AALBORG UNIVERSITET

AUTOMATED DATA ACQUISITION

MASTER’S THESIS

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Synopsis: This report explores how data is acquired for Indoor Environment analysis in renovation projects, and how this acquisition process can be optimised and automated.

The report proposes a methodology for selection of handheld lasers and data processing software and how such tools must be used to be efficient.

Through literature review, empiric study and case study, the current data acquisition process was explored, and ways of optimising tested.

Through selection of the right tool depended on the exact data needs defined by the IE- consultant and the data needs defined by the IE- analysis programme, the data acquisition process can become more efficient, and when using a handheld laser in unison with data processing software it is further possible to attain data in multiple formats supporting interoperability and reuse of the acquired data.

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Summary

This Master's thesis is the outcome of a six months long research project at the Department of Civil Engineering at Aalborg University. The title of the report is: Automated Data Acquisition.

In renovation projects today, a key concern is the design of Indoor Environment (IE). To do IE- simulation and calculation (analysis) specific data is needed. The primary data needed is geometric data, which currently is acquired through use of handheld lasers or tape measuring, documented manually on paper or digitally. Automated data transfer between measuring tools and data processing software is however not common practise for IE- consultants in the Danish building industry.

To optimize this process, this report, and the study it contains propose a methodology to help select the right handheld laser, data processing software and how to use such, in order to automate the data acquisition.

The research question answered in this report is:

> *How can data for IE- analysis and simulation be collected through Automated Data Acquisition (ADA)?*

The report is divided into 9 chapters. The first three chapters introduces background knowledge on IE and the IE- analysis programme BSim. It further contains the description if research methodology and a literature review, where theory regarding ADA is presented.

The chapters 4 and 5 presents the empiric data collection, regarding how data for IE- analysis is acquired currently in the Architectural, Engineering, Construction, and Operation (AECO) industry. How handheld lasers are used, and can be used and what criterion lasers and data processing software must be selected on is also presented.

A case study is presented in chapter 6, where the ADA methodology is tested in a building, by a test person to find advantages and limitations of using ADA.

The chapters 7 through 9 discusses and concludes the subject in respect to the research question and presents future work with ADA.

The reader is recommended to take notice of the appended material to the report to gain a deeper understanding of the results presented, discussed, and concluded upon.

Keywords: Indoor Environment, IE- analysis, Automated Data Acquisition, Laser measuring, Building measuring.

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Julie – this is to you!

Randers, January 2018
Simon Christian Ravn

Contents

Chapter 1
Introduction

Optimization of indoor environment (IE) and building energy design demands a great amount of building data. Geometry- and building material's data are amongst the most important data for IE- and Energy Design analysis, calculation, and simulation in renovation projects.

A more detailed understanding of how to select an appropriate tool for data acquisition and how to automate such process is however needed.

Buildings are designed to meet a wide range of functions, regarding both Architecture, Engineering, Construction, and Operation (AECO) [Baudains et al., 2014]. In design of new buildings and in renovation projects some of the same modelling, management and data storing technologies can be used. To uphold end- user and AECO demands along with building regulation, many design- build projects uses Building Information Modelling and Management (BIM) for modelling and data-storing.

In renovation projects the data collection is unique when compared to design of a new building. The data can, be more or less, the same but the means of attaining said data is not. New building designs is created based on end-user demands formulated in conceptual designs and outline proposal's. Design models for renovation is however founded on existing geometry, making manual measuring and registration necessary. This process can be time consuming and thereby expensive for the client, especially if the acquisition must be done multiple times by various AECO branches.

Many tools exist to support data acquisition, and some even allows some degree of automatization. Many applications furthermore, allows for interoperability between two or multiple technologies, e.g. data transfer from a handhelds laser measuring tool[1] to data processing software on a handheld tablet device.

Automatization[2] in the building industry has been a key AECO topic since the introduction of digital tools like Computer Aided Design (CAD), Computer Aided Engineering (CAE), and Building Information Modelling (BIM) and Building Energy Modelling (BEM), which can function as design tool of geometry and for data

1 Handheld Laser Measuring Tools are hereafter mentioned as handheld lasers. The report does not differentiate between laser scanning and laser measuring.
2 Automatization is to be understood as a process made automatic, as by electronic devices reducing human intervention to a minimum or removing it. In respect to automatic data acquisition in this report, "reducing intervention" is the key definition.

storing. It is though crucial that the data created or stored therein is defined, for the data acquisition to be done efficiently.

This report investigates what measuring technologies can be used for data acquisition on renovation projects for IE calculations and simulations (analysis), and how such data can be stored and shared.

The research question of this report is:

> *How can data for IE- analysis and simulation be collected through Automated Data Acquisition (ADA)?*

Even though IE simulation and Energy Design share many of the same needs for data this report will primarily concentrate on the data needs of IE.

1.1 Data

Data and information have no explicit conceptualisation or definition agreed upon across industries Information is however, defined as what is true in opposition to misinformation [Mingers et al., 2017]. Information can be true or false though, dependent on the viewpoint, from which it is seen. This report therefore uses the word 'data', to define the "information's" stored in building data repositories, because data must be, and understood as the same, regardless of whom sees or uses it, amongst AECO partners [Mingers et al., 2017].

The word data, as defined by the Oxford Living Dictionary (2017), is derived from the Latin noun: Datum, meaning "To give", and is described as facts or statistics, collected together for reference or analysis.

1.2 IE specification

In simulation of the Indoor Environment (EI) the subjects of interest are the thermic, atmospheric, visual, and acoustic climates. These subjects are as shown in figure 1.1,

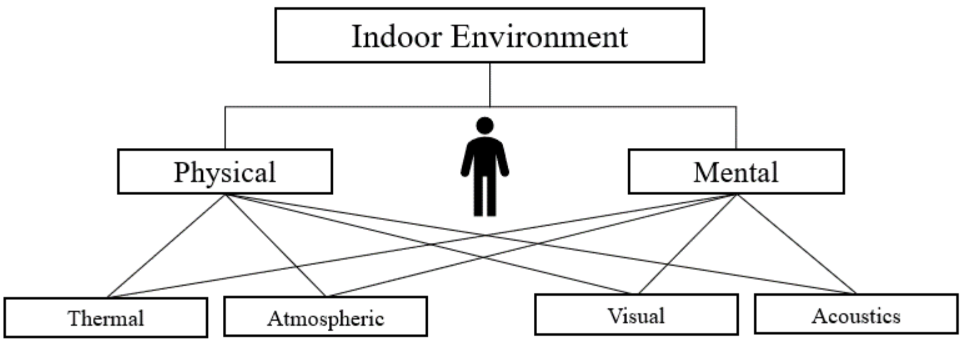


Figure 1.1 Topics to consider regarding the indoor environment, adapted from Hyldgaard et al., (2001).

dividable into physical IE or the mental IE, demanding equal amounts of and in many situations the same data.

To better understand what data to use, and how to acquire it, one must understand what the four IE subjects consists of. The following definitions of the IE is presented as described in the REBUS report: Central Parameters in specification of the Building Indoor Environment (2017) (Centrale Parametre til Karakterisering af Bygningers Indeklima).

Thermal IE
- Operative temperature in the “Summer half” of the year.
- Operative temperature in the “Winter half” of the year.
- Draft.

Atmospheric IE
- Influence from external air.
- Influence from buildings and materials.
- Influence from use.

Visual IE
- Daylight.
- Direct sunlight.
- View out, View and Shading.

Acoustic IE
- External noise.
- Noise from neighbours.
- Internal noise.

1.3 Building Data Manipulation and Simulation

Statens Byggetekniske Institut – SBi (Danish Building Research Institute) is the producer and distributer of the main simulation programme BSim, used for IE- manipulation and simulation in Denmark.

BSim is compiled of six programme modules.

SimView	Geometry and System Visualisation and Modelling.
Tsbi5	Hydrothermal Building Simulation.
XSun	Sunlight Ray Calculation.
SimLight	Daylight Calculation.
SimDXF	CAD – import.
SimDB	Building Element Database.

Each module has its own functions, whereas SimView handles the graphic data representation including the geometric modelling. Tsbi5 handles the actual simulation of IE and Energy Design and makes it possible to select solutions based on simulation. It further has the capability of data export usable for e.g. CFD (Computational Fluid Dynamics) [SBi, 2017].

XSun analyses and simulates sunlight and shadows within the building geometry and SimLight handles calculation of daylight on exact locations within simple geometric rooms, based on algorithms. Results of SimLight can further be transferred to the Tsbi5 module and be used to select or optimize selection of IE solutions [SBi, 2017].

SimDXF[3] offers the possibility of importing CAD data in the DXF format. This makes re-use of design data and data collection through the DXF format achievable and feasible. To use CAD data, it is however necessary to select the proper geometric lines and points, which then can be used as the base for the 3D representation BSim views in the SimView module.

To use DXF in BSim one must create a new model in SimView, select a database to copy and select the desired profile, but not add a building. Instead one must select the entry Edit → Insert → Project and open the relevant DXF-project.

In case of a multi-story building, one must create a separate model in BSim for each story [SBi, 2018].

The final module of BSim is the SimDB or Simulation Data Base[4]. This database consists of multiple building materials and their calculable data, which can be attached to the geometry, imported through SimDXF, viewed in SimView for simulation in the Tsbi5, based on data from XSun, SimLight and SimDB, which can then be exported through Tsbi5 for Energy Design use [SBi, 2017].

BSim further has the capability to export its simulation results to Be10 and Be15 for use in Energy Design Calculations, through the BeXML format.

BSim is in Denmark a de-facto standard [Bonde et al., 2016], which is why further interoperability between BSim, Be10 and Be15 and other Energy Design programmes, CAD, and Data Acquisition should be investigated.

1.4 Automated Data Acquisition

Geometry is the most important data for IE, which in renovation projects must be acquired through a data acquisition process. Such process can be aided through multiple tools. Laser[5] measuring is one way to optimize and automate data acquisition (ADA).

3 SimDXF is found in the program folder of BSim.
4 The database is a relational Database based on MS Access.
5 Abbreviation of: Light Amplification by Stimulated Emission of Radiation [Oxford, 2017a]

Laser measuring works through a laser light being send towards a target where the time it takes for the reflection to return to the place of origin is measured to calculate the distance [CorDEX, 2017] [Acuity, 2017] [LTI, 2017].

The concept of laser measuring however, fathoms more than just one technology. Laser measuring can be divided into three key groups:

A) Stationary lasers and scanners.
B) Handheld lasers and scanners.
C) Self-transportable lasers and scanners.

Stationary lasers and scanners are defined by being uneasy to move around, compared to e.g. handheld lasers. Handheld lasers are on the other hand defined by being easy to more around, and handle on the move, which can also be described as having a high degree of portability.

Self-transportable lasers and scanners, can be Drone, Robotic and/ or Satellite based. This kind of technology can i.e. be used for building site planning and management, however for geometric measuring inside buildings, handheld lasers are more efficient to use.

The various groups of technologies can intertwine though. Handheld lasers can work both separately with data export in specific formats directly to a repository or through a data processing software on handheld devices like phones and tablets.

Energy Consultants must measure the buildings they classify energy-wise [HB, 2016]. It might not matter what laser the Consultant uses if all he needs is lengths and widths used in for manual IE- calculations. However, through use of a handheld laser and the right data processing software, the Energy Consultant might be able automated his/ hers work, and additionally capture building data that can support other branches in the AECO- industry.

The lasers used by e.g. Energy Consultants[6] does not necessarily have to be handheld, but because handheld lasers are easy set up and use, such lasers can be considered very efficient to use for Energy Consultants.

Figure 1.2 further illustrates the concept of ADA, going from building measuring to use of the measured data for IE analysis. However, as chapter 4 shows, this is not how the process of data acquisition currently is.

As shown in the flow- model (figure 1.2) knowledge of the building and a measuring ruleset is needed when choosing the proper handheld laser. What dictates the

6 ”Consultant” is in this report used as a description for all people working with, acquiring, processing, storing and reusing data in the ADA process, independent of work title.

measuring ruleset, is defined by the IE- and Energy Design Consultant(s) and the AECO branches based on their need for data to calculations and simulate.

Further on, the software used for calculation and simulation dictates what formats the laser must be able to export in: to be processed, stored, or exported anew.

Many different types of repositories exist, however, not all will be discussed in this report.

In this report selection of handheld laser, processing software, formats and repositories are based on the needs of an IE- consultant in need of geometric and material data, to simulate the Indoor Environment using BSim, as the primary application.

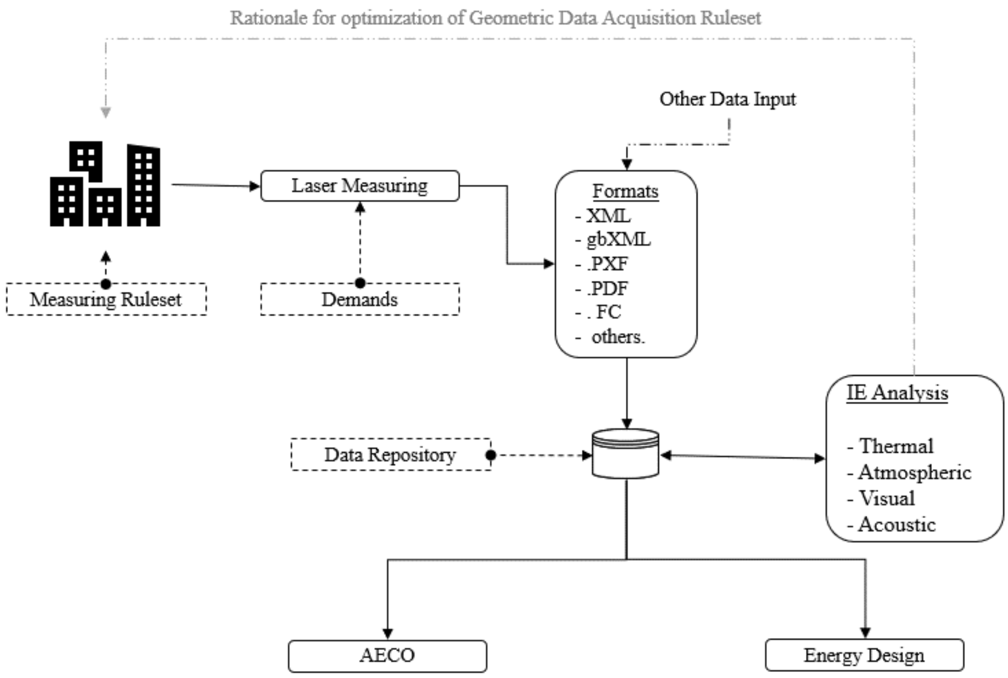


Figure 1.2 ADA process, going from ruleset to measuring through method, formats, data storing and data reuse by IE, Energy Design and AECO branches.

The use of said data for Energy Design and for other AECO branches, like Building Design and Structural Engineering, will also be addressed in respect to reuse of data from a data repository.

The use of data collected by AECO and Energy Design consultants to be reused by IE- Consultants is not discussed in this report. However, data sharing between all parts of the building industry should be studied to make further developments in automatization.

Chapter 2
Methodology

In this chapter the methodology of the research is described and critiqued in order to establish the reliability of both literature review, technology testing, collection of empiric data and the final conclusion.

2.1 Literature review

The initial literature search was done using the search function at Aalborg University Library "Primo", based on specific keywords and various keyword combinations, found through analysis of interrelation between the keywords.

The top 100 abstract of each keyword group were reviewed, based on content, keywords, and citation, validated through the databases: 'Scopus' and 'Web of Science'.

The selected keywords were: "Information Delivery", "Building Analysis", Automatic Measurement, Laser measuring, "Building Information Modelling" (BIM), "Energy Potential", "Indoor Environment" (IE), "Interoperability", "Exchange Requirements" (ER), "Energy Design", "Information Delivery Manual" (IDM) and "Model View Definition" (MVD).

2.2 Methods for analysis

To find and analyse the process of data acquisition, multiple work model techniques are used. To find the initial issues in data acquisition, data export and data storing, the Contextual Design methodology as described by Beyer et al. (1998) was used. This method is also used to visually illustrate how Automated Data Acquisition (ADA) should be structured.

Flow, sequence, and artefact models are all used, to make analysis of all actants of the ADA process visible. This makes it possible to take more than just technologies into account in analysing ADA, which is why this report uses the term actant to describe all technologies and humans implicated in the process, as equally important for how the process work.

The flow model show how actions between actants is structured in a process. The sequence model further specifies the way actants decisions effects the process, and what triggers actions in the process.

Artefact models views exchange of artefacts. An artefact tells a story about a part of the work. To automate processes and parts of the work sequences in the workflow, it is imminent to understand how artefacts are exchanged and presented, and what they are made of. If this is compassed it will be easier to analyse how to optimize or/ and automated.

Before making the models, an inquiry is however needed to attain the data, visualised in the models.

Contextual Inquiry, also described by Beyer et al. (1998) was used as the primary interview tool, making it possible to get answers on specific questioning and observe how the interview persons were *actually* working with technology and data acquisition. This made it possible to analyse tacit knowledge and make a factor to consider in respect to proposed solution.

The inquiry followed four steps.

- Conventional Interview
- Transition
- Contextual Interview Proper
- The Wrap Up

The four steps of inquiry were aided by the "object – subject" method [Rienecker et al., 2012]. The interviews were documented in notes and flow- charts.

Interview persons in this project was limited to students and employees at Aalborg University.

2.3 Empiric study

A handheld laser and two data processing software's were tested to understand the process of ADA and highlight tacit knowledge when using them. Tool and software were selected based on multiple technology- analysis's. Those analysis charts are presented as a part of the Case Study, to illustrate how to select tools and software for ADA, and what parameters such selection must be based on.

By using the Case Study method for collection of empiric data documentation is of the essence. The process was further documented using the Contextual Design models and Integrated DEFinition Methods (IDEF).

The IDEF system used in IDEF 4, which is made for Object Oriented Design, and often used for visualisation and design of client/ server systems [IDEF4, 2016]. An IDEF 4 chart is compiled of IDEF 4 building blocks for behavioural description. Such blocks consist of 3 levels.

1. Message
2. Class
3. Method + Signature

Level 1 can translate into: Action to take while level 2 translates into: whom to manage action.

The advantage in using IDEF 4 for documentation and visualisation of processes regarding data in- and export, is that the design system can be built on with other IDEF systems, making it possible to illustrate more than just object-oriented design. The modelling system was therefore used as part of the sequential illustration of how data is extracted from on format for use in another.

The case study methodology was used to attain data regarding capabilities and use of ADA, and test out the selection process of handheld lasers and data processing software.

2.4 Empiric method Criticism

Contextual Design as method for empiric data gathering has proven efficient. It can however be hard to apply the full methodology due to how substantial it is.

The cultural model, as described by Meyer (1998), was not used in the contextual study. The model is used to analyse and visualise defined expectations, desires of the artefacts, policies of the organisation hosting the work- flow, and assign values to the actants. When this is understood implementation of a new work- flow, se-

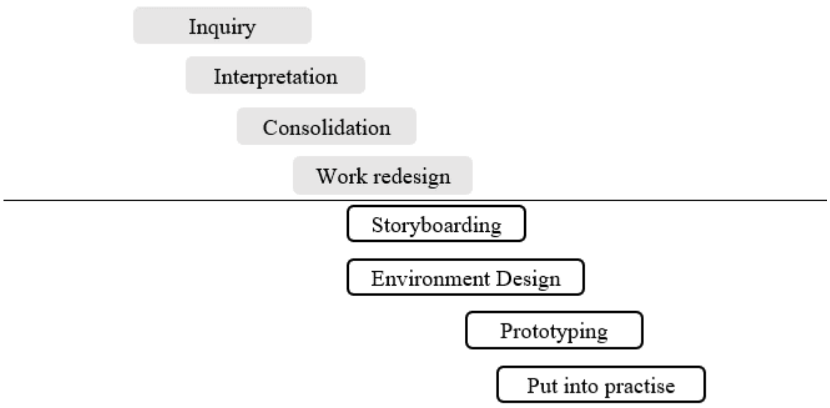


Figure 2.1 Contextual Design timeline as described by Beyer (1998)

quence or artefact can be adapted to fit as many as possible in the organisation.

This study does only concern itself with the first four phases of contextual design, as shown in figure 2.1. The cultural model was therefore not used. It must however be used in future works with ADA to explore organisational structures, policies or conflicts that might affect implementation and use of ADA.

When using Contextual Inquiry, the four steps of interviewing can further be hard to apply in projects done over short time, as the method can take up to 6 months to apply fully [Meyer, 1998].

The use of Contextual Interview Proper can further be hard to apply, as many people find it uncomfortable to be “looked over the shoulder” for longer periods of time.

This interview form was therefore only used sporadically to gain an overview understanding of how the interviewees uses Indoor Environmental Simulation programs and applies data transfer between applications.

Interviews was documented in writing, which limits reliability and heightens the risk of misunderstanding and misinterpretation.

The case study approach to attaining knowledge of how ADA works proved efficient. However, to improve accuracy of the study, at least one more case study would have been beneficial regarding reliability in the conclusion.

Chapter 3

Literature review

In this chapter previous works in respect to data needs for Indoor Environment (IE) in renovation projects, how to attain data through laser measuring and how to store such data is reviewed.

3.1 Data needs

Simulation models are used as supporting tools for many industries in order, to comprehend and handle complex design concepts and attain an opportunity to plan quality, time, and cost efficiently [Naraghi, et al., 2017] In IE- planning and design, simulation models have the same purpose. To make simulation models building and user data is however imminent. This process can however be time and financially consuming [Valavanoglou et al., 2017].

IE- simulation models is one type of Virtual Environment (VE), which based on the accuracy of the real-life representation it offers, can simulate design and energy solutions, and create a better foundation for decisions for both Users and Consultants. The process of making such simulation models can though be expensive [Tupper et al., 2010] [Gerrish et al. 2017] [Reeves et al., 2015].

Pitt et al. (2005), argues that it would be wrong to assume that VE's must represent full realism to be effective. VE's can be understood as a cognitive tool, and an enhancer of understanding, especially in project with high complexity or low user knowledge [Dayan et al., 2017]. The enhancing of understanding together with simulation data, can therefore secure more energy efficient and effective buildings, and a better IE.

At present, there is much focus on closing the gap between predicted and actual energy performances in a building [Baudains et al., 2014], and research happening currently investigates how the IE and other areas of the value chain in renovation projects can be optimized, for building Users, the Industry, the Environment, and the National Economy [Rebus, 2017].

According to Knight et al, (2007), the use of building occupant surveys and other post occupancy evaluations is considered another useful method to attain data, to improve the model accuracy.

3.2 Measuring technologies

Selection of tools for data acquisition and data processing is depended on the tools abilities to translate data (sets) and export the proper formats. Furthermore, how data is interpreted is decisive for repositories like e.g. BIM being interoperable with Building Energy Models (BEM) [Gerrish et al., 2017].

The variety of laser measurers is massive and many different brands providing similar handheld lasers are available on the market.

Multiple techniques also exist when using handheld lasers. Dependent on the capabilities of the laser, one can use contact or contact free measuring. Contact measuring is when holding the laser towards one surface whilst measuring the geometry opposite the laser [Werner et al., 2013].

Contact free on the other hand is when the laser is stationed on a fix-point making all measurements based on that fixpoint. This process is also referred to as laser tracking [Werner et al., 2013].

3.2.1 Photogrammetry

Photogrammetry is the technique of measuring objects through images [Ordóñes et al., 2010]. When using this measuring technology indoor lighting, complex room layouts, clutters and occlusions can be challenging making it difficult to make measurements [Ordóñes et al., 2010] [Ochmann et al., 2015].

This process has proven to be an efficient way of creating point clouds with ability to be manipulated into 3D geometric objects. Ochmann et al. (2015) conclude that walls must be connected in both ends to be represented… or captured through the photogrammetry approach.

3.3 From handheld laser to repository

From handheld laser to a data repository, each measuring point must be documented in a coordinate system. To save memory in the laser, DXF is often used as data format for exchange and storing.

DXF was initially made by Autodesk, to heighten interoperability between AutoCAD and 3D modelling programs made by other software producers. DXF stands for Drawing Exchange Format, and allows for storing of CAD data like coordinate points and lines. A feature of DXF is that it can exist text- based. However, it does not have the same capabilities as DWG which allows for storing of colouring, line weights and x-refs in the format [Computerdk, 2017] [Autodesk, 2017].

DXF is for exchange, and can hold line, point, dimension, and text data, which makes it ideal for data transfer from a handheld laser to data processing software, and between processing software to a repository [Autodesk, 2017].

After having attained building geometry by laser measurement, through DXF, data processing software can make it possible to store the data in either a database or in a XML- repository, using eXtensible mark-up language (XML), Green Building Extensible mark-up language (gbXML) and the Industry Foundation Class (IFC), which is open standards which allows for interoperability between proprietary CAD and CAE software.

DXF can on some handheld devices be transferred directly to CAD software either through Bluetooth or USB [Leica, 2015].

Proprietary (non-open) technologies are barriers for cross- domain innovation and implementation. Especially because such technologies do not provide open interfaces [Buda, et al., 2017]. This can however be solved through the use of DXF, IFC and XML.

3.4 Data storing

Many formats exist to uplift various tasks. Some are proprietary like rvt. (Revit), dgn. (Design) i.a. Others are open source or standards like Portable Document Format (PDF), XML, gbXML, IFC.

XML and IFC is likely the most used formats and the easiest to implement, given they are open standards. The Industry Foundation Class (IFC) provide the building blocks for interoperability through its non- proprietary data schema [Venugopal et al., 2012].

Both IFC (ifcXML) and (green building XML) gbXML has the potential to store building information and parameters attached to the geometry [Gerrish et al., 2017], IFC is though considered to play an important role of translation from BIM and other data repositories to energy simulations, because of its format neutrality [Kota et al. 2014]. These schemas thereby create a common language for data transfer between different software platforms and analysis applications [Niu et al., 2016], like BEM.

Choi et al. (2016) further notices that data models such as IFC and XML are imperfect and do not always provide reliable geometry data and construction information. Data exchanges can further be distorted by lack or misuse of the format the information is transferred through [Gerrish et al., 2017]. Careful consideration in selecting what format to use it therefore paramount, together with attention to what application is used to make, store or transfer data.

3.4.1 Building Information Model (BIM)

In recent years Building Information Modelling and Management (BIM), has been a key topic in the AECO industry. CAD and building data combined in one model or model group, can act as a repository for data for most building analysis's. According to Gerrish et al., (2017) BIM offers an extensible medium for parametric information storage, creating a reliable basis for decisions during its Life cycle (LC).

BIM is a shared knowledge resource for information about a facility, forming a reliable basis for decisions during its LC; defined as existing from the earliest conception to demolition [Baudains et al., 2014]. At least if the data the model is compiled of is accurate.

When used for design decisions, multiple studies show BIM as a profitable methodology when implemented in the earliest phases of a design project [Eastman et al., 2011] [Vestergaard et al., 2012] [MacLeamy, 2004].

Following the establishment of BIM in the building industry in the 2000s., other types of models and data repositories has risen. E.g. Building Energy Modelling (BEM). BEM is used for Energy Design and EI simulation and analysis throughout building design and construction [Reeves et al., 2015], and can be used in both design of new buildings and in renovation projects.

When using a BIM as the central part of the AECO process in the building LC, it is possible to optimise the BEM- use more in the various design, build and operation phases, as geometry does not need to be recreated in certain BEM- platforms [Reeves et al., 2015]. The same is assumed to be the same when BIM and BEM is used in unison for renovation projects.

3.4.2 Bridging the gap through BIM

The use of standards for e.g. BIM/BEM makes it possible to streamline the design and building process, creating a more integrated connection between the people designing and the people building. The integration between models and constructers is however often done on an ad hoc basis [Baudains et al., 2014], which is why standards, not just for building information modelling, but also for data sharing based on BIM is needed.

Consistency in BIM data is key, and a necessity for it to work as basis for BEM and IE simulations [Choi et al., 2016] [Choi et al., 2015].

3.4.3 Level of development (LOD)

One way of defining data in BIM is through defining Level of Developments[7] (LOD), however consistency is in many situations depended on the modelling discipline of the ones providing BIM/BEM.

In the United Kingdom specific BIM levels for building design projects, as defined by National Building Specification (NBS), have been mandated since 2016 [NBS, 2014], and in America and in various European countries specific demands and standards have also been implemented in recent years, to support and aid BIM use for design, Energy Design, and IE- simulations [BIMforum, 2017] [Hore et al., 2017] [Gerrish et al., 2017].

However, BIM must be used as a method to both include the manipulation of building data and an ability to be a data repository, for it to be relevant in Automated Data Acquisition for IE [Ugliotti, et al., 2016].

3.5 Data export specification

After data has been collected it is important to define how such must be delivered and viewed.

7 This report uses the definition Level of Development instead of Level of Detail, as the latter as described by BIMforum (2017) indicates how much information is included in the model element, whilst Level of Development indicates the degree to which the element geometry and attached data has been though through.

When exchanging data, another key topic is interoperability. Interoperability is defined as the ability of one system to work with other systems without any effort on the part of the end user of the system [Costin, 2016] [Costin et al., 2017].

In addition to how measuring tools work in unison with data processing software, additional descriptions and standards can be used to heighten the quality and interoperability possibilities.

3.5.1 Information Delivery Manuals

An Information Delivery Manual or Plan (IDM) is a description of what and how information must be delivered in a data exchange. This could be between applications like Autodesk Revit and Energy10.

An IDM is divided into two parts:

1) Process
2) Data

[ISO 29481-1:2016] [ISO 29481-2:2012].

By using IDM, BIM use as both design tool and repository for building data in renovation projects can become more efficient [NBS, 2017]. According to Niu et al., (2016) the information that is needed to perform energy analysis, as well as the desired output information, is not clearly defined by any standards. Because of that the process and data described in an IDM can vary greatly from project to project.

3.5.2 Model View Definitions

A Model View Definition (MVD) is according to Venugopal et al. (2012), a requirement for specifying exactly what information should be exchanged and in what form and structure the IFC entities are to be used. However, defining what to exchange is not a unique demand only needed when using IFC.

Eastman et al. (2011) defines model view as: "*an identification of what should be expected to be exchanged*" between to actants "*to be effective*". That way the exporter knows what can be expected and acted on.

Model Views define what is to be implemented for the implementers of the exchanged data, "*so that both export and import are aligned*", which eliminates mismatched assumptions.

Chapter 4
Current Data Acquisition

This chapter describes and presents the results from the empiric data gathering on how data is currently acquired for IE- analysis in the building industry. The results are presented through flow, sequence, and artefact models to provide a deeper understanding of the processes of data acquisition.

4.1 The current process

Even though all buildings are different most of the data needed for doing IE- analysis is the same. Calculation and simulation of the thermic, atmospheric, and acoustic climate are primarily based on geometric data, such as room with, length and height.

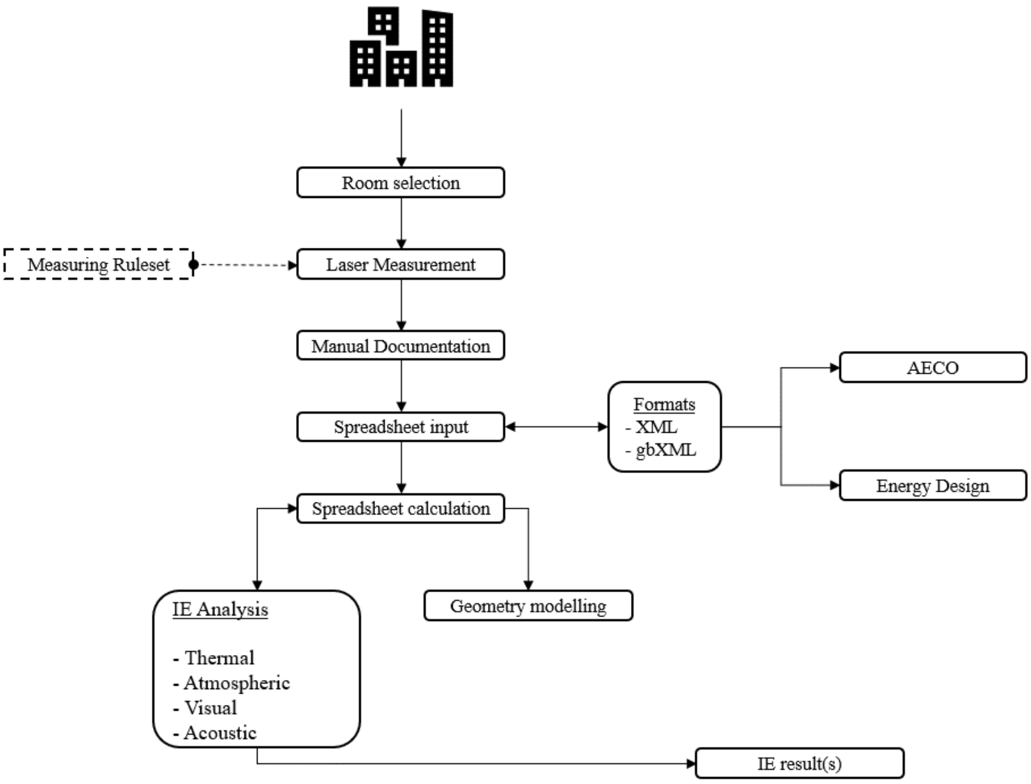


Figure 4.1 Data acquisition flow currently practised in the building industry.

Interviews[8] with multiple people working with IE- analysis in various software assigns geometry as key to calculation. The geometric measurements are furthermore needed in order to build virtual representations (VE‘s) of the geometry.

The process of data acquisition currently being practised in the industry, is shown in figure 4.1.

Laser measuring is widely used by IE- consultants however, without linking it directly to data processing tools. One of the most used tools for data documentation and processing for IE- consultants is Microsoft Excel. As shown in figure 4.1. the use of Excel is based on manual input, and not automated data export from neither laser, data processing software or repositories.

After data is typed into Excel, data can be copy-pasted into other calculation schemes, or exported to other software’s thorough XML, XLSX or XLS.

To attain better understanding of the data acquisition process, looking at the process in a sequence makes it possible to determine at what time decisions, in a IE-analysis process, occur and influence others.

As shown in figure 4.2, the acquisition of data is highly effected by what final output one wants.

4.2 Data needs

Interviews reviled that data needed for IE- analysis can be divided into three groups.

1) Internal geometry
2) Materials (glass/ walls/ floors etc.)
3) External geometry

The internal geometry is measurable based on laser or tape measuring tools. As is the geometric data for building materials like windows and doors. However, for both materials and external geometry human observation and data selection is needed.

As shown in figure 4.2 the observation of materials and geometry can be depended on the output one wished for, creating a bias, which can in the end effect the reliability of the IE- analysis, or other VE’s and calculations reusing the collected data.

Rules for data registration is therefore needed.

8 Interview persons is shown in appendix 2.

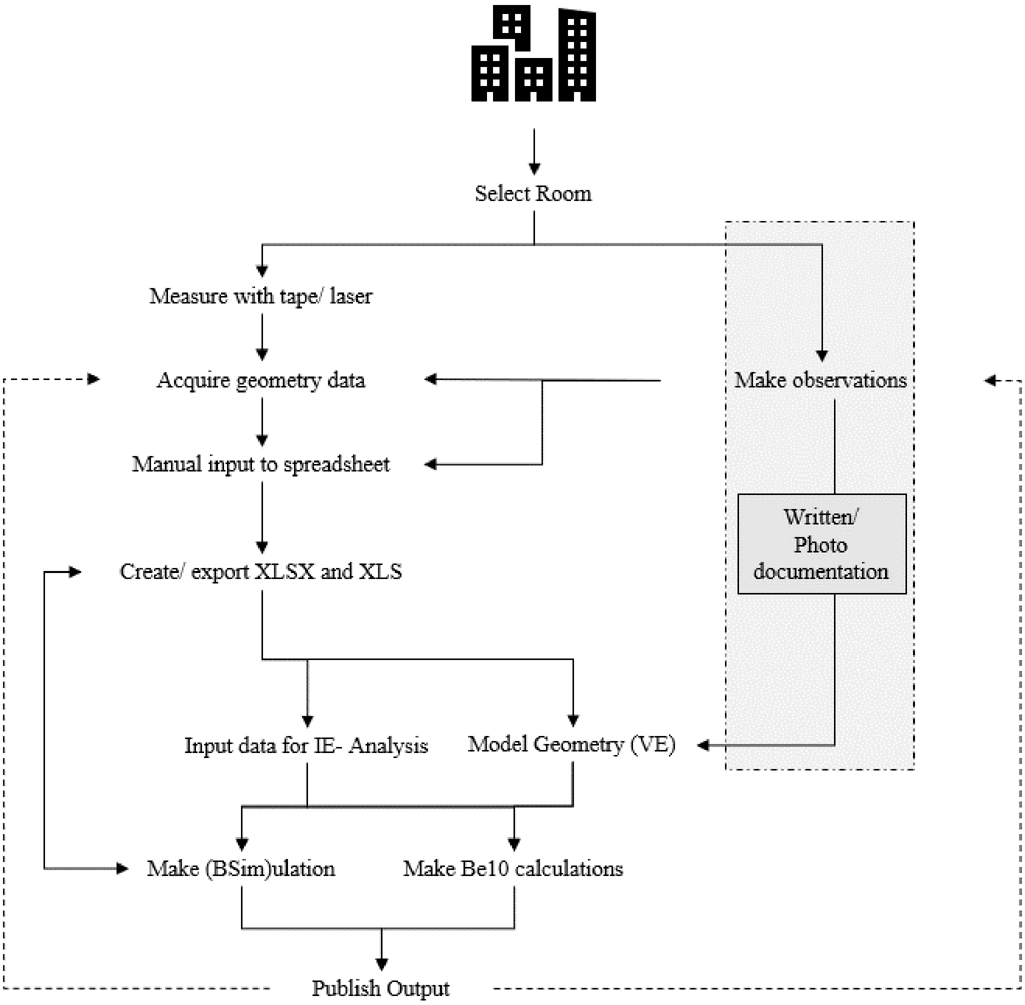


Figure 4.2. Sequence of data acquisition from a room geometry is selected to a final output is published.

In order to determine which rules should be implemented to secure reliable data, figure 4.3, shows the sequence of data acquisition through observation.

Most of the observational data is rather easy to gather reliably. But in case of estimation of comfort and building components types, it can be hard to be completely accurate.

”Håndbog for Energi Konsulenter or HB16” provide guides and regulation to energy consultant doing Energy classification, but is also used by consultants doing IE- analysis. The guidebook contains norms for calculation for various energy and IE- parameters and further contains standard or average values usable for calculation of thermal, atmospheric, visual, and acoustic climate in a room or building.

A report in respect to data acquisition for BSim by Dolejan et al., (2017)[9], indicates that length and width is key, but placement of building openings are also imminent in order to do reliable analysis's in BSim.

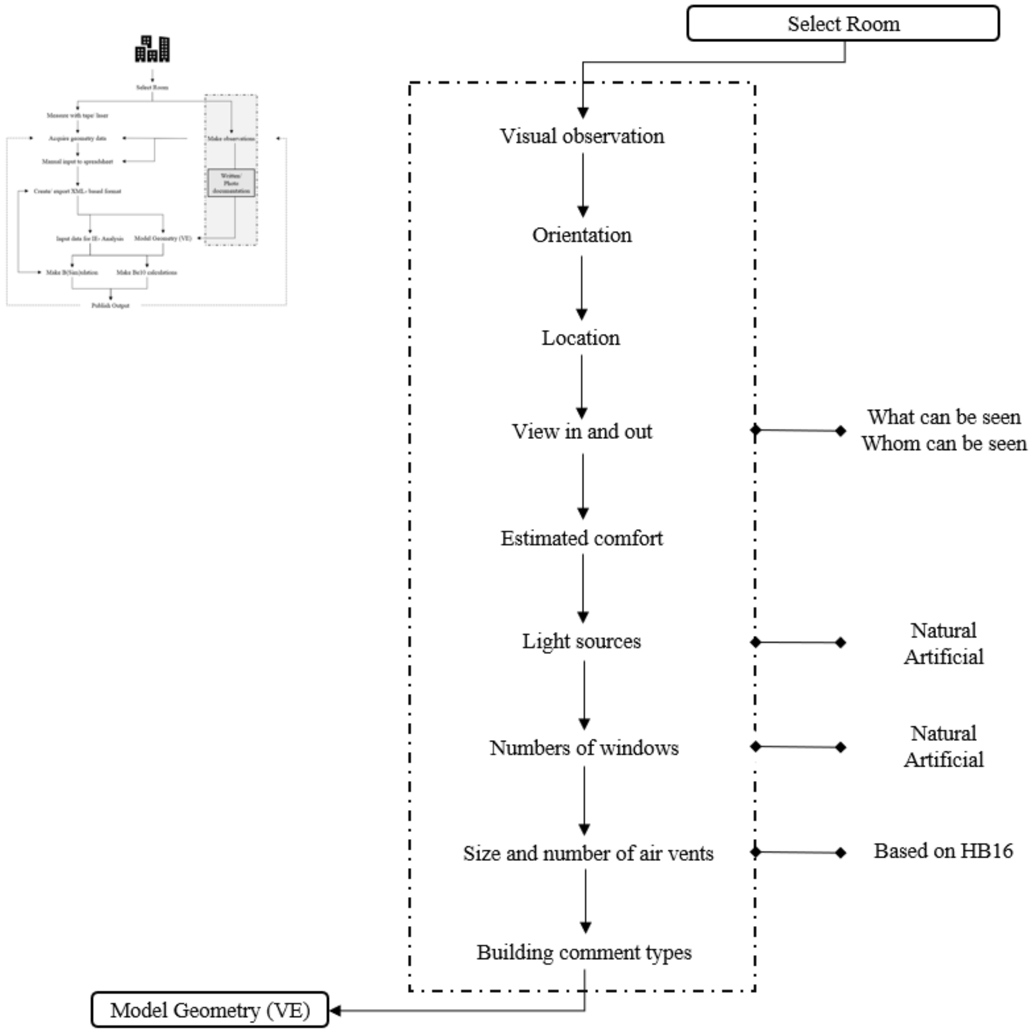


Figure 4.3 Sequence diagram of visual observations taken during data acquisition.

Another factor is as mentioned external geometry. The ability to measure neighbouring buildings and flora (neighbouring objects) shadowing (or obstructing views from) the building one is measuring, is rather important, to calculate thermal, atmospheric, and visual IE.

9 See Appendix 1.

Thermal parameters calculated in BSim are according Dolejan: Operative temperature summer and winter and draught. Atmospheric parameters are impacts from the building, like natural ventilation and HVAC.

For the visual part of the registration, daylight and direct sunlight are the key parameters. These are measured in intensity, and distribution of light, and the time it occurs in.

Most of these data can be calculated based on knowledge of building geometry, building orientation, and building location. However, rules for measuring from location "A to B", and from where one measures distance and height of external buildings must be established.

4.3 Measuring rules

Some geometries can be hard to measure accurately. Bay windows e.g. do not necessarily have easy calculable forms, and because of that, rules for measurement of such geometries must be determined.

Dolejan et al., (2017) proposes measuring geometries with odd shapes by measuring a series of fix-points which afterwards are connected to form an accurate representation of the real-life bay-window or other distinct geometries.

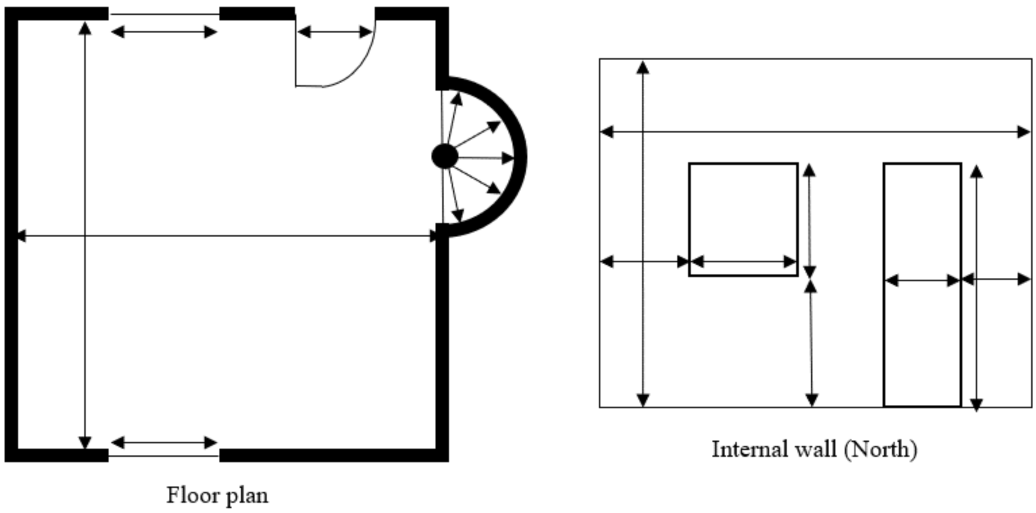


Figure 4.4 Illustration of measurements needed for IE- analysis and where to measure between. Based Dolejan et al. (2017).

Figure 4.4 views the measurements that needs to be acquired. A measurement, not viewed in the figure, is the depth of the door and window and their placement depth in the wall, which are both important in order make accurate simulations of the room.

When measurements presented in this chapter is collected through either laser or measuring tape, they are written down in an Excel spreadsheet, and afterwards modelled in a CAD programme if it is needed.

4.4 External measuring

External geometry like neighbouring buildings and flora is essential in IE- calculations to analyse and simulate shading, view obstruction and lighting [Dolejan et al., 2017].

Façades visible, distance to neighbouring objects and rotation of objects compared to the focal building is what is needed [Dolejan et al., 2017]. Such measurements can be made through a serious of points documented in DXF, or through triangulation of points from a fixpoint, from where all measurements are taken.

How measurements are taken, depends on what tool is used and a ruleset defining from "where to where" one must measure, is the key to secure that all data needed is acquired.

One way of acquiring data about external objects is photogrammetry, as described in chapter 3.2.1 [Ochmann, 2015]. Another way is through handheld lasers. When selecting handheld laser, an ability to consider in the tool is the distance the laser is capable of measuring. The ability to photo document measurements when doing the measuring is further a point to consider when selecting a handheld laser.

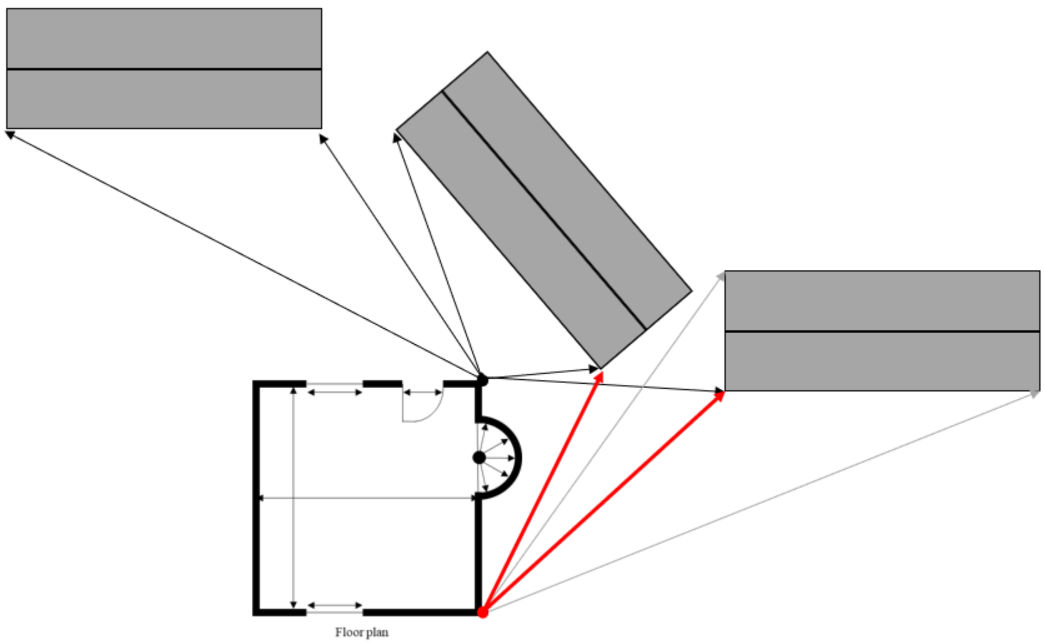


Figure 4.5 Illustration of how to measure distance and height of neighbouring buildings (objects). The red measurements are control measurements, used to secure accuracy of object angle, when using more than one fix point.

Dolejan et al. (2017) presents a solution of how to acquire distances to neighbouring objects from the focal building[10]. Using handheld lasers, distances and heights of neighbouring objects can be acquired quite easily, as seen in figure 4.5. By establishing one (or two) points of measurement, from where all neighbouring objects can be seen and measured, one only needs to set up the laser a few times. All measurements will furthermore refer to the same fixpoint(s), making it possible to update orientation of the focal building, without it interfering with any measurements.

As shown in figure 4.5 it is necessary to measure some points twice, when having multiple fixpoints. By doing such extra measurements the angle of the external geometry can be established accurately.

Height of neighbouring objects must also be measured from the same point, for all data to correspond correctly with each other.

A measurement needed to create pitched roofs is the height of the roof eave. Making building top height, eave height and building foot needed [Dolejan et al., 2017]. To capture rationale behind measurements, photo documentation of measurements taken is recommended. By doing so, measurements can be repeated and validated.

Data acquisition of neighbouring objects is not tested in this project, but must be included in future work.

4.5 Data transfer

Many artefacts are exchanged between actants from start to end of a renovation project in respect to IE. Figure 4.6 shows which artefacts are exchanged in the process currently used by IE- consultants.

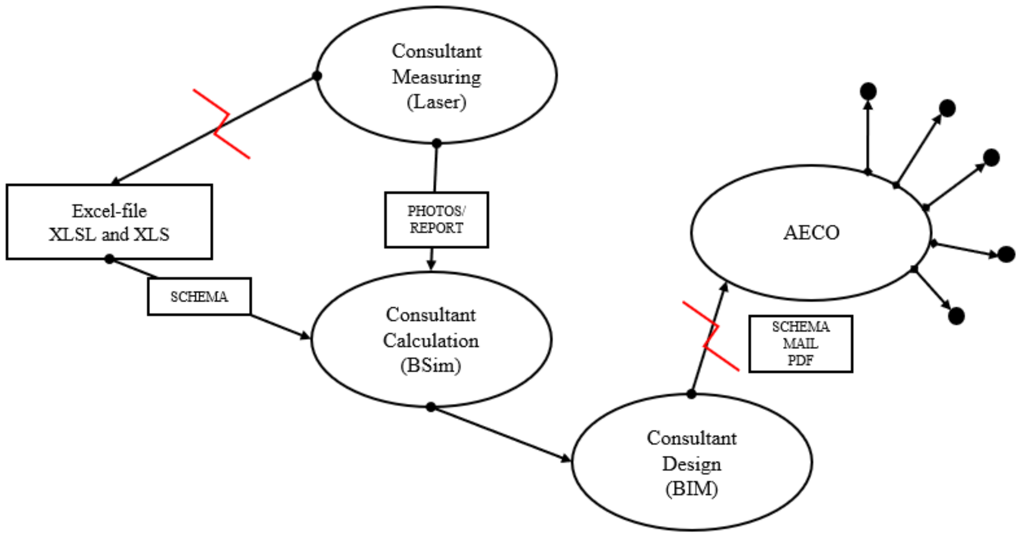


Figure 4.6 Artefact model of the data acquisition process currently used.

10 See appendix 1.

As shown, the process starts with the IE- consultant measuring geometry using a laser. The data is then manually typed into a spreadsheet, often Microsoft Excel. Photos taken at the registration and a written report is then often also sent to the consultant doing the IE calculations in e.g. BSim.

When data has been processed manually, by the Consultant doing the calculations, it can be distributed to those doing design and other AECO partners.

As illustrated by the red lightnings, some processes are completely manual though, and based on typing and mail correspondence. This is far from optimal if a laser with interoperability and exportability capabilities is used for the measuring.

It is therefore important to select tool and method for data acquisition based on what output and how much automatization one wants.

Chapter 5
Handheld lasers in use

This chapter describes how handheld lasers can assist data acquisition and what must be considered before selecting measuring tool and data processing software.

5.1 Digital Technologies on site

Use of handheld devices like phones and tables[11] have become an increasingly common practice on building sites in Denmark in recent years. These technologies have supported a change in the industry, going from use of paper drawings and printed building descriptions as the standard procedure, to paper/ print free building sites.

The introduction of handheld devices on building sites has further made it possible to introduce many new concepts to the construction workers e.g. Virtual Reality (VR), Augmented Reality (AR), 3D model detail views, and use of laser measuring devices.

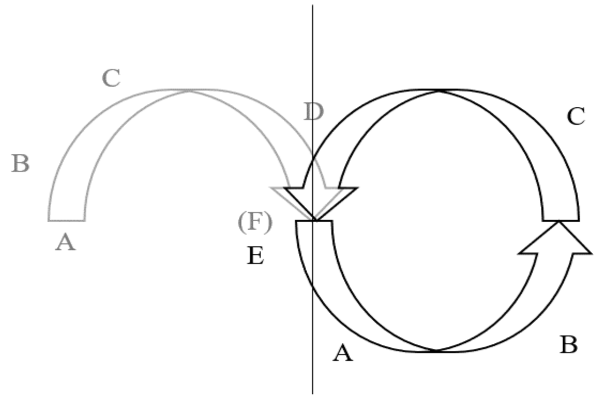


Figure 5.1 A) Design B) Construction C) Operation D) Deterioration E) Renovation F) Grave/Cradle

In renovation projects architects need geometric data to redesign rooms and functionality of the building. Engineers need geometry and material data of the load-bearing elements and material data.

The Constructers of the building need data delivered by the Architect and Engineer, to renovate the building, whilst the building Operators need room- volumes and

11 Phones and tablets will in this report be referred to as handheld devices.

building opening sizes along with insulation data, to calculate and simulate the Indoor Environment (IE). Operation further needs area and surface information to maintain the building both internally and externally.

As shown in figure 5.1, design of a new buildings only happens once. In case of renovation in the end of this first building Life cycle (LC), a "new" cycle can then start over repeatedly until the building owner, later decides to break down the building and thusly finish the LC, by either putting the materials to the grave or recycle the materials, starting a new building LC.

5.2 A need for Handheld- Devices and Lasers

Buildings set for renovation rarely have other than 2D paper drawings and written buildings descriptions as documentation. Occasionally documentation can be very good, but often new registration is imminent. The use of handheld devices and the internet in unison, has furthermore made it possible to make 3D details accessible on the building site, making them a tool for construction, and not just visualisation for design. [Eastman et al., 2011] [Godtsygehus, 2017].

Handheld lasers in consolidation with data processing software, either on handheld devices or stationary devices like computers, have proven efficient as tools for automated "geometric building" data acquisition (ADA). However, converting the gathered data and using it for more than geometric calculations and simulations has yet to become common practise.

Preparation of simulation models can be a lengthy and laborious process that demands many resources, manual labour and translation of data [Kota et al., 2014]. However, with the use of handheld lasers and the right data processing software, this "laborious process" can be aided.

To select a handheld laser, one must first consider what format is needed? What exportability a project demands, and the degree of interoperability one needs.

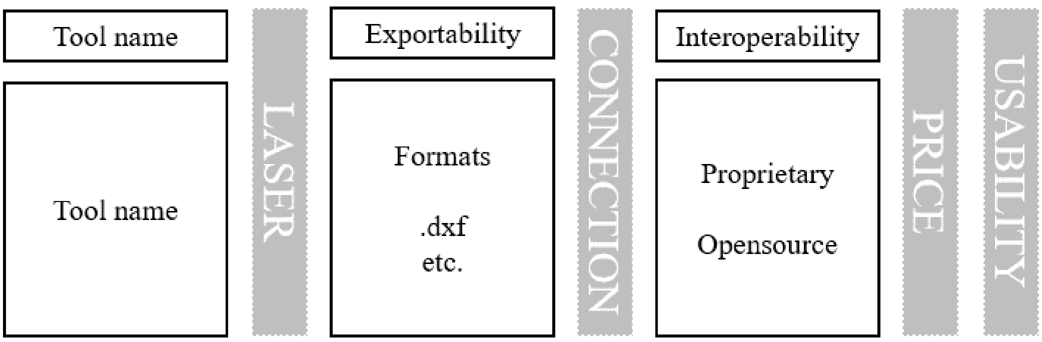


Figure 5.2 Things to consider in selecting of a handheld laser, to aid the data acquisition process.

As illustrated by the grey boxes in figure 5.2, method of measuring, how to establish connection between the handheld laser and the data processing software, the price of the handheld laser and its usability, can also be important factors in tool selection. These is however not further described in this report, as the primary focus here is exportability and interoperability of the measuring tool.

5.3 From geometry to exportable data

When measurements are acquired through a handheld laser, data can be transferred either directly to: CAD, Repository, or through a data processing software.

Figure 5.3 shows the sequential process of data acquisition using a handheld laser and data processing software, either stationary or handheld.

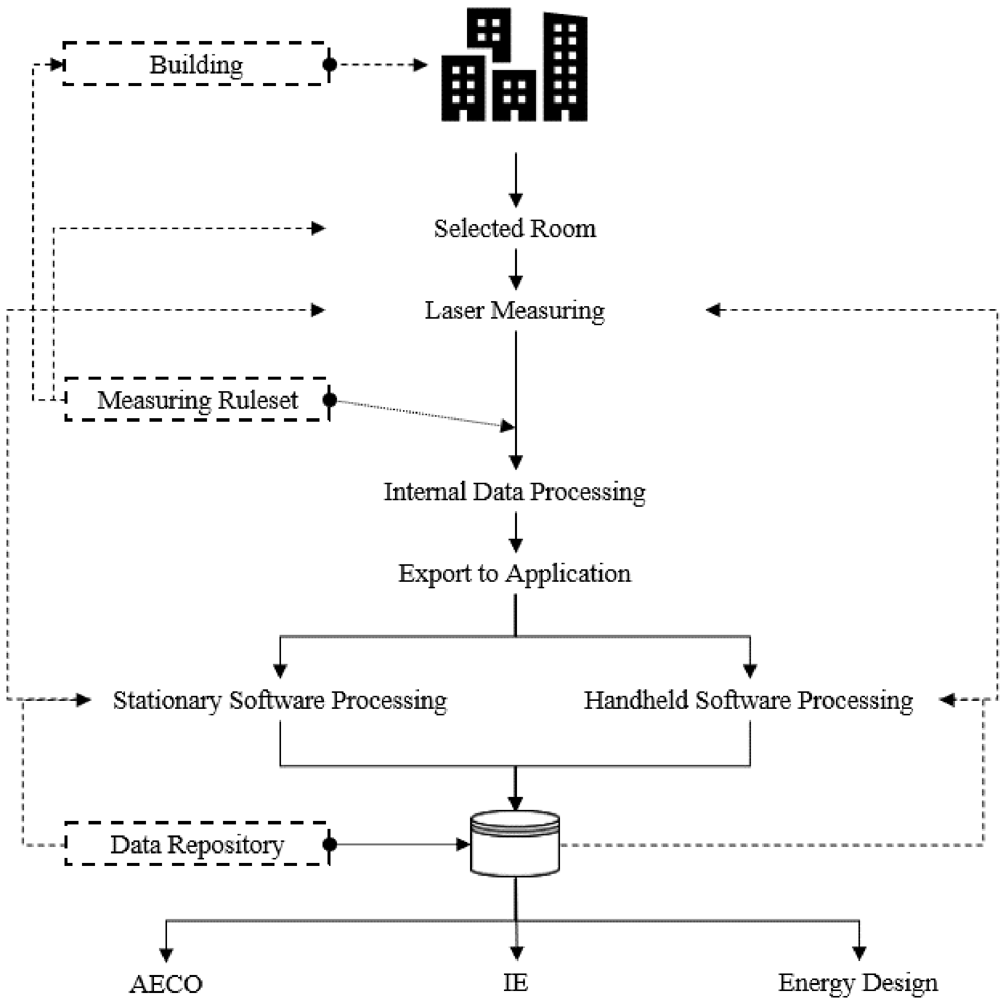


Figure 5.3 Sequence model visualising the steps of data acquisition going from a geometry, tool, processing software, storing and export to other branches.

As shown in the figure 5.3, many of the processes in the sequence influences others. And most of them leads directly back to which laser is selected to do the data acquisition, giving argument to why the selection of a handheld laser is of utmost importance.

5.4 Exportability

Exportability is the ability to transfer a format from a Data Acquisition tool or Data Processing Software useable for other actants. At least in this project.

This ability is one of the keys to selecting a handheld laser and data processing tools. The more formats the laser or the software is capable of handling and process, the more likely the tools is to be usable for multiple branches of IE, Energy Design and the rest of the AECO industry.

5.5 Interoperability

Interoperability is defined as the ability of one system to work with another system without any effort on the part of the end user of the system. In respect to ADA, it is important that the laser is compatible with multiple types of software, making the laser usable for more than one project or type of project.

Even though the cost of laser and data processing software is not a criterion for selection of tool in this project, it is though important that the cost of equipment (laser and software) does not make it less feasible to use ADA financially.

The more data processing software a laser can use, and the more lasers data processing software is compatible with, the more feasible this author argues the handheld laser and the data processing software is.

Chapter 6
Case Study

To test selection a handheld laser and data processing software, a case study was conducted. The use of a selected handheld laser and data processing software has furthermore been tested, which is presented in this chapter.

6.1 Selection of handheld laser

Exportability and interoperability are the key parameters for selection of a handheld laser. Based on the selection method presented in figure 5.2, a handheld laser was chosen.

4 handheld lasers were analysed for the Case-Study. As shown in figure 6.1, the Leica S910 handheld laser was the one with most export options and with most interoperability options, which is why this tool was selected.

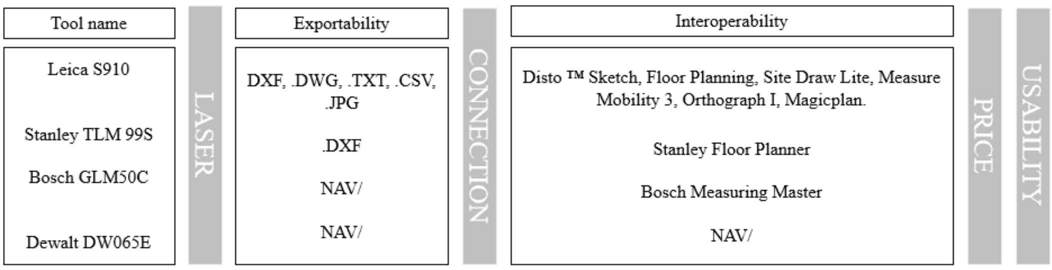


Figure 6.1 Selection of handheld lasers.

The laser has the capability of measuring distances from 0 to 300 meters. Further it can measure heights within that distance [Leica, 2015].

The handheld laser has a built-in camera, making it possible to document measures taken and it can export both images and measurement data directly to a computer through USB and through a data processing software on a handheld or stationary device [Leica, 2015].

The format the handheld laser export is DXF, which makes it possible for multiple CAD programs to use the direct output from the tool. It further export JPG images. The selection of the Leica S910 handheld lasers does not mean this author does not recommend other brands or types of handheld lasers. But in this study, this handheld laser proved to be the most feasible to test.

6.2 Interoperability with data processing software

The export format from the handheld laser can as shown in figure 6.1 be used by multiple data processing software applications (software).

An analysis was conducted to select the best software to process the data.

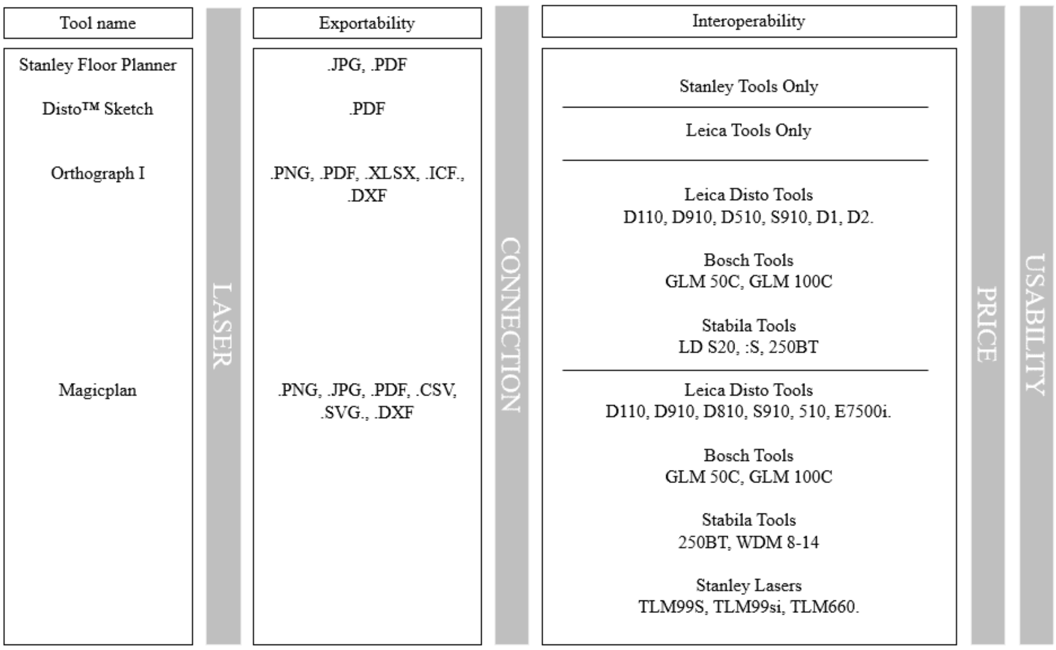


Figure 6.2 Selection of data processing software.

The analysis was done using the same method as the selection method for lasers (figure 6.1).

The software analysed was based on which handheld lasers that were tested in the study. Downloads on App Store and Google Play was further factors considered in software selection.

Exportability is this context is to be understood as a format that can be exported, after the data has been processed by the software.

Most software that can be downloaded to handheld devices can export JPG and PDF. Those formats can be used for documentation and building management and operation. The use of those formats for IE- analysis and simulation is however limited.

The formats weighted as best, in respect to exportability, are therefore IFC and DXF.

As shown in figure 6.2, only two software can export DXF, and only one IFC.

The software selected for testing was Magicplan, as it is capable of DXF, CSV, SVG export. Orthograph I was also used in the case study to test usability of the two software. The selected test software was however Magicplan, due to its free of charge use, and interoperability with more handheld lasers than Orthograph I.

6.3 Test area

To test the handheld laser and data processing tool (ADA tool), a test area was selected.

The test area is an orthodontist clinic, which closed for practise, a few days before ADA was tested. The building is to be renovated, and be made into a small family apartment, which is why geometric data is needed for both design and IE- analysis.

The building was furthermore selected because it is a building which can represent use of ADA for both industrial and private buildings.

The test area of the building is 66 m^2. It consists of 6 rooms in various sizes. The building was erected in 1967, and lives up to the Danish building regulations of that period.

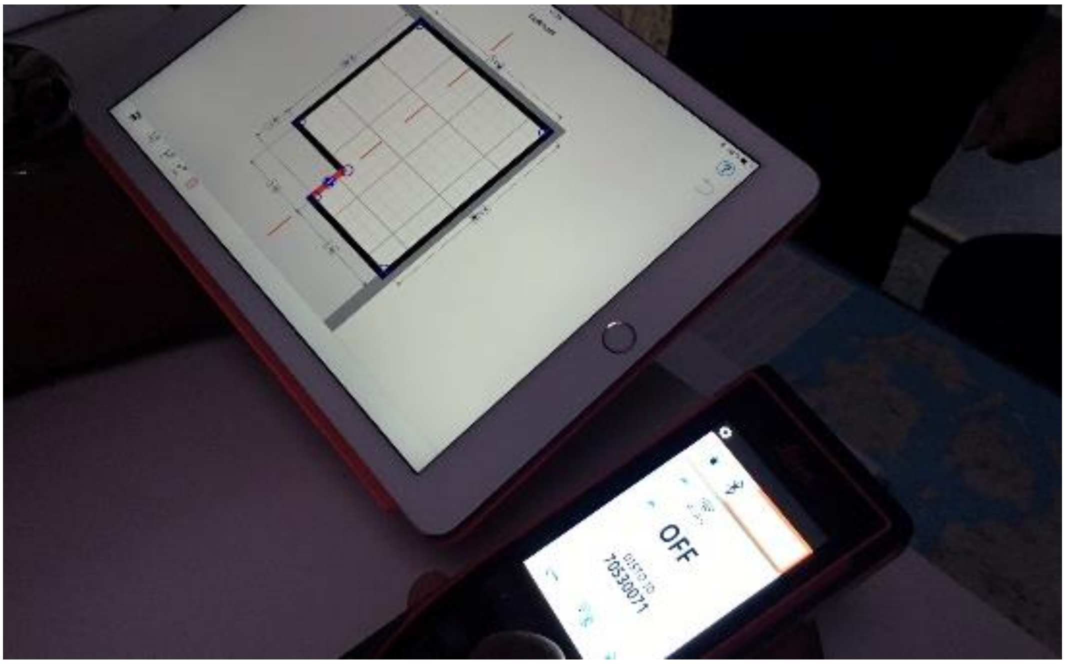
6.4 Test person

Picture 6.1 The outer perimeter of the test area [Villaurrutia, 2018].

In order to create a test result representing use of ADA for both amateurs and experts, one test person was chosen. The test person had no former experience with building measuring, and no educational background in building architecture and engineering.

The test person was explained to, how to measure the test area, and which rules applied, and which building objects was relevant to acquire.

The test person was then left to himself to measure the building, with no interference from the test overseer (this author).



Picture 6.1 Handheld laser in use in unison with Magicplan data processing software on an iPad.

When ADA was completed, the data was sent to the test overseer, whom controlled the data both sent in PDF and in DXF[12].

The test person was then given instructions to how the measuring could be optimized, and what data was missing from the output.

6.5 Usability

The tested data processing software: Magicplan turned out to be easy to use and able to produce an output usable for IE- analysis.

The first issue that rose whilst measuring the test area, was making the handheld laser connect to the software through Bluetooth. The software allows for two ways of connection. Either making the connection through the laser's user interface (UI), by selecting the iPad on the UI, or by connecting the laser through the software. The latter turned out to be the least efficient way of connecting the laser and software.

When connection was established, the room geometry of the test area, without doors and windows was measured. This took 15 minutes and produces the plan drawing shown in figure 6.3.

The second attempt to use ADA in the test area, included measuring rooms, doors, and windows. At this point the test person had grown accustomed to both the laser

12 The first ADA- output sent to the test overseer is attached to this report in appendix 3.

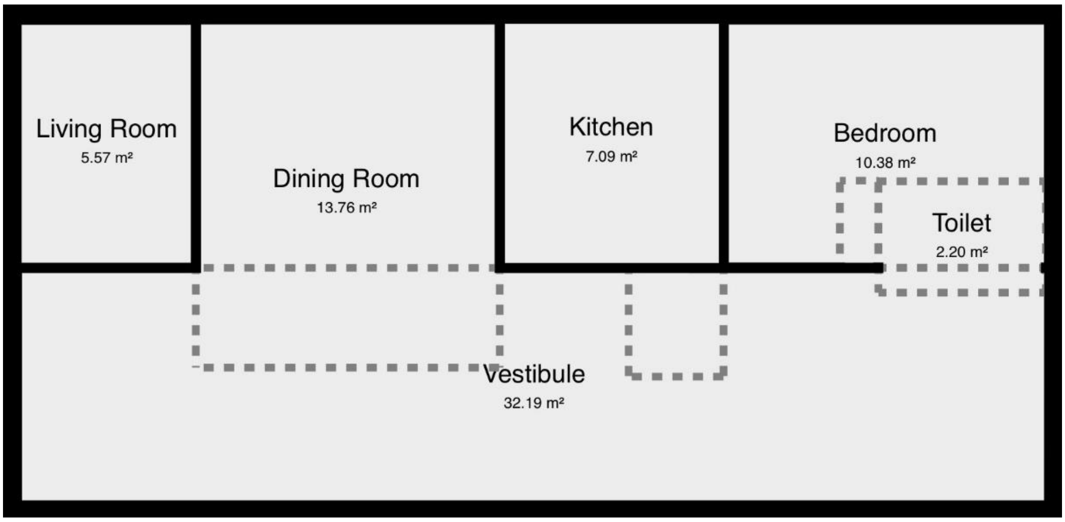


Figure 6.3 First floor- plan output from Magicplan

and the software, which resulted in a final output with a higher degree of detail and use. When measuring and digitalising geometries and in this case room boundaries, one can use two approaches.

The wall by wall method: The first way to measure and document the measurements through the software, is to draw walls as they are measured. This approach however proved to be difficult to use with oddly shaped rooms, due to software limitations. More practise using the software might though be the key to solve the problem though.

The room by room method: The second approach to measure and digitalise the measurements in the software does solve the “wall by wall method” issue.

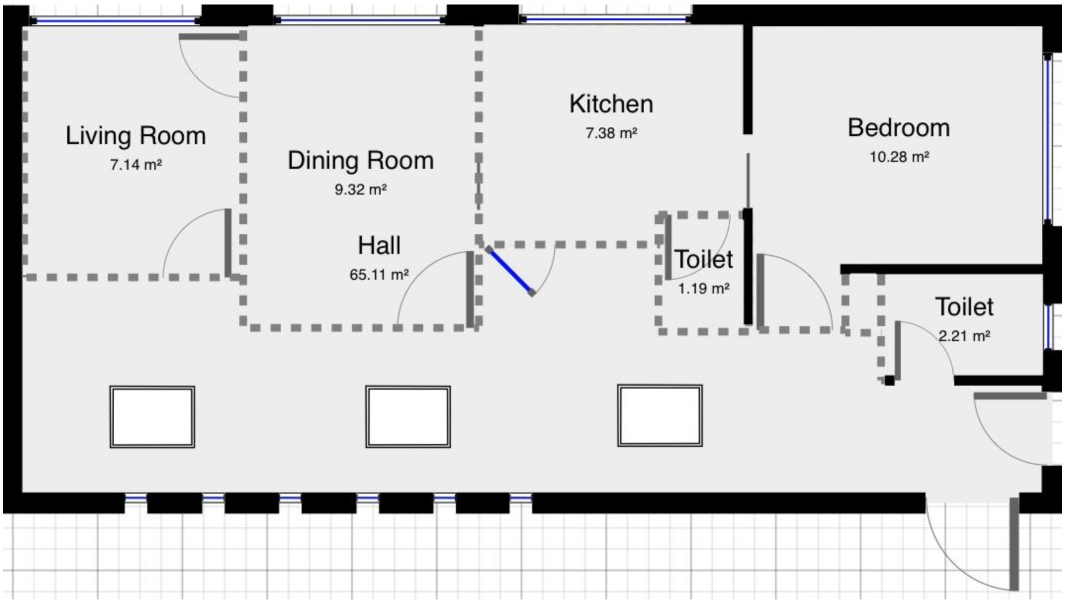


Figure 6.4 Floor plan using second approach of data processing.

By measuring and digitalising the measurements of the bounds of the full test area first and then measuring all rooms afterwards individually, it was possible to create all geometric shapes of the test area, without problems.

By measuring all rooms individually, the report generated from the software, made it possible to extract room data with heights, length, and widths, and not just areas, as shown in figure 6.4 and 6.6. The report exported in PDF format from the software, furthermore included doors and windows attached to the room geometry.

As presented in figure 6.4, the visualisation of the test area, is faulty, as the internal walls are only viewed as dotted lines. The report generated from using the room by room method does however make up for the faulty visualisation of the 2D floor plan[13].

When viewing the geometry in 3D through the software, the visualisation does give a good Virtual Environment (VE)- representation, heightening the tangible understanding of the geometry.

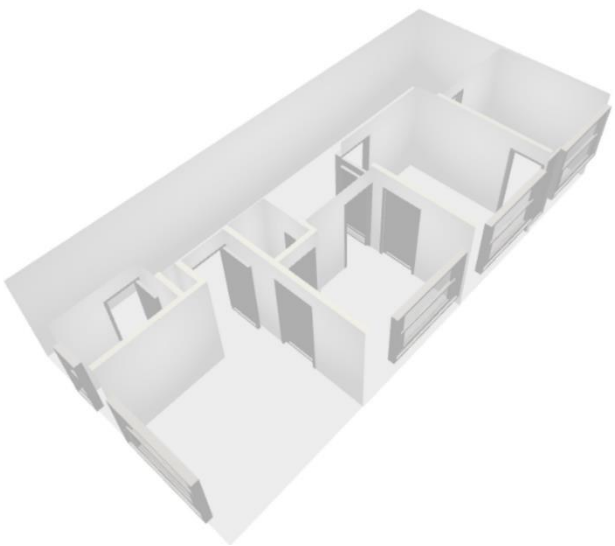


Figure 6.5 3D visualisation of the test area based on the measurements acquired from through ADA.

As it can be seen in figure 6.5, 3D visualisation of the plan drawing (figure 6.4) makes it easier to understand the complexity of the geometry, and it further makes it possible to control observational documentations, and where those vary in relation to the model.

3D does also make it possible to see holes in the model, not viewed in the 2D floor plan. This allows for validation of the accuracy of the model, and make sure it is usable for BSim and other tools for design, energy and EI analysis.

13 See appendix 3.

6.6 Use of data from ADA

The output from ADA was tested in two ways. First the DXF- output and then the PDF report output.

As described earlier, BSim has the ability to import DXF into the program through SimDXF. The author of this report tried to import the Magicplan DXF output into BSim. The limitations of this author in regard to the program, however, made it impossible to do the import. This must therefore be tested by people working with the programme professionally, to make testing possible and ensure the accuracy of the testing results.

The second way of attaining data from the Magicplan output it through the report published in PDF format. Figure 6.6 shows an example from the test area. Such a report contains all information needed to do IE- analysis.

The report therefore needs to be converted into a format that can be read by e.g. Microsoft Excel, which is used by BSim for data handling.

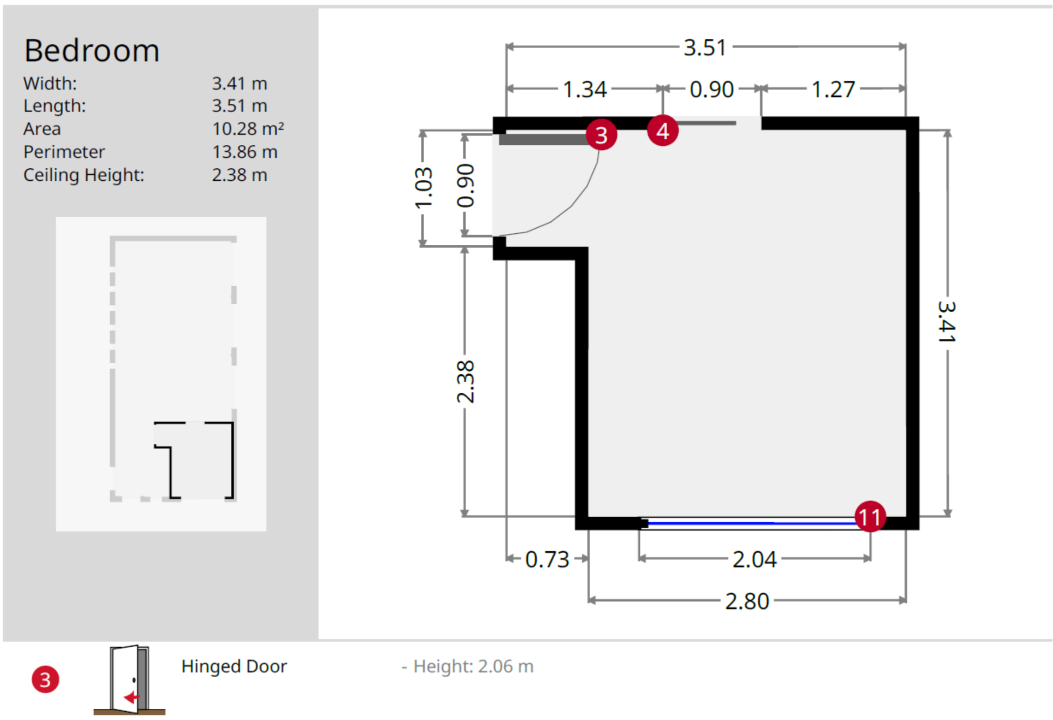


Figure 6.6 Viewing of PDF report made with Magicplan, through the ”room by room” method.

6.7 From PDF to BSim

From PDF it is quite easy to get an XML file. This can be done through the: ”save as” function in Adobe Acrobat, which allows for the data to be stored in XML 1.0. Another format one can get from PDF is XLSX (Microsoft Excel Workbook). The use of this particular file format based on PDF is limited though, as many of the data is placed in one “cell”, making it impossible to copy-paste the data into another spreadsheet for use in IE- analysis.

The final format, considered in this report is the TXT format. By saving a PDF- as a text- document from a PDF report from Magicplan, one gets the result, showed in figure 6.7.

```
2.052.66
2.032.46
2.90
HALL
65.48 m² (12.03 × 5.44)
BEDROOM
10.28 m² (3.41 × 3.51)
KITCHEN
7.38 m² (3.06 × 2.53)
TOILET
2.21 m²
1.85 × 1.19
CLOSET
DINING ROOM
9.32 m² (2.66 × 3.50)
LIVING ROOM
7.14 m² (2.46 × 2.90)
TOILET
0 1 2 34m
```

Figure 6.7 TXT version of the Magicplan PDF report.

The format attained through the PDF output from Magicplan, selected to work with and test conceptually is the XML 1.0 format.

6.7.1 eXtensible Mark- up Language

XML is based on the SGML (Standard Generalised Mark- up Language), defined in the ISO 8879: 1986. It is as the name indicates a generalised mark- up language, and is structed on different types of nodes.

The types of nodes are:

- Document nodes: “When the document is the node”.
- Element node: “The element defined by start and end tag, holding one or more elements”.
- Text node: “Text tagged as the node”.
- Attribute node: “Attributes can be attached tags to hold data for a specific element”.

```
</Table>
<P>Plan 2 </P>
- <Figure>
    <ImageData src="images/Plan 2_img_34.jpg"/>
    2.032.46 0.762.04 2.90 0.811.58 2.46 2.90 16 7 8 Living Room Width: 2.46 m Length: 2.90 m Area 7.14 m² Perimeter 10.72 m Ceiling Height: 2.38 m
</Figure>
- <Figure>
    <ImageData src="images/Plan 2_img_35.jpg"/>
    7
</Figure>
<P>Hinged Door - Height: 2.07 m </P>
```


Figure 6.8 Example on Living room tagged in XML. Full XML report can be found in appendix 4.

The tags are what is key in extracting data from XML, because the tags indicate where the data one needs is stored. The room name, functions as a tag, to which to data is attached.

As seen in figure 6.8. The XML code contains the length and the width and height of the room, which is the key parameters needed for IE-analysis, in this case ignoring observational data necessities for IE- analysis.

6.8 Conceptual solution

To make an artefact exchange process, as shown in figure 6.9 possible, this author proposes writing a programme automating the process and data transfer from data processing software, to further use of said data.

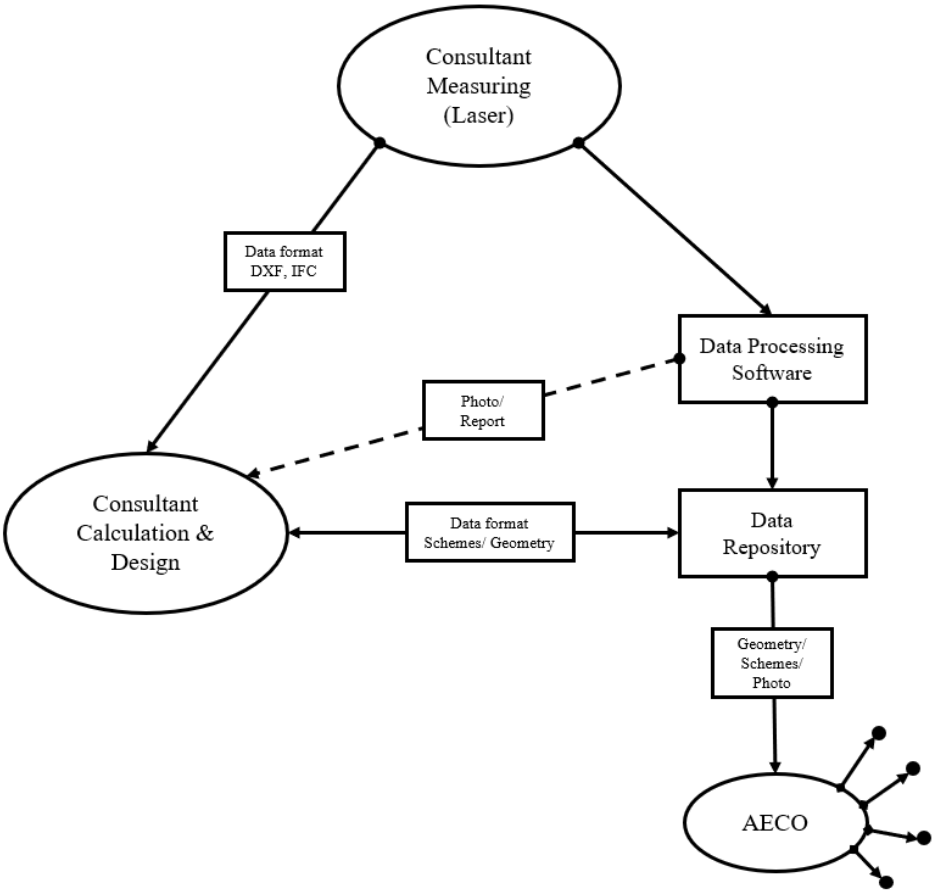


Figure 6.9. Artefact model showing the optimal process of data exchange using ADA.

The program must include following elements, in order to provide all the data, the IE- consultant for calculation and design needs. The solution will be presented on a conceptual level through a sequential model with help from the IDEF4 methodology.

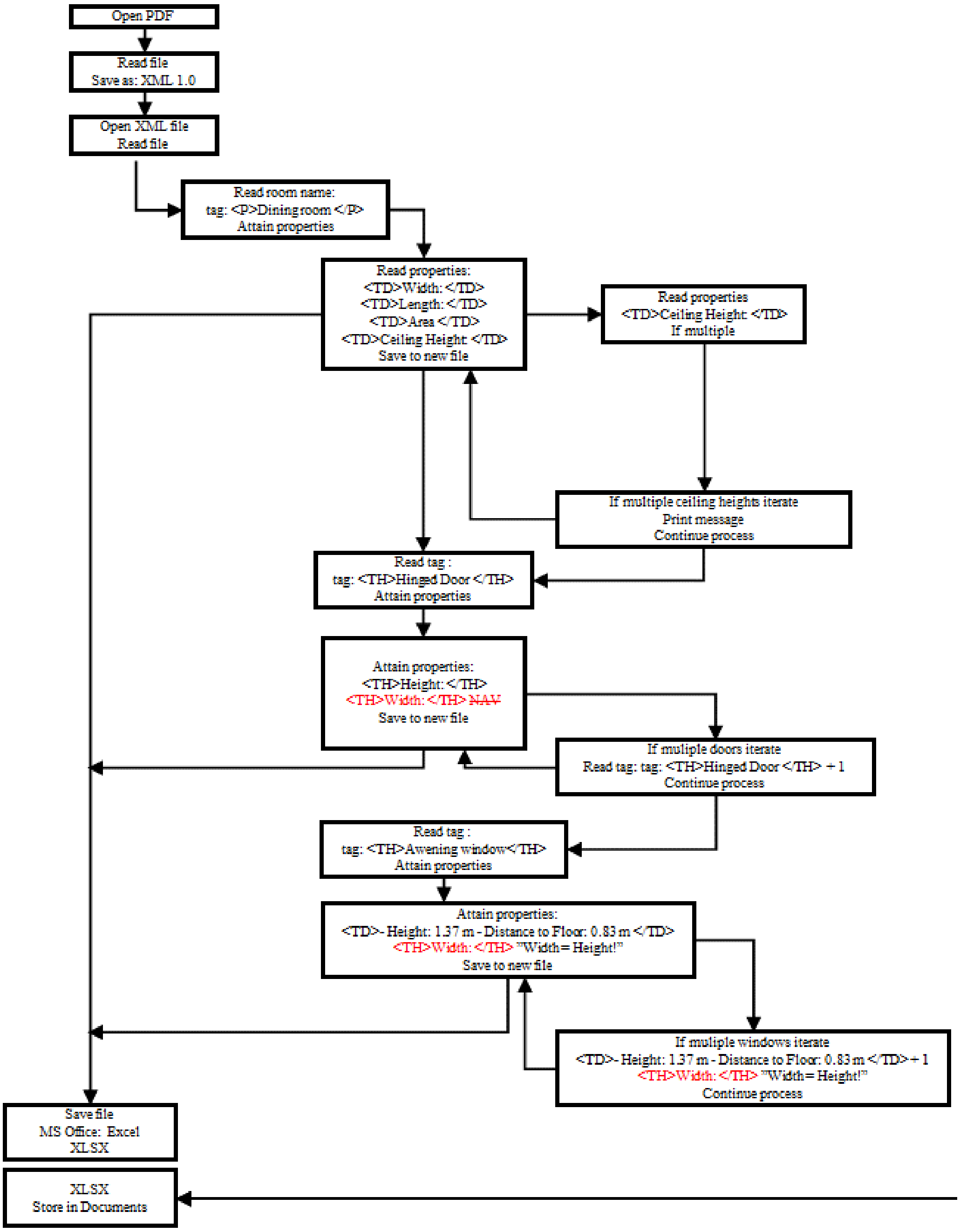


Figure 6.10 Conceptual visualisation of a program attaining data from an XML file made using Magicplan. Red text is data not attainable in the XML file at this time. The full model can be found in appendix 5.

The model shown in figure 6.10 is based on the needs of the persons interviewed in the empiric study for this report, and the minimum data needs for IE- analysis through BSim. The model must though be updated and build upon, to attain all parameters needed to optimize the process of data acquisition and further use of data.

To ensure accuracy in coding, a professional programmer must make the code, with the assistance of the models in this report. That way functionality of the programme and the further use of it can be ensured.

6.9 Case study summary

The case study has shown it is possible to select an efficient laser based in certain demands for exportability and interoperability. The same approach used for laser selection can be used for choosing the most efficient data processing software. In this case the two primary tools for ADA was the Leica S910 laser and the software was Magicplan.

As discovered through use of the tools, certain tasks success was dependent on how the tools were used, and not on the tools themselves.

Knowledge on how to take measurements is of the essence, and depends on which tools are used, whereas the measurements needed are fairly straightforward.

Use of DXF directly from the handheld laser, would have been the fastest way of going from measurements to IE- analysis, in BSim. Practical knowledge on how to use BSim is however a necessity to test direct DXF use.

Writing a programme able to pull data from PDF- reports, published by the data processing software, is another solution that can be used. What language such programme should be written in, has not been studied, however, given visual programming for data extraction in Dynamo and Grasshopper is beginning to be a common practise in the building design industry, this might also be useable for data extraction from PDF and XML i.a.

Lengths, widths, and heights are the key geometric parameters, needed for building a geometric representation of a room for analysis in BSim, and these data was in this chapter proven to be attainable from a PDF report. The next step for ADA- becoming a methodology which is implementable in the building industry is writing a programme able to extract the right data for IE- analysis, and to test out the full ADA- method in real life situations.

Chapter 7
Discussion

The various results from the literature review, the empiric study and the case study are discussed in this chapter, to gain a deeper understanding of the use of Automated Data Acquisition (ADA) and how it can benefit Indoor Environment Analysis and other branches of the AECO industry.

7.1 Basis for discussion

The process of ADA has multiple stages, and each step is needed for data acquisition to be used for firstly, Indoor Environment (IE) analysis and secondly for all other AECO branches on a renovation project.

Figure 7.1 shows the steps of ADA in a sequence, and in what order the different processes takes place.

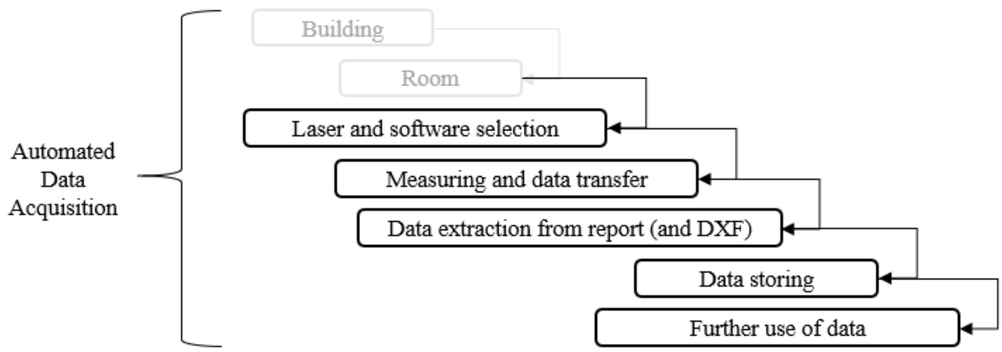


Figure 7.1 The process of Automated Data Acquisition.

Data gathering for IE- analysis and simulation and calculation for Energy Design or Design in general, is today heavily based on manual labour, and without use of the automated capacities many tools for measuring possesses.

Even though handheld lasers are widely used in the AECO industry, the documentation of measurements is mainly done by reading the measuring results on the user interface (UI) of the laser, and then writing it down manually in a spreadsheet.

A process automating this practise therefore seems advantageous.

When selecting a laser, focus should be on its abilities in exportability and interoperability and not just usability and price.

By choosing a handheld laser capable of providing the format one needs for IE-analysis or other simulations and calculations, either directly or indirectly, time and thereby money, will be saved.

Financial gain is the typical reason for companies optimizing or changing procedures and the use of ADA can be considered a valid reason for procedural change in that regard.

7.2 From laser to data processing software

By selecting a handheld laser based on interoperability one can gain the ability to process data in multiple data processing software's (software), which can translate e.g. DXF data from the laser into other formats and create visualisations of the measurements, heightening understanding of a building, for those processing the data.

Some types of software can export IFC, making it possible to use the data for design modelling and store it in BIM or other repositories for design. Others can help add information to the original DXF and make the data usable for both IE- and Energy Design analysis.

Most software types can export pictures and PDF. This could seem to limit the further use of the data, however, through the right use and processing of such data, it can be possible to do IE- and other analyses based upon said data.

The selection of laser and software was tried out in the case study presented in chapter 6, and resulted in data acquisition usable for more than just IE- analysis.

A laser with high exportability and interoperability was selected, and so was the software which processed the data afterwards. The two in combination made it possible to measure a test-building in approximately one hour, including processing the measurements and exporting data reports in both DXF, JPG and PDF.

Reflection was then given to how the measuring and data processing could be optimized through better use of the ADA- tools, which resulted in the plan drawings and 3D visualisations presented in figure: 6.4 and 6.5.

7.3 What about BIM?

In today's building industry BIM seems to have become a buzzword embracing whatever one wants it to embrace. From 3D visualisation to Excel spreadsheets with building data. This is not necessarily a problem, however in respect to ADA, BIM is not a solution for data acquisition, but can be a supplementary process for data storing, if the data acquisition is done with intention of using the data for design and geometric modelling for renovation models.

Many of the modelling tools used for building information modelling can use DXF data, and almost all such programs can handle and manipulate IFC data.

The software used in the case study did not have the ability to export IFC. But other software, analysed in the case study's software selection process does. Like DXF, IFC is an open format making it possible for two proprietary building modelling programs to exchange data. Further research into DXF and IFC as data exchange formats for building information modelling must be done, in order to further optimize the ADA process and expand the use of it to more and more branches of the building industry.

BIM can be used as a repository for geometric data storing and function as the centre of communication for all consultants and branches on a renovation project. But if the data is only used for IE- analysis in BSim, using a database in Structured Query Language (SQL) or simply storing data in Microsoft Excel might prove more efficient, as no manipulation of the geometry is needed in such case.

3D is not the primary focus in ADA, however when using software like Magicplan or Orthograph I, the 3D is automatically generated, which clearly heightens the tangible understanding of the geometry and opens op for immersive simulations, like Virtual Reality (VR) and Augmented Reality (AR). How VR and AR can be generated based on ADA, has not been tested in this project, but will be a part of future work with ADA.

7.4 Current data acquisition

When comparing flow and sequence models of the current data acquisition and the ADA process, the differences is limited. Most of the processes are the same and the end result of the acquisition is also more or less the same.

The key difference between the current process and ADA, is the thoughts one put into collecting the data and selecting the tools for it, combined with automating many of the data exchanges.

ADA is not an automatic method; it is automated though. This means that the data output stored in a shared data repository, might be copy pasted manually from one spread sheet into another. This process can naturally also be automated, but at this time focus must firstly be on automating the data acquisition.

If all branches of the AECO industry collects their own data individually, as it often happens, variation of data and formats will increase as a consequence of the increase in tools being developed for data acquisition.

By collecting data once, for all branches and storing them in a shared repository, only one type of data is accessible and if that data is then stored in an open format like, XML, DXF or IFC, interoperability between AECO branches can be heightened.

7.5 Automated Data Acquisition now and onward

Many tools and methodologies exist to support gathering of data, but to the knowledge of this author no method exist to support the full process of data acquisition from selection of what measurements are needed, through selection of acquisition tools, to use of the acquired data.

Thermal, Atmospheric, Visual and Acoustic environment is what the Indoor Environment consists of. Geometric data is key in analysing said parts of the IE. Measurements is however not enough. Observations is a big part of the data acquisition process. To fathom gathering of observational data, a parameter for selection of handheld laser and data processing software is rationale documentation. The laser used in the case study, had the capability of photo documenting the situation of the measurement[14]. This extra feature of the laser was not a criterion in selection. But as handheld lasers undoubtedly will become more advanced in the future, with capabilities of documentation of rationale of the measurements, this parameter must become another factor to consider in ADA.

As shown in figure 6.10, some of the data needed for IE- analysis exist in the PDF report published from the data processing software, but is not always represented in the XML file generated from the PDF. The data exist, but is removed from the format unintentionally. This problem can be solved and must be, for ADA to become a fully feasible methodology for data acquisition for IE- analysis, Energy Design and Design simulation and calculation.

Some of the data needed for IE- analysis is data on external objects like buildings and flora. This can be acquired through use of handheld lasers and data processing software, at least theoretically. This was not tested in the study, but must be in later work with ADA. This addition in use of ADA can make the methodology more feasible for IE- consultants to use, as the data on external objects is a key parameter in many of the IE- simulations.

The building industry from design of architecture to operation of the final building continues to strive for effectiveness. Using handheld lasers, as they are used currently is more effective than using measuring tape. However, by using Automated Data Acquisition as presented in this report, effectiveness is not the only advantages. Efficiency can be achieved. This means data acquisition will not only be faster, but also better and usable for and by more actants.

14 The situation of measurement is to be understood as the point to point of the distance measured.

Chapter 8
Conclusion

Automated Data Acquisition is a methodology to ensure the right steps are taken to secure the right and needed data for IE- analysis. Even though the methodology has been developed with IE in mind, the method can be used for data acquisition for all branches of the AECO industry.

The key question of this report presented in the first chapter was:

> *How can data for IE- analysis and simulation be collected through Automated Data Acquisition (ADA)?*

Data can be collected through a handheld or stationary lasers measurer, used for measuring distances (height, length, and width). A handheld laser was tested in the case study, and proved efficient. Data from the laser can be used either directly or through data processing software.

Direct input from the laser to software on a computer can be established through USB connection, whereas data transfer to data processing software happens through Bluetooth or internet connection (wireless transfer).

The key concern with lasers and data processing software, is how they are selected. The ADA- method proposes exportability and interoperability as the key criterion for selection. But price, usability and rationale documentation can be other factors to consider in selection of handheld laser and data processing software.

When data has been acquired through the laser and processed through software, it must be stored in a format which makes it possible to transfer it into IE- analysis software, like BSim. But by establishing what format is needed before the data is collected, it can be possible to support the needs of other AECO branches as well.

Open formats like DXF, IFC and PDF makes it possible to make data readable for almost all computers and modelling programmes. DXF and IFC can be used directly in CAD and stored and used for building information modelling (BIM). PDF on the other hand needs to be manipulated into another format in order to make it readable for IE- analysis software.

A programme that can automate the conversion of PDF into XML and extract the data needed for IE- analysis must be written. This was done conceptually in the case study. A professional programmer must write the real programme though, based on the description of data needs explained in this report.

Data extraction from PDF reports, DXF and other formats must however be further tested and used in real life situations, in order to validate the results of this report, to create a proper foundation for a complete ADA method, going from a handheld laser acquiring data to use for multiple AECO branches.

The answer to the research question is therefore.

> Data for IE- analysis and simulation can be collected: Through handheld lasers, selected based on the exact data needs for IE- analyses, processed in a way that allows for data extraction in a proper format, that can be used and stored in a repository that makes it possible to reuse acquired data for both IE- consultants and other branches of the AECO industry.

Chapter 9
Future work

To evolve Automated Data Acquisition, more testing of the selected laser and data processing software must be done. This will be done by measuring and processing data from more buildings and storing and extracting data in more formats to test the feasibility of the formats and the reusability they provide.

Data transfer from the laser directly to a computer and the IE- analysis tool: in this case BSim, must be tested by professional users of BSim, to prove direct transfer of DXF data into BSim through SimDXF as feasible or infeasible.

Only on laser and one data processing software was tested in the case study. In future work more lasers and software should be tested in different situations, to find advantages and limitations of said tools.

Data needed for IE- analysis not tested in this study, is the acquisition of external object geometry. A test of ADA for external geometry and use of it for IE- analysis in BSim must be tested in future work.

The described data need in the report was based on interviews with students and researchers at Aalborg University. In future work Contextual Inquiry should be used to attain empiric data from the industry, to heightening the reliability of the study.

The proof of concept in the report, is based on a conceptual model, explaining what data must be extracted from a PDF, after the PDF has been converted into XML. In future work a programme capable of doing the file conversion and data extraction must be written.

When solutions is found for the tings considered in this chapter, ADA can be implemented for beta testing in the industry. This testing must be studied in order to optimise the methodology and the tools it consists of. Thereafter the methodology will be ready to implement as an optimal tool for Automated Data Acquisition.

Lastly the use of ADA as the basis for Virtual Reality and Augmented Reality must be explored to support the current increase in use of said tools in the Danish building industry.

Appendix

1) Dolejan et al., 2017 rapport.

2) List of interview persons.

3) Magicplan rapport.

4) XML- output from PDF.

5) Conceptual sequence model of programme.

Vocabulary

Automatization	a process made automatic, as by electronic devices reducing human intervention to a minimum or removing it
Exportability	The ability to transfer a format from a Data Acquisition tool or Data Processing Software useable for other actants.
Immersive	computer-generated 3D image appearing to surround a person via some sort of medium. Involves the thought of submerging into something.
Interaction	active engagement of a person or one's senses, that may or may not cause change or altered perspective or mental state.
Interoperability:	is defined as the ability of one system to work with other systems without any effort on the part of the end user of the system.
Tangible	perceptible through touch or closeness to something real or immersive. Involves the thought of experiencing something as real, rather than imaginary or visionary.

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