BIM4EEB

BIM based fast toolkit for
Efficient rEnovation in Buildings

D5.1 Report of Existing Techniques and Recommendation of Mapping Technique

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D5.1 Report of Existing Techniques and Recommendation of Mapping Technique

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EXECUTIVE SUMMARY

In this report two things have been investigated. One, how to perform fast mapping of building geometry and two, how to scan walls in order to find out the structure and material of a wall as well as the location of pipes cables etc.

In regards to mapping buildings the most common ways to do this today is by either by measuring the building manually and then creating a floor plan or use 3d laser scanning which depending on the equipment will yield an extremely precise modell. In this report we have also found other techniques such as apps utilizing image recognition or IR light combined with cameras to create 3d models. Most of those techniques however lacks precision below the stated project goal of 1cm. Many techniques (including the manual measurement) also requires several hours of post processing in order to convert the measurements och scannings into a model. The post processing will generally increase the more data we capture but is also connected to the scanning technology. A 3d laser scanning of 100 sqm will only take 3-4 hours but requires 2 days of post processing.

Only one solution tested for this report actually matched the project goal of reducing the time for mapping a building. That was the the app called Magic floor plan. In this app the user is aided with image recognition and AR technology to select only the important features of a room (such as corners). This data is then instantly converted to a 3d model (but with a low accuracy).

In terms of the scanning walls we have in this report listed a number of solutions based on the sensor technology they are using. From a workflow perspective there are basically two different categories of scanning namely contact scanning (such as stud detectors) and contactless scanning (such as heat cameras). None of the products we have found uses a positioning system to automatically create a model of the scan results. To automate the scanning of walls floors and ceilings we therefore suggests using these devices in combination with positioning systems. In this report we have found several interesting indoor positioning systems from the area of virtual reality solutions. These systems can often provide positioning with high accuracy (down to 2 mm). They are however sometimes limited in the size of the area they can cover. More work therefore needs to be performed in order to understand how a process where several scans and repositioning of the positioning system can be turned into a time efficient and easy to perform workflow.

Furthermore we suggest that positioning of the scan device should also be investigated as a way to record the geometry of the walls. In this way the user can capture geometry, temperature, thickness, capacitive and inductive features of a wall at the same time. With a button the user could also be able to mark key features of the room such as corners or anchor points for later combining several scans.

PUBLISHING SUMMARY

Fast mapping of buildings is a key factor in the renovation process. This report investigates different mapping techniques and gives a recommendation for the use in BIM4EEB project.

Recommendations of fast mapping technique depends on how fast the mapping needs to be and also how good accuracy that is needed. The accuracy decided in the project goals should be not more than 1 cm deviation.

Only one solution tested for this report actually matched the project goal of reducing the time for mapping a building. That was the the app called Magic floor plan. In this app the user is aided with image recognition and AR technology to select only the important features of a room (such as corners). This data is then instantly converted to a 3d model (but with a low accuracy).

In terms of scanning walls, investigations of different sensing technologies has been done. Because none of the products meet the requirements themselves, the recommendations are to combine technologies and positioning systems.

A solution that automatically create a model from scanning has not been found.

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1 Introduction

This report describes the results of task 5.1 in the proposal describes at the following.

T 5.1 Benchmarking of existing tools (Lead participant: RISE; Participants: PoliMi, VTT, SOL, UCC, CGI, Prochem)

The task aims to benchmark existing tools used for mapping of buildings in different countries. Usability, accuracy, type of data output and type of market-available device are important parameters to investigate. Examples of techniques are (others may apply):

- Laserscanning and/or various photogrammetry approaches to capture spatial data
- Thermo mapping, in combination with the spatial capturing or standalone
- Magnetic sensors and/or backscattering x-ray to detect cables, pipes and other structures in walls and floors
- Spectrometer to determine the type of material

Each technique will be investigated and assessed and the relevance to this project will be determined. The output will be a report of existing techniques and recommendation of mapping technique (D5.1).

The goal of the project is to produce tools that will allow us to in a relatively easy and cost efficient manner scan an existing building both for later off site review as well as on site review. In order to understand the usefulness of different technologies they need to be evaluated based on both cost, availability, usability and how the workflow would look like using these technologies. In addition, we also need to consider what kind of processing of the data that needs to be done in order for the scanning to be converted to objects in a BIM file or some viewable result in the viewing technology that will be selected.

While there is a wide abundance of sensor technologies available out there most of them lack interfaces for collecting the data measured and/or lack positioning. For this reason we will either need to manually input measured data into a BIM model or combine sensor solutions with some kind of positioning. This report is therefore structured so that we will start with a walkthrough of the different sensor technologies that can be used for surveying a building. After that we will present some of the indoor technologies that exist. After that we will discuss possible workflows and user scenarios for collecting the data before we then provide a discussion about which path to take forward. More information about the solutions considered in this report are available in an appendix.

2 Sensing Technologies

There are several technologies that can be employed for scanning features and inside structures of buildings. Each of these will have their own unique set of advantages and disadvantages. Some requires contact measurement or while others can be used from a distance. Some provide high resolution scanning while others will provide a more rough scanning of the features. In this section we will go through each of these technologies and their pros and cons.

2.1 Impedance (Stud Detectors and Metal Detectors)

Electrical impedance is a measure of the opposition that a circuit presents to a current when a voltage is applied[1]. Typical electronic components used to design the impedance are capacitors and coils. A capacitor is basically two plates parallel to each other that is able to store a charge. Depending on the medium in between the plates the capacity for storing charges changes. By letting a wall or object become the material between two plates that we charge we can simply measure the permittivity of a material where permittivity is the measure of a material's ability to store an electric field in the polarization of the medium.

In general, permittivity is not a constant, as it can vary with the position in the medium, the frequency of the field applied, humidity, temperature, and other parameters. But since all materials have different permittivity we can measure when something changes inside the wall as we drag the sensor across it. It is precisely this ability that is used in normal stud detectors.

Figure 1: Stud detector

With coils we can do a similar thing, but we will in that case measure the magnetic permeability of a material. The inductance of a coil i.e. its ability to oppose a change in the electric current flowing through it is determined both by the design of the coil and the magnetic permeability of surrounding materials. This kind of sensor is therefore really good when designing metal detectors.

When measuring permittivity or magnetic permeability the values we get will be determined by the combination of materials that surrounds our measurement device and the closeness of the materials to the measuring device. We will therefore not be able to distinguish the individual materials. But since the permittivity or magnetic permeability is different at different frequencies in different materials we can measure the two properties at different frequencies and even single out specific materials or the level of moisture in the walls.

[1] https://en.wikipedia.org/wiki/Electrical_impedance

There are several affordable options when it comes to this kind of sensing technology. Most stud detectors (Appendix A Table X Y Z) use either capacitance or a combination of capacitance and inductance sensing and can costa as little as €10. There is however not many off the shelf sensors with an interface where the measurements can be retrieved and stored. Some phone apps utilise the phones built in magnetometer detect metal inside walls. There is also the Air metal detector (table X) that connects to your phone via bluetooth. Similarly the stud detector Wallabot is also a smart phone connected hardware. This particular solution does however not use impedance with rather radio.

2.2 Voltage Detectors (Radio Receivers)

While a radar will typically emit a radio signal and then detects its reflections we can also detect electrical circuits by just listening for a specific radio signal. Since most electric grids are running at either 50 or 60 Hz frequency the power lines in the wall will also (unless shielded) emit a radio signal at 50 or 60Hz. The level of this signal typically gets stronger the closer we are to the power line. This sensing technology is used both in Testers or non-contact voltage detectors as well as in most stud detectors. A contactless voltage detector cost around €10.

Figure 2: A contactless voltage detector. The read light at the tip shows that the cables are alive.

2.3 Infrared Sensing

All objects above absolute zero (273,15°C) emit infrared light (black body radiation). By sensing this radiation with an IR-sensor the temperature of an object can be determined remotely and without contact. This is the technology employed both in handheld infrared thermometers as well as heat cameras. In many ways the handheld infrared and contactless can be seen as an 1-pixel heat camera.

Infrared sensing in both as cameras or contactless thermometers are a well established technology than is often used for checking energy performance of buildings.

Heat cameras can be used to see objects behind an object with uniform temperature, find heat leaks, or detect faulty electric cabling.

Figure 3: Studs visible in the wall due to their heat conducting properties.

There are cameras available on the marker where pictures can be taken and stored. Transfer from the camera can be done by either USB or WIFI. The most affordable solutions are so called plugins to mobile phones which cost around €500. There are currently two different solutions of such plug-ins the Flir One (Appendix A, Table X) and the Seek Thermal Compact (Appendix A, Table X)

Figure 4: Picture 3 Flir One (left) and Seek termal Compact (right).

2.4 Radar

Impulse radar or Ground Penetrating Radar (GPR): Uses electromagnetic radiation in the microwave band (UHF/VHF frequencies) of the radio spectrum, and detects the reflected signals from subsurface structures. (Usually polarized) radio waves in the range 10MHz to 2.6GHz. One particular solution in this regard that both provides an API as well as a cost efficient solution is the Wallabot (Appendix table X). Which cost around €84.

Figure 5: The Walabot.

2.5 Lidar / 3D Laser Scanning

Lidar or 3D laser scanning is a technology that creates an 3D-image of surroundings by moving the laser beam and calculate the time of flight (the time it takes for the laser beam to travel to the target and reflect back), This creates a point cloud that gives a 3D visualisation of the surroundings. This technology although has been used by scientists at NASA since 1960 now implemented in robotic vacuum cleaners, autonomous vehicles, Jet fighters and so on. It is a proven technology where the tools also develops fast. In site surveys it has become more and more popular to use despite the fact that 3D laser scanning equipment can be very expensive (€23000 and up) and that a lot of work needs to be put into cleaning up the point cloud from noise and reflections and converting the point cloud into meshes and objects. Its benefits are first of all precision.

Figure 6: 3D-laser scanning unit.

A similar technique to this is also used in the Microsoft Hololens and Kinect. However in these devices, the laser is not rotated but instead an IR flash is generated and the time of flight is measured on a per pixel basis in a camera. This technology is also used by for example the Cloud.io room scanner for iPads.

2.6 Photogrammetry

Photogrammetry is a technology where you use a normal digital camera and create a 3d model based on several images taken from different angles in a room. This makes the hardware cost very low. There are several steps involved in this but the main things are that we find edges and feature points that correspond in the different pictures by computer vision algorithms and then calculate a 3d model from that.

Photogrammetry is often wrongly considered less precise than laser scanning technique but can under the right circumstances yield very precise measurements. A problem with this case is if a room lacks visual features (i.e. white featureless walls). The software for photogrammetry is also still quite unforgiving and cumbersome to use although they are improving at a fast rate. Generating good photogrammetry models therefore requires a certain degree of expertise. Post processing time, once very time consuming, is becoming always better owing to new calculation algorithm of software.

There are several photogrammetry based softwares available for mobile phones. Most of those are however aimed at scanning small objects and not rooms. Magic plan is an app specifically target at creating drawings of rooms and apartments. It can be said to be using a kind of assisted photogrammetry methods as the users manually marks where corners in the room are by pointing it out in the picture while moving the camera.

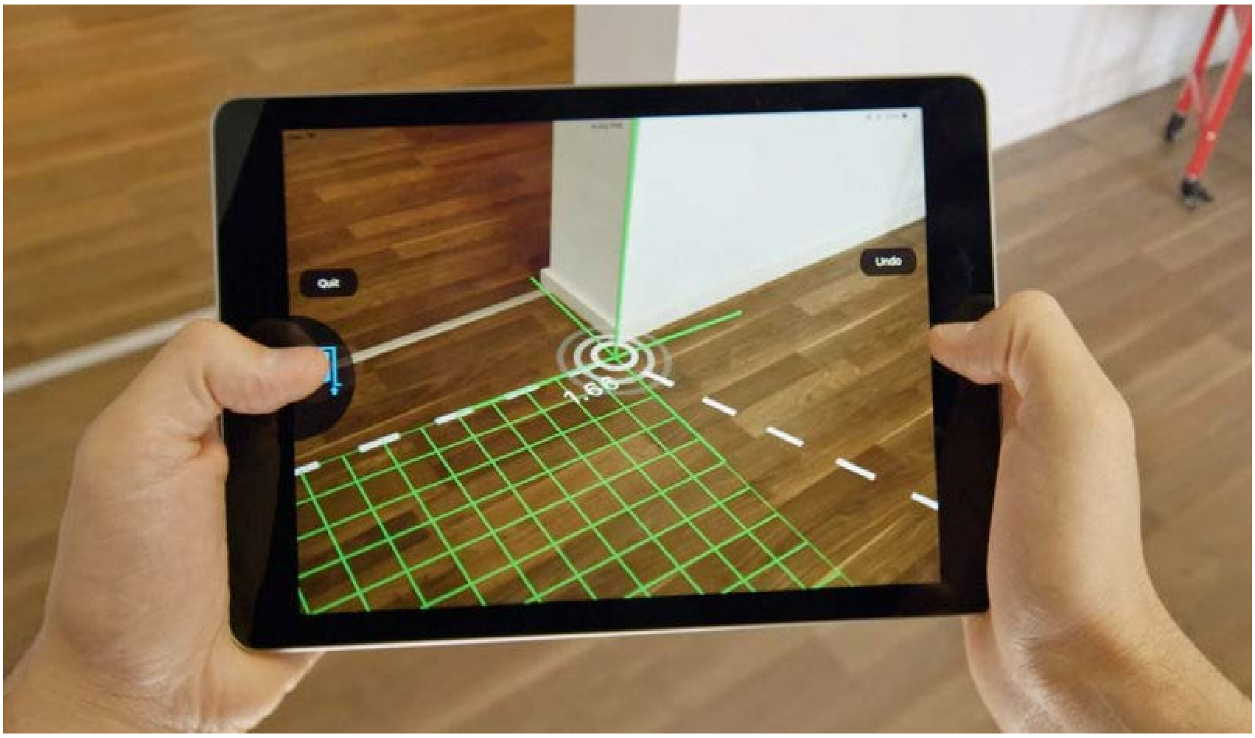


Figure 7: Magic plan app.

2.7 X-ray

In standard X-ray an x-ray beam penetrates the object/material and a CCD-plate is placed on the other side of the object that absorbs the x-ray energy and creates an image. Since equipment needs to be deployed on both sides of a wall this sensor technology becomes quite cumbersome for surveying purposes. Backscattering x-ray however (Z-backscattering) is a low energy x-ray that penetrates the material and uses the reflection of x-ray to create an image of what is under the surface. The later technology has recently become popular for example in airport security. Handheld backscatter X-ray units such as the Mini X (see Appendix , table X) can be obtained for around €45000.

Figure 8: The MiniZ a portable radar scanning device.

2.8 Ultrasonic

Ultrasonic range sensors produces a beam of ultrasound that is sent out and reflects back from the object, this allows the sensor to measure the distance to the closest object as well as when the density of a wall changes. Ultrasonography (often used in the medical sector) works in a similar way but utilizes an array of receivers, multiple and frequencies to create a multidimensional image of the inside of a wall or a human. With the doppler effect it can also detect moving fluids inside water pipes or blood vessels. However ultrasound imaging systems require a continuous, high quality acoustic transmission path between the transducer and the “hidden” object. This typically requires the object to be immersed in a transmissive medium like a fluid in order to maintain range and detain in the image. A portable unit will today cost around €1300.

One specific application of ultrasonic sensors in buildings are to measure the thickness of a wall. Devices such as Sauters Ultrasonic thickness gauge (Appendix A Table X) which will cost about €300. This device also has a serial port for collecting the data.

Figure 9: Ultrasonic thickness gauge.

2.9 Spectroscopy

Every molecule emits or absorbs only a certain frequency of light and under the right conditions this can be measured and used as a fingerprint to identify the material and to derive what kinds of molecules or what kind of substance that can be found on a surface.

Neither our eyes or cameras are full spectrum sensors. We can therefore not distinguish between different wavelengths or for example green but rather the balance of how our red, green and blue colours sensors are stimulated that makes us experience colour. But by using a prism the different kinds of green, red and blue can be made visible.

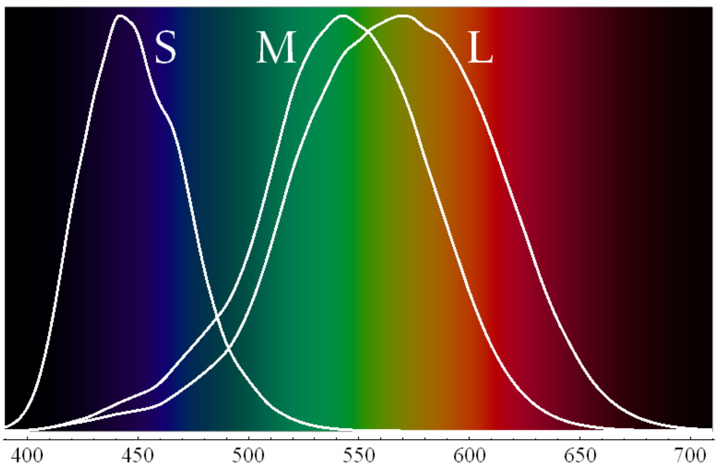


Figure 10: Eyes sensitivity to colors.

By putting a prism in front of the camera on a mobile phone, we can also get the full spectrum of a light source. The visible spectrum is however only a small part of the electromagnetic spectrum. By using a camera without infrared filter we can expand the spectrum that we can detect with a prism. This will give us the ability to determine the source of the light.

If we want to analyse a material that is not glowing in the visible or near infrared spectrum we can instead projekt light onto the material and measure what frequencies of the spectrum that the material absorbs. Instead of using prism we can then also control light that the object is illuminated with and measure how much of it that is reflected back with a single sensor.

There are several. DIY applications and apps for phones where you can transform the normal camera of a mobile phone into a spectrum sensor by adding a prism. There are also several hardware solutions that can be connected to your phone like the SCiO spectrometer or the LinkSquare SDK spectrometer.

Figure 11: Scanning and apple with the LinkSquare to verify its labeling or assess plant growth.

3 Indoor Positioning Technologies

In order to be able to collect data about a building and store it we need to position the measurement we are performing. This can both be done both manually by inputting measurements into a model of the building. It can also be done semi automatically, automatically positioning the measurement with an indoor positioning system. For that we need an indoor positioning system. In some cases we might only need to mark with room and wall the measurement was taken in other to later manually map the photo taken with for example a heat camera onto the 3D model. In other cases we might want to have a more precise positioning in order to paint a picture as as we drag some sensor across a wall. In these cases we might want to precisely position where features such as a 1cm wide electric cable runs in a wall.

Indoor positioning is still a field under early development and there is today a range of solutions that can be employed. Most indoor positioning provides local coordinate systems that then needs to be anchored or maps towards the building model or world coordinated. If this it is a temporary setup of a positioning system this system might need to be re-anchored on every setup.

3.1 Google's Project Tango (discontinued)

Google has long been working on an indoor positioning system containing both hardware and software technology that would enable mobile phones to positioning themselves very exactly indoor. The system utilized motion tracking using visual features. It used two cameras to be able to have depth vision. It also fused the visual tracking data from gyroscopes, magnetometers and accelerometers. In 2017 google abounded the project in favor or the similar platform AR core

(https://en.wikipedia.org/wiki/Tango_(platform))

3.2 AR Core / AR kit

AR Core is a software development kit developed by Google that allows for augmented reality applications to be built. Similarly Apple has its similar platform AR-kit. One of its features is visual motion tracking based on feature detection combined with the phones gyroscopes and accelerometers (MEMS). Positioning with AR-core/AR-kit does not require any other hardware than a smartphone. The precision however can be as low as 7cm unless extra measurements are performed. The solution can also fail if there are no features in the camera image to detect i.e. a completely white wall. This can of course be addressed by manually putting up markers such as QR-codes with also could work in order to anchor the positioning. One example of a software employing this AR core/AR kit is Magic plan (see further down) due to user errors the accuracy can however often be as low as 50cm.

3.3 Kinect and Hololens

The Kinect and Hololens uses a technology that measures the time of flight for IR light and creates a 3d image of the room. By comparing earlier scanning with the current it can then determine where in the room the devices is located. It has the benefit of being able to work in several rooms without any hardware setup. The accuracy is about 3 cm with a worst case scenario of 0.5 m based on test done for this report. The hololens can also fail if the room is to featureless.

3.4 HTC Vive

HTC vive uses a IR-flash followed by sweeping IR-line lasers horizontal and vertical. Positioning is then determined by detecting the pulses of a photoled. The time between the initial pulse and the pulse generated by the line laser will give you the angle between the led and the two lighthouses each containing the horizontal and vertical line laser. In for cycles you will have four angles and can then calculate you position down to a 2 mm accuracy with a 30Hz update time.

Figure 12: Illustration of HTC vives positioning system with IR-line lasers sweeping the room.

It has high precision up to millimeters but is highly dependent on sensor placement.

The vive's recommended room size is 5x5 meters, but it does not limit it to those lengths and one can have virtually any size as long as the sensors can detect the IR signals. Since the solution provides the angle to the lighthouses the error in distance will increase linearly to the distance from the lighthouses.

The setup however requires a high end computer and VR headset to allow tracking. There are examples of DIY projects where a small board with some photosensors and a microprocessor board has been used in a standalone configuration together with the two lighthouses (see https://github.com/ashtuchkin/vive-diy-position-sensor).

This technology would work well combined with say a stud finder, in mapping up BIM data for a room or even retrieving the basic geometries of the room.

3.5 Optical Tracking / Oculus Rift

While the HTC view VR-kit uses a passive sensor sensing on headset, handles and trackers. Oculus rift uses LED markers on the headset, handles and trackers and then uses cameras to track their position. The cameras are both fitted in the headset as well as the on stands in the room. The accuracy of this system is around 3.5 to 12 mm [2] but just as with the HTC vive errors increase on distance to the cameras. There exist both commercial solutions that uses the same principle for tracking but with a custom build hardware such as http://www.ps-tech.com/3d-technology/optical-tracking and opensource solutions for tracking such as https://www.youtube.com/watch?v=g8TE6hJ54_0

With OpenCV (and open platform for computer vision) a Daylight lens and IR LED tracker similar systems can also easily be implemented. The accuracy of a system can be estimated by tan(field of view / sensor resolution) * distance. A Raspberry pi camera where we can get 1920 pixel at resolution at 30 hz would

[2] https://biomedeng.jmir.org/2019/1/e12291/

then yield a 2 cm accuracy on 5 meters. By interpolation we can however get subpixel accuracy. If we also need to track depth we need two cameras where the tracker can be seen or a tracker that is wide enough to use its with to determine its distance.

3.6 Galileo (Satellite Navigation)

European Global positioning system that uses satellites with higher accuracy than US GPS, Glonass or BeiDou. The system is not completed yet, and have had some problems. Galileo is intended to give both horizontal and vertical position measurements with 1-meter position for free users. For paying commercial users the positioning trilateration up to mm precision and is said to be higher effect antennas that could allow indoor positioning. Compatible with both GPS and Glonass because it uses the same chip therefore able to receive with all GPS/Glonass devices. It will fulfill all criteria for accuracy and safety for civil airfraffic. Could be implemented easily in any PCB, or used by microcontroller like arduino.

3.7 BLE, iBeacon, Beacons and WLAN Positioning

These positioning system is using nearby access-points to calculate where the device is located, the accuracy can be improved by placing beacons that is powered by battery. The power consumption of beacons are very low and should last for years on ordinary battery.

The accuracy level is poor , around 1m at its best. These positioning techniques are therefore better to us for determining things like which room or building we are in than the actual position in the room.

Figure 13: WLAN positioning using signal strength.

3.8 QR codes

QR codes attached to objects can be used to track objects with a camera. If the QR code is attached to a fixed object as a reference point geographically that position will be known for a camera. The orientation, angle and the position of the camera can be calculated by register the symmetry and size of the QR-code in the image. Image recognition is used in AR-tools and this allows to anchor/position a virtual CAD to the real world so that they match each other.

Figure 14: Example of QR codes

4 Workflows and User Scenarios

Wherever the sensor data should be inputted manually och automatic it makes sense to start by creating a model of the building on which the values then can be mapped. This could of course be done either with software such as Magic plan or similar tool, with a hololens or with a more accurate 3d scanner.

After the initial scanning of the geometry of the space we could start our scanning of the walls. Scannings can be of two main types namely contactless scannings or contact scannings.

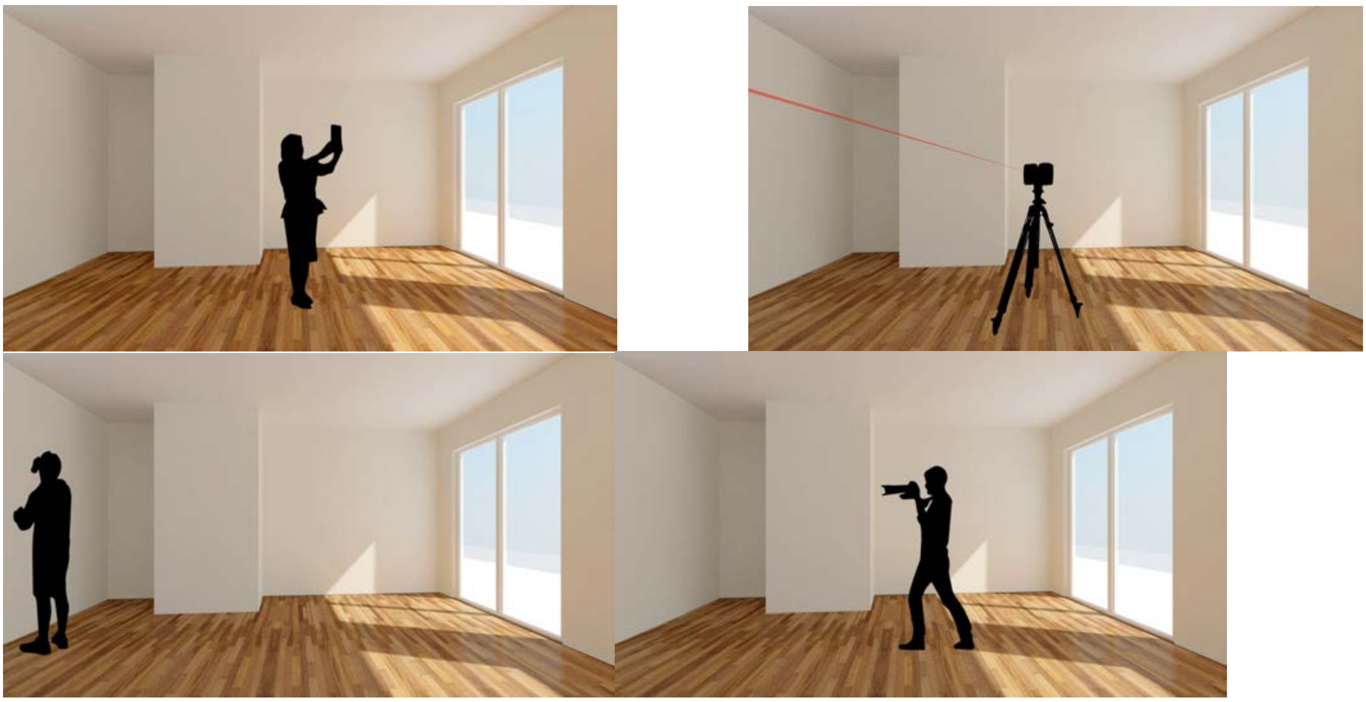


Figure 15: Contact scanning vs contactless scanning illustrated.

If we will input data manually onto a model and the data form the basic geometry scanning needs to be post processed this will mean that we need to revisit the site once this is done. With a positioning system we can possible to this alignment in post processing and thus visit the site only once since a position in local coordinate system will be stored along with the measurement. Automatic positioning will also enable us to record a greater number of measurements. When it comes to contactless measurement (i.e. heat cameras or normal cameras) positioning will also allow us to stitch together close-ups and photos giving an overview to create a better detail where it is needed.

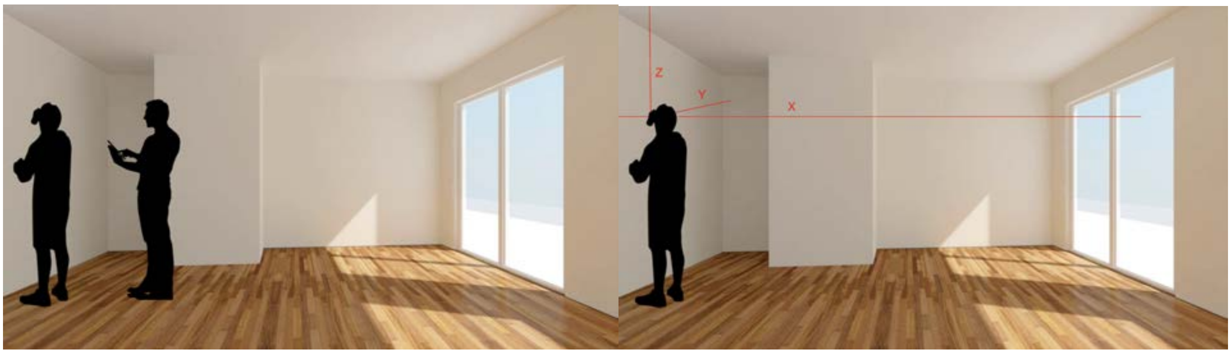


Figure 16: Manual input (left) one person measures and the other enters the data into the 3d model.

Automatic positioning the position of the scan device is stored alongside the values. Data collection can be aligned with 3d model at a later stage visually or by using anchor points.

The detailed workflow for position based wall scanning will most likely involve:

1. Setting up tracking cameras or laser lighthouses.
2. Marking a number of known anchor points in the room with the scanning device. For example corners.
3. Performing the scanning.
4. Reconfiguring the positioning system for other areas of the room.
5. Marking anchor points.
6. Scanning
7. And repeat from 4 if necessary.

Aligning different rooms or scannings in one room will most likely be done in post processing by matching overlapping geometries of the room or using anchor points. It can also be aided by ultrasonic thickness measurements of the wall.

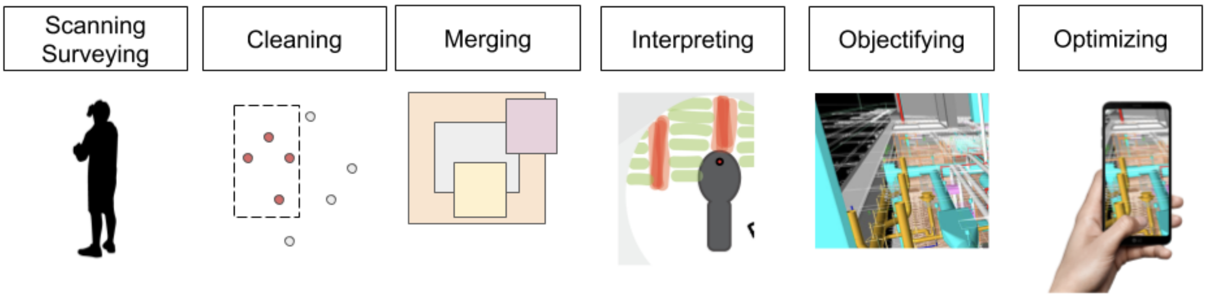


Figure 17: The workflow illustrated.

Post processing will contain actions such as:

1. Cleaning the data. I.e. removing ghosting created by reflections in for example 3d scanning.
2. Merging the different scannings so that features align. This could for example be done in open source software such as Meshlab or Cloud compare.
3. Interpreting and meshifying. I.e converting point clouds to meshes or sensor data into features inside the wall.
4. Isolating certain geometries and tagging then as a certain type of object and then add meta data for the object.
5. Optimizing the model for viewing on devices such as Hololens and mobile phones.

Scannings will either be in the format of pictures in the case of heat cameras for example and point clouds when it comes to 3d and sensor scans.

5 Recommendations / Summary

This section is divided into two parts; technology summary which summarises the findings in this report, and research recommendations which outlines recommended next steps to take for the BIM4EEB project to be successful.

5.1 Technology summary

It is important to remember that none of the solutions presented in this report are in any way complete package solutions for this research project. The ambition in BIM4EEB is to combine 3D visuals with scan data from heat, metal, plastic and electric and merge them all into one coherent 3D view. These scanning and mapping techniques have developed in separate industry contexts and thus adhere to separate standards, many without 3D in mind. We also want all of this to be representable in an AR headset, which is considered one of the most demanding and resource restrictive platforms on the market. These techniques may be possibly to combine but the process from a real world building to a virtual one is currently labor intensive, manual work. Any user will need to go through complex, and to this consortium, unknown scanning and clean-up pipelines. In other words; with current data on hand, the tool developed in BIM4EEB will most likely not be a user friendly tool for the renovation industry. More likely it will be a roadmap for technological experts (or at least tech-savvy engineers and CAD users) on how to combine these different types of scan data into 3D models that can render on head mounted, or mobile, devices. But let's assume there is a more practical and applicable research result to be obtained. Let's, with all of the above challenges in mind, try to unpack and evaluate the current technology in search of a more applicable, user-centered result. In doing so the following three factors ought to be considered:

Affordability	*The cost of the hardware and software needed to perform the scan*
Accuracy	*The ability of the toolset to accurately recreate world features and measurements*
Ease of use	*The complexity of the pipeline, and expertise-level needed to handle the toolset*

All of the technologies listed in this report offer their own pros and cons. Laser scanning for example (like the one made with a Z+F IMAGER® 5010C) is extremely *accurate*. Sub-millimeter measurements can be retained over very large distances and precise laser scanning made from over 180m away. Combining this with the possibility of processing 1 million pixels/second in all directions, and the user will be guaranteed an extremely detailed, and laser-verified 3D voxel representation of any site. But the hardware and software needed to perform these high quality scans is expensive (up towards 100.000$) and the point cloud generated requires specific expertise to handle and the pipeline for doing so is complex and time consuming. Simply put; *affordability* and *ease of use* is sacrificed for an *accurate* result. In contrast; smartphone apps are extremely *easy to use* and *affordable*. Availability is not an issue either as a myriad of measurement apps (Magicplan being one of them) have flooded the mobile application marketplaces the last years. They are also reasonably priced with subscription models at about 10$/month. However these apps are not made for 3D visualisation and seldom support importing or exporting of any 3D data. When attempting to scan complete rooms, or even buildings, these apps are sub-optimal. With drift of up to 30 cm/m they are simply sacrificing too much *accuracy* to be considered viable solutions on their own.

In the future; cheaper and higher quality cameras may very well bring smart device scanning to a whole new level. If smart algorithms and A.I. can help with the reconstruction of the 3D environment the balance between *accuracy*, *affordability* and *ease of use* may very well be attainable within a few years. The question for the BIM4EEB project is if this balance can be attained through some combination of already existing technologies like the ones listed in this report. In order to identify what technologies are most likely to strike a balance between *ease of use, affordability* and *accuracy* we need to know what those words mean to the adopter of the tech. The concepts developed in this project would benefit greatly from any type of early validation from the end user. In the BIM4EEB consortium we need to, as a group, see how our tool fits into the renovation process and their already existing business model.

5.2 Project research recommendations

In this project we need to for example ask ourselves what *affordable* means in the context of building renovations. Is there a price point between 40.000 € and 3.000 € that is acceptable to the businesses interested in the solution we're developing? It is also likely the end user can't answer these questions without first being able to imagine the value of the proposed solution. Answers to the questions, as well as early feedback about our proposed technological solutions, can be turned into an effective framework for development and design as we move forward. It is possible that BIM4EEB could pinpoint and develop, a low fidelity scanning technique that could solve most 3D-needs in the renovation business. But for this to happen a firm understanding of the users limitations, possibilities and expectations is needed. This work will be carried out within T5.2 to T5.4. To do this we propose the following activities as next steps:

User needs workshop - We recommend User Stories and/or User Journeys to be developed which will more clearly explore the possibilities, advantages and disadvantages of each technological proposition for the user. This will be valuable for clarity of vision for our internal collaboration as well as management and end user onboarding. After viable concepts have been pinpointed further tests can be conducted to ascertain technological feasibility.

Technical feasibility study - We recommend that further technological tests (especially to determine *accuracy*) are conducted to verify technology that might be cheaper and more user friendly than current market solutions (like the laser scanning devices ranging from 100.000 $ -). Current discussions in the consortium include combining manual laser measurement tools with market ready measurement systems such as the HTC vive. These suggestions needs to be explored and evaluated.

Market viability - We recommend that the results from the *technical feasibility* study and the *user needs workshop* are combined into concrete suggestions and concepts which are then presented to end users in the renovation business. The consortium should also attempt to calculate the price point of the proposed solution (once developed) to seek a base level understanding of market viability for each concept.

Development- Once feedback from the end user has been absorbed the technical development continues in accordance with plan

5.3 Final recommendations

From the listed technologies in this report we recommend further research around the following for technical feasibility study:

Scanning Device - Laser scanning with a (Scanning takes about 8 hours for 100m2 room) This will give you a point cloud.

- Z+F IMAGER® 5010C5010 76.000 € ca 800.000 SEK (begagnad mellan 53- 58.000 € När man köper nytt får man träning 2 dagar, kalibrering efter 12 månader.
- 10.000 € för mjukvara.
- 1.000.000 pixlar per sekund
- 5016 (Range of 365 meters and corresponding precision increase.
- Price: ca 85.000 €

Clean-up software

- Zuller Fröllis egna programvara (för att eliminera reflektioner tex) (approximately cost 10)
- Leica Cyclone- 3DR be used to clean up and merge of point clouds (8 hour of work) This will give you a *cleaner* point cloud (free from artifacts and unwanted reflections that can disturb further processing).

Polygon conversion software - Leica 3D reshaper - This process will convert the point cloud into a 3D mesh. (16 hours of work for 100m2.)

- Warning: After this step the polygonal mesh needs to be processed further in order to be compatible with XR devices. Today; this processing is done manually by a 3D artist.

When is comes to scanning technology for scanning walls it does not really matter which type of sensors we use since this could and probably should be changed based on the specific needs in the project. There are however the two different classes of scans (remote and contact) with each needs to be tested. Some scans will also need to be treated a bit differently in the post processing (i.e. the thickness of the wall measurements should be visualised in 3d space). The value of precise position to automate scanning of walls is however a really interesting path. For this reason we recommend the use of the technology that provides most easy to interface with in combination with either the HTC vive tracking system or a camera based IR led marker tracking systems. The HTC vive provides a high resolution and solution that we can be up and running with, in a very short time. This will allow us to quickly obtain sample data. The camera tracking solution is promising from the point of view that it is affordable and can be extended with more cameras to cover larger ground or to increase precision at certain locations.

7 References

Websites

[GPR] https://www.sciencedirect.com/topics/engineering/ground-penetrating-radar-systems

[Galileo] https://www.esa.int/Our_Activities/Space_Engineering_Technology/High-performance_ESA_receiver_brings_satnav_indoors

[Wikipedia impedance] Wikipedias definition of impedance. Available at: https://en.wikipedia.org/wiki/Electrical_impedance [Accessed 7 September 2019].

Photos

[X-rahttps://www.rapiscan-ase.com/products/handheld-inspection-2/product/MINI-Z

[WLAN positioning system]
http://www.libelium.com/products/smartphone-detection/

PDFs

[Lidar]
https://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/20040171682.pdf

8 Appendix - Existing Solutions

In this section we provide an overview of the solutions that has been considered

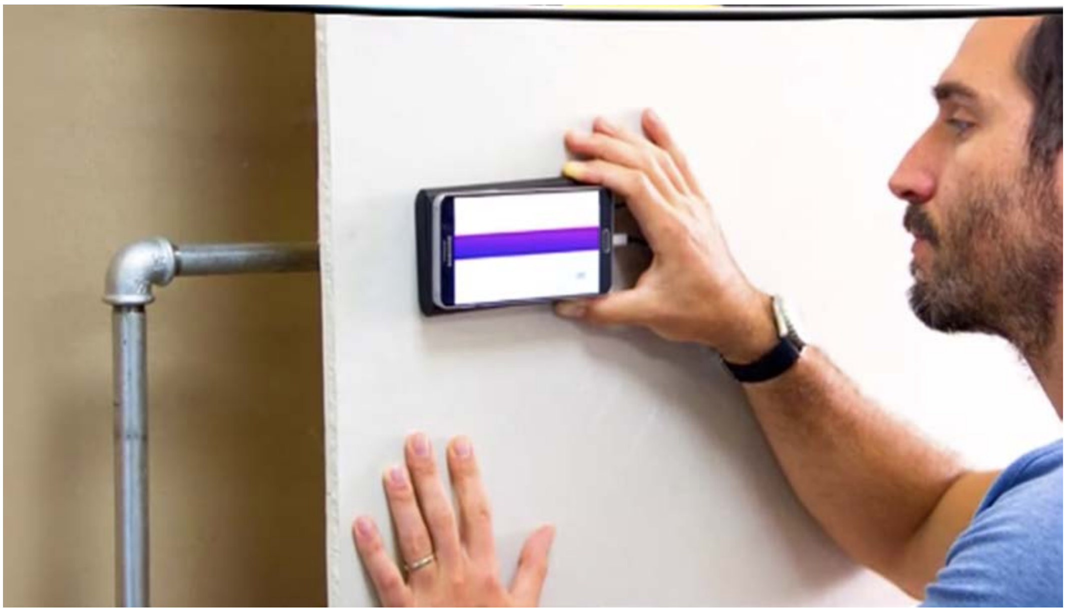
8.1 Products

<table>
<tr><td>Name:</td><td>Magnetic & capacitive stud detectors</td></tr>
<tr><td colspan="2">Description of technology:</td></tr>
<tr><td colspan="2">A stud finder (also stud detector or stud sensor) is a handheld device used with wood buildings to locate framing studs located behind the final walling surface. Most stud finders fall into two main categories: magnetic stud detectors and electric stud finders.

Magnetic stud detectors use magnets to locate metal in the walling material. The strongest attraction point, if due to a metal fastener in the wall, should indicate the location of a stud.

Capacitive stud finders rely on sensors that detect changes in the dielectric constant of the wall. The dielectric constant changes when the sensor is over a stud.</td></tr>
<tr><td colspan="2">Todays use cases:</td></tr>
<tr><td colspan="2">Commonly used in the building industry</td></tr>
</table>

Providers:
Bosch, Stanley, DeWalt, etc
Companies or actors that I know has experience of using this:
Shortcomings:
Spot measurement Magnetic stud detectors may be less useful in homes built with metal mesh lath and plaster. The metal mesh will confuse the signal of an electronic stud finder. Stud detectors work fine for wallboard-covered walls, because the wallboard is thinner than the stud finders depth range. But plaster walls that are thicker and the thickness varies considerably, can result in some false positive readings.
Future potentials
TRL level (used to a wide extent, used in some cases, in development, future potential)
Used to a wide extent
People that contributed to this description (name organisation email):
Vincent Schaller, RISE, vincent.schaller@ri.se

Name:	Walabot stud finder
Sensor technology:	
Radar	
Description of technology:	
Walabot is a programmable 3D sensor that looks into objects using radio frequency technology that breaks through known barriers, bringing highly sophisticated sensing capabilities to your fingertips. Walabot uses an antenna array to illuminate the area in front of it, and sense the returning signals. The signals are produced and recorded by VYYR2401 A3 System-on-Chip integrated circuit. The data is communicated to a host device using a USB interface, which is implemented using Cypress controller. The left picture shows the backside of the board, with the VYYR2401 chip, the USB controller and the micro-USB connectors. The right picture shows the antenna array. This side should be directed towards the objects you want to sense. The Walabot can be bought both as an accessory to an android phone but also in the form of a DIY kit where the solution can be connected to for example an Raspberry PI.	
Link: https://walabot.com/stud-finder-app	
Todays use cases:	
 Used with an Android app to provide very detailed imaging of the object inside the wall.	

https://www.youtube.com/watch?v=kwpVx-Bc3Bc
Providers:
Shortcomings:
Future potentials
TRL level (used to a wide extent, used in some cases, in development, future potential)
People that contributed to this description (name organisation email):

Name:	Air metal detector (product)
Link	https://www.kickstarter.com/projects/airmetaldetectors/air-metal-detector-the-smart-bluetooth-metal-detec
Description of technology:	
Induction Balance, Very-Low-Frequency metal detector that locates metal in the ground. In comparison with traditional metal detectors, the Air metal detector uses a smart phone with an app interface to indicate and control the metal detector. It is connected to the smart phone through Bluetooth 4.0 and can also be paired with headphones. Offers preset programs for coins, large treasures, beach detecting etc.	
Todays use cases:	
Finding metal, coins, jewellry etc. in the ground	
Providers:	
Air metal detector (Kickstarter project)	
Shortcomings:	
Only measures coins down to 12".	
TRL level (used to a wide extent, used in some cases, in development, future potential) The specific product is still on Kickstarter and although the funding limit has been reached the product has not hit the market yet.	

Name:	**Ultrasonic thickness gauge**
	
Description of technology:	
Uses ultrasonic waves to measure thickness of materials, range of 1,2-225 mm.	
Todays use cases:	
Measuring thickness of materials without having to destroy it. The two primary uses are for detection of wall thinning due to corrosion or as a quality control tool for material thickness consistency.	
Providers:	
Olympus, Sauter	
Shortcomings:	
Fluids need to be applied to the material when measuring thickness. Also material, temperature etc. needs to be known for proper measurement.	
TRL level (used to a wide extent, used in some cases, in development, future potential):	
Commonly used today, many manufacturers around the world.	

People that contributed to this description (name organisation email):

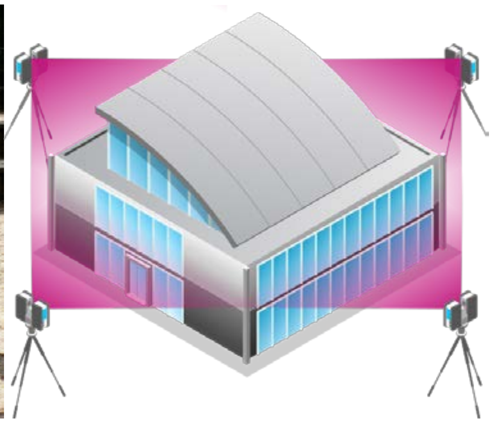
SCIO
https://www.consumerphysics.com/business/solutions/

Santor Walleye 24S millimeter wave camera
https://www.youtube.com/watch?v=1v1UFQGu2to

GoSpectro
http://www.alphanov.com/56-spectroscopy-gospectro---spectrometer-for-smartphone.html

https://www.youtube.com/watch?v=XqJbFn5rJfE

8.3 Technologies

Name:	3D laser (lidar) scanning
 	
Description of technology: A laser scanning device is put inside or outside a building at several locations. The device sends laser beams that measured the distance in every direction that is visible from the device. The device can also capture the color of each of the measured points. The result from the scan is a point cloud i.e a collection of points in 3d space with color coding. In a post processing procedure several point clouds can be combined, cleaned and turned into meshes.	
Todays use cases: Used for accurate measuring of large volume objects or to create digital versions of buildings, crime scenes, cultural heritage sites and much more.	
Providers: Leica, FARO etc.	
Companies or actors that I know has experience of using this: RISE Large volume metrology unit, Politecnico di Milano.	
Shortcomings: Post processing of the point cloud can be very tricky and often requires manual labor. Rooms get ghost duplicates form reflections in windows, mirrors or other reflective surfaces. Dust generates points in free air and so on. The density of the point cloud also varies depending on	

the distance from a surface to the scanning device. Transforming point clouds into meshes can also sometimes be hard to do automatically. Areas occluded from the scanner will not be measured meaning that a room needs to be emptied if you want to capture all the walls.
Future potentials AI is expected to decrease the manual labour of cleaning and transforming point clouds into meshes and even objects.
TRL level (used to a wide extent, used in some cases, in development, future potenial)
9
People that contributed to this description (name organisation email):
Anton Gustafsson, RISE, anton.gustafsson@ri.se Jörgen Spetz, RISE, Petter Wannerberg, RISE,

Name:	Photogrammetry
Description of technology: Photogrammetry allows to rebuild the position, orientation, shape and size of objects from pictures. It is a passive technique considering Laser scanning an active one. A good capture project, good camera. Correct GSD give the opportunity to describe with a high level of accuracy any architecture.	
Todays use cases: any architecture specifically when colour is important, cultural heritage	
Providers: Canon, Nikon, Leica, Go pro, low cost with Iphone or Smartphone	
Companies or actors that I know has experience of using this:	
Politecnico di Milano	
Shortcomings:	
Skills of the professional in acquiring data may be a problem, post processing time consuming	
Future potentials	
New 360 cameras, moving acquisition	
TRL level (used to a wide extent, used in some cases, in development, future potential)	
People that contributed to this description (name organisation email):	
Cecilia Bolognesi, Politecnico di Milano, cecilia.bolognesi@polimi.it	

<table>
<tr><td>Name:</td><td>FLIR heat cameras</td></tr>
<tr><td colspan="2">Sensor technology:</td></tr>
<tr><td colspan="2">IR radiation sensing</td></tr>
<tr><td colspan="2">Description of technology:</td></tr>
<tr><td colspan="2">FLIR have several options for heat cameras. Some of these are designed as standalone digital cameras other as plugs-ins to a mobile phone a third option is a standalone handheld device with WIFI. The cameras combine both a heat camera and and ordinary cameras so that one can view both images in combination. The images can be saved in the app provided with the phone plug-in. In terms of the standalone cameras they can be connected to a computer over USB like any ordinary digital camera as a mass storage device.




</td></tr>
<tr><td colspan="2">Link: https://www.flir.com</td></tr>
<tr><td colspan="2">Todays use cases:</td></tr>
<tr><td colspan="2">Images are taken of a wall or exterior part of the building and analysed either in real time or saved for references. The user needs to keep track of where the images have been taken in the building but the normal images will aid in locating the photo.</td></tr>
<tr><td colspan="2">Companies or actors that I know has experience of using this:</td></tr>
<tr><td colspan="2"></td></tr>
</table>

Shortcomings:
Future potentials
TRL level (used to a wide extent, used in some cases, in development, future potential)
People that contributed to this description (name organisation email):

Name:	Magic Plan
Description of technology:	
An AR application for mobile devices. The application allows for the creation of floor plans using the measurements provided by the applications measuring tool. The application uses the mobile device's camera to measure distances from one point to another by using the images from the camera, and where it is possible to specify where doors and windows are located. Alternatively it is possible to connect a laser to the application to measure distances. The results from the application is a floorplan of the room.	
Todays use cases:	
Used for measuring rooms and create a floor plan detailing where each room is in relation to another, which are used in construction, renovation, inspections, crime, fire departments and retail.	
Providers:	
MagicPlan	
Companies or actors that I know has experience of using this:	
-	
Shortcomings:	
Measurements are not precise, measurements can differ up to 50cm. A textured surface and good lighting is required for the application to work, and to produce better results. The results are better if you walk alongside the wall while measuring meaning that walls need to be cleared so a path to walk alongside the wall exist. Currently there is no support in the app to measure height in a room, height data has to be measured manually and entered manually, unless you connect a laser to the app in which case you can use the laser's measurements.	
Future potentials	
Continued development will likely produce less variance and more precise measurements.	
TRL level (used to a wide extent, used in some cases, in development, future potential)	

Link: Ar Measurements
People that contributed to this description (name organisation email):
Joar Henriksson, CGI, joar.henriksson@cgi.com

Name:	HTC Vive PRO
Description of technology:	
HTC vive uses a IR-flash followed by sweeping IR-line lasers horizontal and vertical for tracking of controllers and headset. Position is also calculated using dead reckoning as it allows for higher update frequencies. 3D party libraries/software used during testing: Unity3D, SteamVR2.0 HTC Vive PRO kit pricing: ~1400€	
Todays use cases:	
Mainly used for virtual reality applications and games.	
Providers:	
HTC	
Companies or actors that I know has experience of using this:	
-	
Shortcomings:	
Measurements yield high precision up to mm but is highly dependent on sensor placement. Testing within mapped up play area of SteamVR, 1 - 3 meters yielded little to no deviation. When testing borders of the play area and sensor view small to big deviations appeared, especially when measuring height close by the sensors. One further drawback is that it sensors need to be placed diagonally from each other meaning measurements can only be done in a rectangular space. As for SteamVR while it gives good utilities the necessity to set up a play area and it's requirement for a headset to be connected makes it hard too convert the HTC into something portable. The HTC also needs a stable power supply for both sensors and the headsets linkbox which means that setup might be a problem if no power outlet is close by.	
Future potentials	

High accuracy allows for precise mapping of 3D-space but for the HTC Vive to be a viable choice we would need to circumvent the need for SteamVR and the connection requirement for headset. The Vive is also easy to learn and most people without training could be taught within minutes on how to use it.
TRL level (used to a wide extent, used in some cases, in development, future potential)
Link: Ar Measurements **Link:** Accuracy and precision tests done by I-perception
People that contributed to this description (name organisation email):
Viktor Johansson, CGI, v.johansson@cgi.com

Name:	HoloLens 
Description of technology:	
Microsoft HoloLens is a virtual reality (VR) headset with transparent lenses for an augmented reality experience. According to Microsoft, HoloLens is a “fully untethered, see-through holographic computer. The HoloLens creates a 3d-mesh as an understanding of its environment and lays 3d-objects on top of that for the user to interact with. The device is “hands free” which means that the user doesn't have to use its hand in order to communicate with the device, voice can be used together with hand-gestures. The HoloLens uses a Depth camera, an Inertial Measurement Unit, an ambient light sensor. To test this device we measured a couple of predetermined lengths consisting of 1m, 5m, 10m, on the horizontal plane and 1m together with 2.4m on the vertical plane. The test result shows an average error of 3.2 centimeters on the horizontal plane and an average error margin of 3 centimeters on the vertical plane.	
Todays use cases:	
Used in a wide variety of applications ranging from the automobile industry to the medical field. The device itself goes for around 3000$ and is generally not used by the public.	
Providers:	
Microsoft	
Companies or actors that I know has experience of using this:	

CGI, Volvo
Shortcomings:
In the tests we did, we had some trouble in lightly lit and poorly textured environments, although the test results were pretty good, about 3cm accuracy when measuring 1 + 5+ 10 meters, this might not be good enough for this solution. The 2-3 Hour Battery might also be a setback.
Future potentials:
HoloLens 2 will have better sensors, full hand recognition, eye tracking, a wider field of view. All this adds to the user experience and we can expect that it will be more widely used. An example is that Microsoft won a $479 million contract to supply the US Army with a version of its HoloLens 2 that along with its base features also has Thermal sensors.
TRL level (used to a wide extent, used in some cases, in development, future potential)
Used in some cases
People that contributed to this description (name organisation email):
Anders Bratt, CGI, anders.bratt@cgi.com

Name:	Thermal imaging

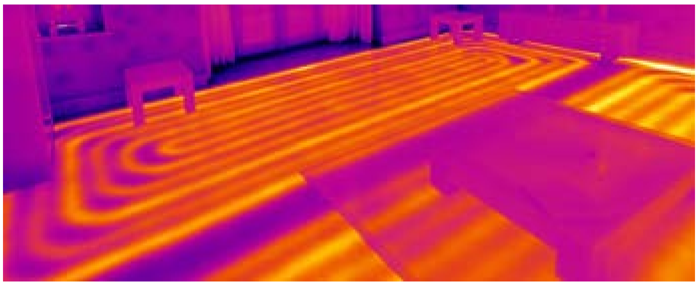
Description of technology:

A thermal imaging camera records the intensity of radiation in the infrared (IR) part of the electromagnetic spectrum and converts it to a visible image. It is a non-contact instrument which is able to scan and visualize the temperature distribution of entire surfaces quickly and accurately.

Some of the factors influencing the temperature readings for building applications are for instance:Type of materials used in the construction (thermal conductivity, emissivity, reflection), relative temperature differences, reflections from the surroundings.

Modern thermal imaging cameras are compact, lightweight and easy to use. They typically look like a digital video camera or digital photo camera. Some advanced models have a GPS feature for tagging the thermal image with its geographic location. Wifi technology can enable the thermal imaging camera to communicate wirelessly, for instance by sending images directly from the camera to a smart phone or a tablet PC.

Thermal imaging cameras are a widespread and non-invasive tool that is used for building inspection.



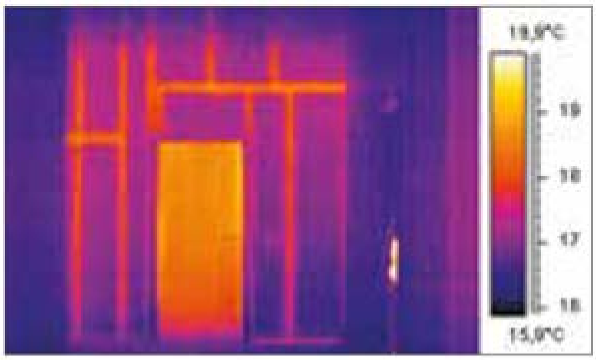
Todays use cases:

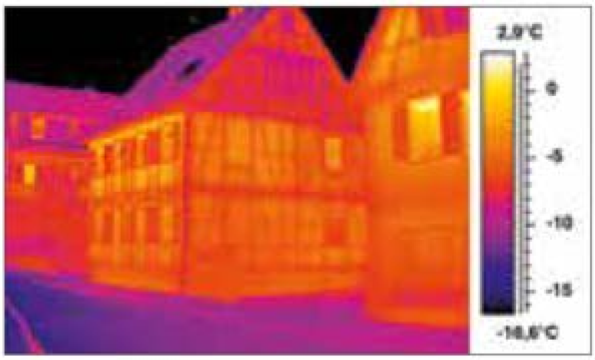
In the building industry, thermal imaging is used for building diagnostics inspection: Visualize energy losses, detect missing or defective insulation, source air leaks, find moisture in insulation in roofs and walls, detect breaches in hot-water pipes, detect construction failures, find faults in supply lines and district heating, detect electrical faults.

A thermal imaging camera can, for instance, scan heating, ventilation and air conditioning (HVAC) installations.

Thermal imaging is an easy-to-use tool to find heating pipes and plumbing installations. Even if the pipes are laid under the floor or inside a wall it can be possible to determine the location by having hot water flowing through the pipes. The heat of the pipes radiates through the surface and the pattern can be easily detected with a thermal imaging camera.

For building renovations, thermal imaging provides information during the renovation of buildings and monuments. Framework constructions hidden by mineral plaster can become visible in a thermal image. It can then be decided whether exposure of these structures is useful. The detachment of plaster from walls can also be located in a very early stage so that preservation measures can be taken.





Providers:

FLIR Systems, Fluke, etc.

Shortcomings:

In order to interpret the thermal images correctly, it is important to know how different materials and circumstances influence the temperature readings from the thermal imaging camera. For instance:

- Some materials reflect thermal radiation, which can lead to misinterpretation of the thermal image
- Furniture and wall decorations can have an insulating effect. If these things are taken away from the wall, this will change the thermal pattern, which might confuse the

interpretation of the thermal image.
Future potentials
Image fusion, by combining images from a digital camera and the thermal imaging camera, can allow to see more precisely where the features shown in the thermal image are located.
TRL level (used to a wide extent, used in some cases, in development, future potential)
Used to a wide extent
People that contributed to this description (name organisation email):
Vincent Schaller, RISE, vincent.schaller@ri.se

Name:	Radar technology
Description of technology:	
A radar system consists of a transmitter producing electromagnetic waves in the radio or microwaves domain, a transmitting antenna, a receiving antenna (often the same antenna is used for transmitting and receiving) and a receiver and processor to determine properties of the object(s). A few stud finders use ultra-wideband radar scanners. They are based on the micropower impulse radar stud detector. Micropower impulse radar is a low-power ultra-wideband radar used for sensing and measuring distances to objects in proximity to each other. Micropower impulse radar has a considerably greater range than capacitive technology, between several centimeters and meter deep.	
Todays use cases:	
In the building industry, the newest stud finders implement radar technology. Using raw signals transmitted by their sensors, they are able to classify different wall types as well as the material behind the walls. Commercial stud finders based on radar technology can detect different materials, for instance: ferrous and non-ferrous metals, wood, electric cables, and water-filled plastic pipes. 	

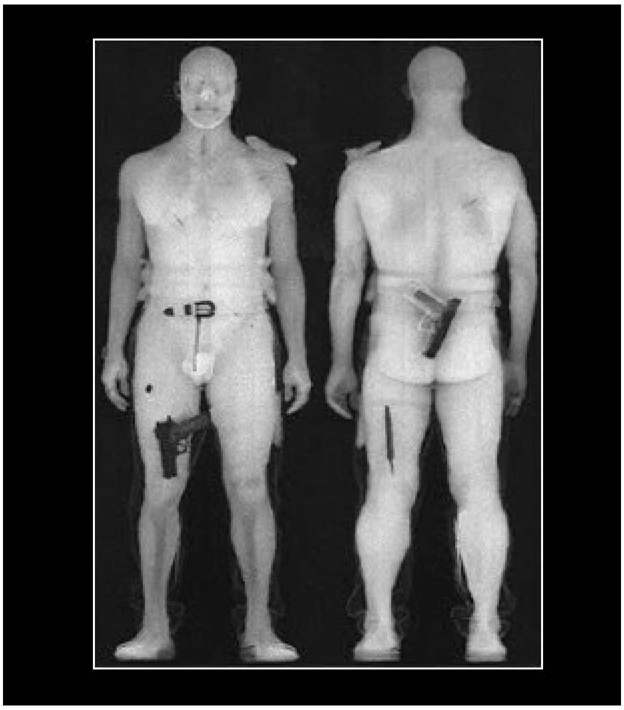
Another example is smartphone-connected Walabot DIY wall scanner that can detect wood, metal studs, electrical wires and cable up to 10 centimeters deep into the walls. Compatible with Android smartphones. 
Providers:
Bosch, Stanley, DeWalt, etc
Companies or actors that I know has experience of using this:
Shortcomings:
Spot measurement
Future potentials
TRL level (used to a wide extent, used in some cases, in development, future potential)
Used to a wide extent

People that contributed to this description (name organisation email):
Vincent Schaller, RISE, vincent.schaller@ri.se

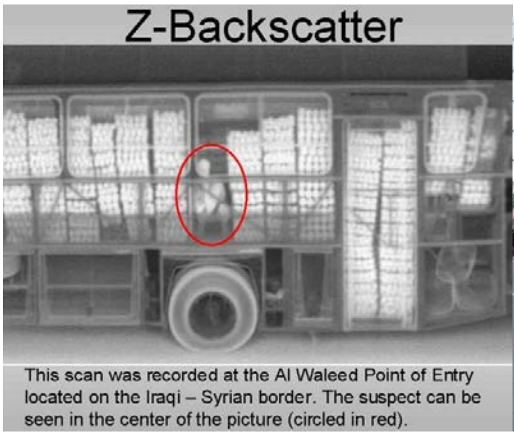
Name:	Backscattering X-ray (Z-backscattering)
Description of technology:	
Backscattering x-ray, Low energy x-ray that penetrates the material and uses the reflection of x-ray to create an image of what is under the surface. The technology is most common in airports or for customs control as big scanners along the road for trucks.	

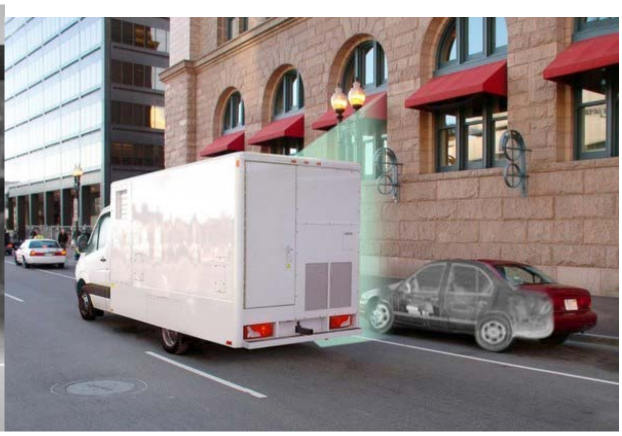
Todays use cases:

Backscattering X-ray is today used in airport security check to scan through clothes.



More powerful backscattering systems is used in customs control for trucks to see what is inside the truck. There are also versions that is mounted inside the controlling truck where you can scan other vehicles on the fly.





Some small new handheld devices is out on the market to be able to check vehicles and bags on the fly. It uses WIFI to send an image to a handheld screen/display.

Providers:

Rapiscan systems, Quantum RX,

Companies or actors that I know has experience of using this:

Used by customs control for trucks.

Shortcomings:
Only lead sheets stops the image, handheld device 45 000Euro
Future potentials
Tag the different objects inside the wall.
TRL level (used to a wide extent, used in some cases, in development, future potential)
Used to a wide extent (except for the handheld that is new)
People that contributed to this description (name organisation email):
Henrik Karlsson (henrik.u.karlsson@ri.se)

Name:	gSKIN® Heat Flux
Description of technology:	
There are several product types offered, e.g. - The gO Measurement-System, which is a cloud-based, wireless system for U-value, R-value, surface temperature, and humidity measurements. https://www.greenteg.com/gO-Measurement/ - The gSKIN® U-Value Kit is a complete measurement tool for measuring the thermal insulation quality (U-value) of materials. It is often used in the field of building physics. Further information including application notes and case studies is available here: https://www.greenteg.com/U-Value/	
Todays use cases:	
U-value, R-value, surface temperature, and humidity measurements.	
Providers:	
The “greenTEG AG Switzerland” company, several products.	
Companies or actors that I know has experience of using this:	
Researchers from Politecnico di Milano, Italy, investigated breathing walls using greenTEG’s gSKIN® XM heat flux sensor. There is a publication about that: Alongi Andrea, Angelotti Adriana, and Mazzarella Livio (2019): Measuring a breathing wall`s effectiveness and dynamic behaviour. *Indoor and Built Environment.* https://doi.org/10.1177/1420326X19836457 There are other publications covering these technologies implementation: https://www.greenteg.com/heat-flux-sensor/heat-flux-sensing-resources/	
Shortcomings:	
Further progress with recently developed new “reduced-scale” hot box method for the thermal characterization of window insulation materials that can be used for small samples. This new set-up contains greenTEGs gSKIN® XO-heat flux sensor.	
Future potentials	
The developed measurement methods for the thermal properties of insulation materials will help to facilitate the development of novel materials for energy-efficient buildings.	

TRL level (used to a wide extent, used in some cases, in development, future potential)
Used in some cases with future potential for initial renovation assessment and later commissioning.
People that contributed to this description (name organisation email):
Dr. Andriy Hryshchenko, UCC, Cork, Ireland. a.hryshchenko@ucc.ie

Name:	Galileo Satellite navigation system
Description of technology:	
European Global positioning system that uses satellites with higher accuracy than US GPS, Glonass or BeiDou. A combination of all satellite navigation systems improves the accuracy even more. Accuracy in one meter and with a paid encrypted signals accuracy of 20cm. Combination of other satellite navigation system will allow positioning trilateration up to mm precision and is said to be higher effect antennas that could allow indoor positioning.	
Todays use cases:	
Up and running with some satellites but have problems.	
Providers:	
Satellite navigation providers, paid by EU	
Companies or actors that I know has experience of using this:	
Shortcomings:	
High accuracy position outdoors and indoors, aiming towards autopilot landings for airplanes. Military, agencies, building and construction companies are the main target groups.	
Future potentials	
Improving accuracy combined with other systems.	
TRL level (used to a wide extent, used in some cases, in development, future potential)	
In development.	
People that contributed to this description (name organisation email):	

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8.4 Inertial Navigation System (INS)

INS is a navigation device that uses a computer, motion sensors (accelerometers) and rotation sensors (gyroscopes) to continuously calculate the position, the orientation, and the velocity (direction and speed of movement) of a moving object without the need for external references. Usualy in microscale as MEMS (Micro Electronic Mechanical Systems). Used on vehicles, AR-glasses and simulator systems. Also often used in support or correcting accuracy in other navigation systems.