



D7.2

SME Use Case - Design and Retrofitting

DURAARK

FP7 – ICT – Digital Preservation
Grant agreement No.: 600908

Date: 2015-03-31
Version 1.0
Document id. : duraark/2015//D.7.2/v1.0



Grant agreement number	:	600908
Project acronym	:	DURAARK
Project full title	:	Durable Architectural Knowledge
Project's website	:	www.duraark.eu
Partners	:	LUH – Gottfried Wilhelm Leibniz Universitaet Hannover (Coordinator) [DE] UBO – Rheinische Friedrich-Wilhelms-Universitaet Bonn [DE] FhA – Fraunhofer Austria Research GmbH [AT] TUE – Technische Universiteit Eindhoven [NL] CITA – Kunstakademiet Arkitektskole [DK] LTU – Lulea Tekniska Universitet [SE] Catenda – Catenda AS [NO]
Project instrument	:	EU FP7 Collaborative Project
Project thematic priority	:	Information and Communication Technologies (ICT) Digital Preservation
Project start date	:	2013-02-01
Project duration	:	36 months
Document number	:	duraark/2015/D.7.2
Title of document	:	D7.2 SME Use Case - Design and Retrofitting
Deliverable type	:	Report
Contractual date of delivery	:	2015-03-31
Actual date of delivery	:	2015-03-31
Lead beneficiary	:	CITA
Author(s)	:	Martin Tamke < martin.tamke@kadk.dk > (CITA) Henrik Leander Evers < heve@kadk.dk > (CITA) Sebastian Ochmann < ochmann@cs.uni-bonn.de > (UBO)
Responsible editor(s)	:	Martin Tamke < martin.tamke@kadk.dk > (CITA)
Quality assessor(s)	:	Michelle Lindlar < Michelle.Lindlar@tib.uni-hannover.de > (TIB) Martin Hecher < martin.hecher@vc.fraunhofer.at > (FHA)
Approval of this deliverable	:	Jakob Beetz < j.beetz@tue.nl > (TUE) Stefan Dietze < dietze@l3s.de > (LUH)
Distribution	:	Public
Keywords list	:	Stakeholder, Evaluation, Integration, use cases

Executive Summary

The Deliverable is part of Task: SME Use Case - Design and Retrofitting. The Deliverable investigates, how data from a long-term archive can be re-ingested into the design and construction of architectural structures in a BIM context. This part of the digital building lifecycle includes the documentation of the current state of a building through 3D scan, and the merge of information with existing BIM data. The deliverable evaluates, especially how the so far existing DURAARK components can support stakeholder processes in the future, and how the modular approach of the DURAARK system allows for the integration of components into the stakeholder's processes. The evaluation took place through, in a for this purpose developed, test environment on the base of the stakeholder software Rhino/Grasshopper. This allows to handle BIM files while existing Point Cloud objects of Rhino where extended for this task. Collaborations with stakeholders allowed to align the tool and workflow to the stakeholder expectations, evaluate the DURAARK components on a qualitative level and provide insights, how the DURAARK workbench and components and their GUI can be further developed in order to provide a high level of usability and relevance for stakeholder practice.

Table of Contents

1	Introduction	5
1.1	Aim and focus of the Deliverable	6
2	Methods, Decisions and Risks	8
2.1	Identified Risks	10
3	Practices and research in workflows with BIM and Point Clouds	16
3.1	Existing practices of SME	16
3.1.1	Modelling paradigms in BIM	17
3.1.2	Modelling paradigms for Point Cloud to BIM modelling	20
3.1.3	Usual architectural workflow for renovation project	24
3.2	Existing practices in research	26
3.3	Potential for practice through a digital life-cycle of building documents	26
4	Workflow integration	28
4.1	Proposed Workflow for the re-use of digital building information	29
4.1.1	Establishment of a common workspace for BIM and Point Cloud	30
4.2	Stakeholder software package	30
4.2.1	Rhino	31
4.2.2	Grasshopper	31
4.3	Grasshopper Components	32

4.3.1	Import	33
4.3.2	Allocation	35
4.3.3	Query and Select	37
4.3.4	Analysis	38
4.3.5	Output	41
5	Case Studies with DURAARK components	43
5.1	Diakonissestiftelsen	43
5.2	LE34 - Façade	47
5.3	LE34 - Højbro Plads	49
5.4	Plan3D - Haus 30 and Stattsbyg - Risløkka	53
5.5	Nygade	62
6	Conclusion and Impact	71
6.1	Workflow Integration	72
6.1.1	Workflow integration - Compliance with stakeholder interests	72
6.1.2	Workflow integration - Compliance with stakeholder processes	72
6.1.3	Workflow integration - Gains in productivity for stakeholders	73
6.1.4	Workflow integration - Adaptability through DURAARK modular approach	73
6.1.5	Workflow integration - Registration of Architectural datasets	74
6.1.6	Workflow integration - Further extensions	74
6.2	Validation	75
6.2.1	Validation - Filter and Select	75
6.2.2	Validation - Difference detection component	75
6.2.3	Validation - Reconstruction component	76
7	Licenses	77

1 Introduction

A digital lifecycle is emerging (Fig. 1), in which building information is continuously retrieved, analysed, enriched, re-used and re-archived. The contact of a potential stakeholder from SME with a system that follows the DURAARK approach occurs in two points of time:

1. When ingesting data to the DURAARK long term archive (Deliverable 7.3), where these have to be appraised and enriched by the user to be re-used and re-ingested into the archive. This part is mainly situated in the domain of building owners and institutional stakeholders as archives.
2. When retrieving data from a potential long term archive and interlacing it with workflows related to the planning of retrofitting and other planning tasks related to existing structures. These tasks are mainly executed by engineers and architects. (Fig. 1)

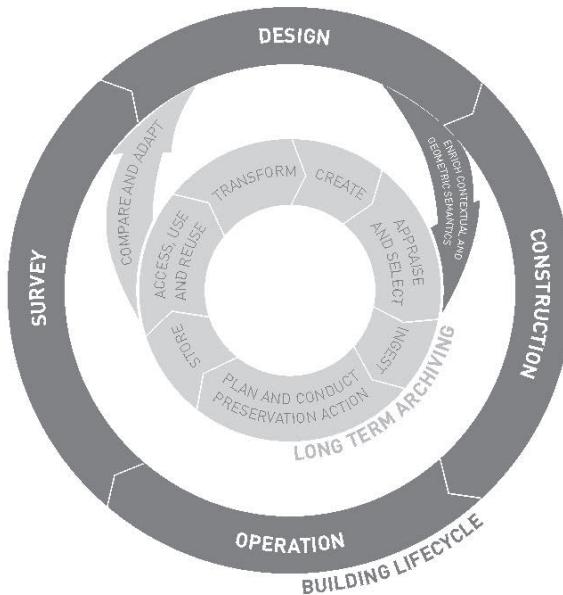


Figure 1: The future lifecycle of building data with points for ingest and retrieval / use of data between a digital archive and the stakeholders workflows.

While the DURAARK Deliverable D7.3 examines the affordances for stakeholders to archive data in their current and future workflows and how the DURAARK approach can

enable this practice, it is the aim of this Deliverable to examine how archived building data can be reused in future workflows of the architectural planning profession.

The Deliverable D7.1 identified the challenging current condition for the reuse and especially the combination of different types of digital building data in the stakeholders practices. It identified gaps, as the processes of stakeholders are currently missing means, that allow for the integration of archived data into workflows, as well as means to assess the quality of the archived data in relation to other archived or new building data. It concluded that archived digital data will only be reused, when it can be validated and integrated with a reasonable effort in the workflows of stakeholders. This is especially true for the two types of data under investigation in the DURAARK project: Point Clouds (E57) and BIM data (IFC).

Chapter 3 revisits and details the current practices of the stakeholders, considered data producers, in order to gain an understanding of the challenges for, and the potentials of, a use of the DURAARK system and components. Architects, land surveyors and engineers were in Deliverable D2.1 identified as a group, which actively engages with building data - they not only use and create data, but also modify the different types of data in their practices. Based on the investigation of the current workflows of the stakeholders in relation to BIM and Point Clouds in chapter 3.1 and a brief overview of the related research in chapter 3.2, the potential for stakeholders through the digital lifecycle of building documents is drafted in chapter 3.3.

1.1 Aim and focus of the Deliverable

The focus for this deliverable is set on the retrieval side of the potential long term archive. We investigate how data retrieved from a future DURAARK long-term archive can be combined, analysed and integrated within stakeholder's work environments. The Deliverable takes a point of departure in the modular setup of the DURAARK approach. Developed tools for the analysis, extraction and enrichment of data during the ingest, have a dual character, as they can as well help stakeholders to retrieve information from archived data and make this usable in their workflows. Chapter 4 investigates means to integrate the DURAARK modules into the workflow of SMEs from the building profession. The integration effort is based on use cases defined in D2.1 and pays attention to the fact that architectural projects are highly diverse in nature. In existing stakeholder practise,

this often leads to required adaptation and further development of workflows to satisfy the projects' needs. These findings motivated the establishment of a test bed, which is flexible and modular and can through this adapt to the stakeholders' specific approaches towards projects. This required a closeness to the stakeholders' practice and pointed at the use of stakeholder software as mean to evaluate the workflow integration of the DURAARK components. The Chapter 4.2 introduces the chosen stakeholder software environment and its integration in a BIM workflow. Chapter 4.3 shows the developed steps and components to integrate and validate archived building data into stakeholders' workflows, while chapter 5 evaluates the developed DURAARK tools in real-world cases from stakeholders.

The conclusion in chapter 6 discusses finally, how the data that stakeholders extracted and refined from archived building data can be re-ingested into a long-term archival solution and proposes further steps in the DURAARK project.

2 Methods, Decisions and Risks

The evaluation of the DURAARK tools and the underlying modular architecture of the DURAARK toolset is undertaken with a practice based method [2] on the base of use case UC7: Plan, document and verify retrofitting/energy renovation of buildings defined in D2.1. The width of architectural practice in relation to design and retrofitting suggests a targeted approach undertaken through the implementation of the tools and conceptualised workflows in processes of stakeholders. This approach allows for a constant evaluation of the development against the architectural project and feedback through the stakeholder group. For this task stakeholders have been chosen, that:

1. Have a practice with BIM
2. Have a portfolio of design and retrofitting related projects
3. Have ongoing cases, which relate to the task of this deliverable

The evaluation takes place in a hands-on scenario under involvement of stakeholders from professional practice. The description of the stakeholders' practice is based on recorded interviews with them.

It was decided, that the evaluation would take place in the actual work environment of the stakeholder. The reasons for this were:

- prevent stakeholders to be confused and have to invest extra time in the learning of a new tool.
- a generic tool might appear distant to the stakeholders and impede meaningful answers from them.
- create a link to the stakeholders' current practices will make the evaluation as realistic and meaningful to them as possible.
- give stakeholders a good opportunity to speculate about other future applications of the DURAARK tools and concepts in their practice.

The evaluation of the workflow takes place in a scenario, which is set between the retrieval of archived documents and before the actual design and planning of retrofitting work of architects and engineers is finished. The evaluation of a base functionality to query and retrieve data from a long-term archive is assumed to be given for this deliverable. Our

scenario takes place after a stakeholder did a query and retrieval action in a DURAARK long-term archive for architectural data relevant to the respective design and retrofitting project. We secure this decision and the link to a future DURAARK archive, as we limit the used data formats in this deliverable to those, that are archived in a DURAARK long-term archival solution.

The development necessary to integrate DURAARK tools into the work environment was guided through a regular dialogue with the stakeholders. The concept and progress were presented to them and the comments directly influenced the next steps on the developers' side. A flexible development platform was necessary, which can be quickly adopted to the stakeholders' needs on a higher level, while leaving the underlying DURAARK tools untouched. This platform has to be similar to those used by the stakeholders. Dynamo for Revit¹ and Grasshopper for Rhino² were here identified as programming platforms already familiar to the SMEs. The DURAARK tools and other libraries and software necessary for the implementation effort would be integrated into this platform by means of Python Wrappers. This can easily be achieved, as Rhino³ and Dynamo⁴ both have an implementation of Python⁵. This allows for an exchange of the Python code between both platforms and serves as a contingency plan, if problems in the implementation in one platform occur or stakeholders prefer another one. Initial tests with the exchange of code between the platforms were positive.

The decision to implement DURAARK tools in the environments of stakeholders requires to compile the code of the DURAARK tools from the original Linux based development platform to the Windows platform. The effort to compile code is a good test for the robustness of the code, but means as well, that the implemented and hence evaluated tools are often not representing the latest version. This lack does not conflict with the interest of this deliverable, which has a focus on the general workflow integration and the evaluation of the principal concepts of the developed tools.

¹<http://dynamobim.com/>

²<http://grasshopper3d.com>

³<http://wiki.mcneel.com/developer/python>

⁴<http://www.youtube.com/watch?v=iTWWnpURVEw>

⁵<http://ironpython.net/>

2.1 Identified Risks

Risks associated with the process:

#	Risk Description	Risk Assessment	Contingency Solution	Project Relevance
1	The chosen methodology is too case-specific and subjective, not allowing for generalizable answers	Impact: High Probability: Low The subjectivity is a risk of any qualitative study and partially intended, as it allows for a direct dialogue on the surveyed material.	A too narrow approach for this deliverable is counteracted by three measures: (1) a detailed plan for the process (2) the study being executed and monitored by several project team members from different domains and (3) the review process of the deliverable, bringing in yet two more views.	Low Not observed

Continued on next page

Table 1 – *Continued from previous page*

#	Risk Description	Risk Assessment	Contingency Solution	Project Relevance
2	The implementation of the DURAARK tool in the stakeholders software environment is not possible	Impact: High Probability: Medium. The implementation of tools into other platforms is always challenging and endangered by details, that were not foreseeable in the beginning and through changes in either of the involved software environments.	Such a change was observed, when AUTODESK pulled the support for PointClouds out of the API of their latest REVIT release. Giving preference to their own undocumented and inaccessible ReCap PointCloud engine ⁶ , the ability to implement DURAARK tools on a test-base into REVIT was made impossible. The contingency plan to execute the evaluation on a second BIM platform worked successfully.	Low Observed

*Continued on next page*⁶<http://www.autodesk.com/products/recap/overview>

Table 1 – *Continued from previous page*

#	Risk Description	Risk Assessment	Contingency Solution	Project Relevance
3	Not enough feedback from stakeholders is available to conduct an evaluation	<p>Impact: High</p> <p>Probability: Medium</p> <p>The DURAARK partners come from different domains, they have established networks within their areas, which includes contact to stakeholder groups involved in this deliverable. New contacts were established during DURAARK dissemination activities, e.g., through follow-up conversations to presentations given at conferences and targeted search and contact. As the project has peaked the interest of those dealing with building information data and works in a field highly relevant to the profession (BIM in retrofitting), it is unlikely that not enough stakeholders can be gathered for feedback.</p>	If the initially selected stakeholders are not providing sufficient answers or do not have the necessary resources or cases to do an evaluation, other stakeholders will be contacted and involved in the evaluation activities related to this deliverable.	<p>Low Not observed</p>

Continued on next page

Table 1 – *Continued from previous page*

#	Risk Description	Risk Assessment	Contingency Solution	Project Relevance
4	The evaluation puts forth that the developed DURAARK methods and tools do not align with user expectations	<p>Impact: High</p> <p>Probability: Low</p> <p>The project regularly monitors the state-of-the-art development connected to DURAARK research and developments. In consortium-wide meetings and discussions, planned development is presented and discussed. The consortium includes representatives of the cultural heritage, software vendor and research domain. Furthermore, close connections to the architectural, engineering and land surveying domain exist. Therefore, requirements and expectations of the relevant domains are well known to the consortium and it is not expected that the DURAARK development is totally missing the target group.</p>	This deliverable is tasked with the evaluation of the DURAARK developments. Any feedback from practice is welcome at this stage and can be encountered in the upcoming 3rd year of the DURAARK project.	<p>Low</p> <p>Not observed</p>

Continued on next page

Table 1 – *Continued from previous page*

#	Risk Description	Risk Assessment	Contingency Solution	Project Relevance
5	The evaluation takes place on outdated DURAARK components	Impact: Low Probability: Low.	This lack does not conflict with the interest of this deliverable, which has a focus on the general workflow integration and the evaluation of the principal concepts of the developed tools.	Low observed
6	Parts of the DURAARK components are not ready for evaluation	Impact: Low Probability: High.	Delays and changes of plan are common imponderabilities in research projects. The modular approach of all parts of the DURAARK project allows to replace the functionality of one or several defaulting components with manually proxy solutions. This would fill the gap between components and gives stakeholders still the ability to evaluate all other steps in the evaluated workflows. The modular approach might as well allow to reconfigure a workflow in the chosen Grasshopper prototyping environment.	Low not observed

Table 1: Risks identified and assessed

3 Practices and research in workflows with BIM and Point Clouds

This chapter investigates current practices in profession and those in research, which will affect the in chapter 1 identified stakeholders concerning their workflows with Point Cloud and BIM related workflows. This non-exhaustive survey is based on interviews and an investigation of the collected DURAARK repository of Point Cloud and BIM datasets. The latter originates, as described in D7.1, from practices, which are pioneering the still emerging practices with BIM and Point Clouds.

3.1 Existing practices of SME

Currently the work environments at stakeholders for Point Cloud and BIM files are almost totally separated. The investigation of stakeholder design and construction software in D7.1 showed the lack of sufficient integration of tools to support an integration of Point Cloud data. This situation hasn't changed since the delivery of the above mentioned deliverable. BIM software assumes a refinement of Point Cloud data in third-party software. The software described in D7.1, such as i.e. Kubit Point Sense⁷ or the newly released EdgeWise BIM suite⁸, which allows automated feature detection of architectural elements in Point Clouds from within BIM software (Revit), addresses through pricing, handling and functionality specialists situated outside the realm of the investigated stakeholders. Specialist tools are not only expensive in terms of cost and training for operating personnel, but create as well hurdles for the data flow, as interfaces between the tools always result in loss of information.

The success of companies like the in D7.1 presented Plan3D, consisting entirely of architects, shows hence that the stakeholders themselves are at the moment best suited to consolidate Point Clouds into BIM data. They have the architectural knowledge to abstract BIM models from Point Clouds, which follow the setup and modelling conventions needed to create an integration into workflows. The interviews done for this report with stakeholders from architecture, engineering and land surveying underline this finding. It becomes clear, that the current practice is laborious and especially not well suited to generate BIM data for retrofitting of buildings.

⁷<http://gb.kubit-software.com/CAD/Products/PointSense/index.php>

⁸<http://clearedge3d.com/products/edgewise-bim-suite/>

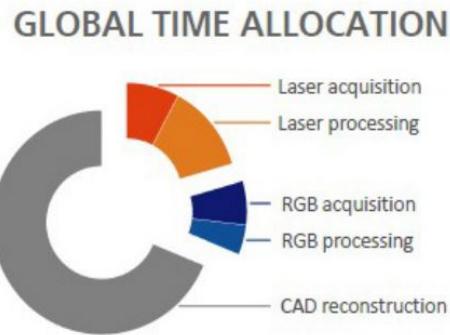


Figure 2: In current practices only 30 percent of the global time are needed to take scans and photos of a building, while 70 percent of time is occupied with BIM creation. [1]

As a result professionals have to spend considerable effort to convert existing building data into forms that can be used in planning and design. Recent publications [1] on the creation of BIM data from Point Clouds with specialists and specialised proprietary tool indicate, that even here around 70 percent of the global time is spent on this task solely.

The following chapters 3.1.1, 3.1.2 and 3.1.3 provide insights into the related architectural practices, especially in relation to BIM.

3.1.1 Modelling paradigms in BIM

In order to familiarize the reader with modelling in BIM this section will briefly summarise the current strategies available in most BIM software packages. Commonly three modelling approaches are provided in BIM.

3.1.1.1 BIM Modelling with 2D lines or points is the most commonly used method of modelling in a BIM environment. For walls the user picks a specific wall object to model and draws 2D lines on a specified level. The wall alignment to the 2D line, the dimensions and internal structures are parametrically defined by the object parameters. For doors, windows etc. the same object based modelling approach is used. Here a 2D point on a level defines the position of e.g a window. The vertical position and the sizes and internal structures of that window is then defined by the object parameters. (see Fig 3)

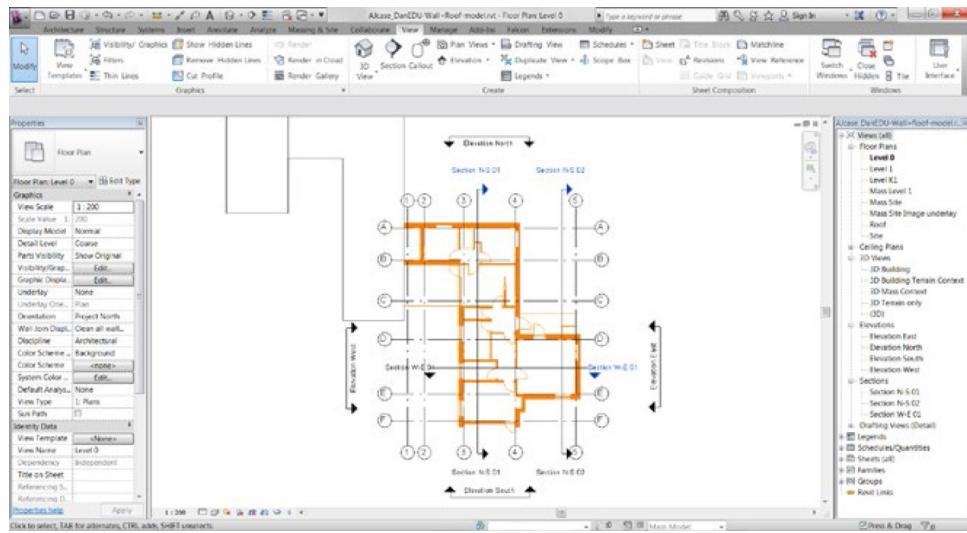


Figure 3: Screen capture from Autodesk Revit displaying a level with walls, doors and windows modelled by 2D lines and points. Besides this the level contains helping grid lines and elevation and section arrows.

3.1.1.2 BIM Modelling with 2D foot-print is another parametric modelling approach for BIM objects. An object's foot-print is a 2D bounding curve drawn in a projection view, e.g. plan, section or elevation. The object's 3rd dimension is defined by the object parameters. This is a common way of modelling roof slabs, floor slabs etc. In Fig. 4 (left) the pink line is the 2D foot-print of a roof-slab drawn in plan (view in 3D) while the slope of the roof surface is defined by the object's "slope" parameter.

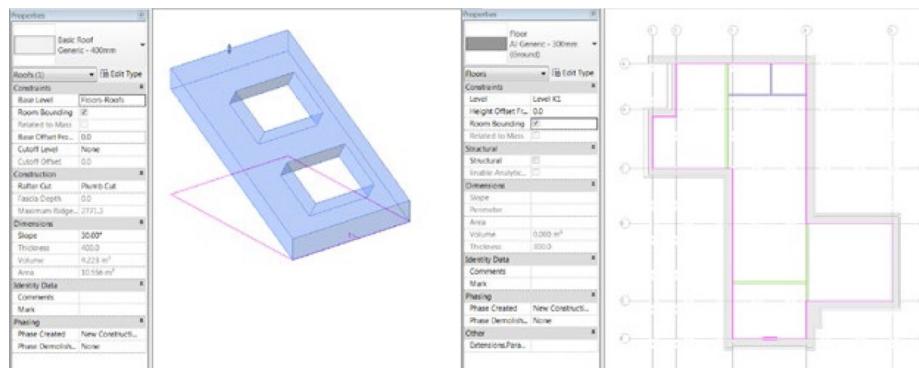


Figure 4: A BIM object's foot-print is a 2D bounding curve drawn in a projection view, e.g. plan, section or elevation. The object's 3rd dimension is defined by parameters. Here the pink line is the 2D foot-print of a roof-slab drawn in plan (view in 3D) (left) and a floor slab (right). The slope of the roof surface and the floor thickness is defined by object parameters.

3.1.1.3 The Face-based modelling approach gives the user the option of modelling with volumes. The user can define more complex shapes than with the other approaches. After a volume has been defined certain objects like walls or a roof are attached to faces of the volume. Being parametric, the volume can be changed later in the process and the attached objects follow the changes. This approach is used for the conceptual modelling phase of a design project or for achieving more complex shapes in a BIM environment, which often limits the designer by the rigidly defined objects. This parametric modelling approach is however prone to errors, as it contradicts the rigidity of the generally library based modelling paradigm in BIM software. It hence is not often used. (see Fig. 5)

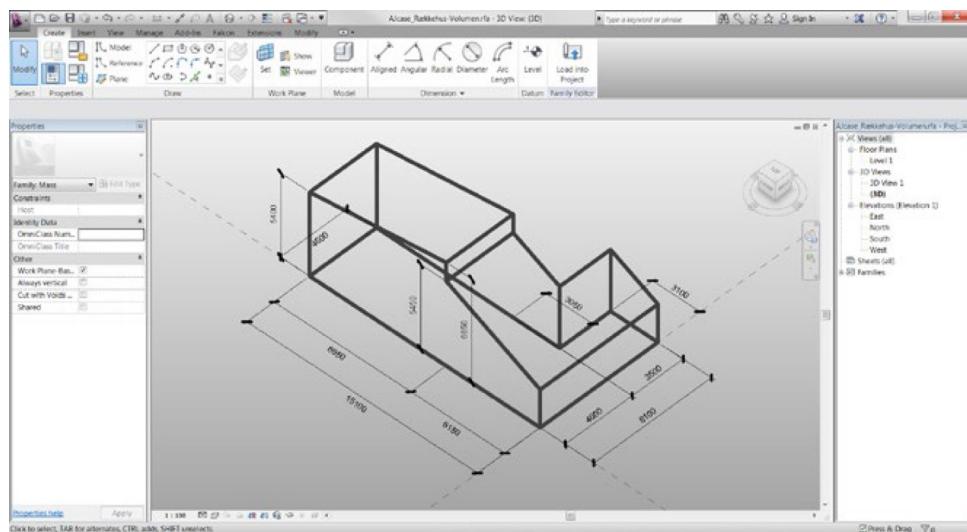


Figure 5: A screen capture of a volume modelled from measurements for face-based modelling in Autodesk Revit. In Revit this is called Conceptual Mass family.

3.1.2 Modelling paradigms for Point Cloud to BIM modelling

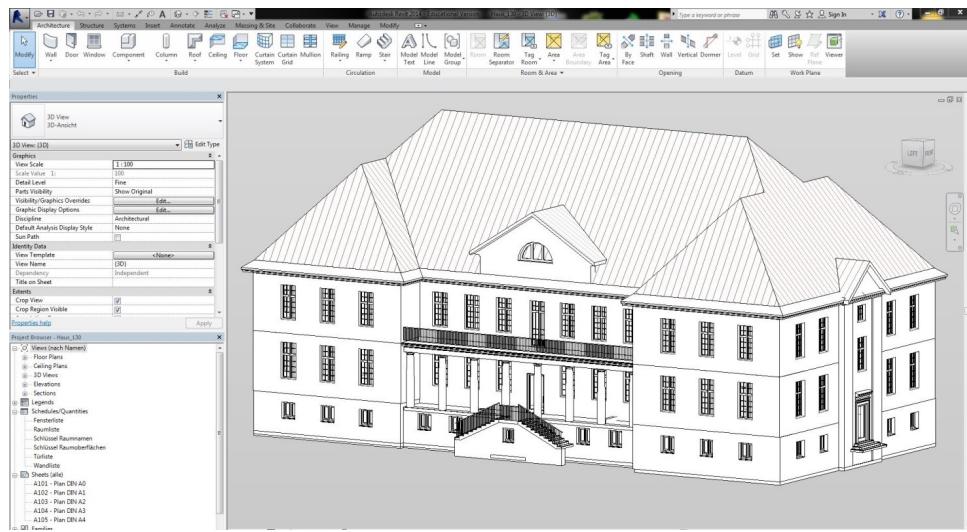


Figure 6: Screen capture of Haus 30 by Plan3D in Revit

This section exemplifies the current workflow from Point Cloud to BIM modelling in stakeholders' software. This is showcased through a project from the DURAARK repository of data sets: The project Haus 30 (Fig. 6) by Plan 3D⁹.

Haus 30 consists of a BIM model modelled in Autodesk Revit on the basis of a comprehensive laser scanning campaign, which resulted in an exhaustive Point Cloud of the building. (see Fig. 7)

⁹<http://www.plan3d-berlin.de>

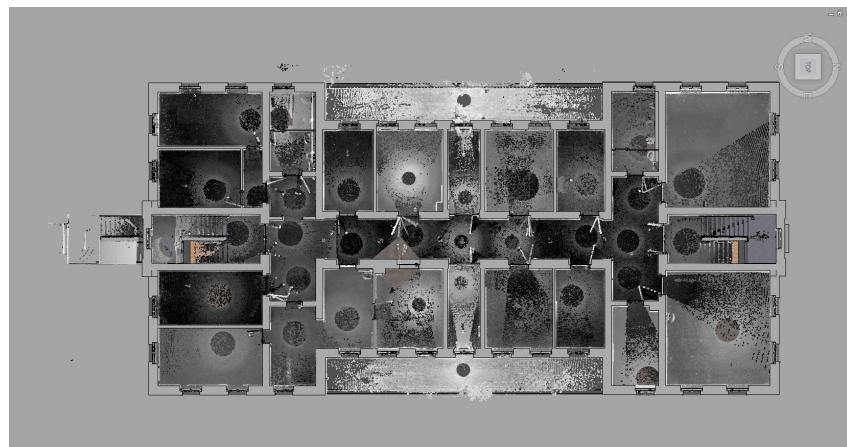


Figure 7: This plan view reveals that at least 38 scanning positions have been engaged to complete the Point Cloud of level 2.

Through investigation of this project and several others from the DURAARK data sets, a common modelling approach becomes evident. The basic steps of this modelling approach consists of the following:

1. Structuring the Point Cloud into clusters for each level. This is done to maintain an overview of the project via the ability to only view the specific floor which is currently being worked on.
2. Setting up a project by creating levels, elevations and sections, as well as importing a project template consisting of generic object types and sizes.
3. On the base of the Point Cloud clusters the walls, doors and windows etc. are modelled on the levels by the 2D line or point modelling approach.
4. And the floor, ceiling and roof slabs are modelled by the 2D foot-print modelling approach.

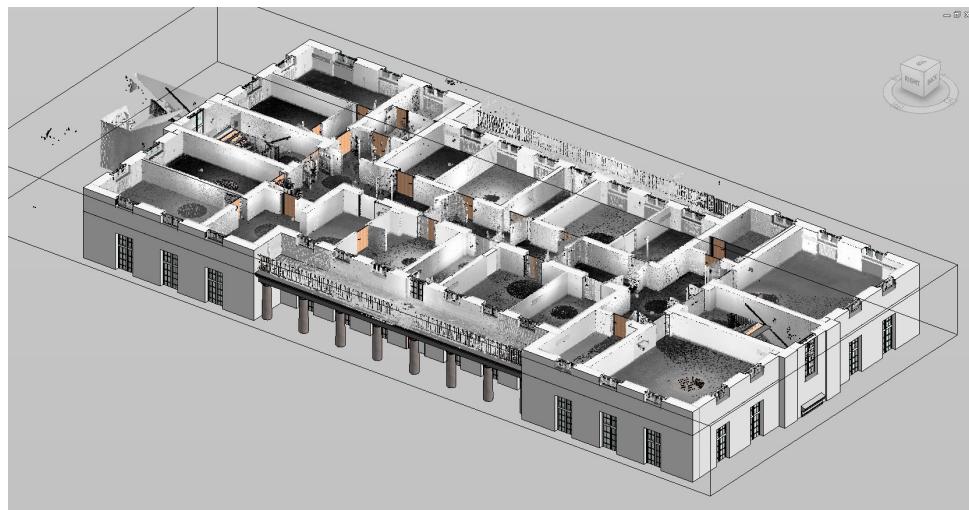


Figure 8: Second floor of Haus 30 with Point Cloud. Haus 30 has been modelled with a very high correspondence to the Point Cloud.

The Haus 30 shows a very high correspondence between model and Point Cloud. The BIM wall objects have been modelled with a tolerance of approx. 1-8 cm (Fig. 9). Windows are modelled with details including mullions and correct proportions of parts.

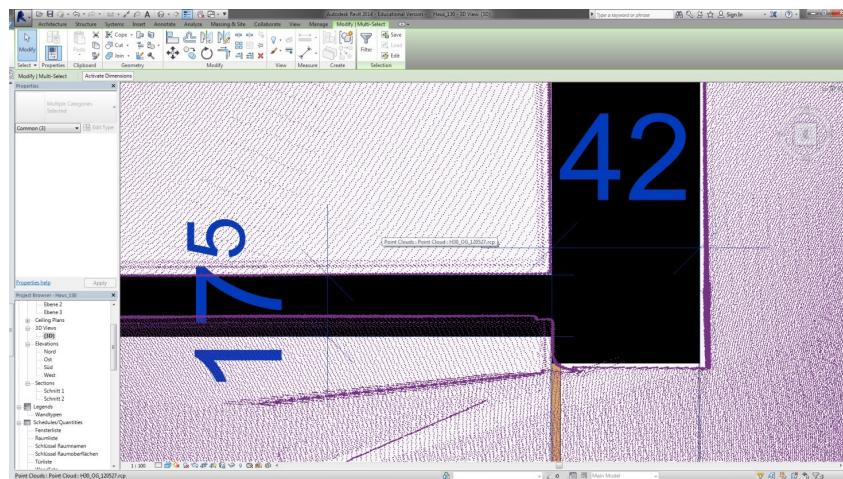


Figure 9: Illustration of tolerance between Point Cloud and BIM model. Image shows plan view of a light inner wall joining a heavy inner wall. The annotation unit is centimeters. Discrepancy between scan and light inner wall is approx. 6 cm in this case.

In a BIM modelling software like Revit the building objects needs to be attached to each other to contain the relations of the objects. This enforces the software to create the right

boolean functions of the geometric representations of the objects. Most of the walls and columns in the Haus 30 project have not been attached to the floors and roofs. This will result in geometric overlaps followed by e.g. imprecise area calculations. (see Fig. 10)

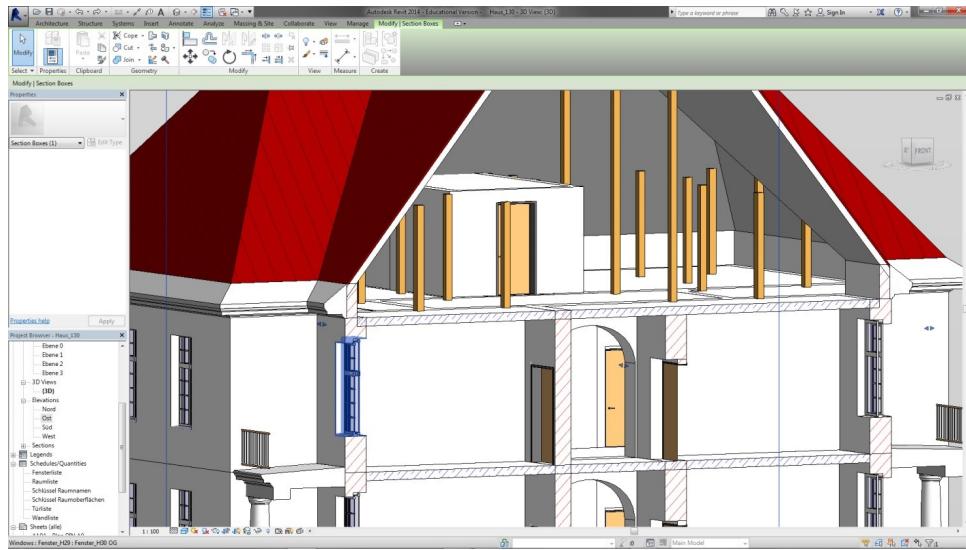


Figure 10: 3D section box view of interior. Image shows that most walls and columns are not attached to floors or roofs. This creates geometry overlap followed by imprecise area calculations.

The Revit project of Haus 30 contains beside the 3D objects:

1. Floor and ceiling plans of all 6 levels (only views, no printable sheets)
2. Elevations (N,O,S,W)
3. Sections (long and short)
4. Legend (brick, steel concrete and plaster)
5. Schedules/Quantities of
 - (a) Fensterliste - Window schedule
 - (b) Raumliste - Room schedule
 - (c) Schlüssel Raumnamen - Room name schedule
 - (d) Schlüssel Raumoberflächen - Room finish schedule
 - (e) Türliste - Door schedule

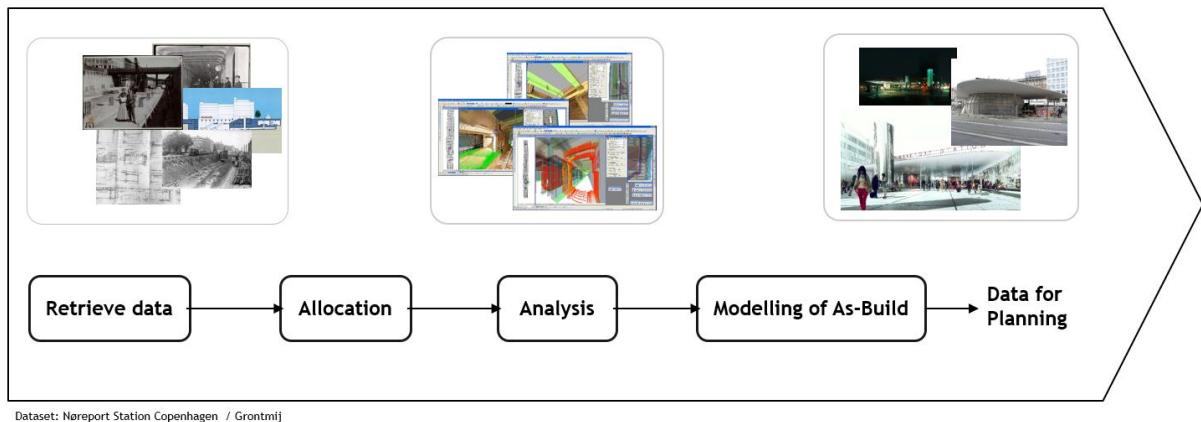


Figure 11: Typical work-steps in a retrofitting project

- (f) Wandliste - Wall schedule
- 6. Object library (families)

3.1.3 Usual architectural workflow for renovation project

Through collaborations and discussions with stakeholders and the tight collaborations with land surveying company LE 34 and the architectural company Zeso Architects, knowledge about the usual workflow in design- and retrofitting projects (UC 7) was established. A pattern of steps is characterising the start-up of a renovation project (DURAARK Use case UC 7) Fig. 11.

3.1.3.1 Retrieval of data consists of gathering all possible data about the site at which the renovation project is situated. This retrieval is done in a targeted way: the stakeholder is informed by the clients ideas and requirements concerning the site and the building program, which underlies the retrofitting project. The stakeholder queries i.e. state archives and the building owner's databases for existing building data. This consists nowadays usually of images or CAD line drawings such as plans, sections and façades, but can as well extend to 3d models, newspaper articles and such.

The stakeholder will also hire a land surveyor company to do a full or partial measurement of a building. A full measurement by a land surveyor is the most precise way to achieve as-build data on a building, but as well expensive in money and time. Stakeholders order hence often just sample measurements on site, which are subsequently used for verification of measurements they do themselves. Measurements are executed during visits to the site.

During these visits stakeholders will as well register non-geometric properties of the building elements, such as the type of wall (heavy or light), their base materials such as concrete or brick, the classifications of fire doors etc. They will as well take notes on the positions of pipes and main electrical closets for the whole building. An extensive photographic documentation is as well part of these site visits, which helps stakeholders to find out about details in their later work at the office.

3.1.3.2 Allocation of data consists of an assignment of the different acquired sets of data to each other. Their position is determined in the building and an overlay of these is created.

3.1.3.3 Analysis and verification of data consist of an assessment of the data in order to determine the individuals data sets plausibility and quality and get an understanding of the completeness and accuracy of the building data on a global level. The verification includes for instance an assessment of the precision of the dataset through an overlay of the sample measurements of the land surveyors and the other drawings in order to check, which parts of the building changed since the original production of the data. This and other results of this step might require further measurement on site.

3.1.3.4 Modelling of the as-built consists of modelling a BIM model based on the knowledge gathered in the previous steps. This means modelling a BIM model based on drawing parts which is up-to-date and model missing parts based on measurements, both from land surveyor and the site visit.

The model will be modelled with levels at the top finish of floors at each elevation, which also apply to mezzanine and smaller level shifts. Where possible the levels will be abstracted to a distance between each other dividable by 200 mm. Model lines will also be incorporated either based on retrieved drawing materials or placement of structural elements. These will, where possible, be abstracted to a distance between each other dividable by 300 mm. The model will be based on a predefined template which consists of a set of generic objects such as slabs, wall, doors and windows based on standard sizes. Where suitable these generic objects will be used.

The last step of the modelling incorporates the meta data about the wall types, classifica-

tions, materials and installations gathered at the site visit.

At this point the as-built model is ready for further development through the design of the renovation project.

In a real world project stakeholders might iterate between the steps. A verification of the data might for instance result in a further measurement campaign on site, while the planning of a building might require at a later stage the creation of a detailed analysis and documentation of the deformation of walls.

3.2 Existing practices in research

The task of reconstructing models from indoor Point Clouds has recently gained a lot of attention in research. The proposed reconstruction methods pursue different goals: Some approaches reconstruct visually-appealing — but not necessarily accurate — models for e.g. visualization and navigation purposes, while other methods try to capture the building's real geometry accurately for usage in the architectural domain. A common drawback of existing approaches is that none of them reconstruct buildings using native BIM entities (e.g. walls, floor slabs, doors, windows), and their relations (e.g. how walls are connected). This limits the usability of the reconstructed models in a BIM workflow. A thorough review of recent related work is presented in D5.3, together with a novel approach for reconstructing BIM models directly from raw indoor Point Clouds which was developed in WP5 during the second project year.

3.3 Potential for practice through a digital life-cycle of building documents

In a future lifecycle of building information a combination of geometry rich architectural data through Point Clouds and abstract semantically rich BIM data sets can deliver a comprehensive data set for future practices in the building industry.

Point Clouds are today easy and fast to create [3] and deliver precise geometric measurements of physical environments. The sheer amount of data makes it however difficult to integrate them into the software environment of stakeholders. The integration of Point Clouds into the practice of the building professions is furthermore challenging, as the stakeholders are used to think in abstract models about the physical environment. Here

the ambiguity of the physical environment, its imprecisions and fuzziness, is idealised to almost diagrammatic representations. BIM models are the current evolutionary peak of this thinking. The Deliverable D7.1 introduced their potential for the stakeholders practices, as they are extremely wide and deep in terms of information, but as well how they are challenged when used in the planning of existing buildings. It seems hence promising to combine the merits of the precision of Point Clouds with the semantic depth of BIM data in future architectural workflows. An archived BIM model, if handled according to the best practices and approaches developed in the DURAARK project, can be easily integrated into the BIM workflow of stakeholders. It can here contribute with semantically rich information. However BIM models need to be reliable and mirror the actual present situation on site to create value in the later workflow of stakeholders. Point Cloud data of existing or former states of the same architectural object can help to determine the accuracy of the existing BIM model.

4 Workflow integration

This chapter describes the efforts in workpackage 7, that allow for a combination of different types of archived architectural data in the workflow of architects and engineers. The focus of this integration is based on the main conclusions of the Deliverable D7.1, which identified two major obstacles of stakeholders when it comes to the handling of existing digital data:

1. Missing integration into stakeholder work environment and workflows
2. Missing approaches for the verification of data

We propose and test a workflow for handling and enriching user-defined data with a potential dataset from the DURAARK long-term archive within a software package familiar to the stakeholders. We concentrate on the two formats under investigation in the DURAARK project (IFC and E57) and integrate and evaluate the geometric enrichment tool sets so far developed and described in deliverable D4.1 and D4.2. We found that these alone are not sufficient to allow for the reuse of architectural data in stakeholders workflows and developed hence a set of tools that prepare data for the DURAARK tools and analyse and visualise their results, in a way that is meaningful for their workflows.

4.1 Proposed Workflow for the re-use of digital building information

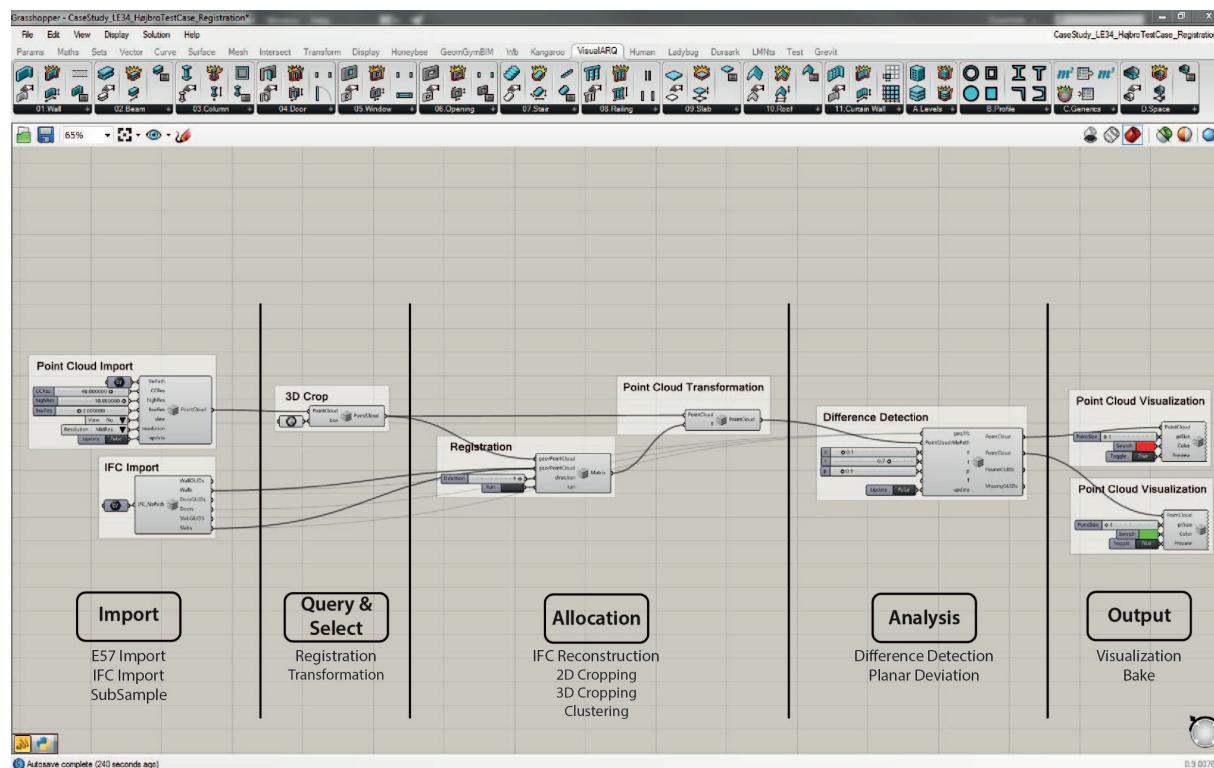


Figure 12: Steps within the modular integrated workflow in a stakeholder software package.

The proposed workflow acknowledges that abstracted data, as in BIM files, is the modus operandi for stakeholders in architecture and engineering. Using DURAARK tools, we propose a workflow where Point Clouds are used as a base for the:

- quality control of existing BIM models
- quality control of new BIM models
- visualisation of differences between BIM and IFC
- visualisation of deviation of the abstracted BIM geometry from the physical world
- adaption of BIM geometry to detected differences
- generation of new BIM geometry to work with

The analysis of the stakeholders workflows showed five basic steps that are executed in order to integrate existing datasets into architectural processes:

1. **Import** The datasets from a long-term archive are made accessible in the work environment.
2. **Allocation** Datasets are set in a state that they can be assessed and are related to other datasets.
3. **Query and extract** Specific parts of the dataset are detected and extracted.
4. **Analysis** Datasets are compared.
5. **Output** Results are visualised and eventually exported.

4.1.1 Establishment of a common workspace for BIM and Point Cloud

Currently the work environments of stakeholders for Point Cloud and BIM files are almost totally separated. Specialist tools are not only expensive in terms of cost and training for operating personnel, but create as well hurdles for the data-flow, as interfaces between the tools result in loss of data.

We propose a process, which allows for the confluence of scan and BIM data integrating the five steps described above. This common interface allows us as well to use a continuous method of structuring the data (i.e. with a common name space for buildings, levels, rooms etc.), while visualizations (i.e. different colors, line weights and shading for BIM objects, point-size and density (subsampling) of Point Clouds etc.) help the user to gain and keep an overview.

4.2 Stakeholder software package

The software package chosen is Rhino with the plug-ins VisualArq¹⁰ and Grasshopper. This package is able to create and modify BIM files, is familiar to most stakeholders and can easily be integrated into their already existing workflows.

¹⁰<http://www.visualarq.com/info/grasshopper-components/>

4.2.1 Rhino

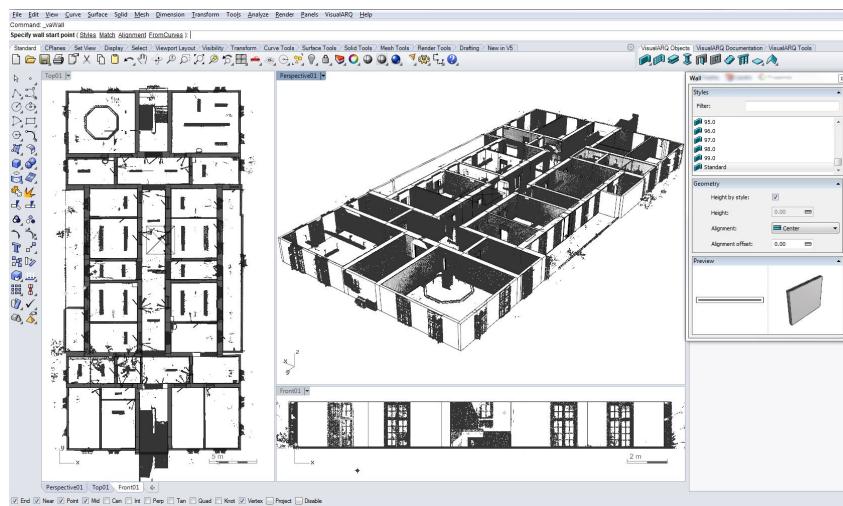


Figure 13: Rhino/VisualArq interface showing Point Cloud and BIM geometry.

Rhino is a versatile CAD software, which can be extended through scripting or a large already existing library of plugins. We have used the plugin VisualArq to deliver basic BIM capabilities to Rhino.

4.2.2 Grasshopper

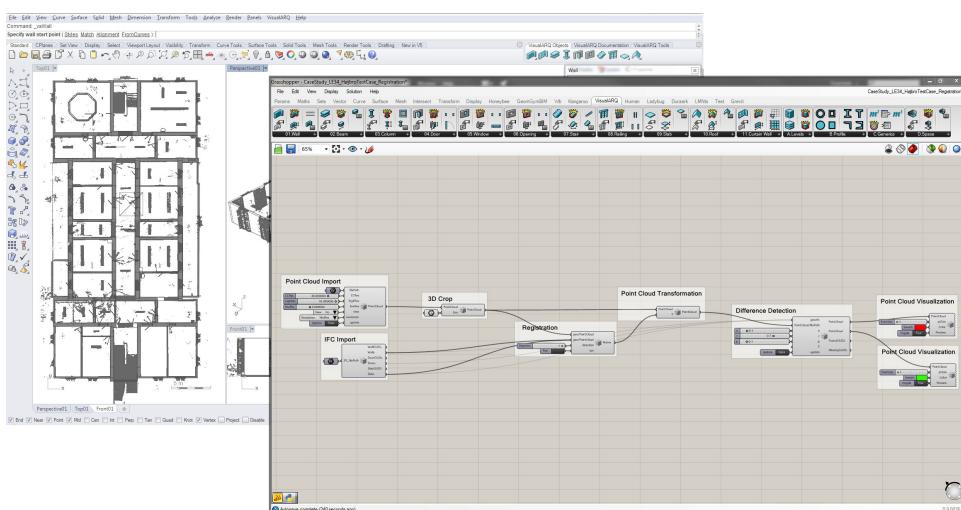


Figure 14: Grasshopper interface. Visual programming for Rhino. Enables manipulation of Point Cloud and BIM parametrically.

Grasshopper is a visual programming language developed for Rhino. This delivers a customizable platform both for the usage of stakeholders by maintaining the modularity of the component setup of DURAARK and for the development of new components (see also chapter 2.1) Grasshopper also have a large variety of open plugins which can easily extend the DURAARK components to other usages.

In these integration efforts we have used the GHpython¹¹, the GeometryGym¹², the VisualArq¹³, the Turtle¹⁴ and the Human¹⁵ plugins for Grasshopper. Besides this, some functionalities of the open source software CloudCompare have as well been used by interfacing it directly from Grasshopper.

4.3 Grasshopper Components

Following the modular approach of both the DURAARK components and Grasshopper, we have developed separate individual components in Grasshopper for each of the WP4/5 tools and a set of WP7 integration components that establish the link between the WP4/5 tools, other specific external tools and the stakeholder workflow in Rhino/VisualArq. This integration is at this stage an experimental setup which uses both basic Python bindings and command-line executables through Python. The components follow the steps described above in 4.1. The modular approach allows however for any other combination of the here described components and for the use of other native or third party Grasshopper components, scripts or links to external software components.

¹¹<http://www.grasshopper3d.com/group/rhinopython>

¹²<http://www.grasshopper3d.com/group/geometrygym>

¹³<http://www.visualarq.com/info/grasshopper-components>

¹⁴<http://www.grasshopper3d.com/group/turtle>

¹⁵<http://www.grasshopper3d.com/group/human>

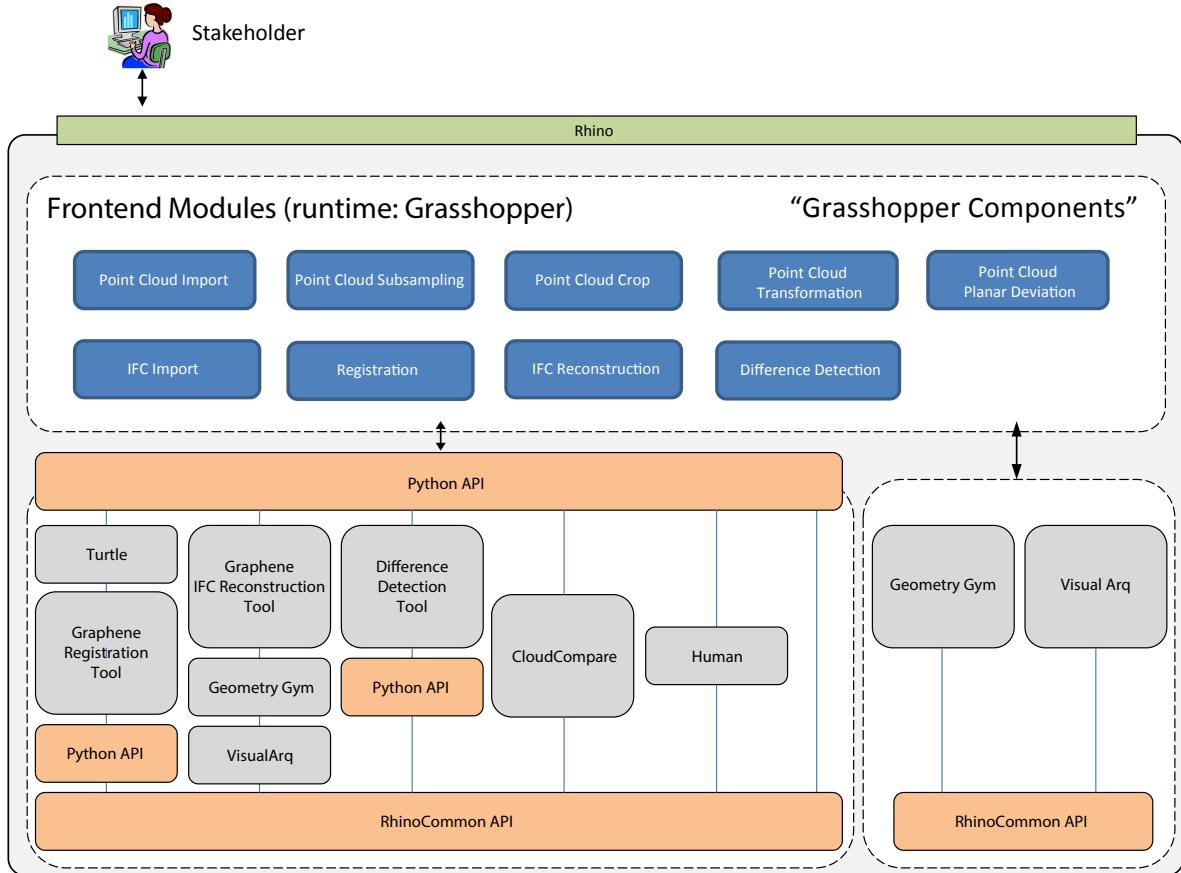


Figure 15: Architectural diagram of current integration setup.

4.3.1 Import

The import related components make IFC and E57 data accessible in the Rhino environment. As Point Clouds (E57) and BIM data (IFC) are not natively accessible in Rhino, the data has to be refined. This is for Point Clouds to subsample them to an extend that allows the user to observe features in the representation without being too heavy on the 3d Graphics engine of Rhino. Instead of importing only geometrical data, which is the native competence of Rhino, the import of BIM files through the Rhino/GH interface rebuilds of the semantic structure of the BIM data in Rhino. This allows to query and access each of the BIM objects and its properties in the parametric environment.

4.3.1.1 Point Cloud Import Components

The Point Cloud Import Component automatically subsamples the Point Cloud to an out of core resolution, a high-, a medium- and a low resolution, and outputs a Rhino Point Cloud class with relevant meta data. This setup has been developed as tests showed large deviation in computing time for different computers. With this setup it is possible for the user to customize the import function to be suitable for the hardware and the project (chapter 5.1). The different resolutions make it possible for the user to do the initial work in a low resolution and then in the end switch to a higher resolution which then will compute all components following the import at that resolution (chapter 5.2). **Dependencies:** RhinoCommon, Rhino E57 Import plugin, GHpython plugin and CloudCompare.

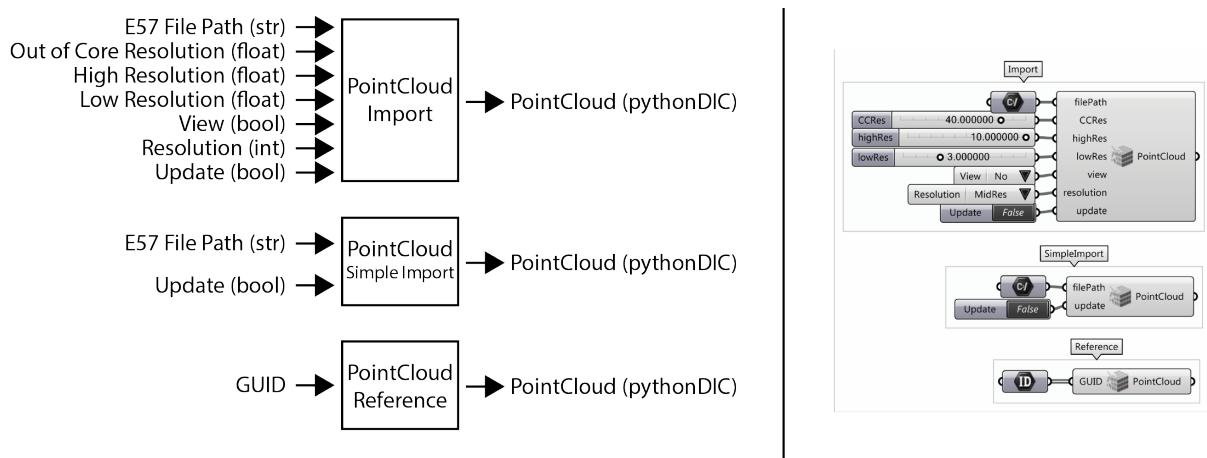


Figure 16: Grasshopper Point Cloud Import Components.

The Point Cloud Simple Import Component imports an E57 Point Cloud file, and outputs a Rhino class with relevant meta data.

Dependencies: RhinoCommon, Rhino E57 Import plugin and GHpython plugin.

The Point Cloud Reference Component references a Rhino into Grasshopper, and outputs a Rhino class with relevant meta data.

Dependencies: RhinoCommon and GHpython plugin.

4.3.1.2 The Point Cloud SubSample Component spatially subsamples the to a giving minimum distance between points. This gives the possibility to have a more even distribution of points. And can for example be relevant for visual purposes (chapter 5.1)

Dependencies: RhinoCommon, GHpython plugin and CloudCompare.

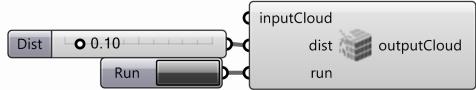


Figure 17: Grasshopper Subsample Component.

4.3.1.3 The IFC Import Components imports an IFC file and outputs the IFC GUIDs for the walls, doors and slabs to be able to interface with the WP4/5 Difference Detection tool. It also outputs the walls, doors and slabs as VisualArq objects. This limitation in objects has been chosen because these are the objects the WP4/5 tools are handling at the moment.

Dependencies: RhinoCommon, GHpython plugin, GeometryGym plugin and VisualArq plugin for Grasshopper.

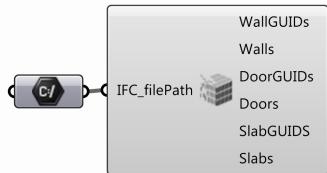


Figure 18: Grasshopper IFC Import Component.

4.3.2 Allocation

In this step data sets are related to other data sets on a global geometrical level. The DURAARK data set, listed in Deliverable D1.7, shows, that 3D models, whether BIM or 3D Point Clouds, are at most times not positioned at the same place – the alignment of large models is a tedious and error prone process, if done manually. The task is especially difficult, if the models represent different states in time of a building or the content differs vastly (detailed BIM to low detailed BIM, partial scan within a larger BIM model, only partial overlap of models). We integrate the DURAARK registration component developed in WP4. A user might however as well move the complete Point Cloud at a later time to be able to see the objects side by side. The transformation can be used here as well.

4.3.2.1 The Registration Component interfaces with the Graphene Registration tool described in D4.1. The user can input geometry, VisualArq objects or Point Clouds. When pressing "run" the Graphene Registration UI opens and the user can perform

the registration. When the registration is done the grasshopper component outputs the transformation matrix. The user also have the ability to choose which order of registration wanted.

Dependencies: RhinoCommon, GHpython plugin , Turtle plugin, and the Graphene Registration Tool.

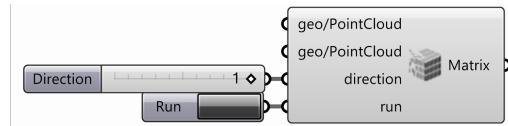


Figure 19: Grasshopper Registration Component.

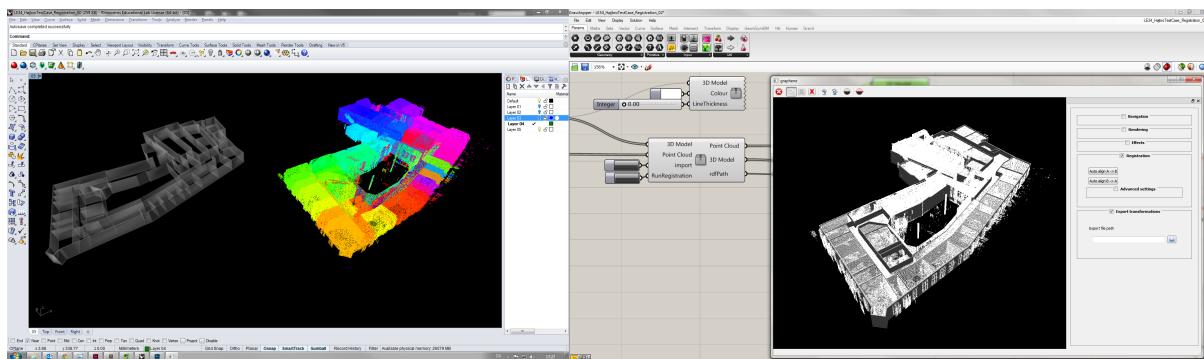


Figure 20: Screen capture of Rhino / Grasshopper and Graphene UI

4.3.2.2 The Point Cloud Transformation Component gives the user the ability to translate a by a user specified transformation matrix or by a transformation matrix outputted from one of the WP4/5 components.

This is useful to move a to a specific location or to interface with the WP4/5 components.

Dependencies: RhinoCommon and GHpython plugin.



Figure 21: Grasshopper Transformation Component.

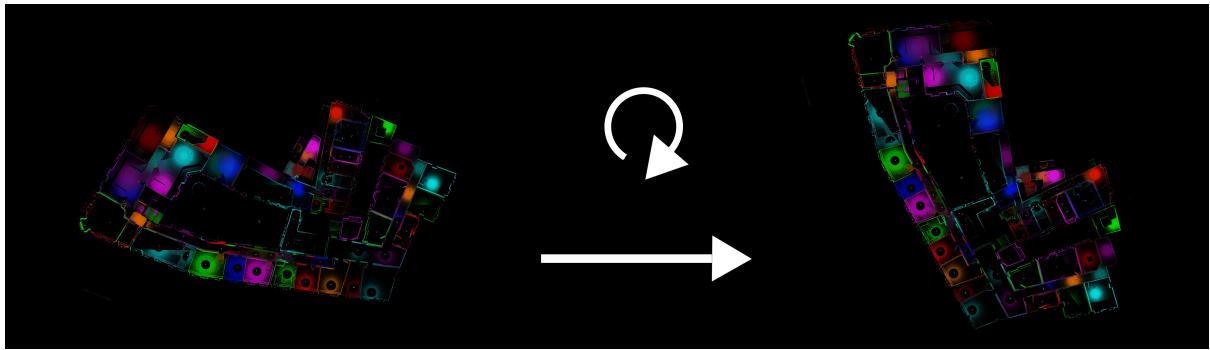


Figure 22: Transformation of consists of moving and rotatating in 3 dimensions.

4.3.3 Query and Select

This set of components filters the Point Cloud. It provides the user with a better overview and allows an assessment of the structure. Especially 3D scans are incomprehensible, as they display many rooms, stories and objects at the same time. The components described here allow users to find and focus on a certain area or elements within the vast set of data. This identification and separation of desirable areas can take place manually or through automatically operating tools, as the reconstruction component developed in WP5.

4.3.3.1 The Point Cloud Cropping/Clustering Components

The Point Cloud 3D Crop/Clustering Component gives the user the ability to crop with a box in Rhino, and outputs a Point Cloud containing the points inside the box (Fig. 31). If multiple boxes are given a clustering is given as output. Here a Point cloud for each box is outputted.

Dependencies: RhinoCommon, GHpython plugin and CloudCompare.

The Point Cloud 2D Crop/Clustering Component gives the user the ability to crop with a planar polyline in the xy plane of Rhino, and outputs a Point Cloud containing the points inside the projection of the polyline. If multiple polylines are given a clustering is given as output. Here, a Point Cloud for each polyline is outputted.

This is useful for the user to be able to manually filter away parts of a not useful for the specific project.

Dependencies: RhinoCommon, GHpython plugin and CloudCompare.

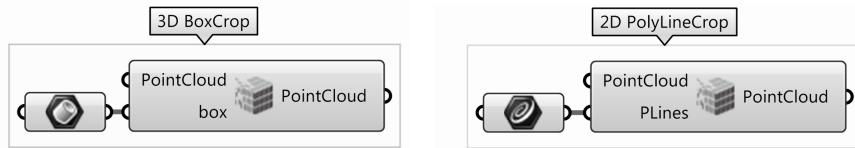


Figure 23: Grasshopper Point Cloud Cropping/Clustering Component.

4.3.3.2 The IFC Reconstruction Component interfaces with the Graphene IFC Reconstruction tool described in D5.1. It automatically segments large Point Clouds into rooms, architectural and structural elements (walls and doors for this deliverable) and creates BIM objects from them. Seen from a user perspective this tool provides a massive support to model BIM geometry from 3D scans, as it minimizes the need for manual modelling dramatically.

The input is via one of the components developed here or as a E57 file path. When the run is initialized, the Graphene IFC Reconstruction UI opens and the user can perform the IFC reconstruction. The output is an IFC file path. This can be passed on to the WP7 IFC Import Component to Initialize Rhino/VisualArq objects.

Dependencies: RhinoCommon, GHpython plugin and the Graphene IFC Reconstruction Tool.

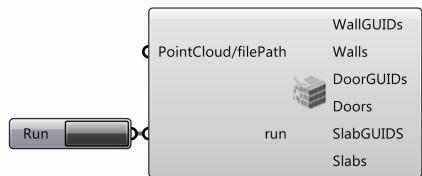


Figure 24: Grasshopper Reconstruction Component.

4.3.4 Analysis

This set of components help stakeholders to evaluate the datasets in a quantitative and qualitative way. The evaluation is executed by means of comparing elements between existing datasets or between a dataset and a defined reference (as for instance a vertical plane in an assessment of deviation from the plane). Differences are detected, measured and displayed.

The Analysis is a key element for the implementation of existing datasets into workflows of stakeholders. It provides them with knowledge about the quality of a dataset and

allows them to assess whether the dataset can be used for a specific task and later to take decisions during the planning process. The analysis allows for instance:

- a quality control of manually created BIM models against archived scans from a building, benchmark them and propose action to remodel parts, if the deviation is above a defined threshold.
- to find out about changes which took place between representations from different times of a building.
- an assessment of an as-built against an as-planned state of a building.
- to detect whether walls or floors are planar enough to install new building elements to them
- to switch from an abstract BIM representation to the precise Point Cloud and find out whether a new element fits

The output of the tools can be both a visual representation of areas of difference or numerical values.

The visual approach allows the user of the system to easily detect and further inquire deviations from an overview of the spaces to the detail. The numeric representation of deviations allows a stakeholder to output quantifiable numerical values, which can be evaluated based on a desired criteria (threshold). This evaluation can take place on a detailed level, i.e. the inspection of the precise value a ceiling is suspended or modelled lower than planned or measured.

A quantification of differences allows stakeholders as well to make a global assessment of a dataset consisting of several models and scans and support the making of qualified global decisions. This is especially important for larger projects, where a good planning and constant control is fundamental, in terms of resources and achievable quality.

The modular setup of the developed components allow again to adapt and combine them to a project's specific needs. A stakeholder can for instance setup a line of components to analyse a dataset automatically in a targeted stepped manner - from the detection of large deviation due to furniture, moving vehicles, persons and 3D scan noise, to the detection of missing or misplaced elements (new erected walls etc.), to the detection of fine deviations of for instance wall thickness's or the angle that a scanned wall deviates from the vertical or another angle given by BIM geometry.

4.3.4.1 The Difference Detection Components The Difference Detection Component interfaces the Difference Detection Tool from D4.2. The input is geometry or and IFC path and a Point Cloud or E57 path. The output is a separated Point Cloud with points associated with objects and points not associated with objects. And the GUIDs for the IFC objects considered scanned and not scanned.

Dependencies: RhinoCommon, GHpython plugin and the Difference Detection Python Wrapper.

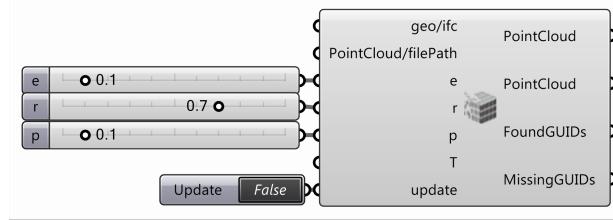


Figure 25: Grasshopper Difference Detection Component.

4.3.4.2 The Point Cloud Planar Deviation Components

The Best Fit Plane Component creates a best fit plane to a given Point Cloud. This component would usually be positioned post a crop component to give the user control over which part of the Point Cloud is considered in the making of the plane. This step allows for later analysis, but helps users as well to model existing spaces manually faster.

Dependencies: RhinoCommon and GHpython plugin.

The Point Define Plane Component creates a best fit plane to a given number of points defined by the user. The user also has the possibility to choose between the original found plane or to either get the best fit vertical or horizontal plane for the defined points. This step allows for later analysis, but helps users as well to model existing spaces manually faster.

Dependencies: RhinoCommon and GHpython plugin.

The Planar Deviation Component gives the user the ability to inspect the deviation from a given plane by numerical values of mean, median and standard deviation and as a color gradient. The user can define this gradient. The Point Cloud output from this component is a Point Cloud colored by the gradient.

Dependencies: RhinoCommon, GHpython plugin and CloudCompare.

The Legend Component draws a legend on the screen of the user corresponding to the color grading set in the Planar Deviation Component.

Dependencies: RhinoCommon, GHpython plugin and Human plugin for Grasshopper.

The Numerical Planar Deviation writes a user defined grid of specific point distances to the plane in the planes coordinate system.

Dependencies: RhinoCommon and GHpython plugin.

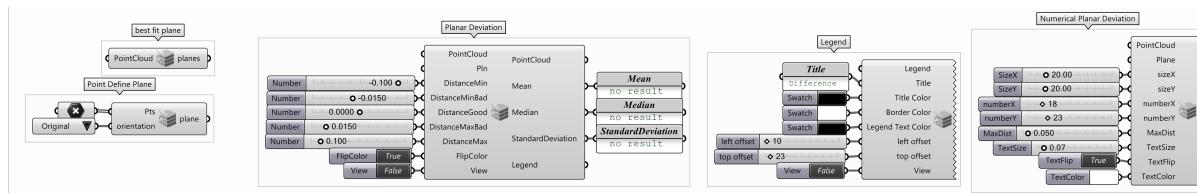


Figure 26: Grasshopper Planar Deviation Component.

4.3.5 Output

The components provides the Rhino/Grasshopper environment with output functionality for Point Clouds - on a visual level and into non-parametric elements, which can be exported to other 3D programs.

4.3.5.1 The Point Cloud Visualization Component gives the user the possibility to visualize the in Rhino. The user can choose from a random color distribution per scan, specify a custom color per scan or for the whole or visualize the colours of the , if the contains colors.

This is useful for understanding the and for delivering the information wanted.

Dependencies: RhinoCommon and GHpython plugin.

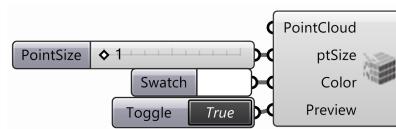


Figure 27: Grasshopper Point Cloud Visualization Components.

4.3.5.2 The Point Cloud Bake Component gives the user the ability to instantiate a native Point Cloud in Rhino. This is because of the way Rhino and Grasshopper works

together. Geometry in Grasshopper is only visualized in Rhino until baked.

Dependencies: RhinoCommon and GHpython plugin.

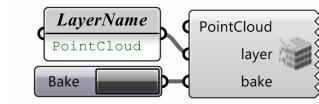


Figure 28: Grasshopper Point Cloud Baken Component.

5 Case Studies with DURAARK components

The evaluation of the DURAARK tools and the underlying modular architecture of the DURAARK tool-set is undertaken with a practice based method [2] on the base of use case UC7: Plan, document and verify retrofitting/energy renovation of buildings defined in D2.1. The width of architectural practice in relation to Design and Retrofitting suggests a targeted approach undertaken through the implementation of tools and conceptualised workflows in processes of stakeholders.

This approach provides the stakeholders with a link to their current practice and makes the work as realistic and meaningful to them as possible. It gives them as well a good opportunity to speculate about other future applications of the DURAARK tools and concepts in their practice.

This chapter is based on the workflows described in chapter 3.3 through 5 case studies. The first 4 case studies investigate subsections of an architectural workflow related to Design and Retrofitting, while the fifth case study investigates the workflow as a whole and examines how the use of archived data can extend and improve the current workflow described in chapter 3.1.3.

5.1 Diakonissestiftelsen



Figure 29: Orthographic elevation of Diakonissestiftelsen made from the Point Cloud.

The case study investigates how to extract relevant and precise information in order to build arguments for design, and how to use the many layers of information from 3D scanning as a resource for inspiration and design exploration.

It probed the developed workflows to map 3D spaces with laser scanning devices and to analyse and process the gathered Point Cloud data. This provided in particular an opportunity to test parts of the integration components developed in the DURAARK project.

This case study was conducted through a student workshop with 24 participants, Hybrid

Registrations¹⁶, in collaboration with Krydsrum Architects¹⁷ and the land surveying company LE34, who consulted and tested the workflow before the workshop.

The task of the workshop was based on the planned retrofitting of the Diakonissestiftelsen in Frederiksberg / Denmark. The building is more than 240m long and consist of several additions to an original hospital building dating from the 17th century (Fig. 29). The participants of the workshop conducted 78 scans with two FARO 3d laser scanners resulting in a dataset of 13GB. A BIM dataset did not exist for the building.

Workflow

The workshop was speculative in nature and used the ability to rearrange and adapt components in the workflow. Several approaches were tested beforehand. The most common **workflow** in the workshop consists of

1. Import - Point Cloud Import and Subsample
2. Query - Cropping
3. Output - Visualization

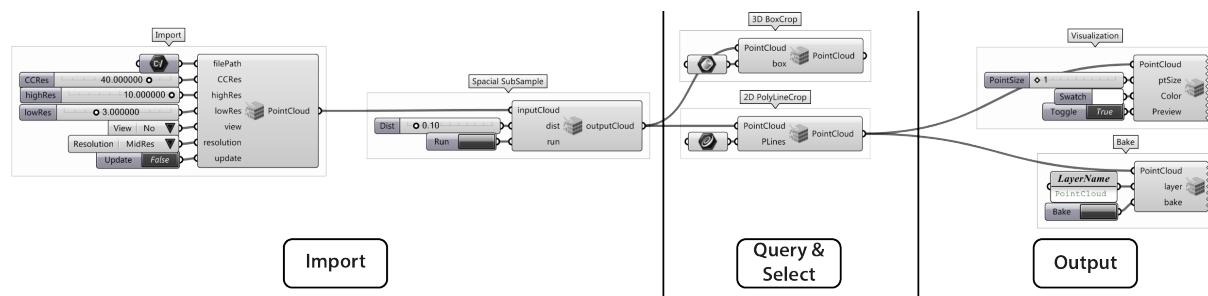


Figure 30: Diakonissestiftelsen Grasshopper setup.

Findings

The case study supported the decision to make customized import subsampling depending on the specific computer working with. But it also showed the necessity of a spatial subsampling for visual purposes.

¹⁶<http://cita.karch.dk/Menu/Workshops/Hybrid+Registrations>

¹⁷<http://www.krydsrum.dk/>

The query through cropping was useful for investigating the Point Cloud and to visualize the desired. Besides this it showed to be useful to develop both cropping inside and outside of a given box or polyline.

For the output of the workflow the ability to customize a point sizes and colours in the visualizations was shown to be very useful.

The case study provided a platform to speculate about future practices of working with 3D registrations in relation to drive architectural concepts and novel ways to represent architecture.

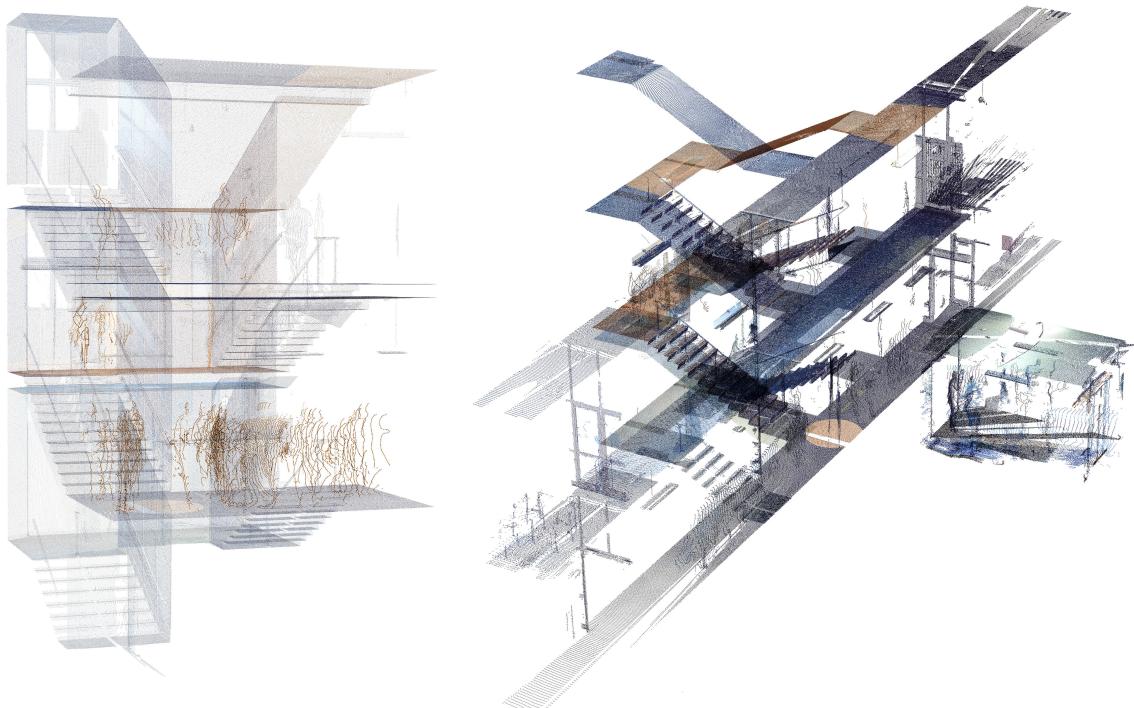


Figure 31: Workshop result: Creating a focused Point Cloud dataset investigating the infrastructure and flow within a building.

Participants investigated how examinations and mappings of Diakonissestiftelsen can be extended through the use of 3D scanning and visualization techniques. The task was to challenge the use of 3D laser scan data for photo realistic “semi objective” representations, which are later redrawn in CAD. Participants should instead use the dataset to create focused subsamples, that provide precise, yet detailed information for design. Another aim was, to provide observers of the work with personal insight about the building’s setup and

atmosphere and to generate a narrative in the representations. Which tools to use was up to the participants. An interest emerged among the participants into hybrid techniques of lines, surfaces and Point Clouds.

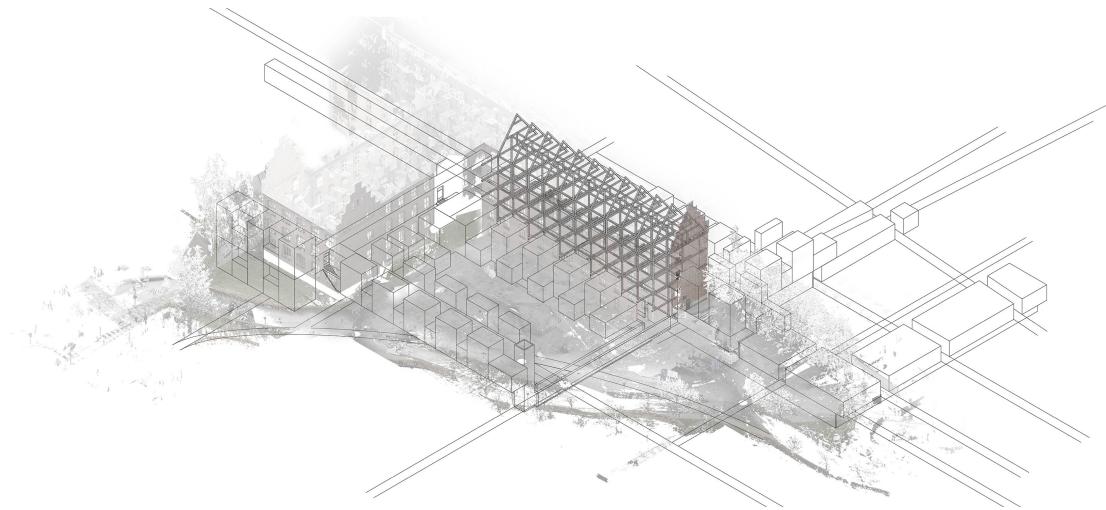


Figure 32: Utilizing Point Cloud as base for investigating extention possibilities.

Outcome

Any architectural design task requires inspiration and information. 3D scanning provides an overload of this information. The current challenge for the use of Point Clouds in architectural workflows is, to find ways to extract data meaningful for the design process from the raw data.

The workshop gave a clear view of the necessity to filter and configure retrieved information in order to integrate it in design processes. The developed cropping and transformation tools as well as visualization tools with custom point sizes and colours were here extremely useful. On a technical level the importance of components to define the resolutions (subsampling) of the Point Clouds, both for processing and for visualization, was underlined. This feature could answer the vast differences in computing power of the many different computers used throughout the workshop.

5.2 LE34 - Façade



Figure 33: Point cloud image of the supermarket facade to be retrofitted with new prefabricated facade elements.

This use case investigates in how far the developed analysis tools can be adapted to the needs of a retrofitting use case - here in the case of the design of new façade elements for an existing building. An understanding about the deviations of a façade from the vertical shall here be created. This understanding allows stakeholders to assess which tolerances have to be considered in the production of prefabricated facade elements.

This case study was conducted in a collaboration with LE34 on a real world project concerning the retro-fitting of a new façade for a supermarket in Copenhagen / Denmark (Fig. 33). The scan data consists of 5 exterior scans with a dataset of 2.5 GB

Workflow

In other software packages LE34 has not found the possibility to have full control of how to display this deviation. Therefore a workflow was set up that facilitates this, which consists of:

1. Import - Point Cloud Import
2. Query - Cropping

3. Analysis - Planar Deviation with full control of plane position and orientation, legend boundaries and numerical values at user specified locations.

4. Visualization

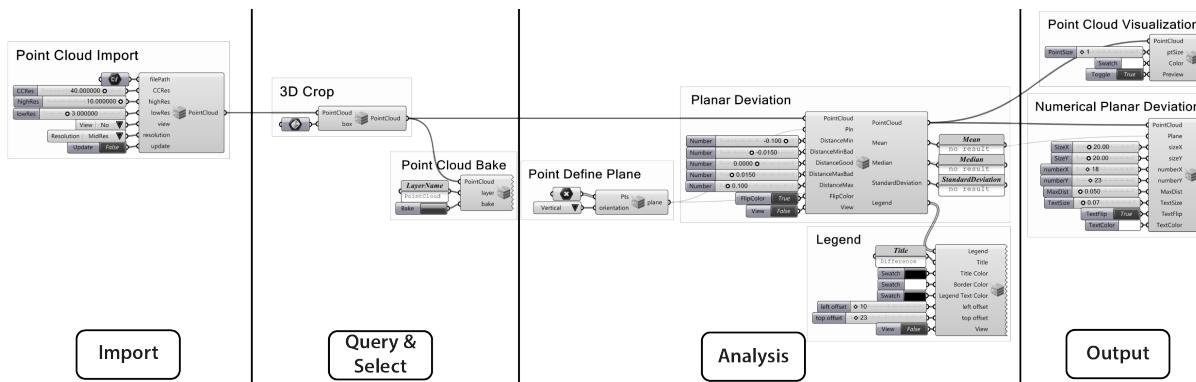


Figure 34: LE34 Facade Grasshopper Setup.

Findings

The case study indicated the lack of customizability in the existing tools to analyse point clouds. Existing software solutions for planar deviation of point clouds do not provide full control and are cumbersome to use. They are specialist software which do not easily integrate into the stakeholder software and workflows.

In collaboration with the stakeholder a workflow was set up, which provided full control of the visual output of the Planar Detection Component. For this workflow a set of components were developed, which provide users with the full control over the reference area to measure deviations from, legend and colours and position and amount of numerical values to display.

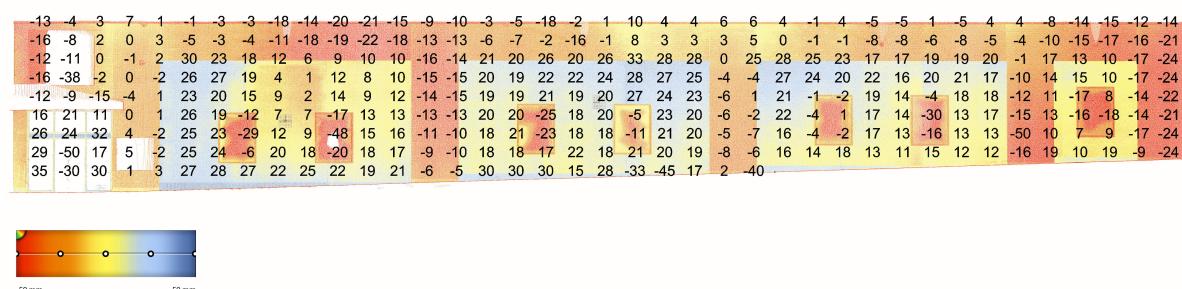


Figure 35: Planar deviation of facade for investigating tolerances for new facade.

The output could then be delivered to the client as images (Fig. 35) or it could be integrated directly into their following workflow.

Outcome

On a technical level this case study showed benefits of being able to do the preparation work (in this case setting up plane, legend and numerical display) in a highly subsampled version of the point cloud, as this allowed for fast feedback and modifications of the parameters through the user. When a good setup is found, the components are set to run through all consecutive steps autonomously in a high resolution of the point cloud. This provides a precise result and it's high quality visualization.

5.3 LE34 - Højbro Plads

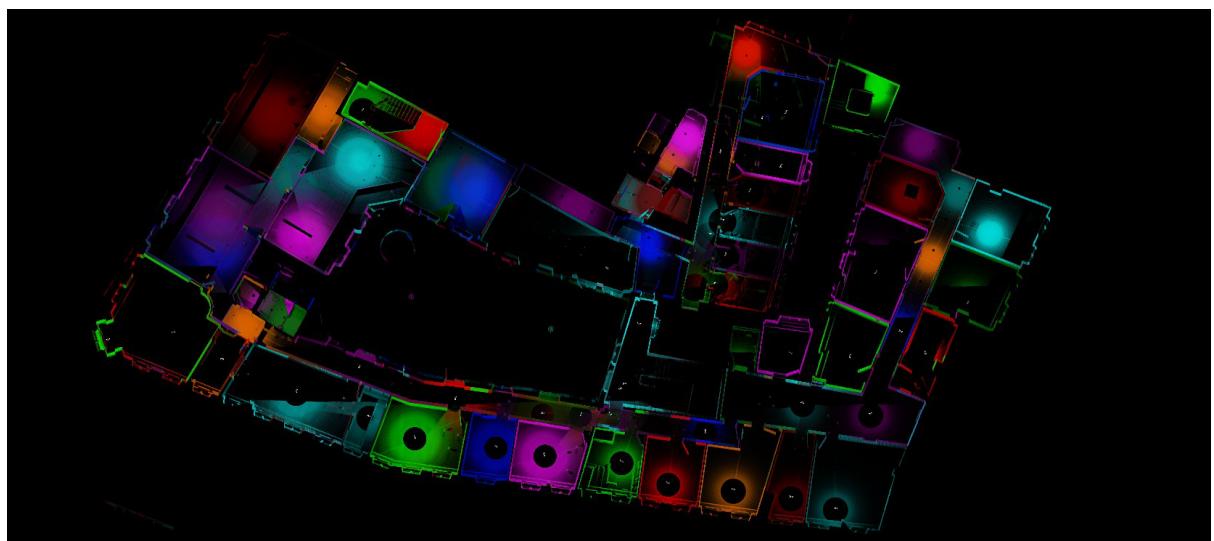


Figure 36: Plan view of 2nd floor of Højbro Plads Point Cloud with separate colors per scan.

This case study examines the workflow for comparing a BIM model with a Point Cloud. This is done by visualizing the difference between the Point Cloud and the corresponding BIM model in the architectural work environment.

For this the Point Cloud of the 2nd floor of Højbro Plads (Fig. 36), Copenhagen by LE34 has been used and a rough BIM model only consisting of walls and slabs was manually modelled. The Point Cloud data set for this case study consisted of 85 scans with a total

size of 20GB.

Workflow

This workflow consists of the steps (Fig. 37):

1. Import - Point Cloud Import
2. Query - 3D Crop
3. Allocation - Registration
4. Analysis - Difference Detection

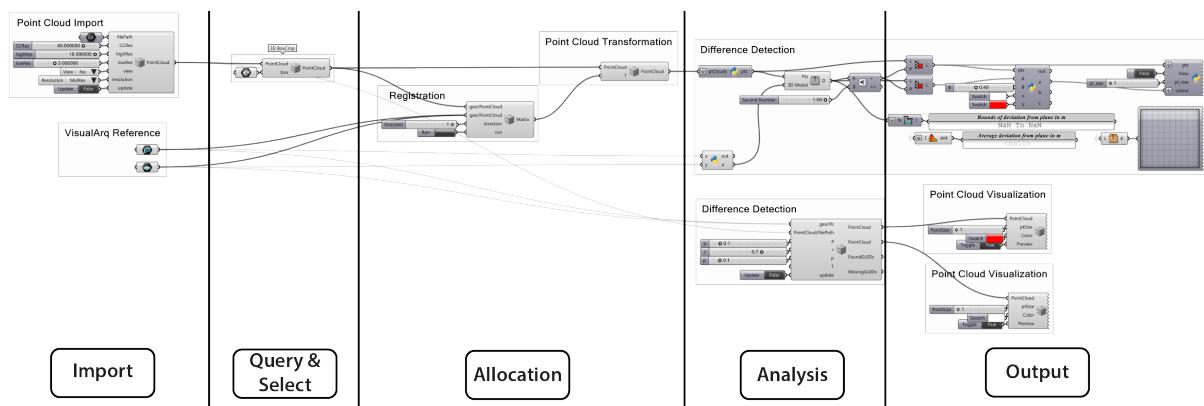


Figure 37: Grasshopper workflow for Højbro Plads case study.

Findings

The first step after modelling a BIM model and the import of Point Cloud is to register the model to the Point Cloud - here executed with the Registration Component (Fig. 38). If done manually the alignment of two representations can be very tedious and error prone. The registration components best fit algorithm and UI showed to be very useful for handling this. One useful feature for the UI at the current state would be the possibility to have different colours for the two representation to be registered. This would facilitate a better manual pre-alignment if needed and visible quality control of output.

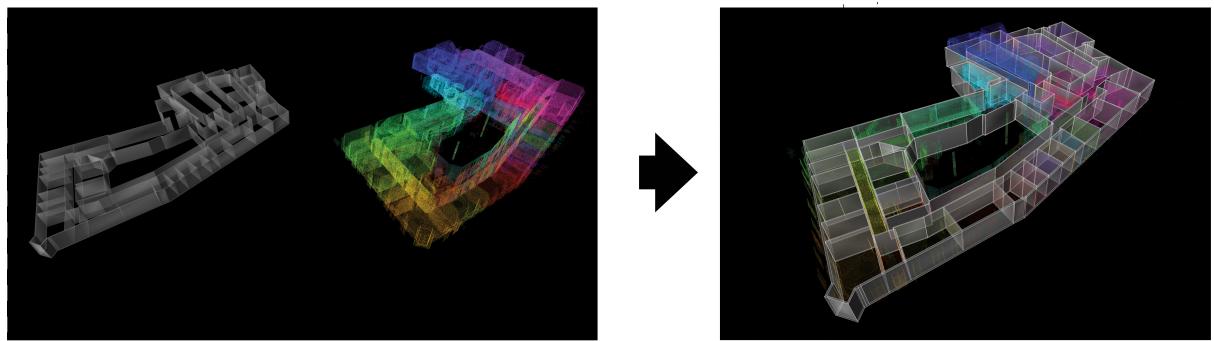


Figure 38: Registration of IFC to Point Cloud with the Registration Component

Next step of the workflow is to calculate and visualize the differences between the two representations (Fig. 39). This case study was conducted before the implementation of the Difference Detection Component. Hence a simple difference detection based on the distance of a point to the nearest geometry was made. A chapter below describes the DURAARK Difference Detection Component, which should result in better results for this use case.

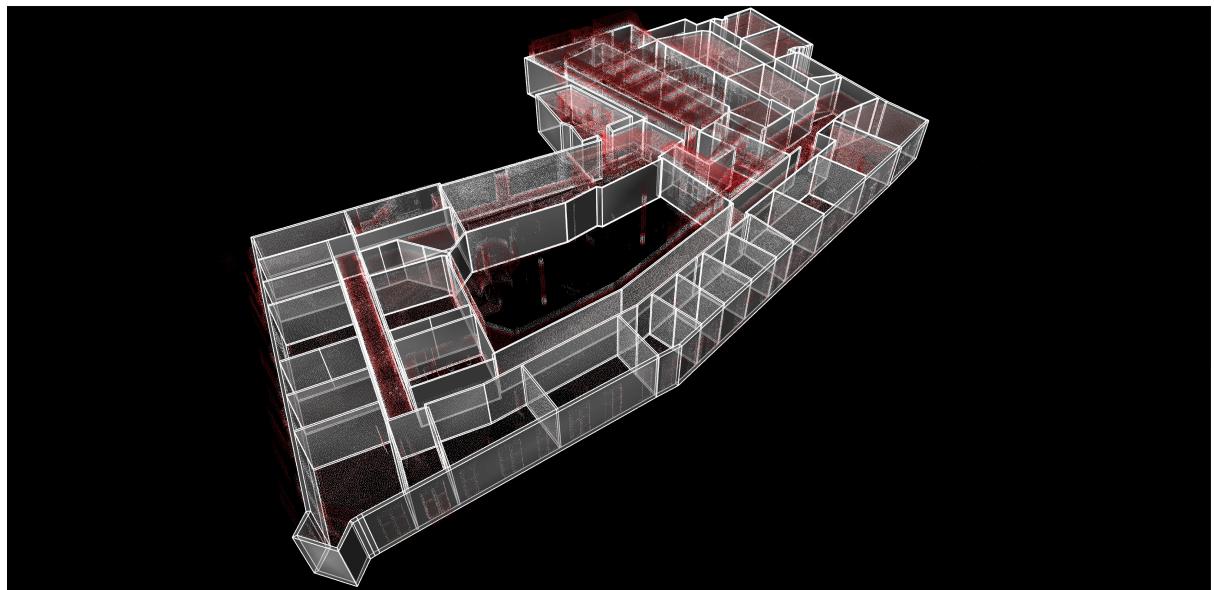


Figure 39: Difference detection with a simplified difference detection analysis based on nearest distance from point to geometry. Could be done with the Difference Detection Component.

The exploration of the visual output of the setup tool reveals differences between the Point Cloud and the model, which could not be observed manually. An example for important

architectural features easily overseen in the current workflows were here suspended ceilings (see Fig. 40) and differences in floor heights, which had not been noticed while modelling.

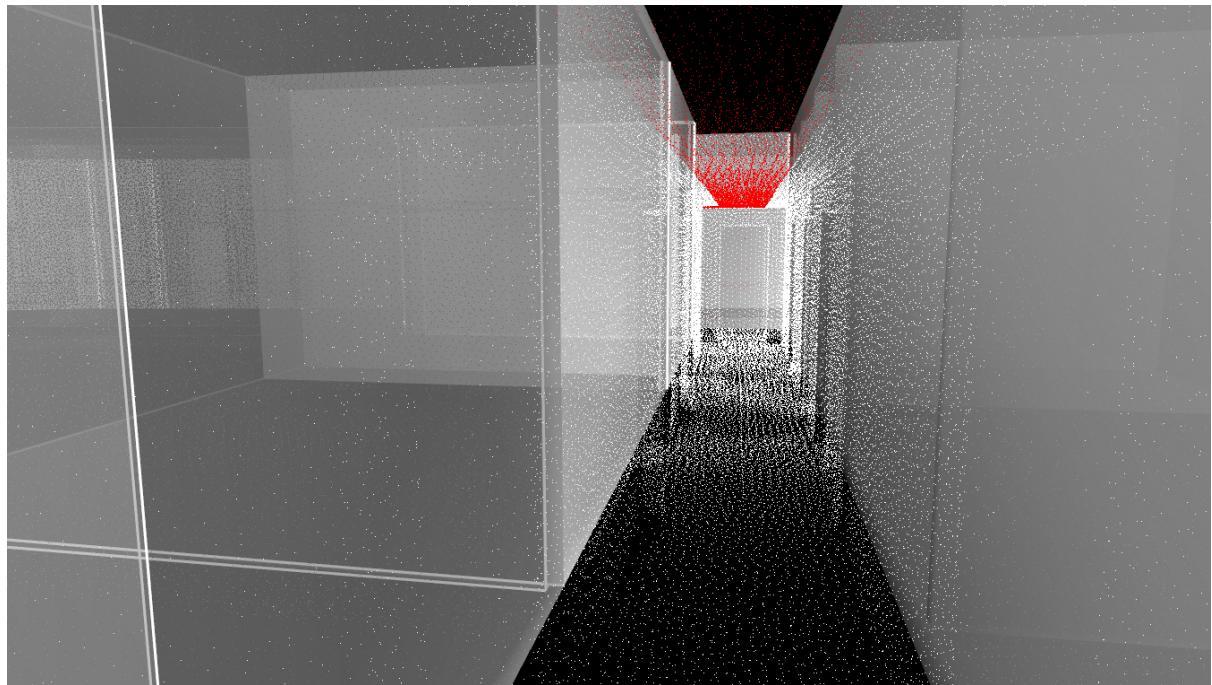


Figure 40: Suspended ceiling marked as red in Point Cloud. This was easily detected as not modelled.

Outcome

The amount of points and information embedded in a Point Cloud can make these incomprehensible. Technical means are necessary to emphasise task specific information. This case study revealed the importance to guide the user, so that the user can achieve the information from the unstructured Point Cloud. A Difference Detection Tool is very helpful for this step.

This case study reveals the importance to gain and refine information directly in the work environment of the architect. This enables a smooth integration and a faster correction of models based on the knowledge embedded in a Point Cloud.

5.4 Plan3D - Haus 30 and Stattsbyg - Risløkka

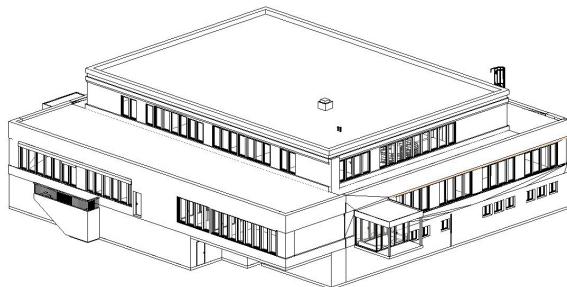


Figure 41: BIM model of Risløkka Trafikstasjon.

Through this case study we investigate and evaluate the workflow of the geometric enrichment (automatic reconstruction of a BIM model from a Point Cloud) in the software of the stakeholders. This is done through the comparison of the output of the Reconstruction Component with professionally modelled BIM models from the DURAARK data sets: **Haus 30 by Plan3D** (Fig. 6). The Haus 30 project consists of a Point Cloud with about 30 scans per floor with a total size of 20 GB and a comprehensive BIM model in IFC. **Risløkka by Stattsbyg**. The Risløkka project consists of a Point Cloud of 88 scans with a total size of 20 GB and a IFC model of the whole building.

The December 2014 version of the DURAARK reconstruction tool was used for this case study.

Workflow

The workflow set up for this case study consists of

1. Import - Point Cloud Import
2. Allocation - Registration
3. Query and Extraction - IFC Reconstruction
4. Output - Visualization

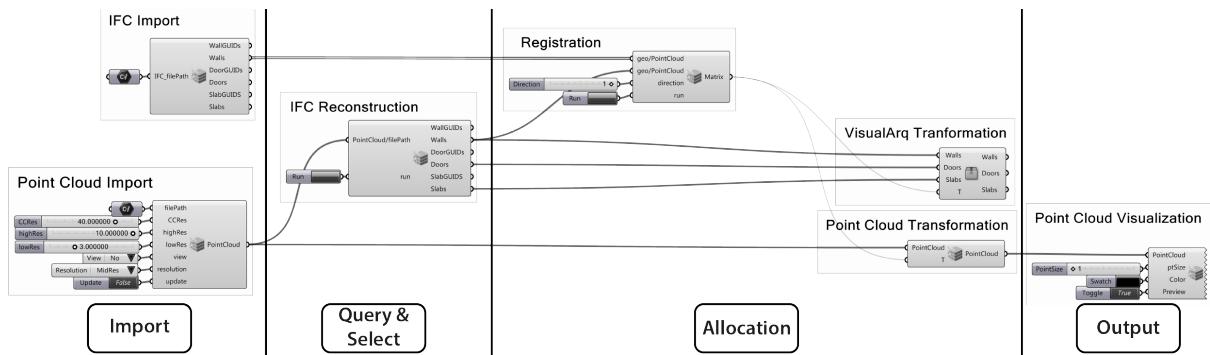


Figure 42: Grasshopper Plan3D and Risløkka setup.

The following descriptions will focus on the Query and Extraction - IFC Reconstruction part of the workflow.

After the Import and Registration steps of the workflow the Point Cloud is parsed into the IFC Reconstruction Component. When pushing the 'run button' the Graphene Reconstruction UI opens and the user can perform the reconstruction of an IFC from the Point Cloud. The user saves the IFC file, closes Graphene and goes back to Rhino/Grasshopper. In Grasshopper the IFC Import Component reads the IFC file and converts this into VisualArq objects.

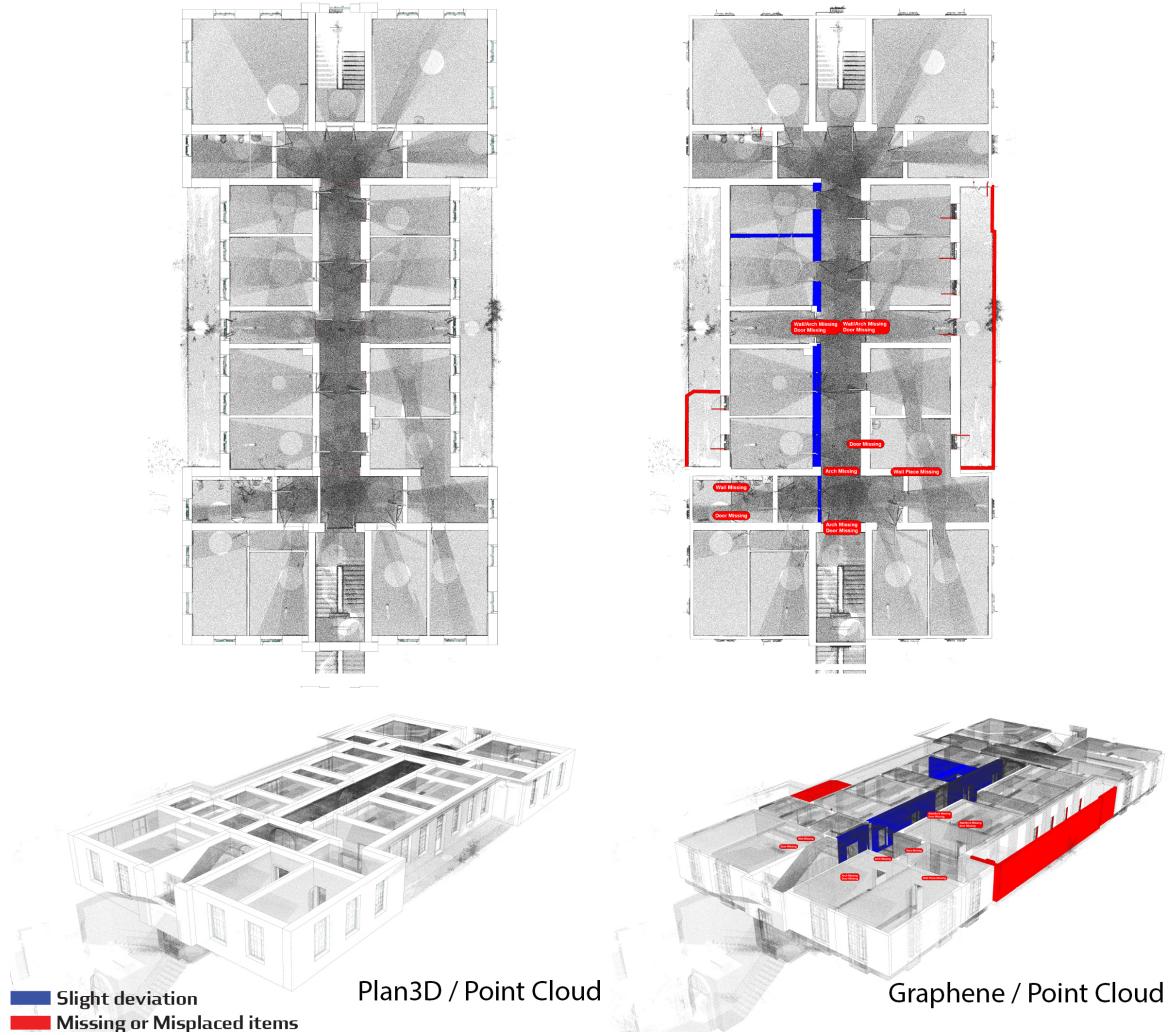


Figure 43: Plan3D Reconstruction difference from manually modelled reconstruction - plan.

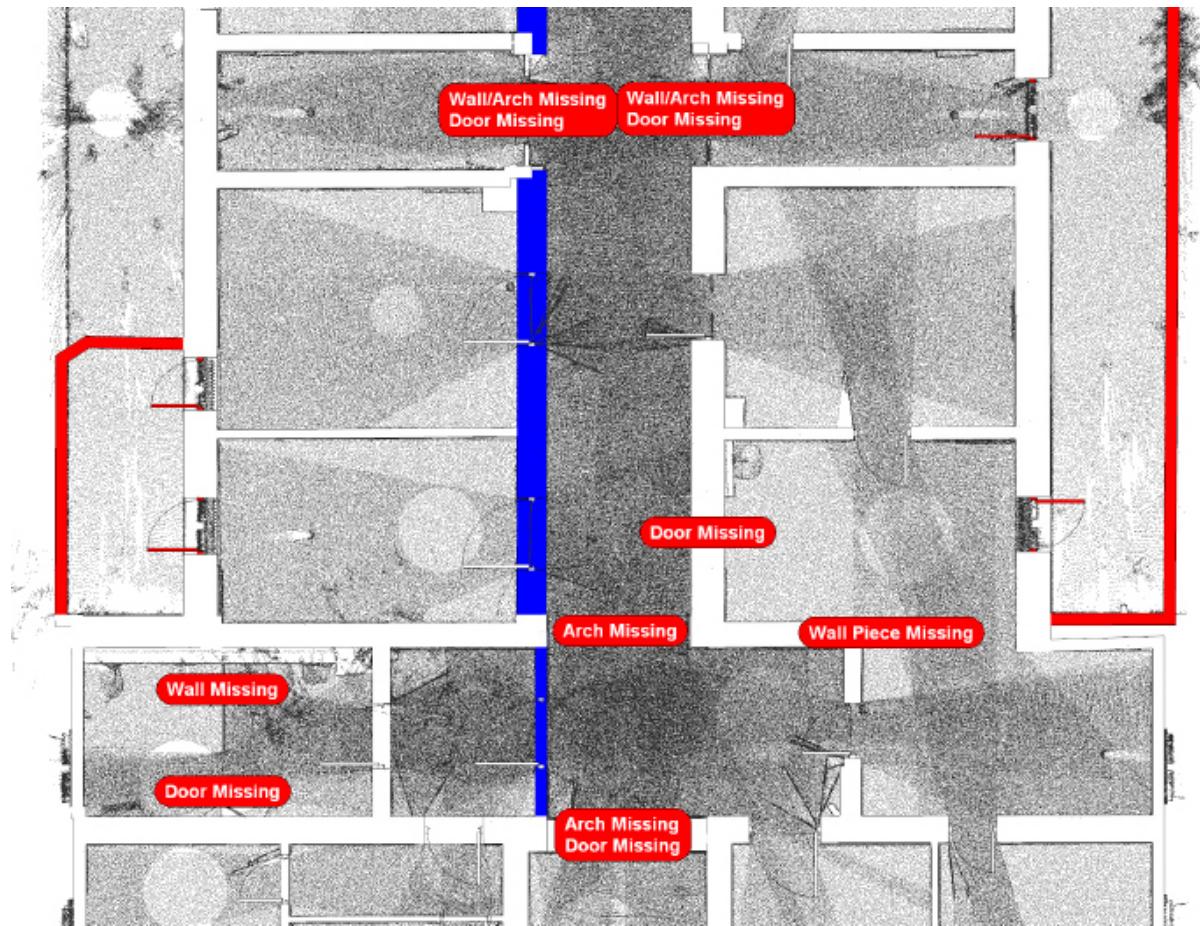


Figure 44: Close-up of plan of reconstructed model and difference annotation.

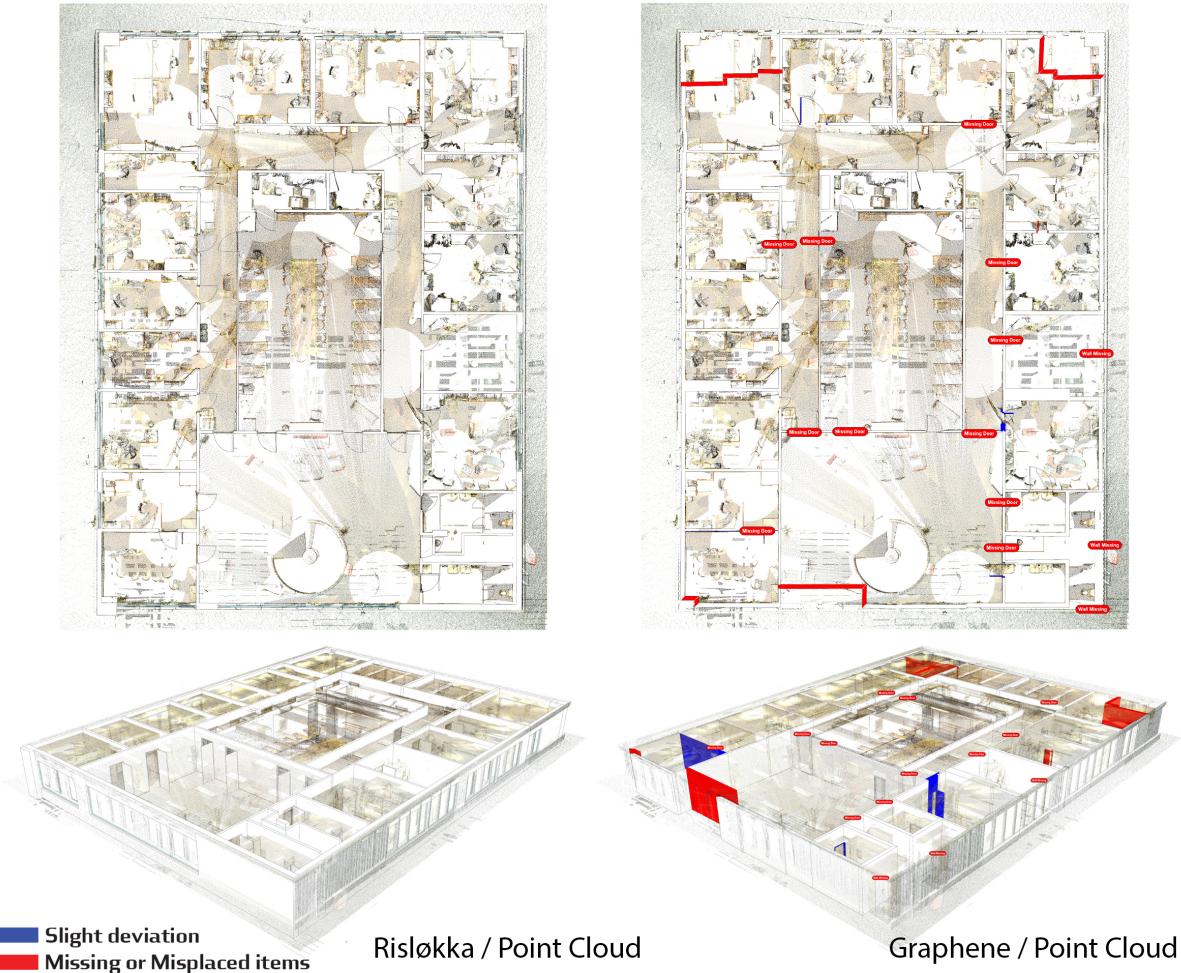


Figure 45: Risløkka Reconstruction difference from manually modelled reconstruction - plan.

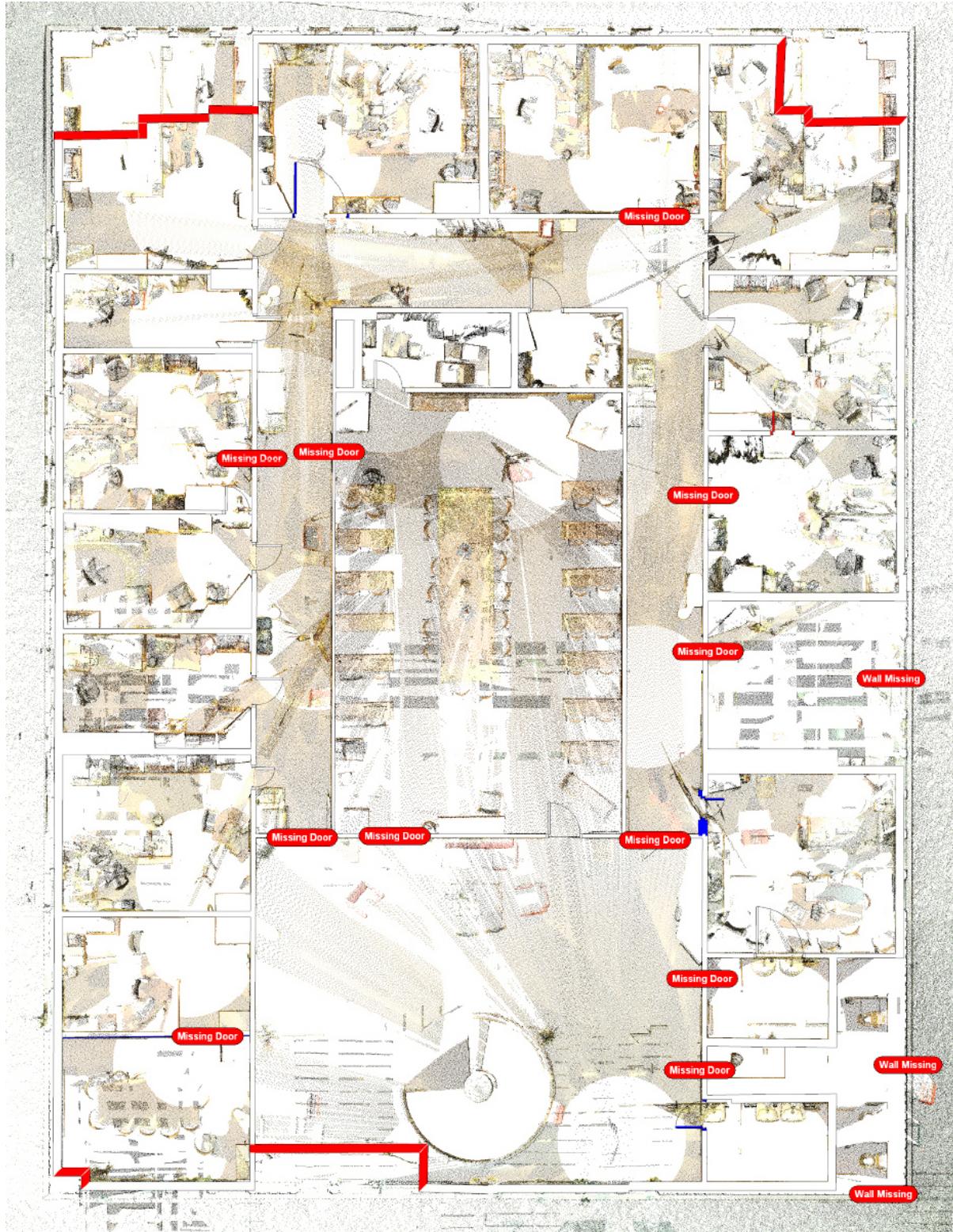


Figure 46: Close-up of plan of reconstructed model and difference annotation.

Findings

Comparing the output of the IFC Reconstruction and the models modelled by Plan3D and Stattsbyg, shows some slight deviations (Fig. 43). In the illustrations above, blue walls show walls slightly off in dimensions. Red walls and doors show misplaced items.

Misplaced Walls and Doors. The misplaced walls of Haus 30 are placed wrongly by the components algorithm, as a railing is considered a wall. The misplaced walls of Risløkka seems to be placed wrongly due to many artefacts in the scanned rooms, which was considered as walls by the algorithm, or by poor scanning or too high subsampling. The misplaced doors of Haus 30 are mostly windows wrongly interpreted at doors. The red dots show missing items, while the missing doors of Risløkka seems to be mainly due to either closed doors while scanning or poor scanning / too high subsampling.

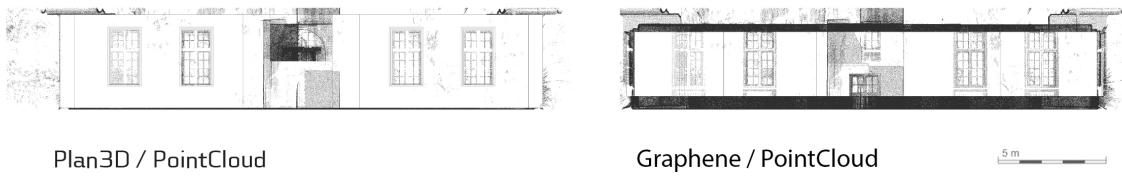


Figure 47: Plan3D Reconstruction difference from manually modelled reconstruction - facade.

Height of Walls. The height of the walls in the model of Haus 30 outputted from the IFC Reconstruction Component does not match the height of the model by Plan3D. The height of the walls in the reconstructed model is 2.5 m, while the height in the model by Plan3D is 3.5 m. The reason for this is that the reconstruction software prototype that was available at the time of our evaluation did not contain an estimation of room heights from the point cloud data. The software delivered as part of D5.3 implements room height estimation.

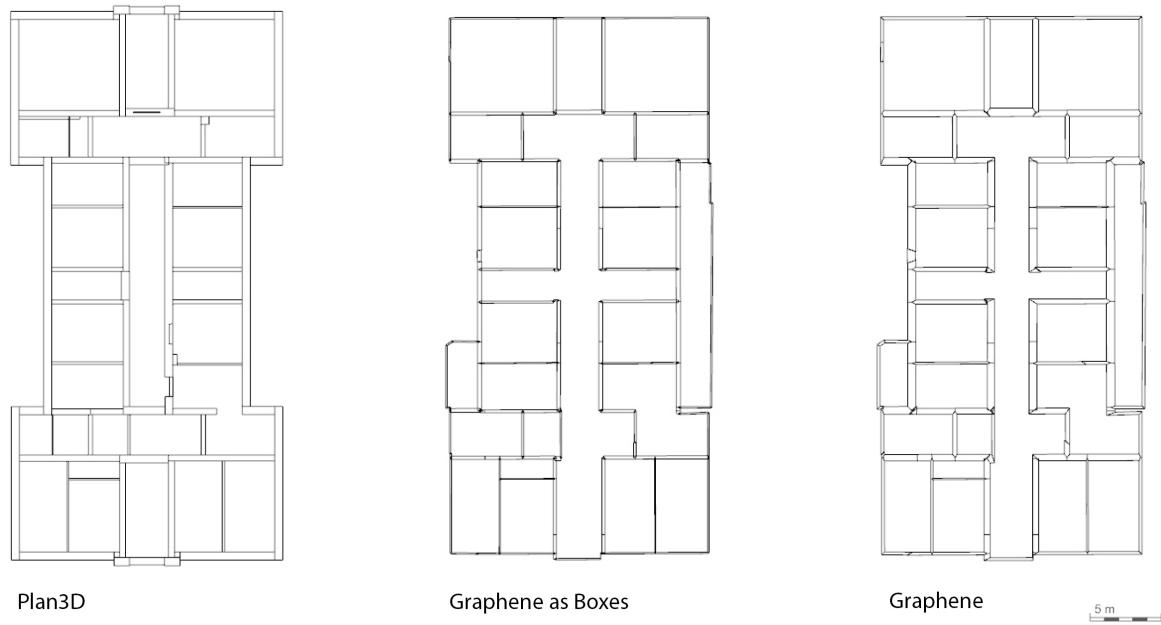


Figure 48: The differences between the different IFC exports from the reconstruction tool and manually modelled of Haus 30 (Same result was shown for Risłøkka). Left: Manually modelled, Middle: from reconstruction as boxes, Right: from reconstruction not as boxes.

Difference in used units. While the numerical representations, such as baseline and thickness's in the IFC files from the Reconstruction Component are measured in meters, the geometric representations are in mm.

Thickness of Walls. The reconstruction tool uses two different geometric representations for walls. The thickness of generated walls of the two is different. The wall thickness's of representation with bevel seems to be the correct, while the wall thickness's of the representation as boxes seems to be too thin. This will have an effect on the area / volume of spaces.

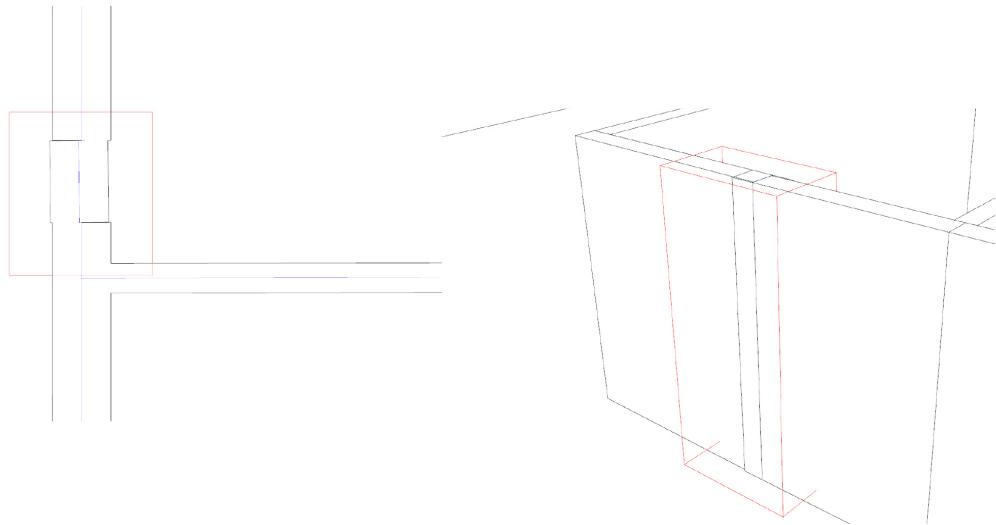


Figure 49: Plan3D drawing convention.

Small breaks and kinks in walls. The comparison of the models shows that a discontinuity in the base-lines for the generation of the walls creates undesired breaks in the three dimensional walls. The drawing convention in architecture would be to ignore small ‘kinks’ in walls and interpolate all to a straight wall. This could in the case of the reconstruction tool be a post rationalization, where the user can define at which minimum sizes and angles between walls should be considered as straight.

Rounding of detected values. The same kind of post rationalization could be applied for the near 90 degree angles between walls, wall thickness’s and door sizes etc. The building profession tries to use as few decimal places as possible. The build reality might deviate from this assumption in parts and detail. A highly abstracted model of a building, as a BIM model, should however follow this convention.

Outcome

This case study indicates general challenges for the IFC Reconstruction Tool, as deviations between the output of the tool and professionally modelled BIM models are found. This will have an effect in a workflow of a stakeholder wishing to integrate such a reconstructed model into their workflow. The deviation which will have the most effect on the workflow are violations of the general modelling conventions, which the architectural profession developed in its practice. This requires in practice a tedious manual correction of the models generated with the DURAARK component (see chapter 5.5). A post rationalisation

of the components output might solve the situation though.

5.5 Nygade



Figure 50: Perspective of Point Cloud project Nygade 1 by Zeso Architects

This case study is based on the renovation project of the building Nygade 1 in the historical centre of Copenhagen.

The case study investigates the potentials of a complex workflow integrating most steps of the previously described potential workflow in chapter 3.3. The case study is closely related to chapter 3.1.3, and investigates how DURAARK components can immediately improve currently existing workflows of stakeholders and where they need to be supplemented with additional processes in order to fulfil this task. The ultimate aim of the case study is to establish a base for the discussion of future workflows with hybrid sets of architectural data.

The project is a refurbishment from offices to apartments of the second floor of the building complex. The building complex has previously been three separated buildings, but has been merged into one as an office complex. As a result of this a lack of reliable and consistent drawing material of the complex impedes a renovation work.

The case study was developed and tested through discussions and hands-on collaboration

with Zeso Architects. For this case study we have provided Zeso Architects with a Point Cloud of the buildings second floor, consisting of 115 scans at a size of 31 GB. We assume, that in the future the Point Cloud is retrieved from the DURAARK long term archive.

Workflow

A workflow from a Point Cloud to a BIM model, which serves as base for further renovation and design work, has been developed in collaboration with Zeso Architects.

The developed workflow consists of 5 steps:

1. Validation of Point Cloud
 - (a) Import - Point Cloud Import
 - (b) Output - Visualization
2. Reconstruction of BIM
 - (a) Query and Extract - Crop and Reconstruction
 - (b) Allocation - Registration
 - (c) Analysis - Difference Detection
 - (d) Output - Visualization
3. Abstraction
4. Refit of BIM model to drawing convention
 - (a) Analysis - Difference Detection
 - (b) Output - Visualization
5. Enrichment and Design Development

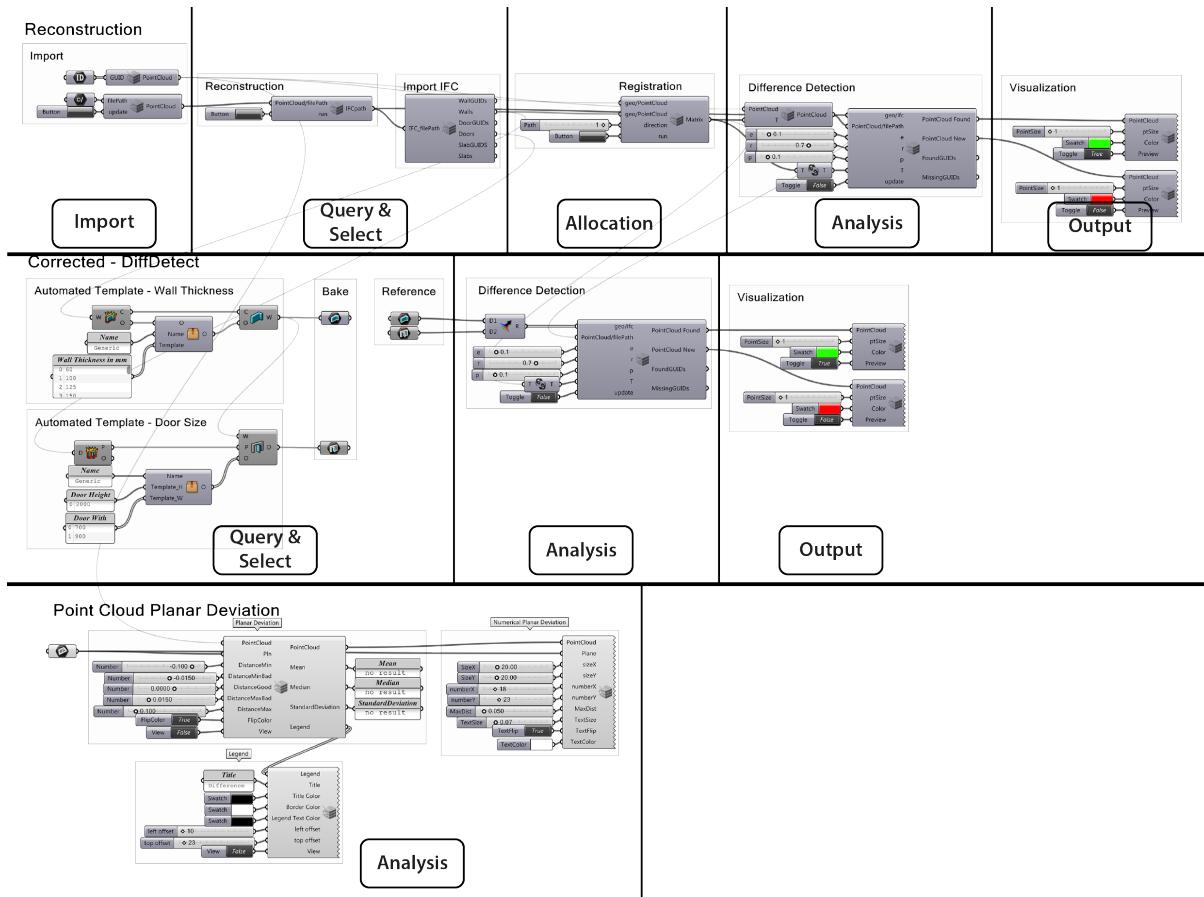


Figure 51: Grasshopper Setup of Nygade case study

The Validation of Point Cloud is done through obtaining sample measurements from a land surveyor and comparing these with the Point Cloud (Fig. 52). This indicates the precision level and hence whether a Point Cloud scan hits the required threshold for major renovations (validity).

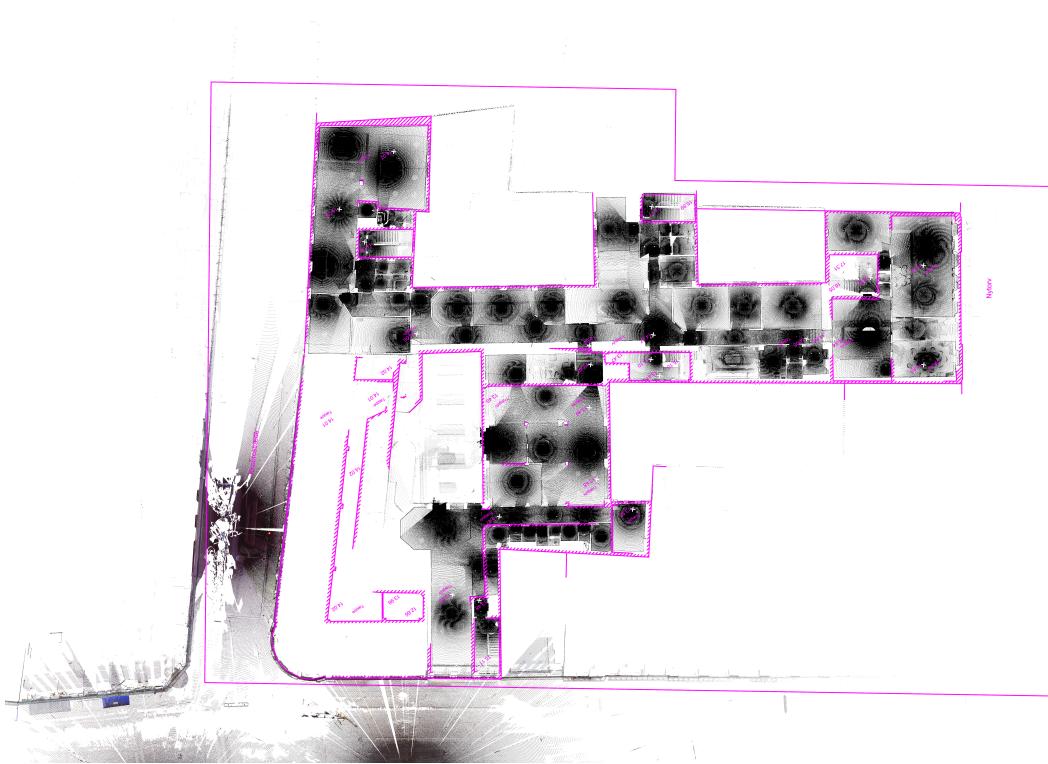


Figure 52: Overlay of Point Cloud and measurements from land surveyor. Pink lines are measurements as delivered from the land surveyor.

The Reconstruction of BIM starts with generating an IFC through the IFC Reconstruction Component. When the Graphene UI is closed the IFC is automatically imported and converted to VisualArq objects.

The next step consists of a quality control of the generated BIM model. This is done by running the Difference Detection Component. Its output undergoes a visual inspection. The output of the Difference Detection Component is coloured in different colours and the user has the ability to turn them on and off separately. This approach supports a swift and still precise query and inspection of the generated BIM model. (Fig. 53)

The Difference Detection Component gives a good overview of the state of the project through visualizing the points which are considered to have associations with objects. The current implementation of the DURAARK component displays BIM elements either as scanned or not scanned. This is not good enough, as e.g. the decision for a wall, which has been partly scanned, is solely depending on the thresholds set by the user. The addition of a third output channel in the tool for probably partly scanned objects might help here. The Registration Component is as well part of this workflow, as this is necessary to register

the Point Cloud and the generated BIM model, if these are not located on top of each other.



Figure 53: Difference Detection of automated reconstructed BIM model and Point Cloud easing the inspection of the model resulting from the registration component. Green depicts points considered associated with objects. Red depicts points considered not associated with objects.

The Abstraction step provides an automated abstraction of the detected wall thickness's and door sizes according to a user defined template. Architects work with a certain level of abstraction and in this phase of a renovation project Zeso Architects uses a set of predefined generic BIM objects for doors and walls. These represent the most commonly used sizes, in this case thickness of walls and sizes of doors and have no meta data attached. By matching the sizes from the reconstructed BIM model to the nearest size in the template, the architect can have a model abstracted to the sizes and templates that they work later with. This enables a smooth transition into the further design work and/or meta data attachment.

The Refit of BIM model to drawing convention step consists of a manual correction of the output from the previous step. As seen in chapter 5.4 the output from the

Reconstruction Component delivers wall elements, which are sometimes segmented into very small pieces. These segments are manually corrected to be continuous walls. The same correction was carried out for walls with small kinks and close to 90 degree corners. The step is necessary, in order to have the generated BIM model comply with the abstraction and simplification level at which an architect is working in a design phase of a project.

A further shortage of the output from the previous steps is that it does not contain information about levels. This was manually defined as BIM objects based on the height of the floors in the Point Cloud. The segments of the BIM model were here moved to their designated height.

This step includes as well a quality control through another use of the Difference Detection Component. This provides a visual feedback of the corrections executed by the user and guides him, whether and where further corrections are eventually necessary (Fig. 54).



Figure 54: Difference Detection of corrected BIM model and Point Cloud. This gives salience to the inspection of the resulting model. Green depicts points considered associated with objects. Red depicts points considered not associated with objects.

The Enrichment and Design Development step is where the model receives the final modifications and can be used for the planning of a retrofitting. The step consists in the case of Zeso Architects of drawing windows, the placement of piping and the attachment of meta data to objects, like the type of wall (load carrying or not), base materials and fire classification.

This phase goes hand in hand with the start of the design phase. DURAARK components, as the Planar Deviation Component, can give here as well support design decisions, as they can be utilized to visualize and quantify the difference between the abstract BIM model representation and the reality illustrated by the Point Cloud.

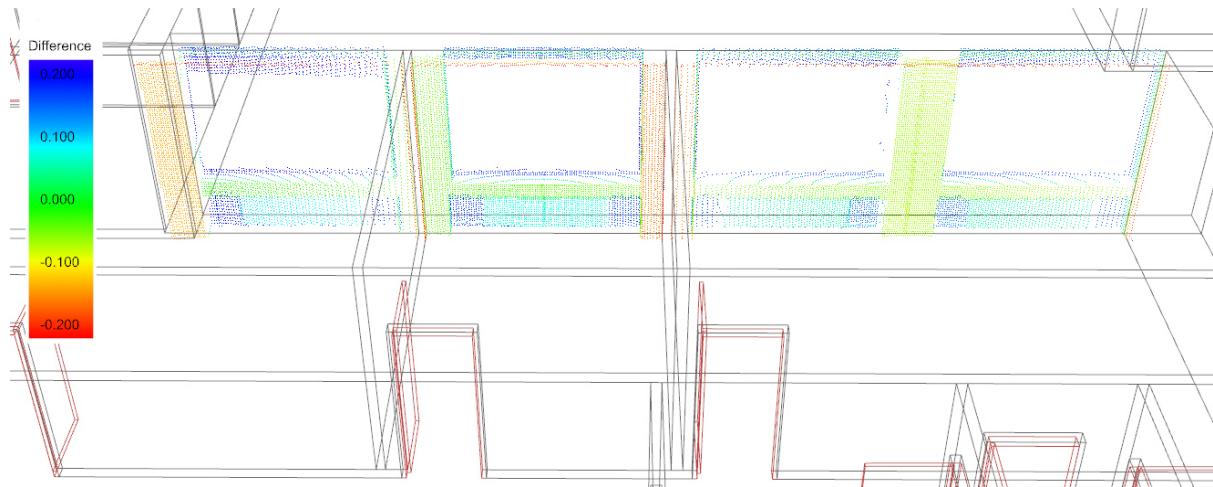


Figure 55: Planar deviation of walls supports design and fabrication decision later in the design process.

Outcome

Developing a complete workflow for the integration of existing data into the design of a retrofitting task was very beneficial for understanding the workflow needed by architects in a renovation project and provide beneficial pointers for the further development of these tools.

1. The auto generated BIM model from the Reconstruction Component can be very useful in the very early stages of a project to deliver a fast visual overview, but is not suitable for integration directly into the workflow of an architect.
A room clustering and connectivity graph as seen in [3] could also be a very useful

visual output in this phase. The spherical images produced by the scanner can be as well of great importance, as they limit the amount of necessary return visits to the site.

2. In this case study the generated BIM model were processed both automatically and manually to fit within the common drawing conventions and templates used by architects. This post processing could become a semi-automated component to be developed within the DURAARK framework as an extension to the Reconstruction component in order to ease the integration into an architectural workflow.
3. Zeso Architects acknowledge the raise in productivity through the use of the developed workflow of modelling the as built state for a renovation project. In order to quantify this we have through conversations with Zeso Architects established the usual amount of hours spend on modelling the as built state of the building under investigation in BIM. Comparing this with the hours spend on modelling the as-built with the DURAARK workflow shows an actual time saving of 22 percent with our experimental prototype. The time needed would be substantially reduced, if a potential DURAARK long term archive could deliver the Point Cloud and if the manual post processing of the results of the DURAARK registration would be unnecessary. This would reduce the time needed for the generation of a directly usable BIM model to 31 percent of the time needed in current workflows of stakeholders. Usual amount of hours spend on modelling as built:

- (a) Measurements: 12h
- (b) Registration of materials and object classifications: 4h
- (c) Modelling: 25h
- (d) **Total: 41h**

Amount of hours spend with DURAARK integrated workflow:

- (a) Scanning: 9h
- (b) Point cloud post processing: 12h (excluded 3h processing time of the DURAARK registration component)
- (c) Reconstruction of BIM model: 1h
- (d) Correction to drawing conventions: 4h

- (e) Registration of materials and object classifications: 6h
 - (f) **Total: 32h**
4. Zeso Architects welcomes the ability to overlay the BIM model during the design phase with detailed information about its deviation from the physical reality. Such possibility to visualize and quantify would limit the necessary return visits to site and allow faster design processes.

6 Conclusion and Impact

This concluding chapter evaluates the steps undertaken to integrate potential data from a DURAARK archive and tools into an architectural workflow. Through exposing DURAARK to real world questions we can deal directly with the digital lifecycle and give valuable insights, how DURAARK tools can be integrated into archive and work environments. This Deliverable focuses on the components of the DURAARK workbench readily available for evaluation in the second year of the project. It paves hereby the ground for the testing and evaluation of other components and concepts currently under development. While D7.3 discusses evaluation criteria and exemplifies the approaches the activities will be reported in the month 36 Deliverable 7.4.

The evaluation has two foci related to the two main concerns with the reuse of data in architectural workflows:

1. Integration in architectural BIM practice (see chapter 6.1): Is a fluent and swift workflow integration achieved? Do the results of the tools fit in quality and quantity to the stakeholders workflows? Does the approach scale to bigger and smaller projects?
2. Validation (see chapter 6.2): How well is the validation of data integrated in the stakeholders workflow? Are the results useful and understandable? Is the precision and speed sufficient and is the approach scalable?

The current processes of stakeholders have problems to integrate the different media carrying knowledge concerning existing building stock. For instance the information that resides within point cloud data can not be assessed by the stakeholders.

The amount of points and information embedded in a point cloud can make these incomprehensible. Technical means are necessary to emphasise task specific information. This case study revealed the importance to empower the user, so that the user himself can obtain the information from the unstructured point cloud. This happens at best directly in the work environment of the stakeholder through the stakeholder. The user knows best about the project, its requirements and how to tackle it. The user should hence be enabled to steer the process. Empowering does not mean "magic buttons" in a software. In general **visualisation, selection and filtering turned out to be powerful tools for the workflow integration.**

6.1 Workflow Integration

6.1.1 Workflow integration - Compliance with stakeholder interests

The developed workflow addresses first of all the needs of architects and engineers in a retrofitting project. Needs of other interested stakeholders, who need more abstract information, such as BIM space definitions for the *use in facility management tools*, could be implemented in the Reconstruction Component.

We found, that stakeholders have very different computing powers. The components within the workflow have to reflect and be able to adapt to this - i.e. with the *use of different resolutions of point clouds*. The ability of components to define the resolutions (subsampling) of the point clouds, both for processing and for visualization, was a major contribution to the workflow to answer the vast differences in computing power found at stakeholders. Being able to do the preparation work in a highly subsampled version of a point cloud turned out to be a good practice, as this allowed for fast feedback and modifications of the parameters through the user. When a good setup is found, the components can now run through all consecutive steps autonomously in a high resolution of the point cloud. This provides a precise result and it's high quality visualization.

6.1.2 Workflow integration - Compliance with stakeholder processes

The planning profession has developed means to abstract the physical reality to useful and directly applicable information. These practices are for instance reflected in drawing conventions, expressed in flexible and non-standardised best and common practices. While these practices have to be critically reflected in the light of better 3d registration tools and information technology in general, the DURAARK components have to obey these as well. *Tools to post rationalize* the values, which DURAARK components find, i.e. near 90 degreee angles between walls, wall thickness's and door sizes etc., would be useful.

The building profession tries in general to use as much repeating elements and as little as possible decimal places. The build reality might deviate from this assumption in parts and detail. A highly abstracted view on a building, as a BIM model should follow this convention to be applicable and understandable in the professional practice. The *highlighting of detected symmetries or near symmetries within the automatically generated models and the use of families of elements*, whether provided by stakeholders

or automatically generated, is another step to ease the use of the DURAARK enriched models in practice.

6.1.3 Workflow integration - Gains in productivity for stakeholders

The investigation in the Nygade case study presented in chapter 5.5 showed already a reduction of 22 percent in regards to the time needed to generate a dataset of existing architecture in comparison to current practice of stakeholders. The time needed would be substantially reduced, if a potential DURAARK long term archive could deliver the point cloud and if the manual post-processing of the results of the DURAARK reconstruction would be unnecessary. This would reduce the time needed for the generation of a directly usable BIM model to 31 percent of the time needed in current workflow of stakeholders.

6.1.4 Workflow integration - Adaptability through DURAARK modular approach

The case study indicated the lack of customizability in the existing tools in the current practice with point clouds. Existing software solutions for i.e. planar deviation of point clouds do not provide full control and are cumbersome to use. They are specialist software, which do not easily integrate into the stakeholder software and workflow. Instead third party tools and external consultants are needed. Specialist tools are however not only expensive in terms of cost and training for operating personnel, but create as well hurdles for the dataflow. Interfaces between the tools result always in loss of data. The established experimental process, shows how a confluence of point cloud and BIM data can be created. The common interface allows us as well to use a continuous method of structuring the data (i.e. with a common name space for buildings, levels, rooms etc.), while visualizations (i.e. different colors, line weights and shading for BIM objects, point-size and density (subsampling) of point clouds etc.) help the user to gain and keep overview.

The modular approach of the DURAARK project turned out to be beneficial, as the components could be integrated at multiple points of the processes. It turned as well out, that the components are of potential benefit during the whole design process of retrofitting projects (see chapter 5.5).

A *consistent programming of interfaces* between the tools is necessary. The different file formats (E57, pcd), Python wrappers, command line interfaces complicate the adaptation of tools, their order and the speed of work. The current state can be seen as experimental

and these flaws will be annihilated in the coming year of the DURAARK project, where a RESTFUL interface and DOCKER components will be implemented in all DURAARK components. This approach will allow to use the components as web application, but as well to integrate them in stakeholder software and workflows.

6.1.5 Workflow integration - Registration of Architectural datasets

The **registration components** best fit algorithm and UI showed to be very useful for the initial handling of architectural data. One useful feature for the UI at the current state would be the *possibility to have different colours for the two representation to be registered*. This would facilitate a better manual pre-alignment if needed and visible quality control of output.

The registration component requires a rough alignment in order to work. Though we found in our tests, that this is often not even necessary, we recommend to invest time to skip this step at all. This effort will take place in year 3.

6.1.6 Workflow integration - Further extensions

An integration of the spherical images produced by the 3d scanner directly into the workflow of an architect working on a reconstruction project can be of great importance and limit the amount of necessary return visits to the site. An integration of the images in the E57 files, which is supported by the E57 standard, would allow for a long-term access to this data.

The registration component produces artefacts, which are of high value for some stakeholders. The segmentation of Point Clouds into rooms (the room clustering) produces Space definitions and connectivity graph, which can be used for Facility Management and processes of spatial planning. The relevance of this approach was documented in the 2014 ecaade paper by DURAARK members [3].

6.2 Validation

6.2.1 Validation - Filter and Select

Any architectural design task requires inspiration and information. 3D scanning provides an overload of this information. The current challenge for the use of point clouds in architectural workflows is, to find ways to extract data meaningful for the design process from the raw data.

Means to filter and configure retrieved information in order to integrate it in design processes turned out to be indispensable. The developed **cropping and transformation tools** as well as visualization tools with custom point sizes and colours were here extremely useful. These tools are necessary to use Point Cloud data and the authors of this deliverable assume, that they will in the future be part of any Point Cloud enabled design and planning tool in the AEC. The DURAARK consortium will support this by publishing the developed Grasshopper Point Cloud on the community webpage and forum Grasshopper3D¹⁸ in year 3.

6.2.2 Validation - Difference detection component

The analysis of datasets with the difference detection tool turned out to be a very useful tool at several points in the process from separate architectural datasets to an integrated design process.

The difference detection allows the user to focus the view. The closer inspection of the difference revealed often previously unobserved, but important features and changes of a building, as it supported the investigation of the reasons for the detected difference.

The Difference Detection Component gives a good overview of the state of the project through visualizing the points which are considered to have associations with objects. The current implementation of the DURAARK component displays BIM elements either as scanned or not scanned. This is not good enough, as e.g. the decision for a wall, which has been partly scanned, is solely depending on the thresholds set by the user. The addition of a third output channel in the tool for probably partly scanned objects will help here. The speed of the component can as well be improved. At present the waiting time for conducting the analysis is too long for a smooth and versatile integration into a workflow.

¹⁸www.Grasshopper3D.com

A smooth integration would for instance allow a user to perform manual corrections in a model with direct feedback from the component.

6.2.3 Validation - Reconstruction component

The case studies indicates an already well working component. The auto generated BIM model from the Reconstruction Component can be very useful in the very early stages of a project to deliver a fast visual overview. The results are at the moment not quite suitable for direct integration into the workflow of stakeholders. **Challenges for the IFC Reconstruction Tool exist**, as the comparison of the output of the tool and professionally modelled BIM models shows too large deviations. This effect the workflow of a stakeholder negatively. This deliverable classifies the found deviations 5.5. The type of deviation, which will have the most effect on the workflow are violations of the general modelling conventions, which the architectural profession developed in its practice. These deviation require currently a tedious manual correction of the models reconstructed with the DURAARK component (see chapter 5.5). A post rationalisation of the components output, as discussed above in section 6.1.2 might solve the situation though.

7 Licenses

The following table gives an overview of the software licences used for the workflow integration efforts of this Deliverable:

IPR Type	IP used or generated	Software name	License	Information
software	generated	Reconstruction Prototype	2-clause BSD	See D5.3 for dependencies
software	generated	Registration Prototype	2-clause BSD	See D4.2 for dependencies
software	generated	Difference Detection Prototype	2-clause BSD	See D4.2 for dependencies
software	used	Graphene	CC0	https://creativecommons.org/about/cc0
software	used	Rhino	Commercial	http://rhino3d.com/
software	used	VisualArq	Commercial	http://visualarq.com/
software	used	Grasshopper	Freeware	http://www.grasshopper3d.com/forum/topics/grasshopper-user-license-agreement
software	used	ironPython	Apache License, Version 2.0	http://ironpython.net/
software	used	GeometryGym	Commercial	https://geometrygym.wordpress.com/
software	used	Turtle GH-plugin	GNU General Public License, version 3	https://github.com/piac/TurtleMesh/blob/master/LICENSE.txt
software	used	Human GH-plugin		http://www.food4rhino.com/project/human?etx
software	used	CloudCompare	GNU General Public License, version 2	http://cloudcompare.org/

References

- [1] G. Thibault J.-F. Hullo and C. Boucheny. Advances in multi-sensor scanning and visualization of complex plants: The utmost case of a reactor building.
- [2] Mette Ramsgard Thomsen and Martin Tamke. Narratives of making: thinking practice led research in architecture. In Johan Verbeke, editor, *Proceedings of the Conference Communicating (by) Design 2009*.
- [3] Martin Tamke, Ina Blümel, Sebastian Ochmann, Richard Vock, and Raoul Wessel. From point clouds to definitions of architectural space - potentials of automated extraction of semantic information from point clouds for the building profession. In Emine Mine Thompson, editor, *Fusion - Proceedings of the 32nd eCAADe Conference - Volume 2*, pages 557–566. ecaade, 2014.