, especially because they work on smaller artefacts and the historical preservation of these.

For the 3D models they don't have any definitions for quality at the moment, because it is mainly used for visualizations. But they see the potentials in a highly semantically enriched BIM model for facilitating their maintenance and renovation projects.

4. Outlook - a shared Vision for 3D objects?

The investigations conducted among prominent stakeholders in the Scandinavian area – usually considered as leading countries in the introduction of 3D object processing (see chapter 2.1.2 and 2.1.3) – reveals a success story. A success story in so far, as the building profession, an industry that is seen as late movers (Smith, 2013), is changing its business concepts from being based on static representation to dynamic information. This story of change is ongoing. And the first steps into a digital lifecycle of building related documents reveal the reciprocal relation between the reality and the visions shared by the international networks of likeminded professionals, as the buidlingSmart community[99].

4.1. 3D object processing becomes information modelling

It is only through the use of Information Modelling that the here investigated communities realize the potentials of BIM and confront BIM on the other hand with real life complexities. The communities understanding of BIM shifts today from the early simplified understanding as "modelling of 3D objects", characterized by Finith E. Jerningan in his book "Little bim BIG BIM" published in 2007 as "Little BIM", to a wide acknowledgement, that the making and processing of information is at the core of each stakeholder's future operations. **3D object processing becomes information modelling** and the questions and demands of the stakeholders are shifting accordingly. The stakeholders realize the limits of the BIM software they are using. These stem predominately from the area of CAD and focus on strong geometry processing. The query among objects, the extraction and comparison of information and the further use in applications as simulations (3.7.1.1) moves (into focus and pushes the tools. Ning Gu argues (Gu, 2013) that the coming set of tools for the industry will see a blend of the strength of design environments and of document management systems, in order to combine the ability to model data, as to visualise data. Related environments are under development and approaches as Bentleys Hybrid Modelling are marketed to offer the "depth of information modelling with breadth of information mobility."[100].

These claims have to be proven, especially within the agile boundaries that characterize design environments, but the understanding that the modelling environment is transformed into an environment for knowledge management is following the demands from the here examined stakeholders. These want to be able to inform their actions that are finally expressed in 3D object modelling through data and increase hence the quality as

[99] http://www.buildingsmart.org/organization/OPEN%20BIM%20ExCom%20Agreed%20Description%2020120131.pdf

[100] http://www.sparpointgroup.com/Blogs/Disruptive-Perspective/Bentley-Systems-and-the-business-of-infrastructure/

well as the speed of their decisions. The necessary data should be directly accessible from within their work 3D work environment with little ease.

4.2. Enriching information

The collected experiences from the stakeholders show that the necessary **enrichment of 3D objects with information** is today a labour-some process, which occupies time of highly qualified and paid employees with tasks in (model) administration. These tasks minimize the efficiency of operation. The streamlining of information enrichment through better software tools, eventually linked to **online based libraries as the Building Smart Data Dictionary[101] or standards as CCS[102]** is in focus of the stakeholders. However this does not solve the challenge that stakeholders, as architects and engineers, are often asked to enrich 3D objects with information, which provides no direct use for them. These tasks are hence executed without proper understanding of the related later their demands for this information. This can results in a lack of quality, as observed by the stakeholders following in the chain (3.4.1), and points at the principal question whether all information has to be set into a 3D object when it is generated or whether an iterative enrichment of information of 3D objects is adequate?

This provides the ground for businesses of a completely new set of external service providers that enrich 3D models with information, as the Norwegian company Cobuilder [103]. This group of knowledge maintainers might be able to solve the tasks of knowledge enrichment in a more purposeful way. They are already today solving the challenge of updating or adding layers of information within existing 3D models.

4.3. Towards a Data lifecycle model

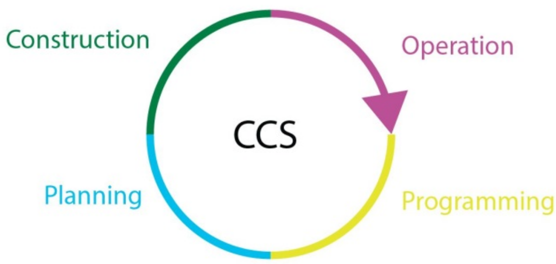


Fig.: 29 Diagram showcasing the intended universal use of the Danish Classification system CCS in all building related phases (image Maja Skovgaard)

The investigation for this deliverable identified the group of building owners as the stakeholder with the most vested interests to establish **BIM as a lifecycle model** (Fig.: 29). The contractual relations that are set up between the stakeholders point at building owners, as the group that finally gathers most of the models produced in the process. These are already today collected for extraction of a diverse range of information for quality control and assessment (3.7.1), but as well for potential reuse in case of a new planning process in the same object or for the creation of data for Facility Management (3.6.3). Other stakeholders (3.4.1) report that Building owners, despite their obvious from a long-term use of data, still hesitate to pay for the creation of an as build dataset of 3D objects. One reason might be that today's economic limits overrule considerations related to the sustainability of data. Another reason might be the difference between the information density and content that is needed for an operational system as Facility Management and the **level of information** that is given within a fully detailed BIM model from the latest stage of building production. Considerations concerning a **data lifecycle** have to take into account that not all knowledge that is stored within a 3D model is polled similarly over time. And as a Facility Manager is only interested in certain information, other information from the original dataset will only be interesting at later times. for instance in case of a building upgrade.

[101] http://www.ifd-library.org

[102] http://cuneco.dk/nyhed/h%C3%B8ringsrapport-om-kodestruktur-cuneco-classification-system-ccs

[103] http://www.cobuilder.com/

The facility management tools that are under development today [104]are not incorporating the native 3D objects, but extract only information from them and are in the best case linking to the original files on a server (3.7.2). And even if a FM model would include a full 3D object, one can assume, that, based on the current stakeholder's realities, the economic realities won't allow the Facility management to update all levels of information within a 3D model all the time. A growing gap in accuracy between the partial operational and the original full model is inevitable.

The idea of a single BIM model that is persistent and updated over a long period of time does not seem to be realistic. Hence an understanding of a model lifecycle has to include alternating **periods of conservation and enrichment** where information heavy building models are informed by light but eventually more up to date facility management models or data from the build environment as through up to date 3D point cloud scans (Brandt, 2012) or other monitoring techniques (Hwang, 2010).

4.4. Verification and updates of models

Scans from physical reality can play an important part in the digital lifecycle as a mean to monitor changes over time and update existing models, but as well as a way to verify these, as for instance seen in the current practice of architectural research (3.5.2).

The verification of models becomes a need for the building profession as 3D object processing becomes core of its business. Where formerly models exposed a high level of abstraction and had a high inbuilt tolerance and were met by industrial and fabrication standards with inbuilt tolerances, we observe a factual and projected decrease of allowed tolerances. Here it is on the one side the inability of CAD systems to work with imprecisions, as the expectations of the stakeholders that the use digital technology comes with a gain in precision and efficiency. This lowers the threshold for numeric tolerances. The industry sees on the other side a further gain in efficiency when processes with low and zero tolerances can be established (Sheil, 2014). In consequence the stakeholders internal processes are seemingly based on external data. This raises the demands towards the level of quality of the input data. Stakeholders exhibit hence **little trust into 3D models** received from external partners (3.4.1) in terms of completeness and accuracy (Gu, 2013). And where stakeholders want to abandon current quality control mechanisms, which imply today often the remodelling of received data, new information based **quality control mechanisms for information models** have to be developed. Existing tools are checking incoming data for level of conformity to BIM standards[105]or extract statistical or other values, which are analysed (7.1) or fed into simulations (3.7.1). These control steps are usually taking place on the interfaces between building partners or at the end of a modelling process[106]. It can be expected that similar methods can be applied for control of internal quality or progress reports within one partner. Tools like Solibri Model checker[107] are offering first steps of rule based checks of for i.e. barrier free access of buildings. The base of all these tools is however the growing understanding of stakeholders of **3D objects as resource of information that can be modelled and queried.**

4.5. Interdependent real-time information models

The current BIM modelling paradigm reach their limits the moment the flow of information is changing from being based on the query of static models to the query of dynamic models (Succar, 2013). These dynamic models are fed by realtime data and lead to the next logical step of development, which Succar calls **interdependent real-time information models** (Succar, 2013). Research into this investigates the link of

[104] http://dalux.dk/flx/dk/produkter/daluxfm/

[105] http://www.dalux.dk/flx/dk/produkter/dalux_bim_checker_kvalitetssikring_af_bim_og_IFC/bim_og_IFC/

[106] http://www.vicosoftware.com/bim-model-quality-assessment/tabid/293414/Default.aspx

[107] http://www.solibri.com/solibri-model-checker.html

BIM models to external real-time data input, as from sensor networks (Attar, 2010) or simulation tools as Autodesk Vasari[108]. This and similar tools can analyse the current performance of a model. They become as well the driver for an optimisation process of the model. Here simulation becomes an integrated part of the design process and triggers the generation or change of existing geometry or properties within the BIM Model. The setup of such automated feedback loops requires **generative abilities within BIM platforms** and hence the ability of users to code directly within the BIM platforms. And although big software companies made according claims already in 2004, i.e. the Global Marketing Director Huw W. Roberts 2004[109] of Bentley System, it took until today to introduce a usable scripting or parametric layer [110] in BIM platforms as Dynamo[111] for Autodesk Revit and several other projects exist that show the coupling of **BIM models with external generative models**. This is seen in research based software projects, as Chameleon[112], Geometry Gym[113], but as well in professional practice, where it is already used in major building projects[114]. The motivation of these links is however partially to overcome the **limited 3D modelling capabilities of existing BIM tools**, for instance of freeform shapes.

The ability to link Building model to other data sources and models allows the building profession to cross the border of its discipline and link to dynamic sources from the web or models of even larger scale, as location based models from Geographical Information Systems (GIS). Methods to integrate the two domains of BIM and GIS are under discussion (Zlatanova, 2013). The access of BIM information through mobile devices is here expected to push BIM even further into being an Information modelling system. Location based mobile applications will for instance allow building owners (3.7.2) to access 3D objects from their Facility Management[115] in order to execute the yearly building checks or repairs (Graf, 2011).

4.6. BIM models as an information resource

The trend shift focus of BIM on 3D modelling and communication within a building project towards the delivery of information implies that Building Information Modelling has to overcome its current limits. The interviewed stakeholders experience here problems in **data query and filtering of information**. The reduction and abstraction of information is of high importance in order to guarantee an efficient process for all stakeholders that are working with BIM models.

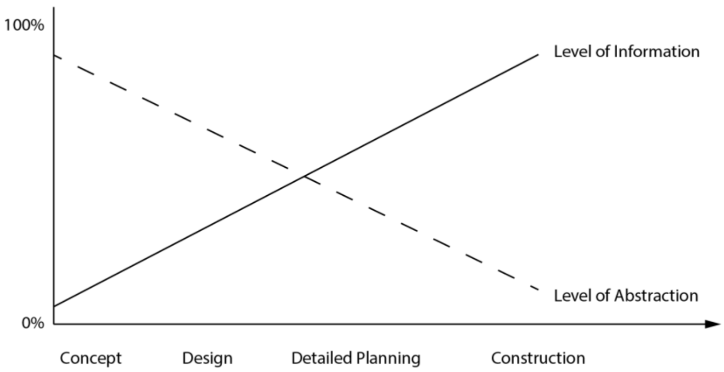


Fig.: 30 Planning Process: Principal relation of level of abstraction and information

Related processes are generally based on models that display different levels of abstraction throughout the process (Fig.: 30). The level of abstraction is traditionally high in the beginning of a process, while the model has a low level of information. All existing information about site, program and other factors are equally abstracted and sorted into a conceptual framework that provides the base of all further planning efforts. The further process is than characterized by a

[109] http://aecbytes.com/viewpoint/2004/issue_5.html

[110] http://www.consortech.com/bim2/documents/bim_parametric_building_modeling_EN.pdf

[111] http://autodeskvasari.com/dynamo

[112] http://rethinkingbim.wordpress.com/2012/11/25/2507/

[113] http://geometrygym.blogspot.dk/

[114] https://www.youtube.com/user/nmillerarch?feature=watch

[115] http://dalux.dk/flx/dk/produkter/daluxfm/fordele/

decrease in abstraction and an increase in level of information in the 3D objects, while they are confronted and adapted to the realities. This process takes usually place in several iterations that have the sole purpose to gain a holistic level of knowledge, which informs finally the building activities. The act of gaining the necessary level and oversight in design to take decisions is hence indispensable connected to the act of abstracting information (Allen, 1984) – however to the right level.

Current BIM models are based on the modelling paradigms of the CAD area. The link to rich information from the web or point clouds questions these paradigms as it exposes the stakeholders to an abundance of information. The interviewed stakeholders are missing tools that allow them to increase and decrease the level of information to the specific needs of their process, which are specific to every project and are not necessarily bound to a geometrical level.

4.7. BIM is inept within the context of existing building mass

While it is succeeding in increasing efficiency in the planning of new buildings **BIM has deficits in supporting the planning within existing buildings**. All stakeholders involved in according planning activities see the potential of 3D object processing to increase efficiency through more rationalised planning processes. They observe however the **gap in precision** between the high abstraction that the current Building Information Modelling paradigm exposes and the need for more precise information. 3D point cloud scans could fill this gap the moment they fit better into the 3D modelling processes. Some stakeholders are challenging this and implement **hybrid models of polygon modelling and point clouds**, in which polygon based 3D objects are positioned, as in the case of the automotive company Volvo (Lindskog, 2012). This can be an appropriate approach for planning processes where the existing architecture does not change too much, as within the design of production lines in 3D scanned buildings. However planning processes which focus on existing building need to transform and add the existing geometry. Appropriate modelling tools to execute these processes on 3D point clouds are not in sight.

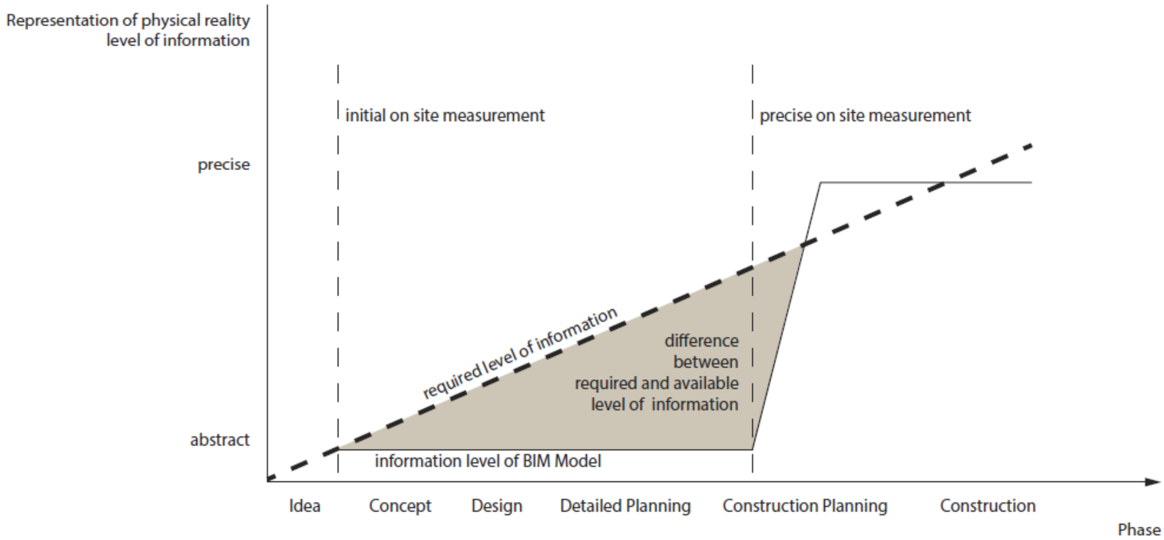


Fig.: 31 Planning Process: Required Level of Information The gap between the models initial level of abstraction and the reality

Building scans might however help to close the gap that emerges between the level of precision in a BIM model and the actually needed level at different points of the planning process (Fig.: 31). The design process is today based on an initial and often imprecise documentation of the site, which is only updated when the detailed construction planning commences (3.4.1). Hence means to gradually increase the level of precision of the underlying data during the planning process could help to **unleash the precision of BIM for retrofitting.**

This could finally help to increase the efficiency on the building site of renovation projects. This is today characterised by ad hoc decisions and imprecisions due to deviation of the database of the planning from physical reality. The integration of the precision of 3D scanning in the further planning processes enables completely new processes, as the merge of high precision input from 3D scans with high precision digital fabrication. Related processes are under development on the building (Brand, 2012) as well as object scale. These developments are partially driven by the stakeholders themselves, as the Danish Land surveyors Lanmålergården, who developed the L3D system[116]. A lifecycle of 3D objects emerges. These contain rich information about themselves as their environment.

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6. Appendix: List of collected datasets from Stakeholders

6.2 3d scan projects form stakeholders - E57 format

DURAARK
DURABLE
ARCHITECTURAL
KNOWLEDGE

Naming convention:
<author>_<project name>_<domain>_<conf/non-conf>_<supplemental information>**.e57**

#	*Project name (for reference only)*	*DuraArk file name (in accordance with file naming convention)*	*Author (full name)*		*Confidentiality status*	*Building type*	*File size (mb)*	*E57 Analysis Status*	*Number of Scans*	*Number of Points*	*Notes*
1	Acadia	Acadia_Acadia_Office_CONF.e57	Acadia	Acadia	confidential	office	500	OK	5	26583109	
2	Restaurant	ATS_Restaurant_Restaurant_CONF.e57	ATS	ATS	confidential	restaurant	7.500	OK	13	352790367	
3	210 King	Autodesk-Research_210-King_Offoce_CONF.e57	Autodesk Research	Autodesk Research	confidential	office					Convert failed
4	Descartes_Workshop	Bentley_DescartesWorkshop_academic_Conf.e57	Bentley	Bentley	confidential	academic					Not Uploaded
5	Pointools Workshop	Bentley_PointoolsWorkshop_academic_Conf.e57	Bentley	Bentley	confidential	academic					Not Uploaded
6	DTU_127	CITA_20130830-DTU127_clean_CONF.e57	CCO - CITA	CITA	confidential	school	20.000	OK	27	829565377	
7	DTU_127	CITA_20130910-DTU127_UnClean_CONF.e57	CCO - CITA	CITA	confidential	school	19.000	OK	27	895615628	
8	DTU_127	CITA_DTU127-Sub5x5.e57	CCO - CITA	CITA	confidential	school	760	OK	27	35840373	
9	DermoidI	CITA_DermoidI_Installation_NON-CONF.e57	CITA	CITA	non-confidential	installation	1.300	OK	6	63506302	
10	DermoidIII	CITA_DermoidIII_NON-CONF.e57	CITA	CITA	non-confidential	installation	11.900	OK	12	496276799	
11	DesignHub	CITA_DesignHub_NON-CONF.e57	CITA	CITA	non-confidential	exhibition space	24.700	OK	31	1021953223	
12	Foundation_EDF_Paris	CITA_Foundation-EDF-01_NON-CONF.e57	CITA	CITA	non-confidential	exhibition space	2.100	OK	9	90107612	
13	Foundation_EDF_Paris	CITA_Foundation-EDF-03_NON-CONF.e57	CITA	CITA	non-confidential	exhibition space	7.000				Analysis not working
14	IAAC	CITA_IAAC_NON-CONF.e57	CITA	CITA	non-confidential	school					Not Uploaded
15	IAAC_Menes	CITA_IAAC-Menes_NON-CONF.e57	CITA	CITA	non-confidential	court yard					Not Uploaded
16	Kronborg	CITA_Kronborg-CleanUp_NON-CONF.e57	CITA	CITA	non-confidential	castle	16.800	OK	19	696880375	
17	PersistentModelling#02	CITA_PersistentModelling02_NON-CONF.e57	CITA	CITA	non-confidential	installation	1.000	OK	4	42681419	
18	ReferenceScans	CITA_ReferenceScans_QualityOfPlanning_Better_NON-CONF.e57	CITA	CITA	non-confidential	room	2.500	OK	3	128109120	
19	ReferenceScans	CITA_ReferenceScans_QualityOfPlanning_Poor_NON-CONF.e57	CITA	CITA	non-confidential	room	2.500	OK	3	128482020	
20	ReferenceScans	CITA_ReferenceScans_QualityOfScan_Cleanness_DarkPoints300_NON-CONF.e57	CITA	CITA	non-confidential	room	900	OK	1	42781414	
21	ReferenceScans	CITA_ReferenceScans_QualityOfScan_Cleanness_StandardFilters_NON-CONF.e57	CITA	CITA	non-confidential	room	900	OK	1	41988962	
22	ReferenceScans	CITA_ReferenceScans_QualityOfScan_Cleanness_StandardFilters_DistanceBased_NON-CONF.e57	CITA	CITA	non-confidential	room	900	OK	1	41442543	
23	ReferenceScans	CITA_ReferenceScans_QualityOfScan_Cleanness_StrayPoints3_0-002_50_NON-CONF.e57	CITA	CITA	non-confidential	room	900	OK	1	42289293	
24	ReferenceScans	CITA_ReferenceScans_QualityOfScan_Cleanness_Unclean_NON-CONF.e57	CITA	CITA	non-confidential	room	900	OK	1	43523989	
25	ReferenceScans	CITA_QualityOfScan_ScannerSettings_005_Res1-5_Q2x_NON-CONF.e57	CITA	CITA	non-confidential	room	600	OK	1	26769847	
26	ReferenceScans	CITA_QualityOfScan_ScannerSettings_006_Res1-5_Q3x_NON-CONF.e57	CITA	CITA	non-confidential	room	600	OK	1	26999699	
27	ReferenceScans	CITA_QualityOfScan_ScannerSettings_007_Res1-5_Q4x_NON-CONF.e57	CITA	CITA	non-confidential	room	600	OK	1	27087959	
28	ReferenceScans	CITA_QualityOfScan_ScannerSettings_008_Res1-5_Q6x_NON-CONF.e57	CITA	CITA	non-confidential	room	600	OK	1	27023026	
29	ReferenceScans	CITA_QualityOfScan_ScannerSettings_009_Res1-20_Q4x_NON-CONF.e57	CITA	CITA	non-confidential	room	30	OK	1	1561785	
30	ReferenceScans	CITA_QualityOfScan_ScannerSettings_010_Res1-20_Q6x_NON-CONF.e57	CITA	CITA	non-confidential	room	30	OK	1	1543788	
31	ReferenceScans	CITA_QualityOfScan_ScannerSettings_011_Res1-20_Q8x_NON-CONF.e57	CITA	CITA	non-confidential	room	30	OK	1	1534793	
32	ReferenceScans	CITA_QualityOfScan_ScannerSettings_012_Res1-16_Q3x_NON-CONF.e57	CITA	CITA	non-confidential	room	50	OK	1	2488893	
33	ReferenceScans	CITA_QualityOfScan_ScannerSettings_013_Res1-10_Q3x_NON-CONF.e57	CITA	CITA	non-confidential	room	140	OK	1	26771673	
34	ReferenceScans	CITA_QualityOfScan_ScannerSettings_014_Res1-8_Q2x_NON-CONF.e57	CITA	CITA	non-confidential	room	220	OK	1	10312165	
35	ReferenceScans	CITA_QualityOfScan_ScannerSettings_015_Res1-5_Q2x_NON-CONF.e57	CITA	CITA	non-confidential	room	670	OK	1	26771673	
36	ReferenceScans	CITA_QualityOfScan_ScannerSettings_016_Res1-4_Q1x_NON-CONF.e57	CITA	CITA	non-confidential	room	370	OK	1	17209927	
37	ReferenceScans	CITA_QualityOfScan_ScannerSettings_017_Res1-2_Q1x_NON-CONF.e57	CITA	CITA	non-confidential	room	1.500	OK	1	70257314	
38	ReferenceScans	CITA_QualityOfScan_ScannerSettings_018_Res1-1_Q1_NON-CONF.e57	CITA	CITA	non-confidential	room	3.400	OK	1	158842317	
39	Room_24_7_Workshop	CITA_20131108-Room-24-7_NON-CONF.e57	CITA	CITA	non-confidential	room	1.000	OK	1	41781164	
40	ScanPrecisionTest	CITA_ScanPrecision_000_Res1_5-Qua3x_NON-CONF.e57	CITA	CITA	non-confidential	room	640	OK	1	26417420	
41	ScanPrecisionTest	CITA_ScanPrecision_001_Res1_4-Qua3x_NON-CONF.e57	CITA	CITA	non-confidential	room	1.000	OK	1	41525933	
42	ScanPrecisionTest	CITA_ScanPrecision_002_Res1_2-Qua3x_NON-CONF.e57	CITA	CITA	non-confidential	room	4.000	OK	1	168209593	
43	ScanPrecisionTest	CITA_ScanPrecision_003_Res1_4-Qua4x_NON-CONF.e57	CITA	CITA	non-confidential	room	1.000	OK	1	41737201	
44	ScanPrecisionTest	CITA_ScanPrecision_004_Res1_4-Qua6x_NON-CONF.e57	CITA	CITA	non-confidential	room	1.000	OK	1	41643641	
45	Building_1	LandGaard_Building-1_CONF.e57	LandmaalerGaarden	LandGaard	confidential	residential					Not Uploaded
46	Building_2	LandGaard_Building-2_CONF.e57	LandmaalerGaarden	LandGaard	confidential	residential					Not Uploaded
47	Building_3	LandGaard_Building-3_CONF.e57	LandmaalerGaarden	LandGaard	confidential	residential					Not Uploaded
48	Exterior	LandGaard_Exterior_CONF.e57	LandmaalerGaarden	LandGaard	confidential	residential					Not Uploaded
49	Roof	LandGaard_Roof_CONF.e57	LandmaalerGaarden	LandGaard	confidential	residential					Not Uploaded
50	Tower	LandGaard_Tower_CONF.e57	LandmaalerGaarden	LandGaard	confidential	residential					Not Uploaded
51	132538_Norsgade	LE34_132538-Norsgade-Gade_CONF.e57	LE34	LE34	confidential	residential	3.000	OK	5	142863736	
52	132538_Norsgade	LE34_132538-Norsgade-Norsgade_CONF.e57	LE34	LE34	confidential	residential	37.000	OK	62	1526304189	
53	132671_Vestergade72	LE34_Vestergade72-afleveret-1sal1_CONF.e57	LE34	LE34	confidential	residential	30.000	OK	52	1437739945	
54	132671_Vestergade73	LE34_Vestergade72-afleveret-2sal_bagtrappe1_CONF.e57	LE34	LE34	confidential	residential	2.000	OK	4	110243254	
55	132671_Vestergade74	LE34_Vestergade72-afleveret-2sal1_CONF.e57	LE34	LE34	confidential	residential	30.000	OK	51	1409515884	
56	132671_Vestergade75	LE34_Vestergade72-afleveret-3sal2_CONF.e57	LE34	LE34	confidential	residential	29.000	OK	50	1382980430	
57	132671_Vestergade76	LE34_Vestergade72-afleveret-4sal2_CONF.e57	LE34	LE34	confidential	residential	22.000	OK	40	1031849001	
58	132671_Vestergade77	LE34_Vestergade72-afleveret-5sal2_CONF.e57	LE34	LE34	confidential	residential	20.000	OK	34	945276542	
59	132671_Vestergade78	LE34_Vestergade72-afleveret-6sal2_CONF.e57	LE34	LE34	confidential	residential	11.000	OK	18	497004804	
60	132671_Vestergade79	LE34_Vestergade72-afleveret-kaelder1_CONF.e57	LE34	LE34	confidential	residential	17.000	OK	29	797316565	
61	132671_Vestergade80	LE34_Vestergade72-afleveret-stue1_CONF.e57	LE34	LE34	confidential	residential	21.000	OK	36	998154403	
62	Gormsgade	LE34_Gormsgade1_CONF.e57	LE34	LE34	confidential	office	7.000				
63	Gormsgade	LE34_Gormsgade3-1sal_CONF.e57	LE34	LE34	confidential	office	3.000				
64	Gormsgade	LE34_Gormsgade3-2sal_CONF.e57	LE34	LE34	confidential	office	1.500				

6.2 3d scan projects form stakeholders - E57 format

DURAARK
DURABLE
ARCHITECTURAL
KNOWLEDGE

Naming convention:
<author>_<project name>_<domain>_<conf/non-conf>_<supplemental information>**.e57**

#	*Project name (for reference only)*	*DuraArk file name (in accordance with file naming convention)*	*Author (full name)*		*Confidentiality status*	*Building type*	*File size (mb)*	*E57 Analysis Status*	*Number of Scans*	*Number of Points*	*Notes*
65	Gormsgade	LE34_Gormsgade3-stue_CONF.e57	LE34	LE34	confidential	office	4.500				
66	Gormsgade	LE34_Gormsgade3-ude_CONF.e57	LE34	LE34	confidential	office	2.000				
67	Kloak	LE34_Kloak_CONF.e57	LE34	LE34	confidential	sewer	700				
68	Haus_30	Plan3D_Haus30_Scene_Haus_130_v2_CITAExport_Cluster-Aussen_CONF.e57	PLAN3D	PLAN3D	confidential	residential	28.000	OK	49	1332364973	
69	Haus_30	Plan3D_Haus30_Scene_Haus_130_v2_CITAExport_Cluster-DG_CONF.e57	PLAN3D	PLAN3D	confidential	residential	10.500	OK	18	496977565	
70	Haus_30	Plan3D_Haus30_Scene_Haus_130_v2_CITAExport_Cluster-Keller_CONF.e57	PLAN3D	PLAN3D	confidential	residential					Convert failed
71	Haus_30	Plan3D_Haus30_Scene_Haus_130_v2_CITAExport_Cluster-OG_CONF.e57	PLAN3D	PLAN3D	confidential	residential	23.000	OK	40	1089075404	
72	Haus_34	Plan3D_Haus_34_Aussen_CONF.e57	PLAN3D	PLAN3D	confidential	residential					Not Uploaded
73	Haus_34	Plan3D_Haus_34_DG_CONF.e57	PLAN3D	PLAN3D	confidential	residential					Not Uploaded
74	Haus_34	Plan3D_Haus_34_EG1_CONF.e58	PLAN3D	PLAN3D	confidential	residential					Not Uploaded
75	Haus_34	Plan3D_Haus_34_EG2_CONF.e59	PLAN3D	PLAN3D	confidential	residential					Not Uploaded
76	Haus_34	Plan3D_Haus_34_EG3_CONF.e60	PLAN3D	PLAN3D	confidential	residential					Not Uploaded
77	Haus_34	Plan3D_Haus_34_GrosserHof1_CONF.e61	PLAN3D	PLAN3D	confidential	residential					Not Uploaded
78	Haus_34	Plan3D_Haus_34_GrosserHof2_CONF.e62	PLAN3D	PLAN3D	confidential	residential					Not Uploaded
79	Haus_34	Plan3D_Haus_34_GrosserHof3_CONF.e63	PLAN3D	PLAN3D	confidential	residential					Not Uploaded
80	Haus_34	Plan3D_Haus_34_KG1_CONF.e64	PLAN3D	PLAN3D	confidential	residential					Not Uploaded
81	Haus_34	Plan3D_Haus_34_KG2_CONF.e65	PLAN3D	PLAN3D	confidential	residential					Not Uploaded
82	Haus_34	Plan3D_Haus_34_KG3_CONF.e66	PLAN3D	PLAN3D	confidential	residential					Not Uploaded
83	Risløkka_Traffikstasjon	Statsbygg_Risløkka-Trafikkstasjon_CONF.e57	Statsbygg	Statsbygg	confidential	infrastructure	21.300				
							463040				

6.1 Building Information Models from stakeholders - IFC format

DURAARK
DURABLE
ARCHITECTURAL
KNOWLEDGE

Naming convention:
<author>_<project name>_<domain>_<conf/non-conf>_<supplemental information>**.ifc**

www.bimsync.com
login: **mm@kadk.dk**
password: **abc123**

#	Project name (for reference only)	Original file name	DuraArk file name (in accordance with file naming convention)	Author (full name)	Author (abb.)	Confidentiality status	IFC version	Original format	Building type	File size (mb)	Size (sqm)	kB/sqm	BimSync upload status	BimSync note [Chrome v. 31.0.1650.57]	BimSync image (thumb)	BimSync project name (+link)	BimSync project name - AUTOFILL	BimSync file name - AUTOFILL
1	Autodesk_Advanced-sample-project	Autodesk_rac_advanced_sample_project.ifc	Autodesk_Advanced-sample-project_Arch_Non-conf.ifc	Autodesk Training	Autodesk Training	non-confidential	IFC2x3	Revit	Educational	37,2	5000	7,4	Uploaded	Works.	Yes	Autodesk Advanced-sample-project	Autodesk_Advanced-sample-project	Autodesk_Advanced-sample-project_Arch_Non-conf
2	Autodesk_Basic-sample-project	rac_basic_sample_project.ifc	Autodesk_Basic-sample-project_Arch_Non-conf.ifc	Autodesk Training	Autodesk Training	non-confidential	IFC2x3	Revit	Single fam house	5,3	113	46,9	Uploaded	Works.	Yes	Autodesk Basic-sample-project	Autodesk_Basic-sample-project	Autodesk_Basic-sample-project_Arch_Non-conf
3	Academic_Barcelona-Pavillon	Barcelona_Pavillon.ifc	Academic_Barcelona-Pavillon_Arch_Non-conf.ifc	Academic Training	Academic Training	non-confidential	IFC2x3	Revit	Pavillion	0,2	800	0,3	Uploaded	Works.	Yes	Academic Barcelona-Pavillon	Academic_Barcelona-Pavillon	Academic_Barcelona-Pavillon_Arch_Non-conf
4	Academic_DDB-massing	DDB_case_Holmen_context_massing_model.ifc	Academic_DDB-massing_Arch_Non-conf.ifc	Academic Training	Academic Training	non-confidential	IFC2x3	Revit	Context volumes	0,02	300000	0,0	Uploaded	Works.	Yes	Academic DDB-massing	Academic_DDB-massing	Academic_DDB-massing_Arch_Non-conf
5	Academic_DDB-Kingo	DDB_case_Kingo_House.ifc	Academic_DDB-Kingo_Arch_Non-conf.ifc	Academic Training	Academic Training	non-confidential	IFC2x3	Revit	Single fam house	0,4	200	2,0	Uploaded	Works.	Yes	Academic DDB-Kingo	Academic_DDB-Kingo	Academic_DDB-Kingo_Arch_Non-conf
6	Academic_DDB-KUA-context-massing	DDB_case_KUA_context_massing_model.ifc	Academic_DDB-KUA-context-massing_Arch_Non-conf.ifc	Academic Training	Academic Training	non-confidential	IFC2x3	Revit	Context volumes	0,4	540000	0,0	Uploaded	Works.	Yes	Academic DDB-KUA-context-massing	Academic_DDB-KUA-context-massing	Academic_DDB-KUA-context-massing_Arch_Non-conf
7	Academic_DDB-Soeholm	DDB_case_Soeholm_w_details.ifc	Academic_DDB-Soeholm_Arch_Non-conf.ifc	Academic Training	Academic Training	non-confidential	IFC2x3	Revit	Single fam house	3,2	215	14,9	Uploaded	Works.	Yes	Academic DDB-Soeholm	Academic_DDB-Soeholm	Academic_DDB-Soeholm_Arch_Non-conf
8	Academic_DDB-Uhrskov	DDB_case_Villa_Uhrskov_w_details.ifc	Academic_DDB-Uhrskov_Arch_Non-conf.ifc	Academic Training	Academic Training	non-confidential	IFC2x3	Revit	Single fam house	1,2	92	13,0	Uploaded	Works.	Yes	Academic DDB-Uhrskov	Academic_DDB-Uhrskov	Academic_DDB-Uhrskov_Arch_Non-conf
9	Academic_CITA-Paris-exhibition	ExhibitRoom.ifc	Academic_CITA-Paris-exhibitopm_Arch_Non-conf.ifc	Academic Training	Academic Training	non-confidential	IFC2x3	Revit	Exhibit room	0,04	60	0,7	Uploaded	Works.	Yes	Academic CITA-Paris-exhibition	Academic_CITA-Paris-exhibition	Academic_CITA-Paris-exhibitopm_Arch_Non-conf
10	CCO_DTU-Building127	CCO_DTU_Building127_Arch.ifc	CCO_DTU-Building127_Arch_Conf.ifc	Studio Christensen & Co Architects	Studio CCO	confidential	IFC2x3	Revit	Educational	11	2000	5,5	Uploaded	Works.	Yes	CCO DTU-Building127	CCO_DTU-Building127	CCO_DTU-Building127_Arch_Conf
11	CCO_DTU-Building127	CCO_DTU_Building127_Eng_CON.ifc	CCO_DTU-Building127_Eng-CON_Conf.ifc	Studio Christensen & Co Architects	Studio CCO	confidential	IFC2x3	Revit	Educational	27	2000	13,5	Uploaded	Works.	Yes	CCO DTU-Building127	CCO_DTU-Building127	CCO_DTU-Building127_Eng-CON_Conf
12	CCO_DTU-Building127	CCO_DTU_Building127_Eng_HVAC.ifc	CCO_DTU-Building127_Eng-HVAC_Conf.ifc	Studio Christensen & Co Architects	Studio CCO	confidential	IFC2x3	Revit	Educational	34	2000	17,0	Uploaded	Works.	Yes	CCO DTU-Building127	CCO_DTU-Building127	CCO_DTU-Building127_Eng-HVAC_Conf
13	CCO_Lund-Kristallen	078 Lund Kristallen F_A_BUILD.ifc	CCO_Lund-Kristallen_Arch_Conf.ifc	Studio Christensen & Co Architects	Studio CCO	confidential	IFC2x3	Revit	Office	206	25000	8,2	Uploaded	Works.	Yes	CCO Lund-Kristallen	CCO_Lund-Kristallen	CCO_Lund-Kristallen_Arch_Conf
14	Statsbygg_Risløkka	MEP_Risløkka.ifc	Statsbygg_Risløkka_MEP_Conf.ifc	Statsbygg	Statsbygg	confidential	IFC2x3	Revit	Office and tech. Garage	54	-	-	Uploaded	Works.	Yes	Statsbygg Risløkka	Statsbygg_Risløkka	Statsbygg_Risløkka_MEP_Conf
15	Statsbygg_Risløkka	A_Risløkka_M.ifc	Statsbygg_Risløkka-M_Arch_Conf.ifc	Statsbygg	Statsbygg	confidential	IFC2x3	Revit	Office and tech. Garage	5	-	-	Uploaded	Works.	Yes	Statsbygg Risløkka	Statsbygg_Risløkka	Statsbygg_Risløkka-M_Arch_Conf
16	Statsbygg_Risløkka	A_Risløkka_B1.ifc	Statsbygg_Risløkka-B1_Arch_Conf.ifc	Statsbygg	Statsbygg	confidential	IFC2x3	Revit	Office and tech. Garage	22	-	-	Uploaded	Works.	Yes	Statsbygg Risløkka	Statsbygg_Risløkka	Statsbygg_Risløkka-B1_Arch_Conf
17	Statsbygg_Risløkka	A_Risløkka_B2.ifc	Statsbygg_Risløkka-B2_Arch_Conf.ifc	Statsbygg	Statsbygg	confidential	IFC2x3	Revit	Office and tech. Garage	6	-	-	Uploaded	Works.	Yes	Statsbygg Risløkka	Statsbygg_Risløkka	Statsbygg_Risløkka-B2_Arch_Conf
18	Statsbygg_Risløkka	A_Risløkka_Terreng.ifc	Statsbygg_Risløkka-terrain_Land_Conf.ifc	Statsbygg	Statsbygg	confidential	IFC2x3	Revit	Office and tech. Garage	11	-	-	Uploaded	Works.	Yes	Statsbygg Risløkka	Statsbygg_Risløkka	Statsbygg_Risløkka-terrain_Land_Conf
19	KIT_FJK	Karlsruhe_FJK.ifc	KIT_FJK_Arch_Non-conf.ifc	Karlsruhe Institute of Technology	KIT	non-confidential	IFC2x2	ADT	Single fam house	14	-	-	Uploaded	Works.	Yes	KIT FJK	KIT_FJK	KIT_FJK_Arch_Non-conf
20	KIT_Smiley-West	Karlsruhe_Smiley-West.ifc	KIT_Smiley-West_Arch_Non-conf.ifc	Karlsruhe Institute of Technology	KIT	non-confidential	IFC2x2	ArchiCad 11	Housing complex	3	-	-	Uploaded	Works.	Yes	KIT Smiley-West	KIT_Smiley-West	KIT_Smiley-West_Arch_Non-conf
21	KIT_Institute	Karlsruhe_Institute.ifc	KIT_Institute_Arch_Non-conf.ifc	Karlsruhe Institute of Technology	KIT	non-confidential	IFC2x3	ArchiCad 11	Office	3	-	-	Uploaded	Works.	Yes	KIT Institute	KIT_Institute	KIT_Institute_Arch_Non-conf
22	Autodesk-Research_201-King	210_King_Merged.ifc	Autodesk-Research_210-King_Merged_Conf.ifc	Autodesk Research	Autodesk Research	confidential	IFC2x3	Revit	Office	151	-	-	Uploaded	Problems uploading ("import failed").	No	Autodesk-Research 210-King	Autodesk-Research_201-King	Autodesk-Research_210-King_Merged_Conf
23	ATP_PR	ATPV1430_PRO_WOF.ifc	ATP_PR_Arch_Conf.ifc	Studio ATP	Studio ATP	confidential	IFC2x3	Revit	Factory	25	-	-	Uploaded	Problems uploading ("import failed").	No	ATP PR	ATP_PR	ATP_PR_Arch_Conf
24	NBS_LakesideAC01	NBSLakesideRestaurant_AC_01.ifc	NBS_LakesideAC01_Arch_Conf.ifc	UK National Building Specification	NBS	confidential	IFC2x3	ArchiCad	Restaurant	41	-	-	Uploaded	Works.	Yes	NBS LakesideAC01	NBS_LakesideAC01	NBS_LakesideAC01_Arch_Conf
25	NBS_LakesideAC10	NBSLakesideRestaurant_AC_10.ifc	NBS_LakesideAC10_Arch_Conf.ifc	UK National Building Specification	NBS	confidential	IFC2x3	ArchiCad	Restaurant	39	-	-	Uploaded	Problems uploading ("import failed").	No	NBS LakesideAC10	NBS_LakesideAC10	NBS_LakesideAC10_Arch_Conf
26	NBS_LakesideRVT01	NBSLakesideRestaurant_RVT_01.ifc	NBS_LakesideRVT01_Arch_Conf.ifc	UK National Building Specification	NBS	confidential	IFC2x3	Revit	Restaurant	37	-	-	Uploaded	Works.	Yes	NBS LakesideRVT01	NBS_LakesideRVT01	NBS_LakesideRVT01_Arch_Conf
27	NBS_LakesideRVT10	NBSLakesideRestaurant_AC_10.ifc	NBS_LakesideRVT10_Arch_Conf.ifc	UK National Building Specification	NBS	confidential	IFC2x3	Revit	Restaurant	37	-	-	Uploaded	Works.	Yes	NBS LakesideRVT10	NBS_LakesideRVT10	NBS_LakesideRVT10_Arch_Conf
28	NBS_LakesideVW00	NBSLakesideRestaurant_VW_00.ifc	NBS_LakesideVW00_Arch_Conf.ifc	UK National Building Specification	NBS	confidential	IFC2x3	VectorWorks	Restaurant	9	-	-	Uploaded	Works.	Yes	NBS LakesideVW00	NBS_LakesideVW00	NBS_LakesideVW00_Arch_Conf
29	PLH_DSV	F_A_DO_X_MAIN_01.ifc	PLH_DSV_Arch_Conf.ifc	Studio PLH Architects	PLH	confidential	IFC2x3	Microstation	Office	129	14200	-	Uploaded	Problems uploading ("import failed").	No	PLH DSV	PLH_DSV	PLH_DSV_Arch_Conf
30	NBU_Duplex-Apt-COBie	2012-03-23-Duplex-Programming.ifc	NBU_Duplex-Apt-COBie_Arch_Non-conf_Programming.ifc	National Institute of Building Sciences	NBU	non-confidential	IFC2x3	?	Residential	0,04	-	-	Uploaded	Problems uploading ("import failed").	No	NBU Duplex-Apt-COBie	NBU_Duplex-Apt-COBie	NBU_Duplex-Apt-COBie_Arch_Non-conf_Programming
31	NBU_Duplex-Apt-COBie	2012-03-23-Duplex-Design.ifc	NBU_Duplex-Apt-COBie_Arch_Non-conf_Design.ifc	National Institute of Building Sciences	NBU	non-confidential	IFC2x3	?	Residential	0,52	-	-	Uploaded	Problems uploading ("import failed").	No	NBU Duplex-Apt-COBie	NBU_Duplex-Apt-COBie	NBU_Duplex-Apt-COBie_Arch_Non-conf_Design
32	NBU_Duplex-Apt-COBie	2012-03-23-Duplex-ProductSelect.ifc	NBU_Duplex-Apt-COBie_Arch_Non-conf_ProductSelect.ifc	National Institute of Building Sciences	NBU	non-confidential	IFC2x3	?	Residential	0,54	-	-	Uploaded	Problems uploading ("import failed").	No	NBU Duplex-Apt-COBie	NBU_Duplex-Apt-COBie	NBU_Duplex-Apt-COBie_Arch_Non-conf_ProductSelect
33	NBU_Duplex-Apt-COBie	2012-03-23-Duplex-ProductInstall.ifc	NBU_Duplex-Apt-COBie_Arch_Non-conf_ProductInstall.ifc	National Institute of Building Sciences	NBU	non-confidential	IFC2x3	?	Residential	0,56	-	-	Uploaded	Problems uploading ("import failed").	No	NBU Duplex-Apt-COBie	NBU_Duplex-Apt-COBie	NBU_Duplex-Apt-COBie_Arch_Non-conf_ProductInstall
34	NBU_Duplex-Apt-COBie	2012-03-23-Duplex-Handover.ifc	NBU_Duplex-Apt-COBie_Arch_Non-conf_Handover.ifc	National Institute of Building Sciences	NBU	non-confidential	IFC2x3	?	Residential	0,55	-	-	Uploaded	Problems uploading ("import failed").	No	NBU Duplex-Apt-COBie	NBU_Duplex-Apt-COBie	NBU_Duplex-Apt-COBie_Arch_Non-conf_Handover
35	NBU_Duplex-Apt-Coordination	Duplex_A_20110907.ifc	NBU_Duplex-Apt-Coordination_Arch_Non-conf.ifc	National Institute of Building Sciences	NBU	non-confidential	IFC2x3	Revit	Residential	2,3	-	-	Uploaded	Works.	Yes	NBU Duplex-Apt-Coordination	NBU_Duplex-Apt-Coordination	NBU_Duplex-Apt-Coordination_Arch_Non-conf
36	NBU_Duplex-Apt-Coordination	Duplex_A_20110907_optimized.ifc	NBU_Duplex-Apt-Coordination_Arch_Non-conf_Optimized.ifc	National Institute of Building Sciences	NBU	non-confidential	IFC2x3	Revit	Residential	1,6	-	-	Uploaded	Problems uploading ("import failed").	Yes	NBU Duplex-Apt-Coordination	NBU_Duplex-Apt-Coordination	NBU_Duplex-Apt-Coordination_Arch_Non-conf_Optimized
37	NBU_Duplex-Apt-Coordination	Duplex_MEP_20110907.ifc	NBU_Duplex-Apt-Coordination_Eng-MEP_Non-conf.ifc	National Institute of Building Sciences	NBU	non-confidential	IFC2x3	Revit	Residential	17,7	-	-	Uploaded	Works.	Yes	NBU Duplex-Apt-Coordination	NBU_Duplex-Apt-Coordination	NBU_Duplex-Apt-Coordination_Eng-MEP_Non-conf
38	NBU_Duplex-Apt-Coordination	Duplex_MEP_20110907_optimized.ifc	NBU_Duplex-Apt-Coordination_Eng-MEP_Non-conf_Optimized.ifc	National Institute of Building Sciences	NBU	non-confidential	IFC2x3	Revit	Residential	10,8	-	-	Uploaded	Works.	Yes	NBU Duplex-Apt-Coordination	NBU_Duplex-Apt-Coordination	NBU_Duplex-Apt-Coordination_Eng-MEP_Non-conf_Optimized
39	NBU_Duplex-Apt-Sparkie	Duplex_Electrical_20121207.ifc	NBU_Duplex-Apt-Sparkie_Eng-MEP_Non-conf_1.ifc	National Institute of Building Sciences	NBU	non-confidential	IFC2x3	Revit	Residential	1,5	-	-	Uploaded	Works.	Yes	NBU Duplex-Apt-Sparkie	NBU_Duplex-Apt-Sparkie	NBU_Duplex-Apt-Sparkie_Eng-MEP_Non-conf_1
40	NBU_Duplex-Apt-Sparkie	Duplex_M_20111024_ROOMS_AND_SPACES.ifc	NBU_Duplex-Apt-Sparkie_Eng-MEP_Non-conf_2.ifc	National Institute of Building Sciences	NBU	non-confidential	IFC2x3	Revit	Residential	8,7	-	-	Uploaded	Works.	Yes	NBU Duplex-Apt-Sparkie	NBU_Duplex-Apt-Sparkie	NBU_Duplex-Apt-Sparkie_Eng-MEP_Non-conf_2
41	NBU_Duplex-Apt-WSie	Duplex_Plumbing_20121113.ifc	NBU_Duplex-Apt-WSie_Eng-HVAC_Non-conf.ifc	National Institute of Building Sciences	NBU	non-confidential	IFC2x3	Revit	Residential	31,3	-	-	Uploaded	Works.	Yes	NBU Duplex-Apt-Wsie	NBU_Duplex-Apt-WSie	NBU_Duplex-Apt-WSie_Eng-HVAC_Non-conf
42	NBU_MedicalClinic	Clinic_A_20110906.ifc	NBU_MedicalClinic_Arch_Non-conf.ifc	National Institute of Building Sciences	NBU	non-confidential	IFC2x3	Revit	Clinic	17,7	-	-	Uploaded	Works.	Yes	NBU MedicalClinic	NBU_MedicalClinic	NBU_MedicalClinic_Arch_Non-conf
43	NBU_MedicalClinic	Clinic_A_20110906_optimized.ifc	NBU_MedicalClinic_Arch_Non-conf_Optimized.ifc	National Institute of Building Sciences	NBU	non-confidential	IFC2x3	Revit	Clinic	12,9	-	-	Uploaded	Works.	Yes	NBU MedicalClinic	NBU_MedicalClinic	NBU_MedicalClinic_Arch_Non-conf_Optimized
44	NBU_MedicalClinic	Clinic_MEP_20110906.ifc	NBU_MedicalClinic_Eng-MEP_Non-conf.ifc	National Institute of Building Sciences	NBU	non-confidential	IFC2x3	Revit	Clinic	202,4	-	-	Uploaded	Crunching ….	Yes	NBU MedicalClinic	NBU_MedicalClinic	NBU_MedicalClinic_Eng-MEP_Non-conf
45	NBU_MedicalClinic	Clinic_MEP_20110906_optimized.ifc	NBU_MedicalClinic_Eng-MEP_Non-conf_Optimized.ifc	National Institute of Building Sciences	NBU	non-confidential	IFC2x3	Revit	Clinic	122,8	-	-	Uploaded	Crunching ….	Yes	NBU MedicalClinic	NBU_MedicalClinic	NBU_MedicalClinic_Eng-MEP_Non-conf_Optimized
46	NBU_MedicalClinic	Clinic_S_20110715.ifc	NBU_MedicalClinic_Eng-CON_Non-conf.ifc	National Institute of Building Sciences	NBU	non-confidential	IFC2x3	Revit	Clinic	18,9	-	-	Uploaded	Works.	Yes	NBU MedicalClinic	NBU_MedicalClinic	NBU_MedicalClinic_Eng-CON_Non-conf
47	NBU_MedicalClinic	Clinic_S_20110715_optimized.ifc	NBU_MedicalClinic_Eng-CON_Non-conf_Optimized.ifc	National Institute of Building Sciences	NBU	non-confidential	IFC2x3	Revit	Clinic	18,9	-	-	Uploaded	Works.	Yes	NBU MedicalClinic	NBU_MedicalClinic	NBU_MedicalClinic_Eng-CON_Non-conf_Optimized
48	NBU_MedicalClinic	Clinic_Electrical_20121207.ifc	NBU_MedicalClinic_Eng-ELE_Non-conf.ifc	National Institute of Building Sciences	NBU	non-confidential	IFC2x3	Revit	Clinic	11,7	-	-	Uploaded	Works.	Yes	NBU MedicalClinic	NBU_MedicalClinic	NBU_MedicalClinic_Eng-ELE_Non-conf
49	NBU_MedicalClinic	Clinic_M_20120330_RevitMEP2013_optimized.ifc	NBU_MedicalClinic_Eng-HVAC_Non-conf.ifc	National Institute of Building Sciences	NBU	non-confidential	IFC2x3	Revit	Clinic	26,7	-	-	Uploaded	Works.	Yes	NBU MedicalClinic	NBU_MedicalClinic	NBU_MedicalClinic_Eng-HVAC_Non-conf
50	NBU_OfficeBuilding	Office_A_20110811.ifc	NBU_OfficeBuilding_Arch_Non-conf_1.ifc	National Institute of Building Sciences	NBU	non-confidential	IFC2x3	Revit	Office building	4	-	-	Uploaded	Crunching ….	Yes	NBU OfficeBuilding	NBU_OfficeBuilding	NBU_OfficeBuilding_Arch_Non-conf_1
51	NBU_OfficeBuilding	Office_A_20110811_optimized.ifc	NBU_OfficeBuilding_Arch_Non-conf_Optimized.ifc	National Institute of Building Sciences	NBU	non-confidential	IFC2x3	Revit	Office building	4	-	-	Uploaded	Works.	Yes	NBU OfficeBuilding	NBU_OfficeBuilding	NBU_OfficeBuilding_Arch_Non-conf_Optimized
52	NBU_OfficeBuilding	Office_MEP_20110811.ifc	NBU_OfficeBuilding_Eng-HVAC_Non-conf.ifc	National Institute of Building Sciences	NBU	non-confidential	IFC2x3	Revit	Office building	64,3	-	-	Uploaded	Crunching ….	Yes	NBU OfficeBuilding	NBU_OfficeBuilding	NBU_OfficeBuilding_Eng-HVAC_Non-conf
53	NBU_OfficeBuilding	Office_MEP_20110811_optimized.ifc	NBU_OfficeBuilding_Eng-HVAC_Non-conf_Optimized.ifc	National Institute of Building Sciences	NBU	non-confidential	IFC2x3	Revit	Office building	40,9	-	-	Uploaded	Works.	Yes	NBU OfficeBuilding	NBU_OfficeBuilding	NBU_OfficeBuilding_Eng-HVAC_Non-conf_Optimized
54	NBU_OfficeBuilding	Office_S_20110811.ifc	NBU_OfficeBuilding_Eng-CON_Non-conf.ifc	National Institute of Building Sciences	NBU	non-confidential	IFC2x3	Revit	Office building	10,8	-	-	Uploaded	Works.	Yes	NBU OfficeBuilding	NBU_OfficeBuilding	NBU_OfficeBuilding_Eng-CON_Non-conf
55	NBU_OfficeBuilding	Office_S_20110811_optimized.ifc	NBU_OfficeBuilding_Eng-CON_Non-conf_Optimized.ifc	National Institute of Building Sciences	NBU	non-confidential	IFC2x3	Revit	Office building	10,8	-	-	Uploaded	Works.	Yes	NBU OfficeBuilding	NBU_OfficeBuilding	NBU_OfficeBuilding_Eng-CON_Non-conf_Optimized
56	NBU_OfficeBuilding	2012-03-23-Office-Arch.ifc	NBU_OfficeBuilding_Arch_Non-conf_2.ifc	National Institute of Building Sciences	NBU	non-confidential	IFC2x3	-	Office building	0,6	-	-	Uploaded	Works.	Yes	NBU OfficeBuilding	NBU_OfficeBuilding	NBU_OfficeBuilding_Arch_Non-conf_2
57	NBU_OfficeBuilding	2012-03-23-Office-MEP.ifc	NBU_OfficeBuilding_Eng-MEP_Non-conf.ifc	National Institute of Building Sciences	NBU	non-confidential	IFC2x3	-	Office building	4	-	-	Uploaded	Works.	Yes	NBU OfficeBuilding	NBU_OfficeBuilding	NBU_OfficeBuilding_Eng-MEP_Non-conf
58	NBU_OfficeBuilding	Office_Electrical_20121207.ifc	NBU_OfficeBuilding_Eng-ELE_Non-conf.ifc	National Institute of Building Sciences	NBU	non-confidential	IFC2x3	Revit	Office building	6,4	-	-	Uploaded	Problems uploading ("import failed").	Yes	NBU OfficeBuilding	NBU_OfficeBuilding	NBU_OfficeBuilding_Eng-ELE_Non-conf
59	NVW_DCR-LOD	DC_Riverside_Bldg-LOD_100.ifc	NVW_DCR-LOD100_Arch_Non-conf.ifc	Nemetschek VectorWorks	NVW	non-confidential	IFC2x3	VectorWorks	Office building	0,2	-	-	Uploaded	Problems uploading ("import failed").	Yes	NVW DCR-LOD	NVW_DCR-LOD	NVW_DCR-LOD100_Arch_Non-conf
60	NVW_DCR-LOD	DC_Riverside_Bldg-ARCH-LOD_200.ifc	NVW_DCR-LOD200_Arch_Non-conf.ifc	Nemetschek VectorWorks	NVW	non-confidential	IFC2x3	VectorWorks	Office building	24,7	-	-	Uploaded	Works.	Yes	NVW DCR-LOD	NVW_DCR-LOD	NVW_DCR-LOD200_Arch_Non-conf
61	NVW_DCR-LOD	DC_Riverside_Bldg-VWSTRUC-LOD_200.ifc	NVW_DCR-LOD200_Eng-CON_Non-conf_1.ifc	Nemetschek VectorWorks	NVW	non-confidential	IFC2x3	VectorWorks	Office building	1,4	-	-	Uploaded	Works.	Yes	NVW DCR-LOD	NVW_DCR-LOD	NVW_DCR-LOD200_Eng-CON_Non-conf_1
62	NVW_DCR-LOD	DC_Riverside_Bldg-HVAC_200.ifc	NVW_DCR-LOD200_Eng-HVAC_Non-conf.ifc	Nemetschek VectorWorks	NVW	non-confidential	IFC2x3	DDS-CAD	Office building	32,4	-	-	Uploaded	Works.	Yes	NVW DCR-LOD	NVW_DCR-LOD	NVW_DCR-LOD200_Eng-HVAC_Non-conf
63	NVW_DCR-LOD	DC_Riverside_Bldg-STRUC-LOD_200.ifc	NVW_DCR-LOD200_Eng-CON_Non-conf_2.ifc	Nemetschek VectorWorks	NVW	non-confidential	IFC2x3	Scia Engineer	Office building	9,1	-	-	Uploaded	Works.	Yes	NVW DCR-LOD	NVW_DCR-LOD	NVW_DCR-LOD200_Eng-CON_Non-conf_2
64	NVW_DCR-LOD	DC_Riverside_Bldg-LOD_300.ifc	NVW_DCR-LOD300_Arch_Non-conf.ifc	Nemetschek VectorWorks	NVW	non-confidential	IFC2x3	VectorWorks	Office building	281,3	-	-	Uploaded	Works.	Yes	NVW DCR-LOD	NVW_DCR-LOD	NVW_DCR-LOD300_Arch_Non-conf
65	NVW_DCR-LOD	DC_Riverside-LOD_300-HVAC.ifc	NVW_DCR-LOD300_Eng-HVAC_Non-conf.ifc	Nemetschek VectorWorks	NVW	non-confidential	IFC2x3	DDS-CAD	Office building	23,5	-	-	Uploaded	Works.	Yes	NVW DCR-LOD	NVW_DCR-LOD	NVW_DCR-LOD300_Eng-HVAC_Non-conf
66	NVW_DCR-LOD	DC_Riverside-STRUC-LOD_300.ifc	NVW_DCR-LOD300_Eng-CON_Non-conf.ifc	Nemetschek VectorWorks	NVW	non-confidential	IFC2x3	Scia Engineer	Office building	10,8	-	-	Uploaded	Works.	Yes	NVW DCR-LOD	NVW_DCR-LOD	NVW_DCR-LOD300_Eng-CON_Non-conf
67	SGD_BARD	Dds_BardNa.ifc	SGD_BARD_Merged_Non-conf.ifc	Selvaag Gruppen / DDS Data Design System	SGD	non-confidential	IFC2x3	DDS-CAD	-	42,7	-	-	Uploaded	Works.	Yes	SGD BARD	SGD_BARD	SGD_BARD_Merged_Non-conf
68	SGD_BARD	Riuska_kontorbygg.ifc	SGD_BARD_Arch_Non-conf.ifc	Selvaag Gruppen / DDS Data Design System	SGD	non-confidential	IFC2x2_FINAL	Rom/Plantegning	-	11,2	-	-	Uploaded	Works.	Yes	SGD BARD	SGD_BARD	SGD_BARD_Arch_Non-conf
69	SGD_Blueberry	VVS_med_gulvvarme.ifc	SGD_Blueberry_Eng-HVAC_Non-conf.ifc	Selvaag Gruppen / DDS Data Design System	SGD	non-confidential	IFC2x3	DDS-CAD Elektro	Single fam house	10,4	-	-	Uploaded	Works (Workspace freezes).	No	SGD Blueberry	SGD_Blueberry	SGD_Blueberry_Eng-HVAC_Non-conf
70	SGD_Blueberry	ARK_Plumbing.ifc	SGD_Blueberry_Merged_Non-conf_Plumbing1.ifc	Selvaag Gruppen / DDS Data Design System	SGD	non-confidential	IFC2x3	DDS-CAD Construction	Single fam house	11,3	-	-	Uploaded	Works (Workspace freezes).	No	SGD Blueberry	SGD_Blueberry	SGD_Blueberry_Merged_Non-conf_Plumbing1
71	SGD_Blueberry	ARK_Ventilation.ifc	SGD_Blueberry_Merged_Non-conf_Ventilation.ifc	Selvaag Gruppen / DDS Data Design System	SGD	non-confidential	IFC2x3	DDS-CAD Construction	Single fam house	8,9	-	-	Uploaded	Works (Workspace freezes).	No	SGD Blueberry	SGD_Blueberry	SGD_Blueberry_Merged_Non-conf_Ventilation
72	SGD_Blueberry	Blueberry081203_mm.ifc	SGD_Blueberry_Arch_Non-conf_1.ifc	Selvaag Gruppen / DDS Data Design System	SGD	non-confidential	IFC2x3	AutoCAD Architecture 2009	Single fam house	3,9	-	-	Uploaded	Works (Workspace freezes).	No	SGD Blueberry	SGD_Blueberry	SGD_Blueberry_Arch_Non-conf_1
73	SGD_Blueberry	Blueberry090812.ifc	SGD_Blueberry_Arch_Non-conf_2.ifc	Selvaag Gruppen / DDS Data Design System	SGD	non-confidential	IFC2x3	DDS-CAD Arkitekt	Single fam house	5,6	-	-	Uploaded	Works (Workspace freezes).	No	SGD Blueberry	SGD_Blueberry	SGD_Blueberry_Arch_Non-conf_2
74	SGD_Blueberry	BlueberryHill_DDS-CAD-Construction.ifc	SGD_Blueberry_Arch_Non-conf_3.ifc	Selvaag Gruppen / DDS Data Design System	SGD	non-confidential	IFC2x3	DDS-CAD Construction	Single fam house	7,8	-	-	Uploaded	Works (Workspace freezes).	No	SGD Blueberry	SGD_Blueberry	SGD_Blueberry_Arch_Non-conf_3
75	SGD_Blueberry	Plumbing.ifc	SGD_Blueberry_Eng-HVAC_Non-conf_Plumbing1.ifc	Selvaag Gruppen / DDS Data Design System	SGD	non-confidential	IFC2x3	DDS-CAD Elektro	Single fam house	11,3	-	-	Uploaded	Works (Workspace freezes).	No	SGD Blueberry	SGD_Blueberry	SGD_Blueberry_Eng-HVAC_Non-conf_Plumbing1
76	SGD_Blueberry	Ventilation.ifc	SGD_Blueberry_Eng-HVAC_Non-conf_Ventilation.ifc	Selvaag Gruppen / DDS Data Design System	SGD	non-confidential	IFC2x3	DDS-CAD Elektro	Single fam house	8,9	-	-	Uploaded	Works (Workspace freezes).	No	SGD Blueberry	SGD_Blueberry	SGD_Blueberry_Eng-HVAC_Non-conf_Ventilation
77	SGD_Blueberry	VVS.ifc	SGD_Blueberry_Eng-HVAC_Non-conf_Plumbing2.ifc	Selvaag Gruppen / DDS Data Design System	SGD	non-confidential	IFC2x3	DDS-CAD Elektro	Single fam house	4,8	-	-	Uploaded	Works (Workspace freezes).	No	SGD Blueberry	SGD_Blueberry	SGD_Blueberry_Eng-HVAC_Non-conf_Plumbing2
78	SGD_Blueberry	VVS+ARK.ifc	SGD_Blueberry_Merged_Non-conf_Plumbing2.ifc	Selvaag Gruppen / DDS Data Design System	SGD	non-confidential	IFC2x3	DDS-CAD Construction	Single fam house	12,8	-	-	Uploaded	Works (Workspace freezes).	No	SGD Blueberry	SGD_Blueberry	SGD_Blueberry_Merged_Non-conf_Plumbing2
79	SGD_CDB-2010	CDB_HVAC.ifczip	SGD_CDB-2010_Eng-HVAC_Non-conf.ifc	Selvaag Gruppen / DDS Data Design System	SGD	non-confidential	IFC2x3	DDS-CAD	-	2,9	-	-	Uploaded	Problems uploading ("import failed" - ifczip-file?).	No	SGD CDB-2010	SGD_CDB-2010	SGD_CDB-2010_Eng-HVAC_Non-conf
80	SGD_BODO	Bodo.ifc	SGD_BODO_Arch_Non-conf_1.ifc	Selvaag Gruppen / DDS Data Design System	SGD	non-confidential	IFC2x2_FINAL	ArchiCAD 7.0	College	23,3	-	-	Uploaded	Crunching ….	Yes	SGD BODO	SGD_BODO	SGD_BODO_Arch_Non-conf_1
81	SGD_BODO	HiB_DuctWork.ifc	SGD_BODO_Eng-HVAC_Non-conf_Ventilation.ifc	Selvaag Gruppen / DDS Data Design System	SGD	non-confidential	IFC2x2_FINAL	DuctWork 6.35	College	46,1	-	-	Uploaded	Works.	Yes	SGD BODO	SGD_BODO	SGD_BODO_Eng-HVAC_Non-conf_Ventilation
82	SGD_BODO	HiB_PipeWork.ifc	SGD_BODO_Eng-HVAC_Non-conf_Plumbing.ifc	Selvaag Gruppen / DDS Data Design System	SGD	non-confidential	IFC2x2_FINAL	PipeWork 6.35	College	71,1	-	-	Uploaded	Works.	Yes	SGD BODO	SGD_BODO	SGD_BODO_Eng-HVAC_Non-conf_Plumbing
83	SGD_BODO	Planer 4B Full.ifc	SGD_BODO_Arch_Non-conf_2.ifc	Selvaag Gruppen / DDS Data Design System	SGD	non-confidential	IFC2x2_FINAL	ArchiCAD 7.0	College	23,3	-	-	Uploaded	Works.	Yes	SGD BODO	SGD_BODO	SGD_BODO_Arch_Non-conf_2
84	SGD_BODO	SB-HIBO-ARK-20070830.ifc	SGD_BODO_Arch_Non-conf_3.ifc	Selvaag Gruppen / DDS Data Design System	SGD	non-confidential	IFC2x3	ArchiCAD 10.0	College	62,6	-	-	Uploaded	Works.	Yes	SGD BODO	SGD_BODO	SGD_BODO_Arch_Non-conf_3
85	SGD_DDS-CAD	DDS-CAD-Construction_SimpleWall.ifc	SGD_DDS-CAD_Eng-CON_Non-conf.ifc	Selvaag Gruppen / DDS Data Design System	SGD	non-confidential	IFC2x3	Hjelpeprogram	Wall(?)	0,2	-	-	Uploaded	Works.	No	SGD DDS-CAD	SGD_DDS-CAD	SGD_DDS-CAD_Eng-CON_Non-conf
86	SGD_Duplex	DDS-DuplexHouse_Sanitary_V1.0.ifc	SGD_Duplex_Eng-HVAC_Non-conf_Plumbing.ifc	Selvaag Gruppen / DDS Data Design System	SGD	non-confidential	IFC2x3	DDS-CAD	Residential	90,6	-	-	Uploaded	Crunching ….	No	SGD Duplex	SGD_Duplex	SGD_Duplex_Eng-HVAC_Non-conf_Plumbing
87	SGD_Duplex	DDS-DuplexHouse_Ventilation_V1.0.ifc	SGD_Duplex_Eng-HVAC_Non-conf_Ventilation.ifc	Selvaag Gruppen / DDS Data Design System	SGD	non-confidential	IFC2x3	DDS-CAD	Residential	3,2	-	-	Uploaded	Crunching ….	No	SGD Duplex	SGD_Duplex	SGD_Duplex_Eng-HVAC_Non-conf_Ventilation
88	SGD_HiTOS	2x3_HiTOS_EL_new.ifc	SGD_HiTOS_Eng-ELE_Non-conf.ifc	Selvaag Gruppen / DDS Data Design System	SGD	non-confidential	IFC2x3	DDS-CAD	-	7,3	-	-	Uploaded	Problems uploading ("import failed").	Yes	SGD HiTOS	SGD_HiTOS	SGD_HiTOS_Eng-ELE_Non-conf
89	SGD_HiTOS	2x3_HiTOS_HVAC_new.ifc	SGD_HiTOS_Eng-HVAC_Non-conf.ifc	Selvaag Gruppen / DDS Data Design System	SGD	non-confidential	IFC2x3	DDS-CAD	-	18	-	-	Uploaded	Works.	Yes	SGD HiTOS	SGD_HiTOS	SGD_HiTOS_Eng-HVAC_Non-conf
90	SGD_HiTOS	HITOS_Architectural_2006-10-25.ifc	SGD_HiTOS_Arch_Non-conf.ifc	Selvaag Gruppen / DDS Data Design System	SGD	non-confidential	IFC2x2_FINAL	ArchiCAD 10.0	-	51,6	-	-	Uploaded	Works.	Yes	SGD HiTOS	SGD_HiTOS	SGD_HiTOS_Arch_Non-conf
91	SGD_Munkerud	Munkerud_2x2.ifc	SGD_Munkerud_Arch_Non-conf_1.ifc	Selvaag Gruppen / DDS Data Design System	SGD	non-confidential	IFC2x2_FINAL	ArchiCAD 7.0	Residential	2,8	-	-	Uploaded	Crunching ….	No	SGD Munkerud	SGD_Munkerud	SGD_Munkerud_Arch_Non-conf_1
92	SGD_Munkerud	Munkerud_BS_Complete.ifc	SGD_Munkerud_Merged_Non-conf.ifc	Selvaag Gruppen / DDS Data Design System	SGD	non-confidential	IFC2x2_FINAL	Electrical Partner 6.35	Residential	34,4	-	-	Uploaded	Problems uploading ("import failed").	No	SGD Munkerud	SGD_Munkerud	SGD_Munkerud_Merged_Non-conf
93	SGD_Munkerud	Munkerud_DuctWork_Complete2x2.ifc	SGD_Munkerud_Eng-HVAC_Non-conf_Ventilation.ifc	Selvaag Gruppen / DDS Data Design System	SGD	non-confidential	IFC2x2_FINAL	DuctWork 6.35	Residential	5,3	-	-	Uploaded	Problems uploading ("import failed").	No	SGD Munkerud	SGD_Munkerud	SGD_Munkerud_Eng-HVAC_Non-conf_Ventilation
94	SGD_Munkerud	Munkerud_Electrical_Complete2x2.ifc	SGD_Munkerud_Eng-ELE_Non-conf.ifc	Selvaag Gruppen / DDS Data Design System	SGD	non-confidential	IFC2x2_FINAL	Electrical Partner 6.35	Residential	14,7	-	-	Uploaded	Problems uploading ("import failed").	No	SGD Munkerud	SGD_Munkerud	SGD_Munkerud_Eng-ELE_Non-conf
95	SGD_Munkerud	Munkerud_hus6_BE.ifc	SGD_Munkerud_Arch_Non-conf_2.ifc	Selvaag Gruppen / DDS Data Design System	SGD	non-confidential	IFC2x2_FINAL	ArchiCAD 8.0	Residential	3,9	-	-	Uploaded	Crunching ….	No	SGD Munkerud	SGD_Munkerud	SGD_Munkerud_Arch_Non-conf_2
96	SGD_Munkerud	Munkerud_PipeWork_Complete2x2.ifc	SGD_Munkerud_Eng-HVAC_Non-conf_Sanitary.ifc	Selvaag Gruppen / DDS Data Design System	SGD	non-confidential	IFC2x2_FINAL	PipeWork 6.35	Residential	10,5	-	-	Uploaded	Problems uploading ("import failed").	No	SGD Munkerud	SGD_Munkerud	SGD_Munkerud_Eng-HVAC_Non-conf_Sanitary
97	SGD_Munkerud	Munkerud_Riuska_2x2.ifc	SGD_Munkerud_Arch_Non-conf_3.ifc	Selvaag Gruppen / DDS Data Design System	SGD	non-confidential	IFC2x2_FINAL	ArchiCAD 7.0	Residential	2,9	-	-	Uploaded	Crunching ….	No	SGD Munkerud	SGD_Munkerud	SGD_Munkerud_Arch_Non-conf_3
98	SGD_HIBO	Statsbygg-HIBO-ARK-20080410.ifc	SGD_HIBO_Arch_Non-conf.ifc	Selvaag Gruppen / DDS Data Design System	SGD	non-confidential	IFC2x3	ArchiCAD 11.0	-	66,9	-	-	Uploaded	Crunching ….	No	SGD HIBO	SGD_HIBO	SGD_HIBO_Arch_Non-conf
99	DTU-204	20470M991.ifc	DTU_Building-204_FM_Conf.ifc	-	-	confidential	IFC2x3	Revit 2014	Educational	37,8	-	-	Uploaded	Works.	Yes	DTU-204	DTU-204	DTU_Building-204_FM_Conf
100	KEJD_Kastelsvej	L0101-292975-001_A8_K13_F1_H0_N01 Bygnings	KEJD_Kastelsvej_FM_Conf.ifc	Københavns Ejendomme	KEJD	confidential	IFC2x3	Revit 2014	Residential?	24,4	-	-	Uploaded	Works.	Yes	KEJD Kastelsvej	KEJD_Kastelsvej	KEJD_Kastelsvej_FM_Conf
101	KEJD_Haveje	F_A_001	KEJD_Haveje_Arch_Conf.ifc	Københavns Ejendomme	KEJD	confidential	IFC2x3	Revit	Kindergarden	51	2500		Uploaded	Works.	Yes	KEJD Haveje	KEJD_Haveje	KEJD_Haveje_Arch_Conf
102	NCC Carlsby	Carlsby-udbud-aug13	NCC_Carlsby-tender_Arch_Conf	NCC	NCC	confidential	IFC2x3		mixed use	27			Uploaded				NCC Carlsby	
103	NCC Carlsby	Carlsby-hovedprojekt-jan14	NCC_Carlsby-detailed_Arch_Conf	NCC	NCC	confidential	IFC2x3		mixed use	72			Failed				NCC Carlsby	
104	Haus_30		Plan3D_Haus30_CONF.ifc	Plan3D		confidential												
105	Haus_34		Plan3D_Haus34_CONF.ifc	Plan3D		confidential												
106	Building_1		LandGaard_Building-1_CONF.ifc	LandmaalerGaarden		confidential												
107	Building_2		LandGaard_Building-2_CONF.ifc	LandmaalerGaarden		confidential												
108	Building_3		LandGaard_Building-3_CONF.ifc	LandmaalerGaarden		confidential												
109	Tower		LandGaard_Tower_CONF.ifc	LandmaalerGaarden		confidential												

7. Appendix: Practice of 3D object processing – An Evaluation

The description of a current practice of 3D object processing could be solely based on work processes and interfaces described by stakeholders. Interviews are however coloured by the interviewed person and might not reflect their practice in an unbiased way. One can however assume that datasets delivered by the stakeholders are reflecting their practices.

We describe in this appendix first in chapter 7.1 the means available and chosen for the investigation of the Deliverables BIM and point cloud datasets in relation to content, quantity and quality of datasets. The following chapters provides the detailed results of the investigations on point clouds (7.2) and IFC files (7.3.). These underlie the summaries on dataset given in chapter 3.

7.1. Means for the assessment of 3D objects on data level

The shift of the building industry to a unified processing of their information on the base of data rich 3D objects provides the ground for novel ways to access and query this data. Where current practices of data assessment in the building industry happen predominately on the level of metadata attached to 3D objects, through journals or individual file inspection if more details are requested, it is the unified structure on datalevel that provides the ground investigate the 3D objects in an automatic way. These processes can derive qualitative and quantitative information from the 3D objects, store this information and set it into relation with each other.

It is this chapters aim to initiate on the example of IFC and E57 files a discussion what information can be found through algorithms and their combination and how this information allows to derive statements about quality and state of the underlying procedure in the building process.

7.1.1. Means for information extraction from Building Information Models

In order to layout means to assess the IFC format we firstly have a look at its generation and the data it may or may not contain.

7.1.1.1. *Structure and generation of IFC files*

The creation of an IFC files begins for the stakeholders interviewed for this deliverable with modelling of a building project in specific BIM software. As IFC is not a file format that any building modeller uses natively, all building information models are created in other software packages using e.g. Autodesk Revit, Bentley Microstation, Graphisoft ArchiCad or Nemetchek VectorWorks, etc. For the modelling of a building, objects are assembled from a library. The library typically contains objects that are delivered by the software company, objects delivered by manufacturers of building parts, and objects that the use has created for own specific purposes. Objects consist of 3D geometry (boundary representation), property data and metadata. This information is preserved when the model is exported to IFC. Other information, especially 2D representations of objects, are not included in the IFC format and hence lost in export from the native file format.

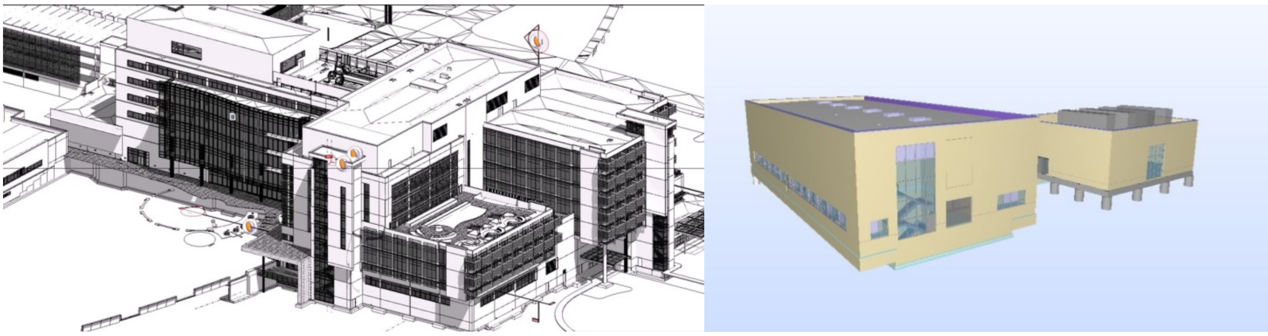


Fig.: 32 BIM models of high (left) and low (right) LOD.

7.1.1.2. *Levels of development (LOD)*

Objects can contain information in different levels of detail and models can be planned to different levels of development (LOD). The LOD indicates to what use the BIM created for. (Fig.: 32)[117]

Low LOD is often used for city planning scale projects, existing buildings in retrofitting projects, energy renovation projects and facility management purposes. Low LOD means that the 3D geometry is less developed but doesn't necessarily imply that the attached information is not rich. This is the case in facility management models where highly detailed geometry is less important than the attached information used for FM purposes.

High LOD model are used for building hand over from entrepreneur to building owner, who often demands an as built documentation in the shape of a BIM. (Fig.: 33)[118]

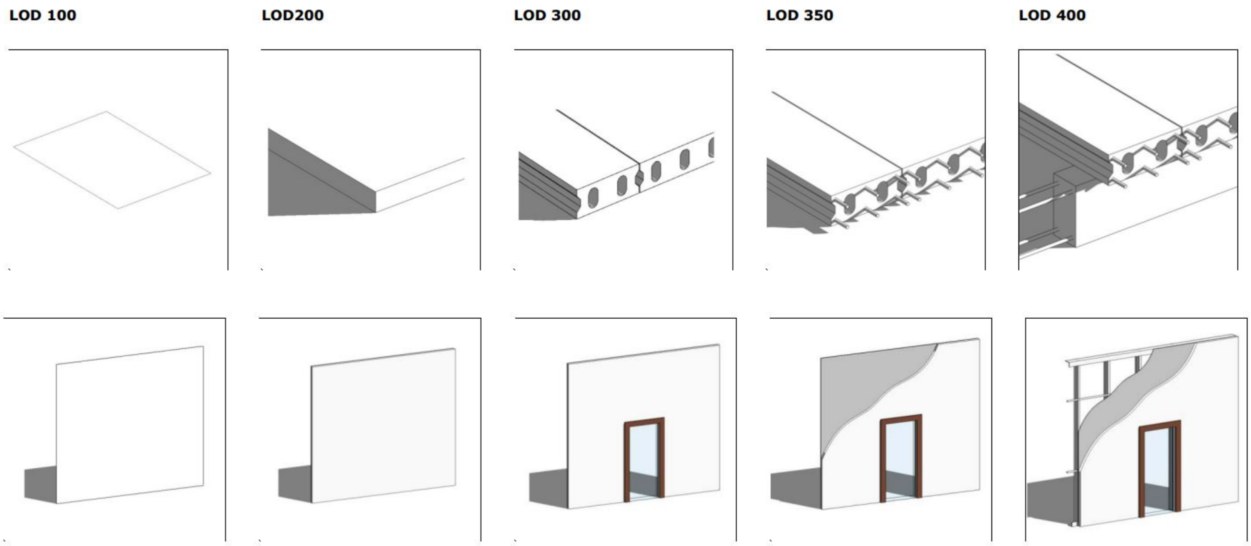


Fig.: 33 Examples of LOD in specific component types (floor slab, inner wall)

7.1.1.3. *IFC quality assessment – Software packages used by stakeholders in Denmark*

[117] http://www.bentley.com/en-US/Products/MicroStation/hypermodels.htm

[118] http://mth.dk/~/media/Files/dk/Bim-bygningsdelkatalog/Bygningsdelkatalog_MTHojgaard.ashx

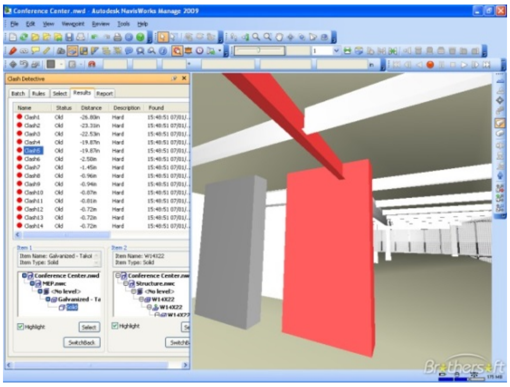


Fig.: 34 Clash detected in Navisworks .

Most building projects using BIM is described are in the design process by multiple building information models. Domain models are the parts of the building that are planned by each of the building domain partners involved in the project. The architect models a mainly visual representation of the building, the structural engineer models the load bearing and structurally important parts for the building, HVAC engineer model the heating, ventilation and air-condition installations of the projects, electrical installations, sewage and drains may also have their individual models. Merging these models into one regularly (e.g. every 2 weeks) in the development phases is called collision control or clash detection. (Fig.: 34)[119] These steps minimize the risks of on-site building mistakes which are often a very expensive addition to the building budget.

7.1.1.4. *Quality Assurance and Quality Control of BIMs*

Quality Assurance and Quality Control of BIMs uses rules to analyse information associated with spaces and elements in the models. Verify and validate information and the absence of it. E.g.: Spatial coordination and Design Version Management (Model Revision Comparison). Focus of the rules is on what is not fitting properly, incorrectly located, duplicated in the model, something is totally missing in the model.

The Following is a brief presentation of the most widely used BIM QC and QA software products in Danish practice:

Navisworks

Fig.: 35 Navisworks user interface

Navisworks (Fig.: 35)[120] is an Autodesk product that we found to be used with several stakeholders. It imports proprietary Revit files (not IFC) to aggregate project data and perform clash detection between domain models. Navisworks can perform time- and cost analysis as well as object animations.

Solibri model checker

Is an advanced IFC model checker stand-alone software tool.(Fig.: 36)[121] It analyses Building Information Models for integrity, quality and physical safety via rule sets that can be imported from external sources or created for project specific purposes. Solibri is the most widely used tool for checking IFC models.

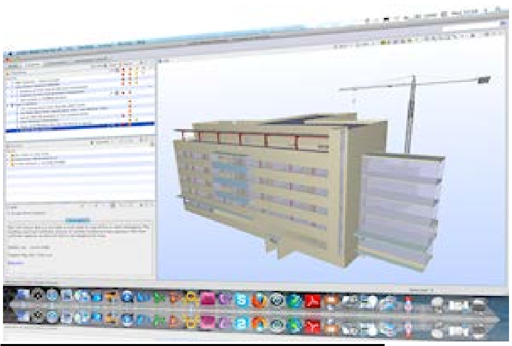


Fig.: 36 Solibri BIM checker user interface .

Advanced rule based checking of is typically performed on the model hierarchy. This rule checks that the model includes a building and floors. It also checks that all components are contained by a floor. Building floors checks that the model doesn't have any empty floor and that each floor has a name. It also checks that there aren't multiple floors with the same elevation. Doors and windows in the model are located in the same floor as the wall they are related to. The rule checks also

119 http://www.brothersoft.com/autodesk-navisworks-175054.html

120 http://www.autodesk.com/products/autodesk-navisworks-family/overview

121 http://www.solibri.com/solibri-model-checker.html

that the model doesn't contain any orphan doors or windows (a door or a window, which doesn't have a relation to any wall). Door opening direction definitions check that id opening directions of doors are defined. They are needed e.g. in Accessibility rules. The component check rule set checks that components have reasonable dimensions and they have located in a correct way. Clearance checks that there is clearance in front of or above certain components.

Deficiency Detection is performed in the relationship between the 3D model and the information it is supposed to include. Typical issues: Components are missing (geometry or spaces), object don´t meet the specifications, lack of consistency with the behaviour of the objects, logical dependencies and relationships: e.g. a space should be bounded by walls, and opposite; there is a space between walls. Or, that columns stand on load bearing structure and support structures above. If this is not reflected in the model, the situation will be identified as a potential problem.

Other possible issues that can be detected include missing components, incorrect locations, object redundancy and consistency issues.

Dalux BIM checker

This is a Danish web-based tool for Quality Assurance and Quality Check for BIM and IFC. Dalux BIM Checker can verify the structure of the BIM and that all building elements and rooms have correct properties and data. All these requirements are typically encapsulated in an IDM: Information Delivery Manual. This enables the model to be used for several automatic analysis and simulations. (Fig.: 37)[122]

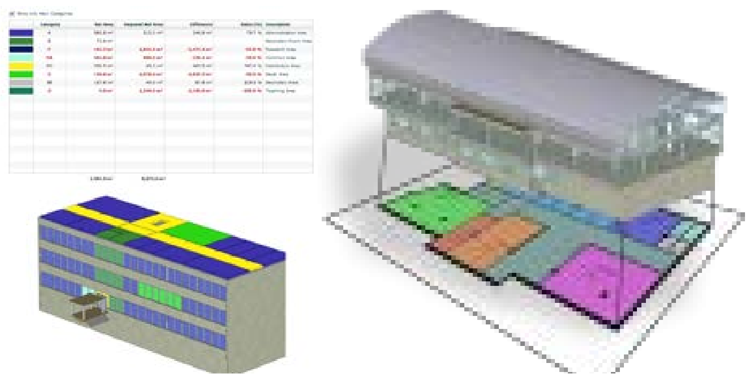


Fig.: 37 Dalux BIM checker user interface.

Typically the checker is used for comparing model areas to wanted areas, do an automatic energy calculation and simulate cost based on areas or building elements.

As the checker is web-based, both in house BIM designers and externals check their models before delivery. It is used in project competitions and during construction by many public and private building owners.

7.1.1.5. *IFC- Data structure and available information*

IFC is a standard for building information models, not for drawings. On a general level it enables its users to exchange information about building structures, elements, spaces and other objects in a Building Information Model. It does this through different means:[123]

- Information Delivery Manual (IDM) Methodology to capture and specify processes and information flow during the lifecycle of a facility.
- Model View Definitions (MVD) IFC files are based on a view definition that determines the scope of the IFC exchange. Model View Definition (MVD) defines a subset of the IFC schema that is needed to satisfy one or many Exchange Requirements of the AEC industry. E.g. Coordination View, Structural Analysis View, FM Handover View (COBie).

[122] http://www.dalux.dk/flx/en/products/dalux_bim_checker_qa_of_bim_and_IFC/

[123] http://www.buildingsmart-tech.org/specifications/IFC-releases/IFC4-release/summary

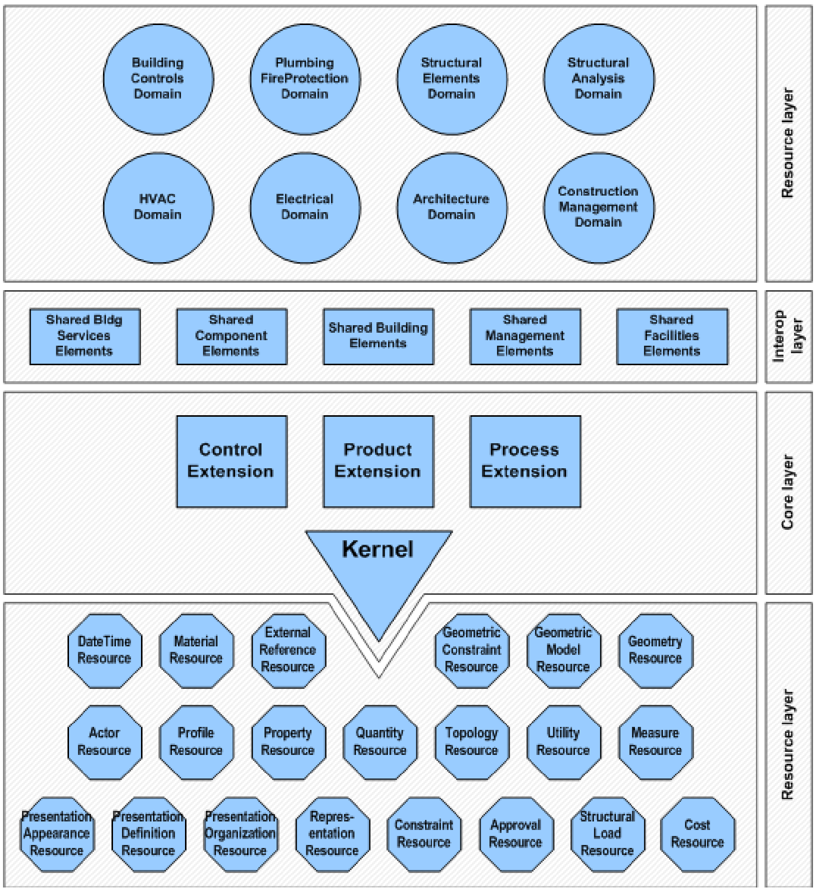


Fig.: 38 Illustration of the information structure of an IFC file.

The content of the IFC file depends on the MVD; It´s 3D, properties and attributes, such as parameters, relationships, connectivity. The objects know what systems they´re in and what they are connected to.

An IFC file should ideally include all necessary information to understand its content on a qualitative (as author, location, etc.) and quantitative level. Where information is not inscribed into the file algorithms should be able to gain this through counting of i.e. elements or measurements of areas. The following chapter provides an overview of information that can be considered meaningful to describe architectural data and how and whether this can be retrieved from IFC files.

The IFC schema contain hundreds of predefined properties that 3D software use to fill in from the native format during export. Many predefined properties are rarely used in a structured and meaningful way by either the persons modelling or the software during export. More notably, IFC has a container for undefined information and geometry which come in use when either the modeller fails to define objects or information correctly (according to IFC) or when an exporter is inefficient. This often leads to information loss and is one of the reasons IFC is not unanimously accepted as the most efficient way of communicating building information. It is though the only file format available for exchanging BIM between different software. (Fig.: 38)[124]

7.1.2. Means for information extraction from 3D Scan data

At present tools that asses 3D point clouds have the purpose to check for the quality of a scan. This is usually understood on the quality of the registration of the separate scans to each other and to surveyed points. Within this document we propose a more in depth quality measurement, which besides the quality level of the registration also takes into account the quality of the scan project on an architectural level, on the level of the planning of the scan project and on the technical level of the scans as e.g. noise and point accuracy.

In this chapter a set of parameters critical to the process, its steps and quality is set up. Means for deriving these parameters automatically is discussed in chapter 7.2.

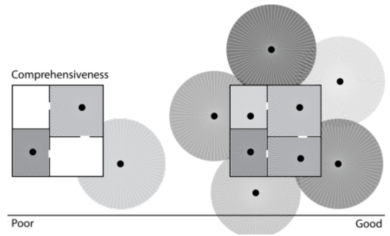


Fig.: 39 Comprehensiveness

On an architectural level a parameter called comprehensiveness is proposed, which depicts how exhaustive a scan project has been scanned. This parameter is based on two sub-parameters – the Exterior Façade Amount and Room Distribution. Exterior Façade Amount shows the amount of the building architecture within the scan project, which is covered by exterior scans in percentage. Room Distribution shows the amount of singled out rooms with no connectivity to other rooms or neighbouring rooms or façades within an appropriate distance threshold set by architectural standards.

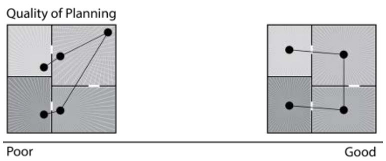


Fig.: 43 Quality of Planning

On the level of planning a parameter called Quality of Planning is proposed. Quality of Planning depicts how well-planned a scan project has been conducted, and is based on two sub parameters – Sensor to sensor distances and Sensor to Point distances. Sensor to sensor distances is the average and standard deviation of distances between scan positions from sequentially connecting scans by which is meant the distance from one scan to the other scan with which it has most overlay of points. Sensor to Point distances is the average and standard deviation between a point and its parent scan position.

Fig.: 40 Sensor to Sensor

Fig.: 41 Sensor to Point

On the technical level a parameter called Quality of Cleaning is proposed. Quality of Cleaning is based on two sib parameters – Point Distribution and Sensor to Point distances (like in previous parameter). Point distribution depicts how evenly the distribution of points are in the scan based on distances to neighbouring points(Point to Point distances), the angle between normal and scanner position.

The quality assessment of the registration of the scans will be shown as a best practice example by ATS Quality Manager, and the latter three will be presented as an idea on how to assess a quality value based on inspiration in the example by ATS Quality Manager. (ATS 2013)

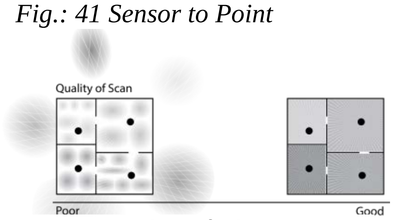


Fig.: 42 Quality of Cleaning

7.2. Assessment of 3D objects with methods and tools developed in WP7

This chapter describes the means that were used in the DURAARK project to derive qualitative and quantitative information from 3D objects in IFC an automatic way. The chapter discusses what information could be found through algorithms and to which extent this information allows to make statements about quality and state of the underlying procedure in the building process.

7.2.1. Assessment of 3D objects registered with 3D documentation techniques

7.2.1.1. *Description of the developed Point Cloud Statistical Analysis Tool*

This chapter describes the processes and tools developed to extract information from 3D point clouds.

7.2.1.1.1. Measures

In its current version, the statistical analysis tool computes the means (μ), variances (σ^2) and standard deviations (σ) of the following intrinsic measures given an input cloud:

- Approximate mean distance of all points to their respective 4 nearest neighbors,
- approximate distance of all points to their respective sensor origin,
- approximate view angle deviation from point normal for all points, and
- distance of all sensors to their neighbor sensor, where the sensor's neighbor is the one sensor having the largest mutual point overlap.

Due to impact of large point clouds on RAM and CPU usage and therefore the feasibility in usage scenarios, the tool computes approximations where necessary. For a detailed description of the simplifications used read the section on *Implementation Details*.

7.2.1.1.2. General Definitions

For any set X with $|X| = n$ and elements $x_i, i \in \{1, \dots, n\}$, define

- $\mu(X) = \frac{1}{n}\sum_{i=1}^{n} x_i$, as the discrete mean of X,
- $\sigma^2(X) = \frac{1}{n-1}\sum_{i=1}^{n}(\mu(X) - x_i)^2$, as the discrete variance of X,
- $\sigma(X) = \sqrt{(\sigma^2(X)}$, as the discrete standard deviation of X.

7.2.1.1.2.1. *Point-To-Point Distance*

For a given point p_i in cloud C, define the nearest-neighbour as

$$N(p_i, C) := \underset{p_j \in C,\, i \neq j}{\arg\min} \|p_i - p_j\|_2^2.$$

Then, the k-nearest-neighbor set may be defined recursively as

$$N(p_i, C)_k := N(p_i, C \setminus N(p_i, C)_{k-1}) \cup N(p_i, C)_{k-1}$$
$$N(p_i, C)_0 := \emptyset.$$

The tool then computes the set

$$P2P_k(C) := \{\mu(\{\|n_i - p_i\|_2 \mid n_i \in N(p_i, C)_k\}) \mid 1 \leq i \leq |C|\}$$

and consequently $\mu(\mathrm{P2P_k(C)}), \sigma^2(\mathrm{P2P_k(C)})$, and $\sigma(\mathrm{P2P_k(C)})$.

7.2.1.1.2.2. *Point-To-Sensor Distance*

For the point-to-sensor measure, the set

$$P2S(C) := \{\|p_i - s(p_i)\|_2 \mid p_i \in C\}$$

is computed, where $\mathrm{s(p_i)}$ yields the sensor location $\mathrm{p_i}$ has been measured from. Consequently, $\mu(\mathrm{P2S(C)}), \sigma^2(\mathrm{P2S(C)})$, and $\sigma(\mathrm{P2S(C)})$ are computed.

7.2.1.1.2.3. *View-To-Normal Angle Deviation*

For all $\mathrm{p_i} \in \mathrm{C}$ define $\mathbb{R}^3, ||\mathrm{n_i}||_2 = 1$ to be the approximated normal of the originally scanned surface at $\mathrm{p_i}$.

Given the set of view direction to normal angles

$$V2N(C) := \left\{\cos^{-1}(\langle n_i, v_i \rangle) \mid v_i = \frac{s(p_i) - p_i}{\|s(p_i) - p_i\|_2},\ p_i \in C\right\},$$

the measures $\mu(\mathrm{V2N(C)}), \sigma^2(\mathrm{V2N(C)})$, and $\sigma(\mathrm{V2N(C)})$ are computed.

Sensor-To-Sensor Distance

Given the sensor positions $\mathrm{s_i} \in \mathrm{S(C)}$ and an overlap measure $\mathrm{o(s_i, s_j)}$, the set

$$S2S(C) := \left\{\|s_i - \underset{s_j, i \neq j}{\arg\max}\, o(s_i, s_j)\|_2 \mid s_i \in S(C)\right\}$$

of distances between each sensor and their neighbouring scan is computed, as well as the measures $\mu(\mathrm{S2S(C)}), \sigma^2(\mathrm{S2S(C)})$, and $\sigma(\mathrm{S2S(C)})$.

For a description of the overlap measure used, see the section on Implementation Details.

7.2.1.1.3. *Implementation Details*

Since full-resolution input data for moderate system specifications often has an infeasible impact on RAM and CPU usage, approximations are used where it results in a sufficiently precise measurement.

In a first step, a rough approximation of the point-to-point mean distance μ_r is determined using a small subset of the scan data. Then the cloud is sampled such that in a voxel of side length $\mu_r *$ “Resample Factor” there is not more than one point, where “Resample Factor” is the input parameter defined using the GUI.

For the following computations, all measurements are taken for this sampled subset of input points (for point-to-point distances, the measurement is done at these sampled points using all points in the respective neighbourhoods; the other measurement are done entirely on the sampled points).

7.2.1.1.3.1. *Processing Order*

The computation is done in the following order:

7. Determine rough approximation of point-to-point mean distance.
8. Sample point subset using rough mean from step 1.
9. Compute finer approximation of point-to-point mean distance.
10. Compute approximation of point-to-point distance variance/std. deviation.
11. Compute approximation of point-to-sensor distances.
12. Compute approximation of view-to-normal angle deviations.
13. Compute approximation of sensor-to-sensor distances.

7.2.1.1.3.2. *Overlap Measure*

For the overlap measure between two distinct scans, the following algorithmic solution is used: For all points in the first scan, a radius search (where the radius is based on the rough point-to-point mean distance determined in step 1 above) is done in the second scan and vice versa.

The measure is then the amount of points in each scan that has neighbouring points in the other scan, divided by the amount of all points in both scans. In this way the overlap measure evaluates to 0 if the scans don’t overlap in terms of the given radius, and 1 if for all points in both scans there exist neighbouring points in the other scan.

7.2.1.1.3.3. *Usage*

The tool is delivered as a GUI software, where the first step is the selection of the input point cloud file.

Once the cloud is selected, the main interface window is shown, which is comprised of

- a small info area where information about the contained distinct scans and images is shown,
- an interactive area, where the (currently) single input parameter can be adjusted and the algorithm may be started, and
- a logging/output area that shows the algorithm’s progress as well as the final result after completion.

For small input clouds, the “Resample Factor” can be chosen close to 1 (if it is exactly 1, the input cloud is not resampled at all and consequently the results are as precise as possible); for large input clouds (of several GiB) factors of 10-20 are suggested. Whether the radius chosen is adequate should be determined by the user based on computation time and memory consumption.

7.2.1.2. *Evaluation of Point Cloud Statistical Analysis Tool*

In order to evaluate the quality of 3D point cloud scans, its creation and processing it is necessary to calibrate the measurements and find out in which of the assumed areas these are effective at all.

The above described Point Cloud Statistical Analysis Tool provides solely statistical measurements, and from these we do an interpretation and comparison to find which steps of the 3D scanning process, and it’s quality, can be traced in the measurements.

7.2.1.2.1. Interpretation of the measurements:

The statistical measurement results from the tool developed have been chosen to be visualized as a modified box-plot with whiskers. This shows the mean value and a theoretical 25 percent deviation box and additional approximate 25 percent deviation whiskers on the positive side based on standard deviation. As this is based on mean value and standard deviation the graphical depiction is for visual comparison of datasets based on their mean value and a theoretical spread of this data.

And from here is also a quality measure parameter calibrated and depicted in percentage to facilitate comparison.

7.2.1.2.2. Relating the measurements to Scan Quality

The physical act of 3D scanning and the post-processing of a scan from its creation, over different filtering and cleaning steps has a big impact on the data quality. In order to find out about the meaning and impact of these steps we separate them and investigate their traces in the data. To be able to do so we are using reference scans that are showcasing good and bad practice examples in a prototypical way. The different steps of the process are separated into the physical act of scanning (the Quality of Planning), the scanner settings and the filters for cleaning up the scans in the post-processing (the Quality of Cleaning). These are informed by the experiences of the stakeholders described in *chapter* 3.2.

7.2.1.2.2.1. *Quality of Planning*

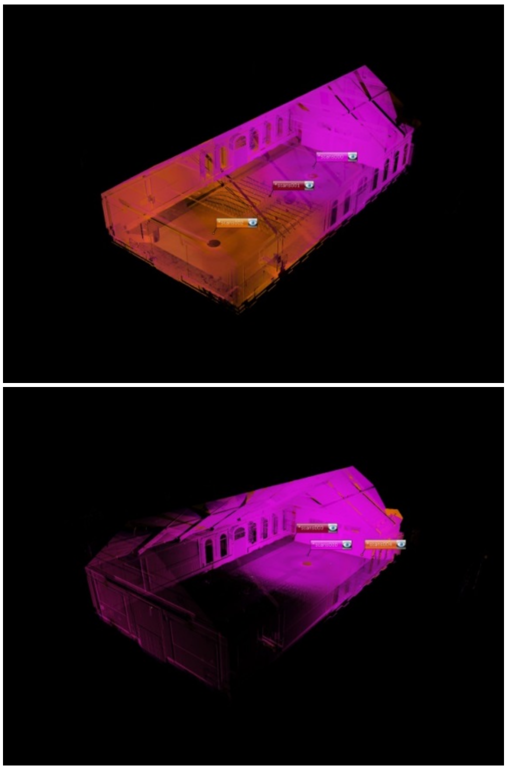


Fig.: 44 Reference for Quality of Planning

In this test two series of 3D scanning were performed – one with an even distribution of scan positions covering the centre line of the room and one with scan positions located in one end of the room. (Fig.: 44)

The assumption that it is possible to assess the quality of planning of the physical act of 3D scanning by combining the results of the Sensor to Point Distances (Fig.: 46) and the Sensor to Sensor Distances (Fig.: 45) would theoretical be possible (demanding more controlled test samples), but without a prior knowledge of the cleaning of the point cloud, the results are obscured by the large effect on these parameters from this process of cleaning. It is though from the Sensor to Sensor distances possible to evaluate parts of the planning process by comparing the distances between the scan positions with recommended range for the scanner used. For example for the Faro Focus scanner it is recommended to reference scans for indoor use at a distance of no more than 15-20 meters, which would mean that a maximum mean value with not too much deviation of the Sensor to Sensor Distances should be within 30-40 meters, and from here we can calibrate a quality measure parameter, Qp.

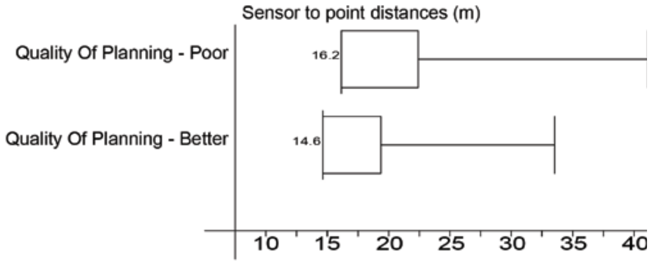


Fig.: 46 Quality of Planning - Sensor to Point distances

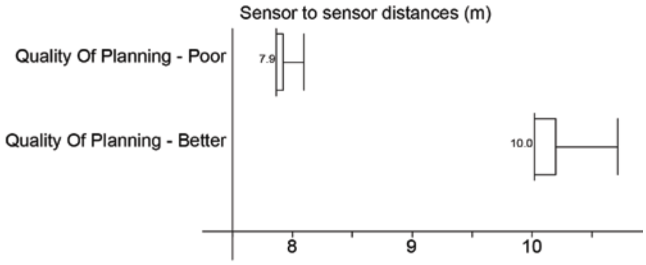


Fig.: 45 Quality of Planning - Sensor to Sensor distances

Below are the parameters of the Point to Point Distances (Fig.: 47) and the View to Normal Angles (Fig.: 48) showing that planning of scanning doesn't have much effect on these results, as assumed.

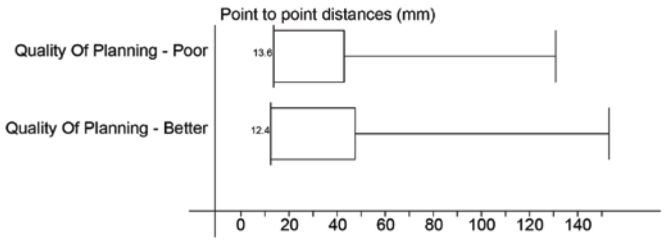


Fig.: 47 Quality of Planning - Point to Point distances

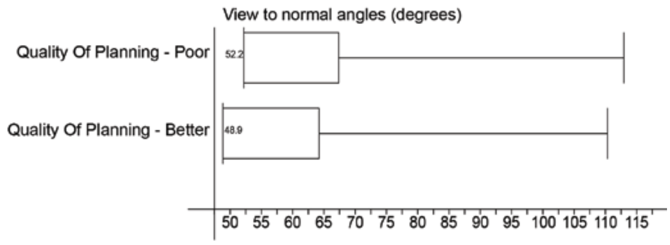


Fig.: 48 Quality of Planning - View to Normal Angles

These tests showed that that the assumption of being able to evaluate the quality of planning would be obscured by the large effects of the cleaning processes. It is though possible to evaluate the sensor to sensor distances in comparison with recommendations for the scan hardware. Quality of planning is:

$$Qp = \left(1 - \frac{\mu_{ss} + \sigma_{ss}}{R}\right) 100$$

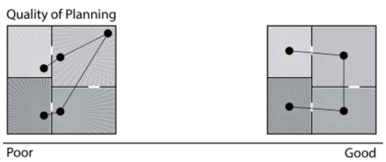
where

R is based on the recommendation for scan hardware, e.g. for Faro Focus

R = 30

And will be depicted as

Quality of *Planning*



$\boldsymbol{Qp}$ as percentage

Derived from

SensorSensor Mean = μ_{ss}

SensorSensor StD = σ_{ss}

7.2.1.2.2.2. *Quality of Cleaning*

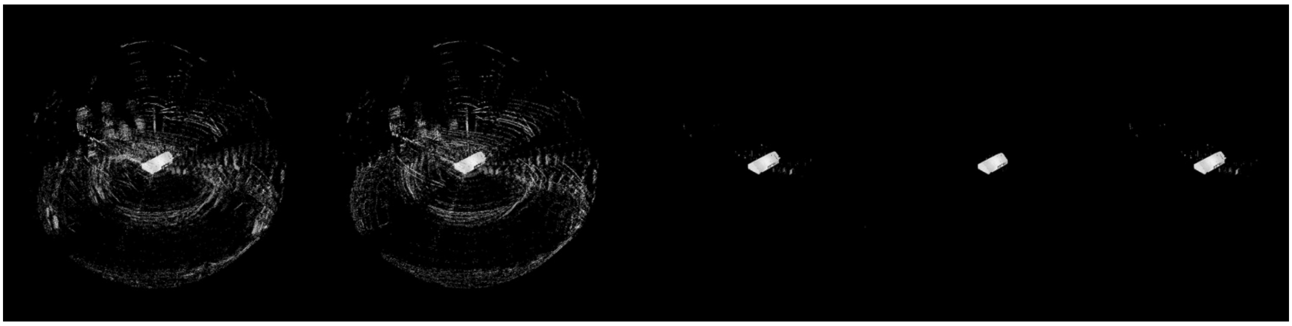


Fig.: 49 Post-processing Filters. From left to right: UnClean, DarkPoints, StandardFilters, DistanceBased and StrayPoints

In this test a series of different filters were applied (Fig.: 49) to the same point cloud and run through the statistical tool developed. The diagrams below show the post-processing of applying filters to 3D point clouds in order to clean them from undesired noise. Our investigation shows that this has a very large effect on the resulting measurements from the statistical tool - especially the parameters of Point to Point Distances (Fig.: 50) and Sensor to Point Distances (Fig.: 51).

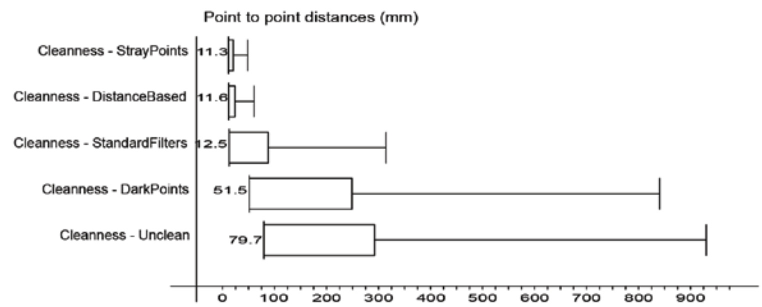


Fig.: 50 Cleanness - Point to Point distances

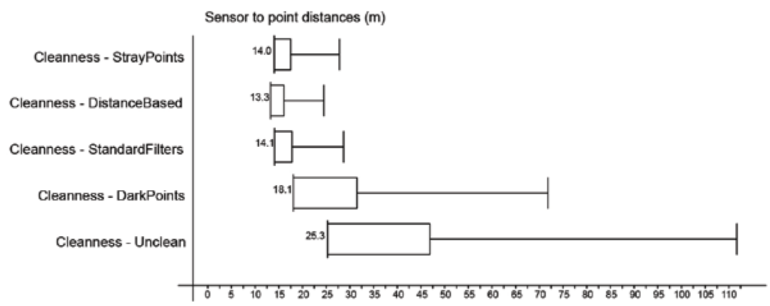


Fig.: 51 Cleanness - Sensor to Point distances

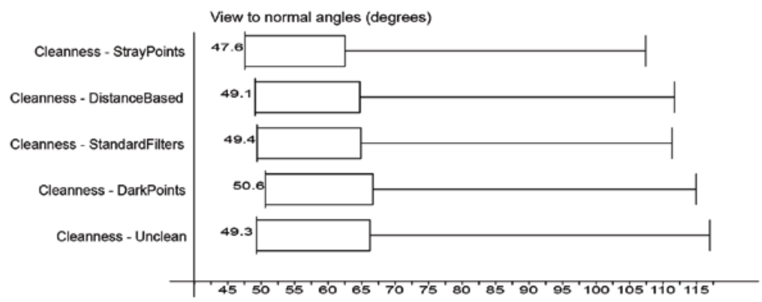


Fig.: 52 Cleanness - View to Normal Angles

The Point to Point Distances show a large effect when filters are applied to a 3D point cloud. The standard filters are the filters which most proprietary scanning software is set to run first time the scan is loaded into the software, and contains a combination of the Stray Point Filter and the Dark Point Filter. We can see that the standard filter has a large effect on the noise reduction in the point cloud, but we can also see that a pure stray filter has a larger effect, probably due to low settings of the standard filter to ensure no data loss.

The same result emerges in the investigation of the Point to Sensor Distances. It is though possible to see that the distance based filter here has a slightly better effect, which can be observed in the image above (Fig.: 49) where the stray filter missed to catch a reflected window.

Our evaluation shows that the View to Normal Angles (Fig.: 52) doesn't get affected much. It shows that this parameter are always situated around 50 degrees. Hence it is not possible to conclude from them on the scanning quality or it processes.

From this we can evaluate if and to some extent to which level a stakeholder has been cleaning up the point clouds in their post-processing phase. And we can calibrate a quality parameter that depicts the quality of the scans. This is done both by calibrating for the behaviours seen in these reference scans and in a larger set of scans from other partners, and by comparing is with recommendations by The Danish Building & Property Agency, in which they state that a point to point distance of 30 mm would be adequate for recognition of building elements, but for a detailed determination of edges a distance of at least 10 mm is required. (Birch, 2010)

The parameter called Quality of Cleaning is calculated and calibrated by

$$Qc = \frac{Qpp + Qsp + Qpp_{recommended}}{3}$$

, where

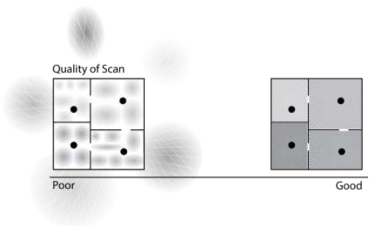
$$Qpp = \left(1 - \frac{\mu_{pp} + \sigma_{pp}}{700}\right) 100$$

$$Qsp = \left(1 - \frac{(\mu_{sp} + \sigma_{sp}) - 1}{700}\right) 100$$

$$Qpp_{recommended} = \left(1 - \frac{\mu_{pp} - 10}{30}\right) 100$$

And will be depicted as

Quality of *Scan*



Qc

Derived from

Quality PointPoint: Qpp

Quality SensorPoint: Qsp

Quality PointPointRec: $Qpp_{recommended}$

7.2.1.2.2.3. *Scanner Settings*

This test was done running one scan with different resolution and different quality settings from the same position. As seen below (Fig.: 53 – Fig.: 58) this has a small effect on the results from the statistical tool, but the effect of the scanner settings would also be obscured by the cleaning processes conducted in the post-processing phase.

Change in resolution settings:

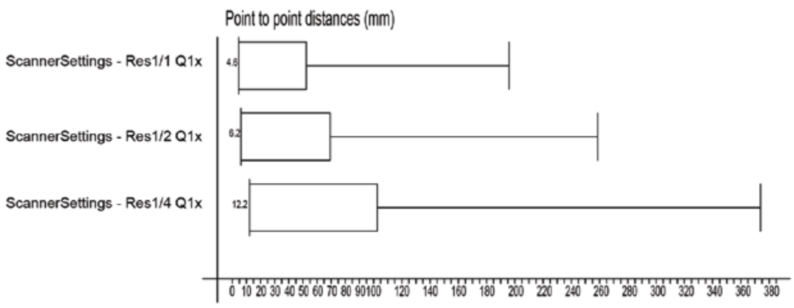


Fig.: 53 Scanner Settings – Resolution - Point to Point distances

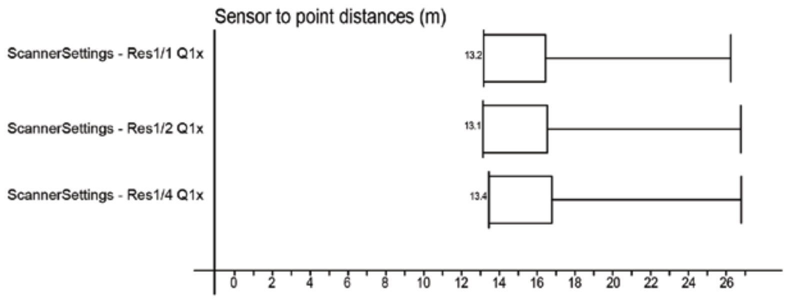


Fig.: 54 Scanner Settings – Resolution - Sensor to Point distances

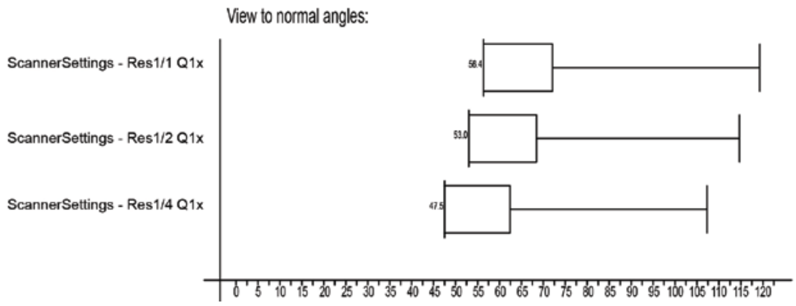


Fig.: 55 Scanner Settings – Resolution - View to Normal angles

Change in quality settings

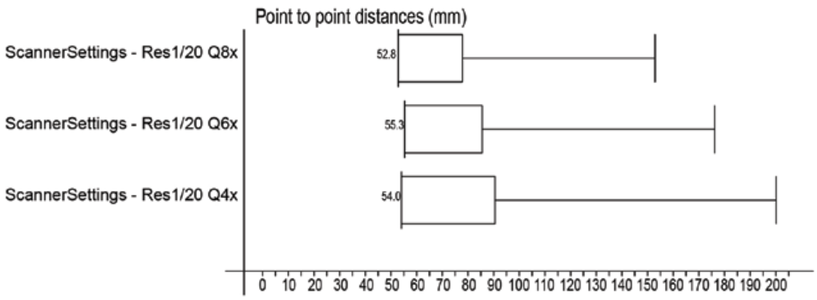


Fig.: 56 Scanner Settings – Quality – Point to Point distances

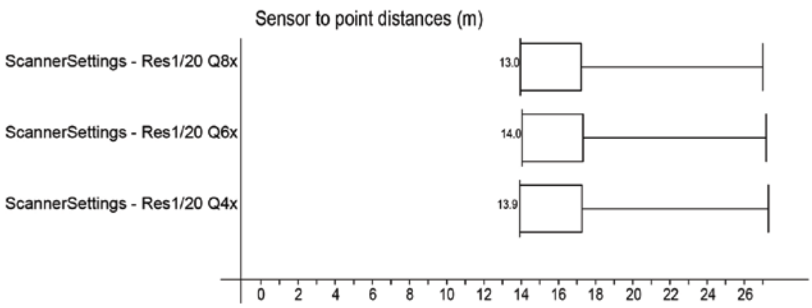


Fig.: 57 Scanner Settings – Quality – Sensor to Point distances

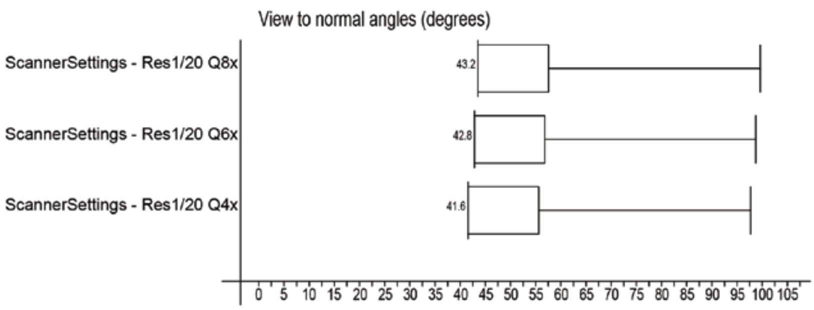


Fig.: 58 Scanner Settings – Quality – View to Normal angles

7.2.1.2.2.4. *Conclusion*

We conclude that it is possible to observe the level of cleaning conducted in the post processing by evaluating the Point to Point Distance parameters and the Sensor to Point Distance Parameters. And from here derive a parameter for the quality of the scan by comparing these figures with recommendations for point to point distances by Danish Building & Property Agency (Birch, 2010). Due to the large effect from this, other scan processes get obscured and can't be evaluated without prior knowledge of the cleaning. To be able to evaluate the quality of these other processes a knowledge of the geometry scanned would have to be taken into account

By comparing the Sensor to Sensor Distances with the recommendations for the specified scanner it is though possible to evaluate parts of the quality of the planning process.

The View to Normal Angle parameter is observed not to be effected by any of the processes and can be discarded.

7.2.1.3. *Investigation of sample dataset and discussion of results*

An evaluation of the quality of the scan data used by stakeholders is here depicted by a set of prototypical scan projects from a set of the producing stakeholders. It is chosen here to evaluate the quality of the data by the means of 4 parameters – Comprehensiveness, Quality of Planning, Quality of Scan and Quality of Registration.

The measures of Comprehensiveness carried out manually by inspecting the point clouds visually. The setup is made so the interior and exterior each consists of 50% of the total quality measure.

The Quality of Planning and the Quality of Scan are statistically measured by the tool developed for this deliverable *(Chapter 7.2.1 Assessment of 3D objects registered with 3D documentation techniques)* and is evaluated as described in *Chapter 7.2.1.2 Evaluation of Point Cloud Statistical Analysis Tool.* A set of scan projects from stakeholders which all had been scanned with scanning hardware with the same specification makes it possible to compare the sensor to sensor distances with a maximum distance of 30 meters, based on these scanner specifications.

The Quality of Registration is evaluated by the best practice example of registration quality measures by ATS – the ATS Quality Manager with the quality baseline threshold by ATS's standard, which sets high quality at a point distance error of 5mm. (ATS, 2013)

7.2.1.3.1. Plan3D

Project House30

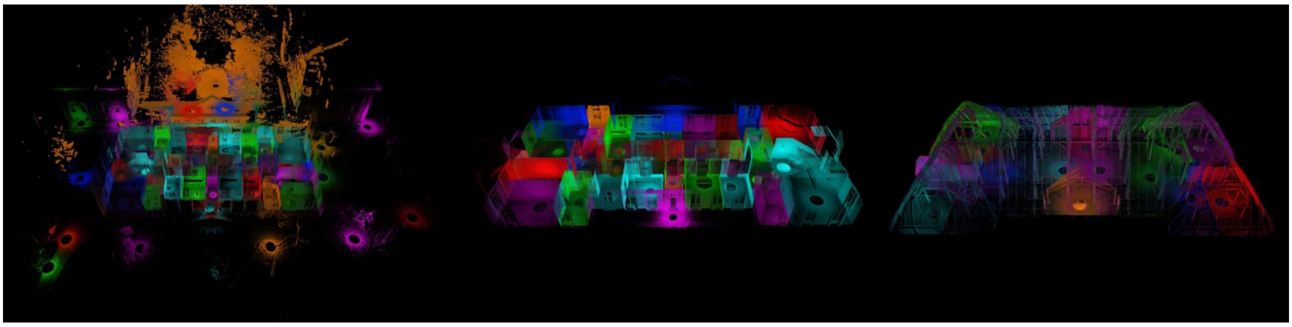


Fig.: 59 Project House30 by Plan3D

Number of scans: 107

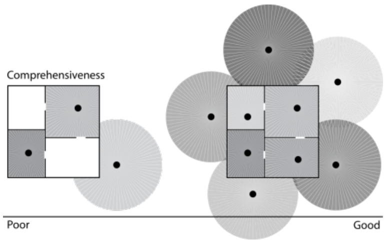
Number of points: 2,9 * 10^9

Project House30 (Fig.: 59) is a large scan project by Plan3D consisting of both interior and exterior scans. The project is by the stakeholder split into floors – Outdoor (consisting of ground floor interior and exterior), OG

(1st floor interior) and DG (attic interior). These floors were not registered together and a full project with all scans registered together has not been made by the stakeholder. The quality evaluation is here carried out on these segmented floors and compiled into one number for the ease of readability of the overall project. The registration evaluation is done on the full project and gives the average of the full project, but doesn't show that the registration of the separate floors was never done.

7.2.1.3.1.1. *Measurements*

Comprehensiveness



90 %

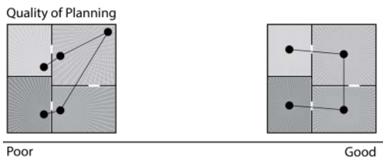
Derived from

Interior 100%

Exterior 80%

This shows a very exhaustive scan project, with all interior scanned and all facades but the roof scanned, and follows the line of work described by stakeholder.

Quality of Planning



57,6%

Derived from

SensorSensor Mean = 7,3 m

SensorSensor StD = 5,4 m

This shows an above average planned scan session with a consistent average of sensor to sensor distances around 7 meters and a narrow spread only just reaching the 30 meter maximum. (Fig.: 60)

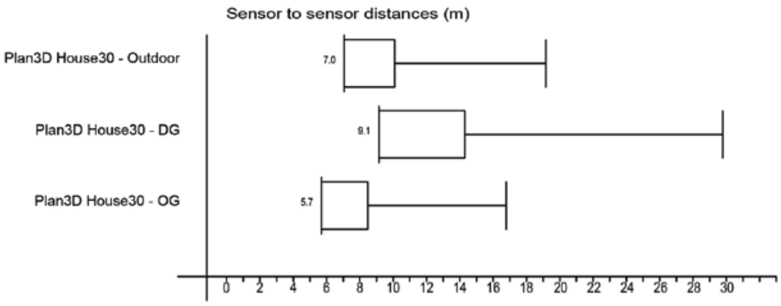
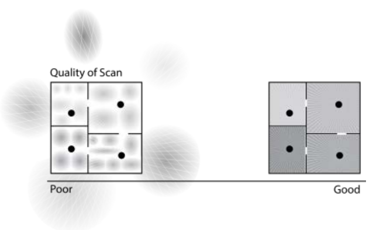


Fig.: 60 Plan3D – Sensor to Sensor distances

Quality of Cleaning



38,6%

Derived from

Quality PointPoint: 8,3%

Quality SensorPoint: 62,6%

Quality PointPointRec: 45,0%

This shows a post-processing of the scan project to be below average, probably conducted only by standard filters. But with a mean of point to point distances just below the recommended 30 mm for architectural recognition. (Fig.: 61, Fig.: 62)

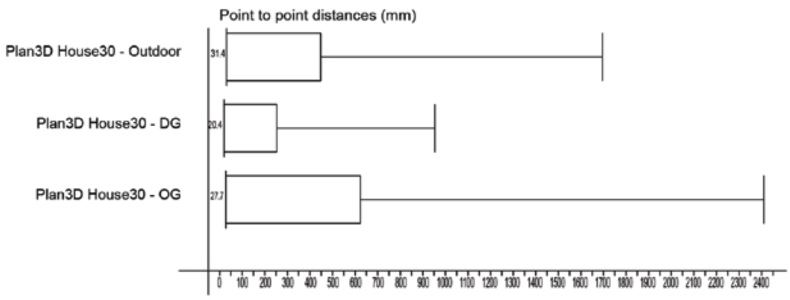


Fig.: 61 Plan3D – Point to Point distances

Average Mean = 26,5 mm

Average StD = 615,1 mm

Quality PointPoint = 8,3 %

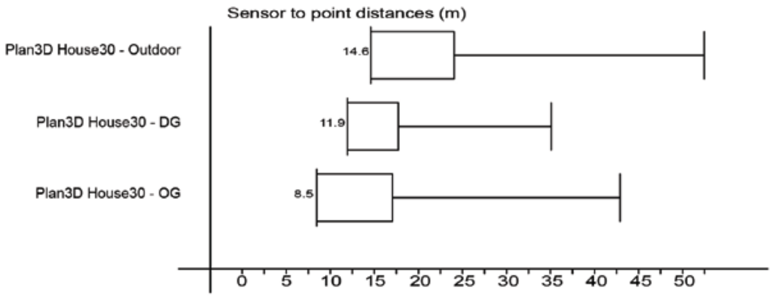


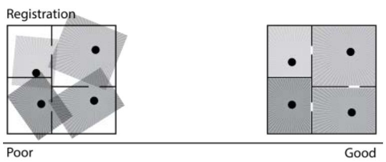
Fig.: 62 Plan3D – Sensor to Point distances

Average Mean = 11,7 m

Average StD = 11,8 m

Quality SensorPoint = 62,6%

Quality of Registration



Average point distance error: 2,6 mm

Surveyed references: 0

Most used number of references: 15

This shows a very good registration process for the segmented floors (which are not registered together) with point distance error significantly below the 5 mm baseline and mainly use of 15 references.

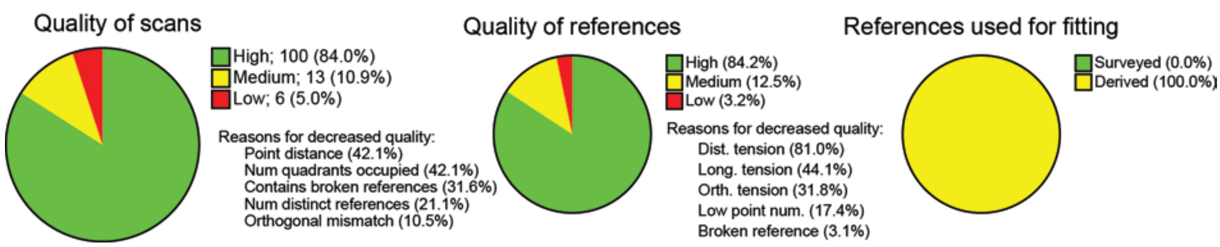


Fig.: 63 Diagrams registration quality from ATS Quality manager. For more information (ATS, 2013)

7.2.1.3.2. LE34

Project Vestergade72

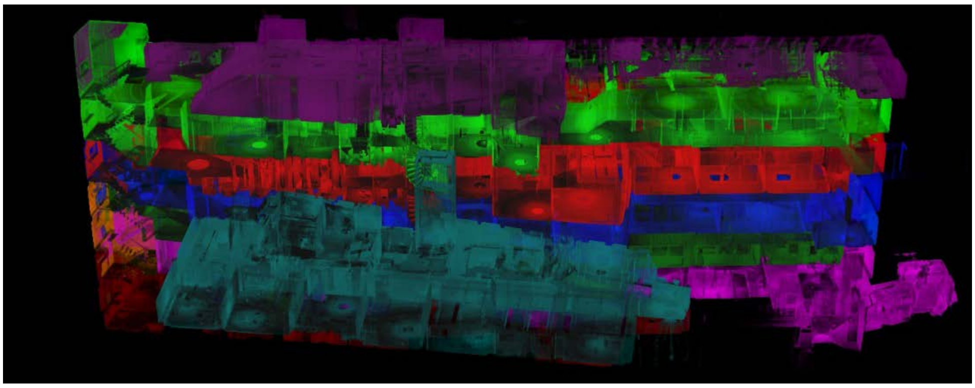


Fig.: 64 Project Vestergade72 by LE34

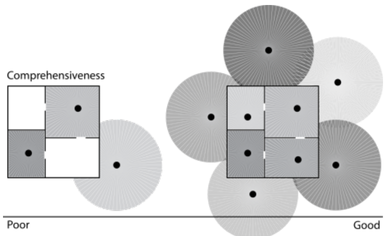
Number of Scans: 314

Number of points: 8,5 * 10^9

Project Vestergade72 (Fig.: 64) is a large interior scan project by LE34 of over 300 individual scans. The project was from the stakeholder’s side split into floors for delivery to client. The quality evaluation is here carried out on these segmented floors and compiled into one number for the ease of readability of the overall project. The registration evaluation is done on the full project with all scans registered to each other, which was also available in the data package from the stakeholder.

7.2.1.3.2.1. *Measurements*

Comprehensiveness



50 %

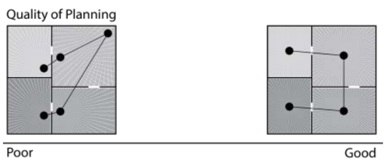
Derived from

Interior 100%

Exterior 0%

This shows a very exhaustive interior scan project, and follows the lines of work described by LE34.

Quality of Planning



75,0%

Derived from

SensorSensor Mean = 4,8 m

SensorSensor StD = 2,7 m

This shows a very well planned scan session with a consistent average of sensor to sensor distances around 5 meters and a narrow spread never exceeding the 30 meter maximum. (Fig.: 65)

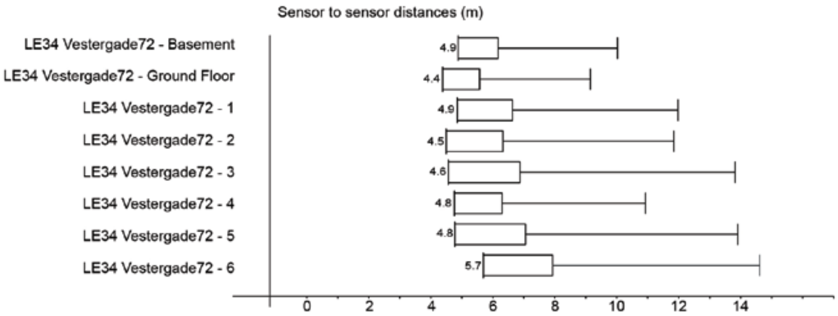
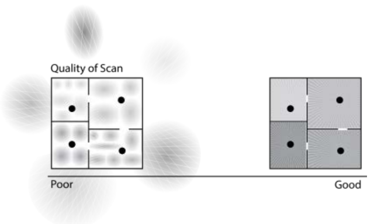


Fig.: 65 LE34 - Sensor to Sensor distances

Quality of Cleaning



50,4%

Derived from

Quality PointPoint: 10,0%

Quality SensorPoint: 66,9%

Quality PointPointRec: 74,4%

This shows a post-processing of the scan project to be average, probably conducted only by standard filters. But with a good mean of point to point distances below the recommended 30 mm for architectural recognition. (Fig.: 66, Fig.: 67)

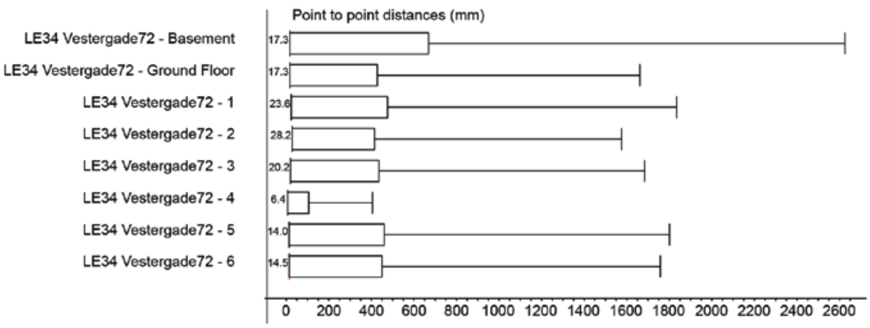


Fig.: 66 LE34 – Point to Point distances

Average Mean = 17,7 mm

Average StD = 611,6 mm

Quality PointPoint = 10,0%

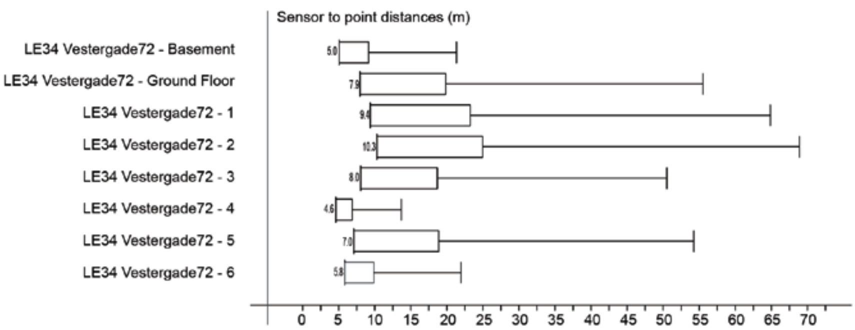


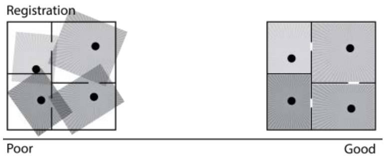
Fig.: 67 LE34 – Sensor to Point distances

Average Mean = 7,3 m

Average StD = 13,6 m

Quality SensorPoint = 66,9%

Quality of Registration



Average point distance error: 4,4 mm

Surveyed references: 4

Most used number of references: 3

This shows a good registration process with point distance error close to the 5 mm baseline and mainly use of the minimum of 3 references and surveyed references.

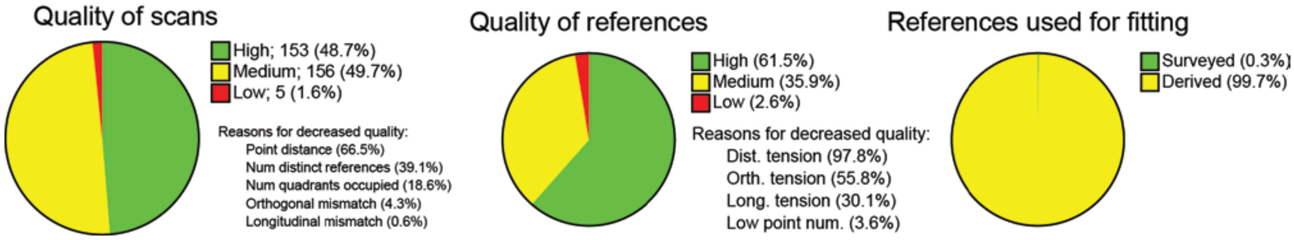


Fig.: 68 Diagrams registration quality from ATS Quality manager. For more information (ATS, 2013)

7.2.1.3.3. CITA

Project Dermoid III

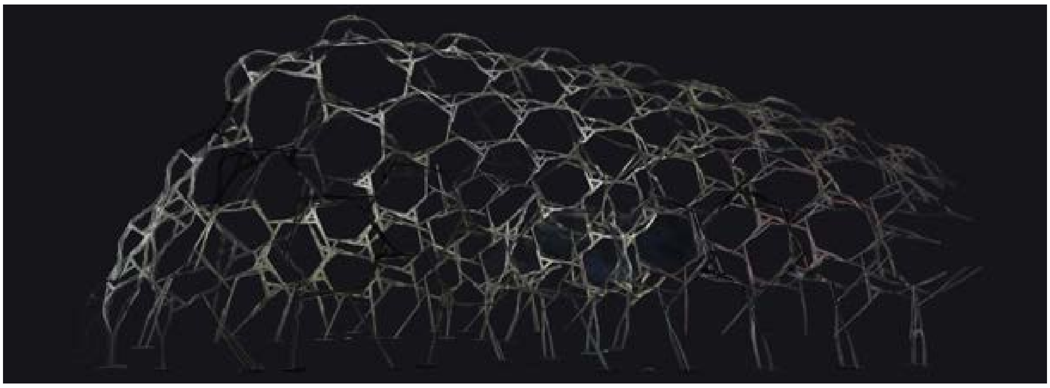


Fig.: 69 Project Dermoid III by CITA

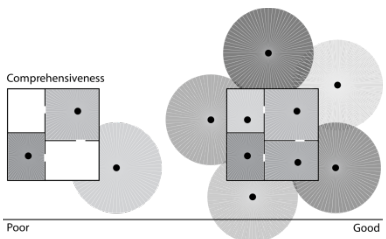
Number of Scans: 12

Number of points: 0,5 * 10^9

Project Dermoid III (Fig.: 69) is a small scan project by CITA consisting of a point cloud of an exhibition object.

7.2.1.3.3.1. *Measurements*

Comprehensiveness



25 %

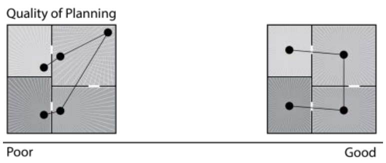
Derived from

Interior 50%

Exterior 0%

This shows a very sparse scan project, with only part of the interior, and follows the line of work described by stakeholder by being focused on scanning a specific object.

Quality of Planning



71,4%

Derived from

SensorSensor Mean = 5,1 m

SensorSensor StD = 3,4 m

This shows a very well planned scan session with a consistent average of sensor to sensor distances around 5 meters and a narrow spread never exceeding the 30 meter maximum. (Fig.: 70)

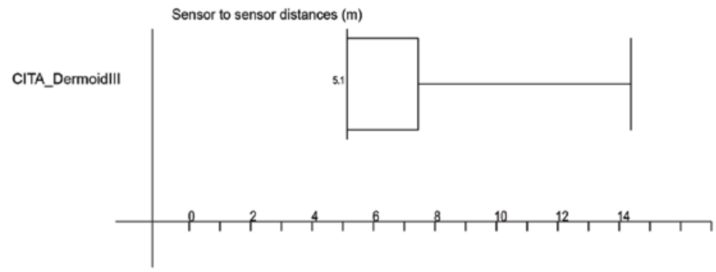
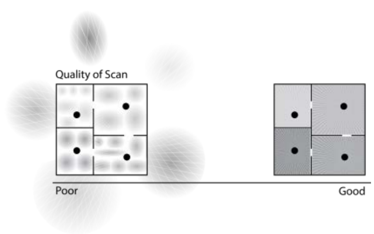


Fig.: 70 DermoidIII – Sensor to Sensor distances

Quality of Cleaning



80,1%

Derived from

Quality PointPoint: 82,0 %

Quality SensorPoint: 68,9%

Quality PointPointRec: 89,5%

This shows a post-processing of the scan project to be very well conducted done with standard filters and stray filter. And with a very good mean of point to point distances close to the recommended 10 mm for detailed architectural recognition. (Fig.: 71, Fig.: 72)

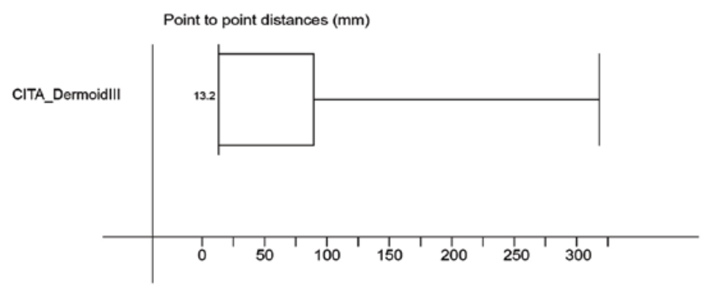


Fig.: 71 Dermoid III – Point to Point distances

Average Mean = 13,2 mm

Average StD = 113,0 mm

Quality PointPoint = 82,0 %

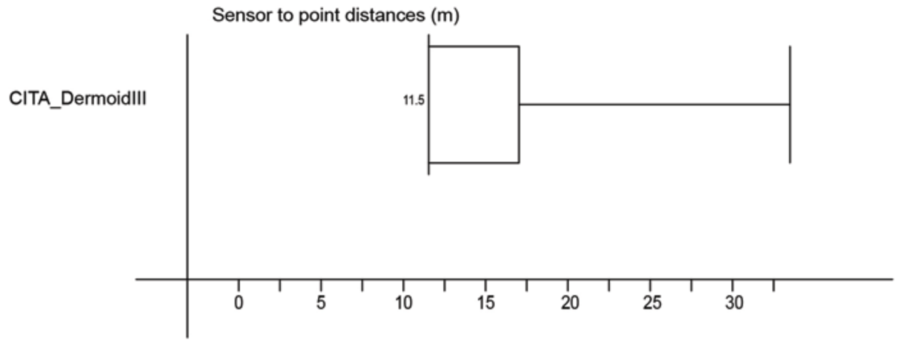


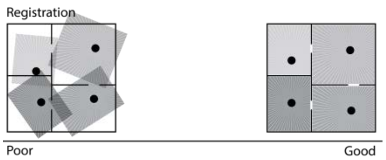
Fig.: 72 Dermoid III – Sensor to Point distances

Average Mean = 11,5 m

Average StD = 8,1 m

Quality SensorPoint = 68,9%

Quality of Registration



Average point distance error: 1,1 mm

Surveyed references: 0

Most used number of references: 3

This shows a very good registration process with point distance error way below the 5mm baseline and mainly use of the minimum of 3 references, but no surveyed references.

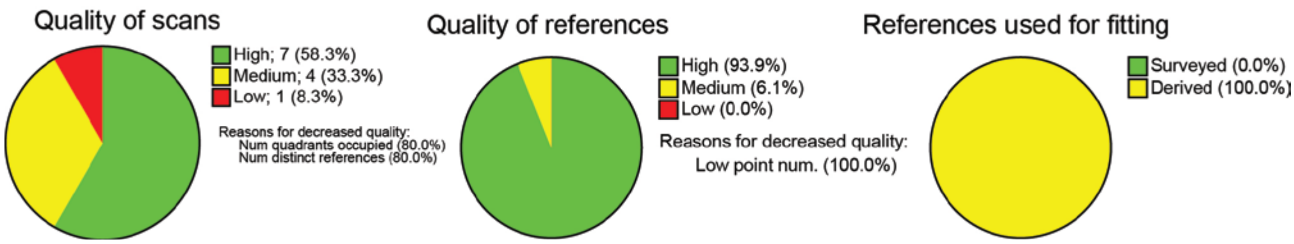


Fig.: 73 Diagrams registration quality from ATS Quality manager. For more information (ATS, 2013)

7.2.1.3.4.   ATS

Project Restaurant

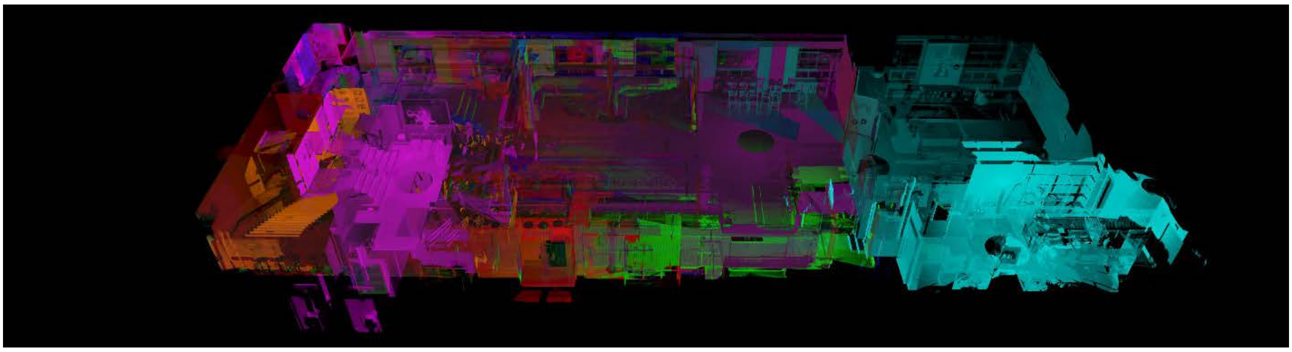


Fig.: 74 Project Restaurant by ATS

Number of Scans: 13

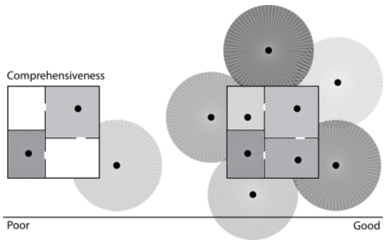
Number of points: 0,35 * 10^9

Project Restaurant (Fig.: 74) is small scan project of the interior of a restaurant by ATS. Because the way the scan data set has been delivered the processes for evaluating the registration is not possible, and will not be available.

The quality measurements show an exhaustive interior project, with a just below average quality of planning. The quality of scan shows an exceptionally well conducted post-processing of cleaning the point cloud, probably done by applying standard filters, stray point filter and distance based filter or manual cropping. And with a very good mean of point to point distances close to the recommended 10 mm for detailed architectural recognition.

7.2.1.3.4.1. *Measurements*

Comprehensiveness



50 %

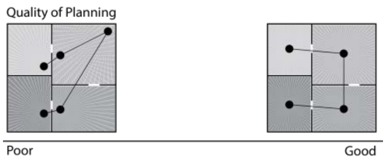
Derived from

Interior 100%

Exterior 0%

This shows an exhaustive interior scan project, with all interior scanned and all facades but the roof scanned.

Quality of Planning



43,8%

Derived from

SensorSensor Mean = 9,3 m

SensorSensor StD = 7,6 m

This shows an below average planned scan session with a consistent average of sensor to sensor distances around 9 meters and a narrow spread only just reaching the 30 meter maximum. (Fig.: 75)

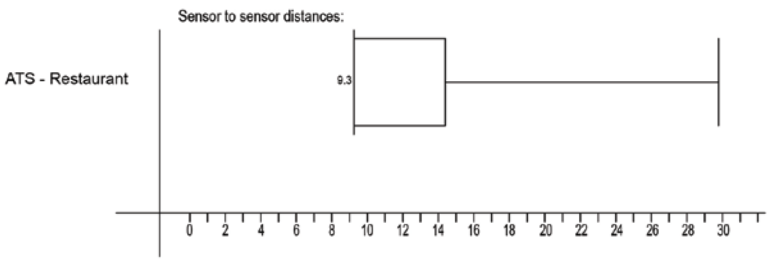
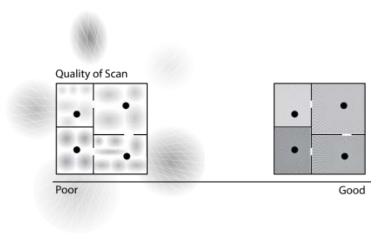


Fig.: 75 ATS Restaurant – Sensor to Sensor distances

Quality of Cleaning



87,2%

Derived from

Quality PointPoint: 94,2%

Quality SensorPoint: 78,5%

Quality PointPointRec: 88,9%

This shows a post-processing of the scan project to be very well processed, probably conducted by standard filters, stray filter and distance based filter or manual cropping. And with a very good mean of point to point distances close to the recommended 10 mm for detailed architectural recognition. (Fig.: 76, Fig.: 77)

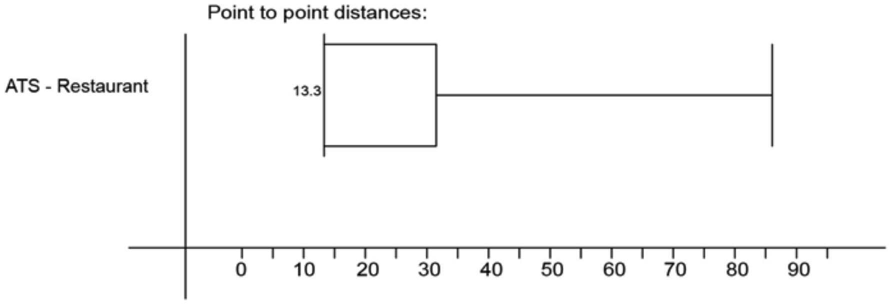


Fig.: 76 ATS Restaurant – Point to Point distances

Average Mean = 13,3 mm

Average StD = 27,0 mm

Quality PointPoint = 94,2%

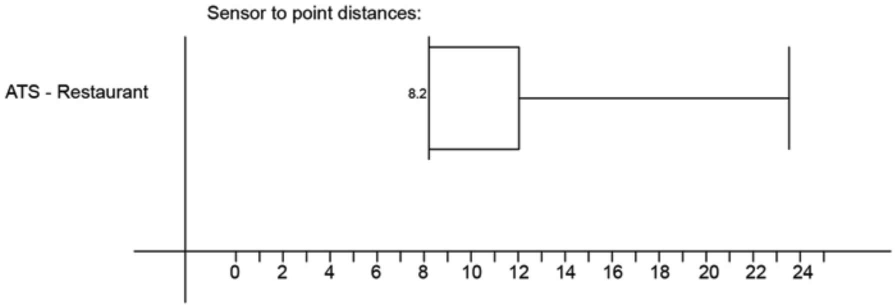


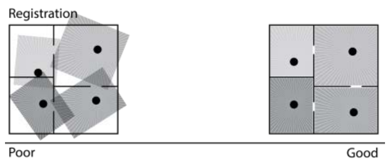
Fig.: 77 ATS Restaurant – Sensor to Point distances

Average Mean = 8,2 m

Average StD = 5,7 m

Quality SensorPoint = 78,5%

Quality of Registration



Not Available

7.3. Assessment of the WP7 IFC sample dataset

The data set of IFC samples was analysed with a tool developed in the Workpackage 7.

7.3.1.1. *Description of developed methods and tools for IFC*

This chapter describes the rule based process used to investigate IFC data on the basis of bimsync. Among others: technical level, libraries used, description of steps in processing of data

The investigation of the IFC files for this takes place on datasets stored in bimsync. Bimsync[125] is a commercial IFC oriented model server developed by DURAARK -partner Catenda. It is built on top of Bimserver. With bimsync it is possible to upload, share, view, annotate, add “issues” (to-do-tickets), tag using IFD/bsDD, and to merge and download IFC-models.

Inside the DURAARK project we developed an “IFC-extractor”. This tool is used to extract “metadata” (number of floors, spaces etc.) from the IFC files stored in bimsync. The tool is created in Java using the “Dropwizard” libraries (a set of best-of-breed libraries for Web Applications, collected by Yammer).

The tool is deployed as a runnable and web-reachable java-application (does not require running inside a servlet server such as Tomcat).

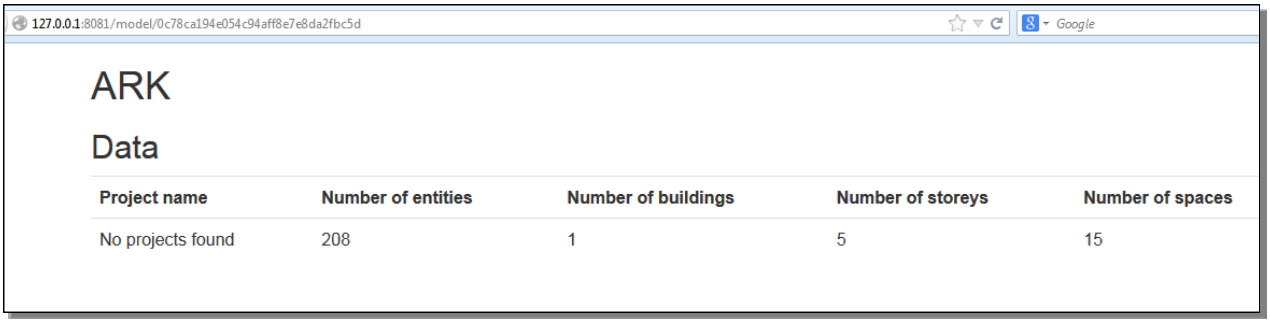


Fig.: 78 screenshot from an earlier version of the DURAARK IFC extractor

Newer versions will provide an «OverView» page where all projects a user has access to is listed, and where the information can be downloaded as an csv file.

The workflow is based on IFC-models that have already been uploaded to bimsync. The user enters the url where the IFC-extractor is deployed, and enters his/her bimsync-credentials. Using the oauth-protocol126 the user is authorized and gives the IFC-extractor (api-based) access to the same files as the user has access to.

IFC-extractor has access to the files using the bimsync-API127 . Access through an API (instead of using a plugin running inside of bimsync) makes it much easier and safer from the bimsync-administrators perspective to run code developed outside of Catenda.

In this way up to date “metadata” is available for all models that the user has access to in bimsync.

The list of relevant BIM-parameters/metadata that are extracted are shown want to extract from the IFC-models is described in the header of the attached document “IFC extracted data 01.xls”.

7.3.1.2. *Evaluation of the developed IFC extractor*

The extractor tool is coded to read IFC data from the Catenda online archive bimsync where all DURAARK models have been uploaded for evaluation. The data is read by the extractor tool from the file stored in bimsync and written to csv file format.

Possible sources of errors within this process are threefold:

[125] https://bimsync.com/developers/reference/api/1.0

[126] http://tools.ietf.org/html/draft-ietf-oauth-v2-22

[127] https://bimsync.com/developers/reference/api/1.0

1. The export from the native BIM format is the first source where translation of objects and data may be at risk.
2. The bimsync server upload and translation is at risk for bugs.
3. The extractor tool may create errors in reading and writing.

It has been observed in a least three cases that the extractor did not count correctly.

A bug in an earlier version of bimsync caused the import not to finish correctly and thereby creating errors in the files stored in the bimsync archive.

Both bimsync and the extractor tool will be improved in the future to meet the needs of the DURAARK research project.

7.3.1.3. *Assessment of the IFC dataset and discussion of results*

The developed tool for data extraction from the IFC files creates an output summarized in the spreadsheet “IFC extracted data 01.xls”.

Evaluation of the extracted data:

- “IFCproject” denotes the number of projects in the file. This should always be 1, but in many cases the number is 0 and in one case the number is 3. Most of the cases of the count of IFCproject being equal to zero are due to a bug in an early version of bimsync, not finishing imports correctly – leading to projects existing in bimsync but without content. In 3 cases the extractor does not count this correctly. The IFCproject with 3 occurences of IFCproject (“Autodesk-Research_210-King_Merged_Conf”) may have been created by merging 3 separate files in a wrong way and retaining the original project counts.
- IFCproduct denotes the number of elements in the model, i.e. combined number of floors, roofs, walls, windows etc. This number should be much greater than 1, but in many cases it is 0. This must be attributed to an error in the extraction tool.
- IFCbuildingStorey denotes the number of floors in the building. A few files have 0 storeys which seem suspicious as every building should have at least 1. A single project turns out 39 storeys which is much too high a number. It may be due to a faulty merger of multiple models as explained above, thus retaining and summing up the original counts.
- IFCspaces denotes the number of rooms in the model. This designation of spaces as rooms is not mandatory; hence the number can be 0 which it is in many cases.
- IFCwall should not be able to be 0, but in many cases it is.
- IFCbeam, -slab, -column, -pipe are objects that are not necessarily present in every model. This is well reflected in the results.
- IFCroof is expected to be greater than 0 in every project, but many have none. This should not be able to happen with projects that otherwise seems nice and definitely have roofs.

Apart from the possible influences of bimsync and the extractor tool on the data, the main reasons for the unexpected results, and generally low data content of the models, might be because of:

- Stakeholders do not use the IFC format in a consistent way. The usage is not dictated by IFC, hence it is possible to make inconsistent models.
- Exports from proprietary formats are not always true to the IFC classes.
- The way the models are built, e.g. some object types does not translate directly into the correct IFC property sets.
- The user’s modelling skills not always sufficient to create optimal IFCs.

- Later stage models from stakeholders not involved in the early stages are more precise.
- Stakeholders minimize the amount of attributes and metadata to their own need.
- Some of the models are technical domain models and do for that reason does not contain the usual building components.

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