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3D Scanning as a Design Support Tool in Power Plant Engineering

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ABSTRACT:

Industrial projects increasingly require accurate documentation of existing facilities. Traditional methods such as manual measurements and photographs are time-consuming, prone to errors, and often result in incomplete data, particularly in brownfield projects. Three-dimensional (3D) laser scanning addresses these challenges by creating detailed point clouds that improve accuracy, reduce errors, and minimize the need for repeated site visits.

This thesis examines first the use of 3D scanning in power plant design by adopting pre-tests with a scanner, expert interviews and then in its final stage develops internal guidelines for standardized scanning practices. The pre-tests included indoor and outdoor test scans with the Faro Focus S350 to evaluate predefined and custom profiles. Semi-structured interviews were arranged with five experts. Based on the findings, a limited number of optimized profiles were selected that balance scanning time and quality.

The scanning tests revealed both strengths and limitations of the technology. HDR settings provided superior color depth in challenging lightning but significantly increased files sizes, while lower quality profiles reduced scanning time but produced results unsuitable for design purposes. The results confirmed that only a few carefully chosen profiles are sufficient to cover most project needs efficiently without compromising quality.

Based on the pre-tests and expert interviews, a set of internal company guidelines that is provided for a clear process for scanning project planning, execution and data handling. They improve efficiency, support knowledge sharing, and ensure consistent quality across projects. The guidelines also help reduce errors and unnecessary site visits, strengthen customer satisfaction by providing accurate as-built data, and clarify the scanning process for employees who are not directly involved in fieldwork. The guidelines are intended solely for company use and are not publicly available.

The thesis was carried out at the request of Cyient Oy, to support execution of power plant projects. The results demonstrate that with optimized profiles and structured workflows, 3D scanning can be a routine and reliable part of industrial design.

KEYWORDS: scanning, measurement, lidar, quality, technology

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TIIVISTELMÄ:

Teollisuusprojektit vaativat yhä tarkempaa dokumentaatiota olemassa olevista kohteista. Perinteiset menetelmät, kuten käsin tehdyt mittaukset ja valokuvat ovat aikaa vieviä, virhealttiita ja johtavat usein puutteellisiin tietoihin, erityisesti brownfield-projekteissa. Kolmiulotteinen (3D) laserkeilaus tarjoaa ratkaisun tuottamalla yksityiskohtaisia pistepilviä, jotka parantavat tarkkuutta, vähentävät virheitä ja minimoivat tarvetta toistuviin työmaakäynteihin.

Tässä diplomityössä tarkastellaan ensin 3D-skannauksen hyödyntämistä voimalaitossuunnittelussa esitestien, asiantuntijahaastattelujen ja lopuksi sisäisten ohjeiden kehittämisen kautta. Esitestit sisälsivät sisä- ja ulkotilojen skannausta Faro Focus S350 -skannerilla, jossa arvioitiin valmiita ja mukautettuja asetusprofiileja. Testien lisäksi järjestettiin haastattelut viiden asiantuntijan kanssa, jossa käytettiin puolistrukturoitua haastattelumenetelmää. Tulosten perusteella valittiin rajattu määrä optimoituja profiileja, jotka tasapainottavat skannausaikaa ja laatua.

Testien tulokset paljastivat teknologian vahvuuksia sekä rajoitteita. HDR-asetukset tarjoavat parempaa värisyvyyttä haastavissa valaistusolosuhteissa, mutta kasvattaa merkittävästi tiedostokokoa. Alhaisemman laadun profiilit lyhensivät skannausaikaa, mutta niiden tuottama aineisto ei soveltunut suunnittelukäyttöön. Tulokset myös vahvistivat, että muutamalla valitulla asetusprofiililla pystyy kattamaan suurimman osan projektitarpeista ilman laadun heikentymistä.

Esitestien ja asiantuntijahaastattelujen perusteella laadittiin yrityksen sisäiset ohjeet, jotka tarjoavat selkeän prosessin skannausprojektin suunnitteluun, toteutukseen ja datan käsittelyyn. Ohjeet parantavat tehokkuutta, tukevat tiedon jakamista ja varmistavat yhtenäisen laadun projekteissa. Lisäksi ne auttavat vähentämään virheitä ja tarpeettomia työmaakäyntejä, vahvistavat asiakastyytyväisyyttä luotettavan lähtödatan avulla sekä selkeyttävät prosessia myös työntekijöille, jotka eivä ole osallisena skannausprojekteissa. Ohjeet on tarkoitettu ainoastaan yrityksen sisäiseen käyttöön, eikä niitä jaeta julkisesti.

Diplomityö totetutettiin Cyient Oy:n toimeksiannosta voimalaitosprojektien tukemiseksi. Tulokset osoittavat, että optimoiduilla profiileilla ja selkeillä ohjestuksilla 3D-skannaus voidaan ottaa osaksi teollisuuden suunnittelua rutiininomaisena ja luotettavana menetelmänä.

AVAINSANAT: skannaus, mittaus, laserkeilaus, laatu, teknologia

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Abbreviations

ToF	Time-of-Flight
LiDAR	Light Detection and Ranging
TLS	Terrestrial Laser Scanner
HDR	High Dynamic Range
3D	Three Dimensional

1 Introduction

The growing complexity of industrial design projects has created an increasing need for accurate and efficient documentation of existing plant facilities, providing a clear understanding of current spaces and supporting the planning of future upgrades. Traditional measurement methods, such as manual tape measurements, photographs, and field notes, have long been used to capture site conditions in industrial environments with extensive infrastructure, including steel structures, piping systems, equipment and electrical installations. While these methods remain functional, they are often time consuming, require multiple site visits, and may lead to incomplete or inconsistent data. In large-scale power plant projects, even small inaccuracies in measurements can result in design errors, costly rework, and delays. These challenges are particularly evident in brownfield projects, where new equipment and systems must be integrated into the environment with limited and often outdated documentation. Brownfield projects refer to modifications or expansions of existing industrial plants, as opposed to greenfield projects, which are designed and constructed from scratch (Blackridge Research, 2025).

Three-dimensional (3D) laser scanning has become an effective tool to address challenges related to the documentation of existing facilities. By capturing millions of data points within minutes, scanners can produce accurate point clouds that provide a detailed digital representation of the physical plant environment. This enables engineers and designers to work with reliable as-built information, minimizing the risk of clashes between new and existing structures. Beyond its accuracy, 3D scanning improves efficiency by reducing the need for repeated site visits and by creating a shared digital model that can be accessed by all project stakeholders. As scanning technology continues to evolve, its role in industrial design and project execution is expanding rapidly.

This thesis focuses on the use of 3D scanning in power plant design, where accurate site information is essential for successful project execution. The research combines theoretical knowledge, practical testing and insights from earlier projects to evaluate scanner settings and their impact on point cloud quality. A series of test scans were conducted in environments to identify suitable predefined and custom profiles, with the goal of establishing settings that can be applied consistently across projects. Interviews with experienced engineers further complemented this work by providing perspectives on practical challenges and highlighting areas where scanning delivers the greatest value. Based on the results from the interviews, this thesis produces a set of internal company guidelines that standardize scanning practices, ensure consistent quality and support efficient workflows.

The guidelines created as a result of this thesis are intended not only for the scanning team but also for other stakeholders within the company. They clarify the entire scanning process, from planning to data handling and provide a foundation for knowledge sharing and training. By documenting proven methods and lessons learned, the guidelines strengthen the company’s capabilities and help integrate 3D scanning as a routine part of engineering design.

This thesis was carried out at the request of the piping and layout team of Cyient, a global engineering and technology solutions provider. Cyient operates in industries such as energy, aerospace, transportation, and telecommunications. They deliver design, manufacturing, and digital transformation services. Cyient Oy is the Finnish subsidiary of Cyient. It originated as Citec Oy, a company established in Vaasa, Finland, which was acquired by Cyient in 2022. Within power plant projects, the company plays a key role in providing detailed engineering support (Cyient, 2025). The development of internal 3D scanning guidelines supports this mission by equipping the team with standardized methods that enhance both project efficiency and quality.

2 Theory

This chapter provides an overview of 3D scanning technology, including the key principles behind its operation. It explains the concept of a point cloud and highlights the main advantages of the system, as well as the reasons why the company is interested in utilizing it.

2.1 Introduction to 3D scanning

The evolution of 3D scanning began in the 1960s with experimental systems using lights, cameras, and projectors to reconstruct objects' surfaces, though these early methods were slow and labor intensive. After 1985, more advanced systems emerged that employed white light, lasers, and shadowing to capture detailed surface geometry. By the mid-1990s, commercial technologies such as REPLICA enabled rapid and highly accurate scanning, and companies like Cyberware began producing color capable scanners. Innovator companies such as Immersion and Faro Technologies made lower cost handheld digitizers available, but these devices remained relatively slow and lacked color capture. Major advances occurred in 1996 with ModelMaker system when the first flexible reality capture solution combining a manual arm with stripe-based scanning to produce complex, textured 3D models within minutes (Acta Simulation, 2018). The technological developments of the 2000s including increased computing power, refined software for point cloud processing and the emergence of structured light and Light Detection and Ranging (LiDAR) scanning greatly accelerated the pace of 3D scanning technology, making it more practical, accurate and accessible (Arrival3D, 2025).

In power plant design, and design in general, it is important to improve both efficiency and accuracy. 3D scanning is used to accelerate the power plant design process and improve the precision of the work. The scanner uses laser technology to produce highly detailed three-dimensional images of environments and geometries within minutes. The result is a point cloud, which is a combination of millions of measurement points (Faro Knowledge Base, 2021). This method helps streamline the measurement phase and reduce design errors by making use of the existing infrastructure (Aveva E3D Design, 2023). For example, the point cloud can be used to position equipment and to route and design potential piping and electrical lines (Aveva Point Cloud Manager, 2022).

2.2 Technology

3D scanning technologies are generally divided into contact and non-contact methods. Contact-based techniques, such as coordinating measuring machines, rely on a physical probe that touches the object's surface to record individual points. These systems provide extremely high accuracy and have been widely applied in industrial quality control (Exact Metrology, 2023).

Non-contact scanning measures surfaces without physical contact by using light, lasers or cameras. These methods are faster, less invasive, and capable of capturing complex geometries and surface textures which make them especially suitable for applications in design, cultural heritage, medicine and consumer electronics (Industrial-IA, 2020). In this thesis, the focus is on non-contact scanning methods.

2.2.1 Triangulation

Triangulation-based scanning determines the shape of an object by projecting a laser beam or light pattern onto its surface and calculating the position of points from the angle of reflection between the emitter, the surface and the sensor. The operating principle of triangulation scanner is illustrated in Figure 1. The method provides high accuracy, typically in the range of 0.01 – 0.1 mm depending on the device and scanning conditions, and is widely used in product design, reverse engineering, quality assurance, and in many handheld 3D scanners. Its limitations include sensitivity to reflective or transparent surfaces and a relatively short effective range (Salvi, Pages, & Batlle, 2004; Creaform, n.d.).

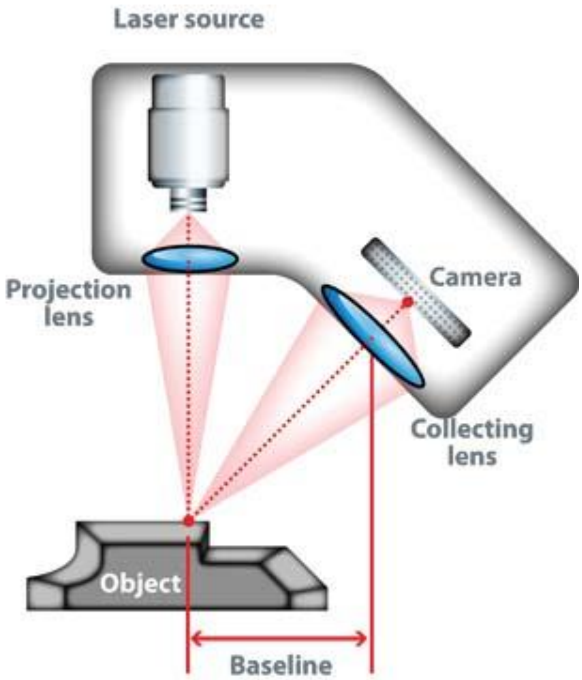

Figure 1. The working principle of laser triangulation 3D Scanners (NeoMetrix, 2016).

2.2.2 LiDAR

LiDAR is one of the most widely applied non-contact scanning methods and is based on the Time-of-Flight (ToF) principle. In this approach, the system emits short pulses of laser light and measures the time it takes for the reflection to return. Because the speed of light is constant, the distance to each point on the surface can be calculated with high accuracy. ToF technology is highly effective for capturing large environments quickly, though its resolution for small details is lower compared to triangulation or structured light methods (IBM, 2023). The working principle of LiDAR technology can be seen in Figure 2, where the laser is directed by a rotating mirror, and the detector measures the ToF of the rejected light to calculate distances.

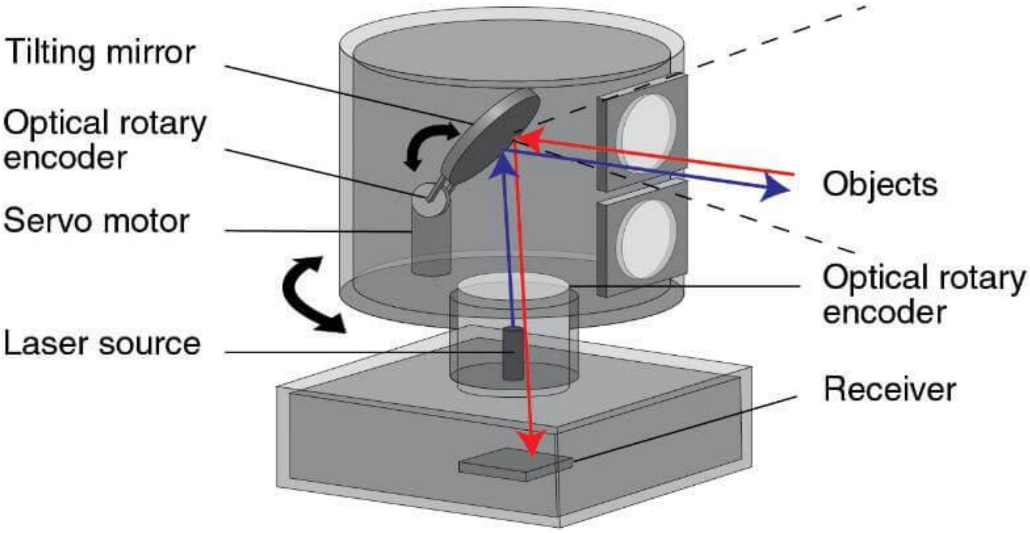

Figure 2. LiDAR components explained (Ghosh, A., 2024).

LiDAR systems are commonly classified into three categories: terrestrial, mobile and aerial (NavVis, 2022). Terrestrial laser scanners (TLS) are typically mounted on a tripod and rotate to capture the surrounding environment. They were the first type of LiDAR scanner to be used extensively for surveying and mapping applications and still provide the highest level of accuracy.

Mobile LiDAR, also referred to as mobile mapping systems, enables scanning while in motion. These systems may be mounted on vehicles, carried by hand or worn on the body and they often rely on simultaneous localization and mapping technology. Mobile LiDAR allows for significantly faster data capture than TLS and has recently achieved a level of accuracy sufficient for most applications. Mobile LiDAR's are especially effective for rapidly capturing roads, railways, and interior spaces.

Aerial LiDAR's are mounted on aircraft, including UAVs, for mapping larger areas from above. It can be applied to both small-scale surveys, where it is combined with GPS and inertial navigation units to map large areas such as forests, coastlines and entire urban regions (NavVis, 2022). A point cloud of a building created with a LiDAR scanner is shown in Figure 3.

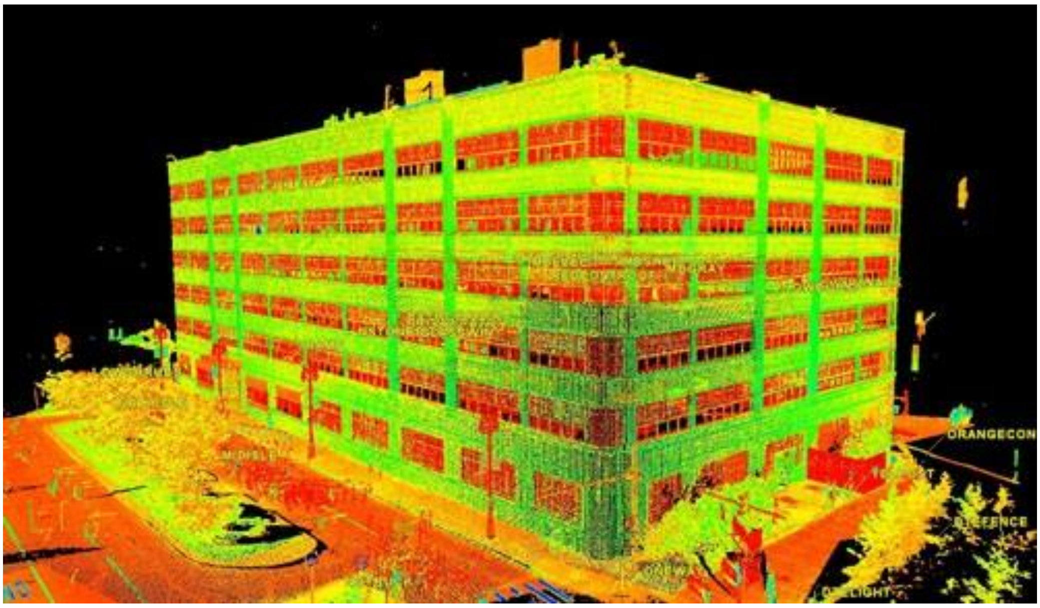

Figure 3. Point cloud created by using LiDAR technology (RemoteScout24, 2021).

In addition to professional surveying and mapping, LiDAR has recently become more common in consumer and automotive applications. Apple Inc., for instance, has integrated compact LiDAR sensors into its iPhone Pro models, enabling augmented reality applications and room-scale 3D modeling (Wired, 2020). Similarly, Volvo Car AB has incorporated LiDAR technology into its next-generation vehicles in collaboration with Luminar Technologies Inc., aiming to improve driver safety and enable autonomous highway driving (Volvo Cars, 2021).

2.2.3 Structured light

Structured light scanning is a non-contact method in which a projector casts a known pattern, such as parallel stripes or a grid, onto the surface of an object, as can be seen in Figure 4. Cameras record how the projected pattern deforms when it strikes the object, and these deformations are then analyzed to reconstruct an accurate 3D model of the geometry. This technique enables rapid and highly detailed digitization, making it particularly effective for small and medium-sized objects. Because of its high resolution, structured light scanning has become widely used in fields such as industrial design, reverse engineering and medical imaging. Its main limitations are the sensitivity to ambient light and difficulties in accurately capturing very shiny, reflective or transparent materials, which can distort the projected pattern and reduce measurement accuracy (PADT, 2022).

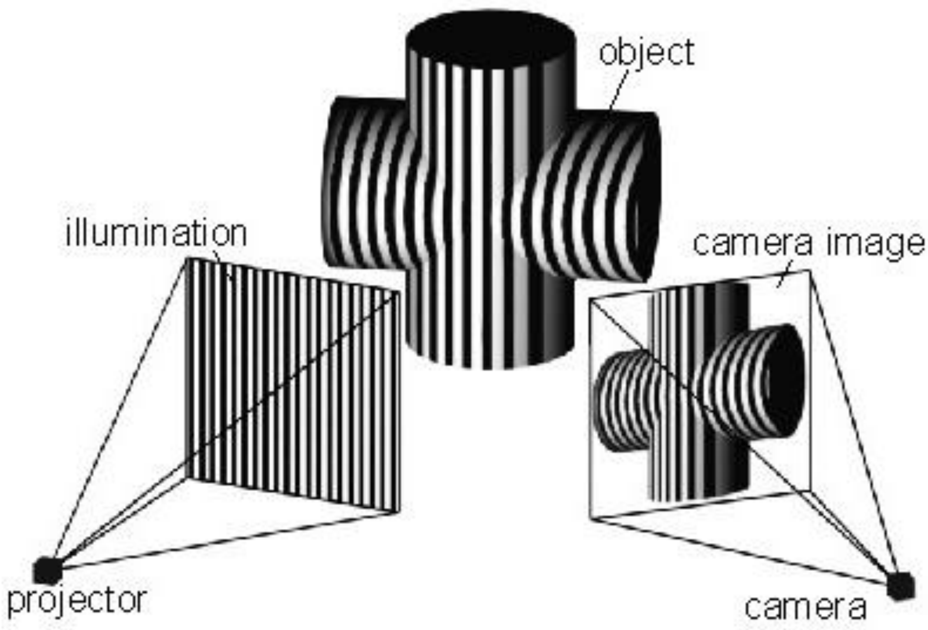

Figure 4. The principle of structured light process (Bitfab, n.d.).

2.2.4 Photogrammetry

Photogrammetry is a technique that reconstructs 3D models from sets of overlapping photographs. By processing these images, specialized software can generate detailed representations that capture both the geometry and surface structure of objects. The method is particularly suitable for documenting large objects and environments, such as archaeological sites or heritage structures, and has increasingly been adopted in engineering and industrial contexts. One of its key strengths is cost-effectiveness, since it requires only standard photographic equipment and appropriate software rather than specialized hardware. The quality of the resulting model depends on factors such as image resolution, lighting conditions, and the skill of the operator in capturing sufficiently overlapping and well-distributed photographs (McCarthy, 2014). Figure 5 shows a browser-based interactive model that was generated using photogrammetry.

Figure 5. Example of photogrammetry scan (Sketchfab, 2020).

2.3 Point cloud

A point cloud is a set of millions of data points in 3D space, typically representing the surface of physical objects or environments. Each point is defined by its X, Y and Z coordinates and may include additional attributes such as color or intensity. Point clouds are the fundamental digital outputs of 3D scanning technologies, including LiDAR, structured light and photogrammetry, and they form the basis for modeling or analysis (NavVis, 2021).

The quality of a point cloud, meaning its density and fidelity, is determined by the scanning method and resolution. Highly detailed point clouds suitable for small objects can be produced using structured light or triangulation, while LiDAR excels at generating vast point clouds of large-scale environments (Haleem, et al., 2022).

Raw point cloud data often contains noise and outliers, which must be reduced before reliable reconstruction can be performed (Zhu et al.,2023). In addition, multiple scans typically require registration and meshing to form continuous 3D models. Once processed, point clouds become versatile tools used in construction for as-builts documentation, and for example in design work when converted into CAD models.

Figure 6 shows how individual points form a point cloud and how different objects can be identified. The scanner is positioned in the corner, where point spacing is the densest, and the increasing distance makes the points appear more widely spaced.

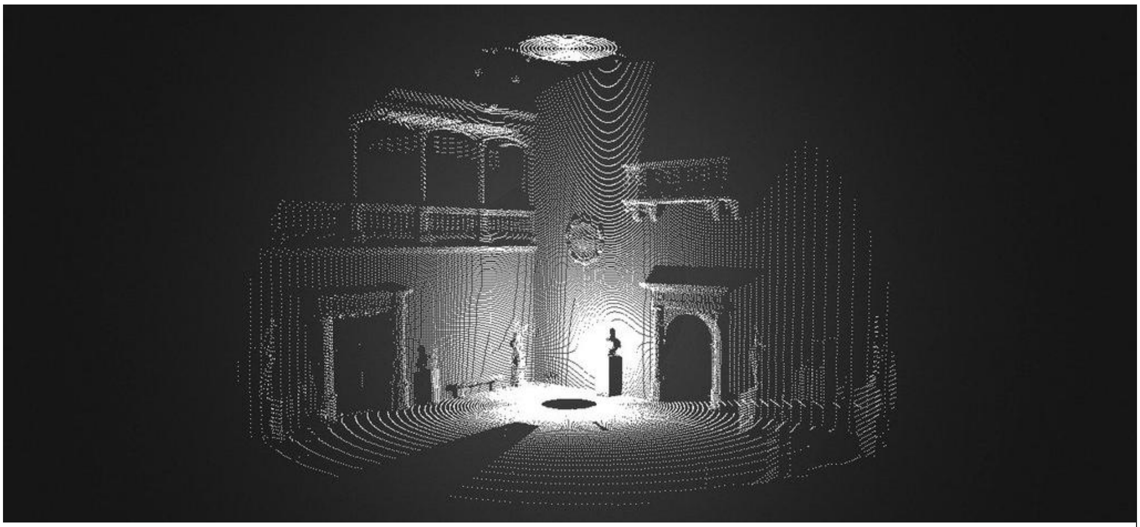

Figure 6. Example of point cloud (Sketchfab, 2015).

2.4 Benefits of 3D scanning in power plant design

The application of 3D scanning in industrial projects provides clear benefits in terms of accuracy and efficiency. By capturing comprehensive as-built data, engineers are able to integrate new components into complex brownfield environments with reduced risk of dimensional errors. Studies have shown that terrestrial laser scanners can achieve accuracies of a few millimeters over tens of meters, making them well suited for documenting large industrial facilities (Leica Geosystems, n.d.). Compared to traditional field methods such as tape measurements or photographic surveys, which often require repeated site visits, 3D scanning allows a complete visual record of the environment to be captured in a single site trip.

While the general benefits of 3D scanning are evident, the choice of scanning technology is crucial when applying it to power plant design. While their operating principles differ, each method provides distinct benefits within its own category, offering varying balances of accuracy, range, and usability in industrial applications such as power plant design. The following part outlines the suitability of the different technologies for use in power plant environments.

LiDAR based TLS is the most widely adopted technology in power plant engineering. This technology is able to capture entire buildings, turbine halls, and for example pipe racks with high precision, often within 2 – 6 mm at ranges of 10 – 40 m (Leica Geosystems, n.d.). TLS is robust under varying lighting conditions, which makes it suitable both indoors and outdoors. Its high point density ensures that new piping, steel structures, and equipment can be modeled with sufficient accuracy to detect clashes during the design stage, effectively minimizing costly on-site rework (AVEVA, 2023b).

Triangulation-based laser scanning provides extremely high accuracy at close range, even below 0.1 mm depending on the sensor and material surface. This makes its suitable for detailed component inspection or reverse engineering of small equipment. Triangulation scanners are limited to few meters in range and are sensitive to reflective or transparent surfaces, so this technology is not suitable for large-scale documentation (Artec3d, n.d.).

Structured light scanning projects a light pattern onto surfaces and derives geometry from its deformation. It achieves very high accuracy in controlled environments, with reported repeatability on the order of 0.05 mm for small objects (Holocreators, n.d.). This makes it suitable for prefabrication or laboratory applications, where components can be scanned before installation. Structured light is impractical for power plants, as performance degrades in strong ambient light and over larger distances. Its use is largely confined to manufacturing quality assurance rather than field documentation.

Photogrammetry is a cost-effective option for documenting large or complex surfaces in power plant environments, with close-range methods achieving accuracies of 0.2 – 0.5 mm at distances of a few meters. While it provides valuable visual and textural information, its geometric accuracy is sensitive to distance, occlusions, and lighting, which limits its use as a primary source for critical dimensioning (Luhmann et al., 2014).

In summary, LiDAR based TLS is the most appropriate solution for large and complex power plant environments, providing a balance of range, accuracy and robustness. Triangulation and structured light scanners, while accurate, are constrained by range and environmental conditions and therefore serve mainly specialized or component level applications. Photogrammetry offers a cost-effective way to produce contextual models but lacks the precision needed for detailed engineering. Cyient uses the Faro Focus S350 scanner, which operates on LiDAR technology and has been applied to the scanning of power plants and similar industrial sites. It has proven well-suited for supporting engineering design.

3 Scanner configuration and testing

This chapter introduces the scanner settings and their evaluation through a series of controlled tests. The aim is to describe the adjustable parameters of the device, explain the predefined and custom scan profiles and present how these settings were tested under varying environmental conditions. The experiments were designed to provide practical insight into the quality of the resulting point clouds and to identify suitable configurations that could be standardized for future use.

The experiment was carried out at an abandoned shipyard using the scanners default settings as well as several custom configurations. The overall objective was to identify a limited set of standard settings that could be applied consistently across various projects, ensuring repeatable and high-quality outcomes while minimizing time spent on site.

The evaluation of scan quality was based on reviewing each scan individually in the post-processing software, where the clarity of the point cloud and the accuracy of the color representation could be immediately observed. A reference checkerboard target paper was placed on a wall at the site to enable direct comparison between different parameter profiles. These observations were recorded in an Excel sheet, along with supporting metrics such as the number of captured points, file size, and scanning time. The official accuracy values provided by Faro were also considered to verify how precise the scanner performs under different environmental conditions. By combining visual assessment, reference target evaluation, and quantitative metrics, the tests enabled a structured comparison of quality across profiles and formed the basis for selecting suitable configurations.

To prepare for the testing, different approaches were considered in collaboration with a expert and it was decided that both the default setting and the selected custom setting would be tested in practice. The abandoned shipyard was chosen as the scanning site because its environment resembled certain characteristics of power plant infrastructure, including high ceilings, pipe networks, windows and extensive surface areas. The location had been out of use for several decades, providing an undisturbed and realistic environment for the experiment.

3.1 Scanner settings

The scanner includes a wide range of adjustable settings, of which the most important are resolution and quality. Resolution can be selected at incremental levels between 1/1 and 1/32, allowing the user to balance the required level of detail against scanning time. According to Faro's documentation (Faro, 2021), scan resolution should be chosen based on the level of detail needed, the distance to the object of interest, and the distance to the reference targets.

The highest resolution setting, 1/1, produces approximately 699.1 million points in the point cloud. Such density should be used for special cases where very fine detail is required. The resolution settings between 1/1 and 1/10 are generally preferred, as lower resolutions tend to reduce point cloud quality to a level that makes them less suitable for the company's applications. For most design tasks, intermediate settings such as 1/4, with around 43.7 million points, provide sufficient accuracy while keeping file sizes and processing times manageable. In large-scale scans, it is not necessary to achieve millimeter precision across every surface. It is generally sufficient to scan only the most relevant areas from multiple positions. Based on the company's practical requirements, an accuracy of approximately 1 – 5 mm indoors and 5 – 10 mm outdoors has proven adequate to support reliable design work.

Configuration of the scanner resolution settings is shown in Table 1, which also explains the situation where each setting should be used.

Table 1. General resolution guidelines.

Resolution	Area of target	Number of points in million
1/1	Objects and small areas	699.1
1/2	Objects and small areas	174.8
1/4	Outdoors and large indoor spaces	43.7
1/5	Outdoors and large indoor spaces	28.0
1/8	Indoors and small outdoor spaces	10.9
1/10	Indoors and small outdoor spaces	7.0

The scan quality setting indicates how many times the scanner rotates 360 degrees on the tripod around its z-axis during the scanning. This can be adjusted in steps from 1x, representing the lowest setting, up to 8x which is the highest. This parameter defines the number of measurements the scanner performs in order to confirm point data. Increasing the quality setting also activates an internal noise reduction algorithm that helps distinguish whether variations in point data originate from true object detail or from measurement noise.

The scanner quality options and the corresponding target areas where each setting should be applied, are shown in Table 2.

Table 2. General quality guidelines.

Quality	Area of target
2x	Optimal conditions (good lighting, good weather) and when time is a concern
3x	Indoors or outdoors with overcast conditions
4x	Outdoors in sunny conditions when range is needed, or in inclement weather
6x	High quality
8x	Ultra-high quality

By default, scans are captured in grayscale. In the case company, only RGB color data is used, as colorized point clouds are significantly easier to read and therefore accelerate subsequent design and analysis work. The drawback of RGB scanning is the longer scanning time. An attempt was made to shorten this by mounting an external Panocam mounted on top of the scanner, but this approach led to reduced image quality and frequent alignment errors, which made it unsuitable for practical use.

The scanner also offers a Speed setting for RGB scanning, which reduces the exposure time for each color image, thereby shortening the overall scan duration. Conversely, the Night setting increases exposure to capture more accurate images in dark conditions, but this also lengthens scan time. Another relevant feature is the HDR function, where the scanner captures multiple images with different exposure levels and merges them into a single high dynamic range image, improving the visibility of details in both bright and dark areas (Dicarlo, 2025). The HDR setting can be selected at three levels, corresponding to 2x, 3x and 5x exposures.

A consistent understanding and use of these settings are essential for achieving reliable results across different scanning environments. By identifying a limited set of predefined and custom profiles that balance accuracy, efficiency and usability, it becomes possible to standardize workflows within the company. This not only ensures reproducible data quality but also minimizes unnecessary adjustments in the field, ultimately supporting more efficient project execution and dependable outcomes.

3.2 Predefined and custom scan profiles

Table 3 below contains the settings that were applied in both indoor and outdoor scanning tests. It presents the specifications of the scan profiles applied during the indoor test scans. Five predefined profiles were tested alongside two custom configurations for the indoor environment (Table 3). For the outdoor environment, three predefined and also the same custom configuration was used (Table 4). The aim was to evaluate how these settings performed in capturing large open areas under varying lighting conditions, while still producing accurate point cloud. The objective of the custom profiles was to create a setup suitable for situations where scanning must be carried out but the highest data quality is not essential. Such cases may include longer transitions between scan locations, where additional scans are primarily required to support reliable point cloud registration rather than to capture fine detail.

Table 3. Indoor test settings.

	Resolution	Quality	HDR	Speed	Time
Indoor 10m Close	1/8	3x	-	-	04:08
Indoor 10m Far	1/5	4x	-	-	07:49
Indoor HDR	1/5	4x	-	-	10:09
Outdoor 20m Far	1/4	4x	-	-	10:24
Outdoor HDR	1/4	4x	4x	-	12:44
Fast 1 (Custom)	1/5	2x	-	x	04:23
Fast 2 (Custom)	1/8	2x	-	-	03:41

Custom profiles can be named and stored in the device memory, allowing them to be used when needed. For the purpose of this test, the profiles were not saved, as the primary objective was solely to obtain data on scan quality. Table 4 below shows the specifications of the profiles used in the outdoor test.

Table 4. Outdoor test settings.

	Resolution	Quality	HDR	Speed	Time
Outdoor 20m Close	1/5	4x	-	-	07:49
Outdoor 20m Far	1/4	4x	-	-	10:24
Outdoor HDR	1/4	4x	3x	-	12:44
Fast 1 (Custom)	1/5	2x	-	x	04:23
Fast 2 (Custom)	1/8	2x	-	-	03:41

These tests were conducted to evaluate the performance of both predefined and selected custom profiles of the scanner. Faro also provides a configuration matrix, which served as a reference in the design of the custom profiles. During the tests it became evident that the actual scan durations were longer than the times indicated in the manufacturer's documentation. This observation is useful for future planning, as it allows more realistic estimates of scanning time.

The configuration matrix provided by Faro shows only the parameters that are relevant for this study (Figure 7). The image was reduced to focus on the essential information while preserving the original content.

Faro Focus^S 350 Firmware 6.6.0.4592*

Resolution	Quality	Scan time in minutes Color mode							Number of points in million	Point spacing 10m distance (mm)
		Grayscale	RGB	Speed	Night	HDR 2x	HDR 3x	HDR 5x		
1/8	2x	<01:03	<03:01	<02:49	<04:31	<04:31	<06:01	<09:02	10,9	12,3
	3x	<01:30	<03:27	<03:16	<04:58	<04:58	<06:28	<09:29		
	4x	<02:24	<04:21	<04:10	<05:52	<05:52	<07:22	<10:23		
	6x	<07:46	<09:43	<09:32	<11:14	<11:14	<12:44	<15:45		
	8x	<29:15	<31:12	<31:01	<32:42	<32:42	<43:12	<37:13		
1/5	2x	<01:45	<03:42	<03:31	<05:13	<04:38	<06:43	<09:44	28,0	7,7
	3x	<02:54	<04:51	<04:40	<06:22	<05:13	<07:52	<10:53		
	4x	<05:11	<07:09	<06:57	<08:39	<08:39	<10:09	<13:10		
	6x	<18:56	<20:53	<20:42	<22:24	<22:24	<23:54	<26:55		
1/4	1x	<01:30	<03:27	<03:16	<04:58	<04:58	<06:28	<09:29	43,7	6,1
	2x	<02:24	<04:21	<04:10	<05:52	<05:52	<07:22	<10:23		
	3x	<04:11	<06:09	<05:57	<07:39	<07:39	<09:09	<12:10		
	4x	<07:46	<09:43	<09:32	<11:14	<11:14	<12:44	<15:45		
	6x	<29:15	<31:12	<31:01	<32:42	<32:42	<34:12	<37:13		
	8x	<115:09	<117:06	<116:55	<118:36	<118:36	<120:06	<123:07		

Figure 7. Faro Focus S350 configuration matrix (Laser Scanning Europe, n.d.).

3.3 Testing of scanner settings under different conditions

The chosen test site was an old shipyard hall in Palosaari, Vaasa, which is no longer in use. The building is well suited for the experiment due to its spacious layout, high ceilings, and the variety of surface types it contains. Brownfield projects are often carried out in similar industrial facilities where new equipment and supporting infrastructure need to be integrated into existing structures. This similarity was a significant factor in the selection of the site. In both the indoor and outdoor environments, Faro's own checkerboard reference target paper was used, which can be seen in Figure 8. The target paper is designed to ease the registration of scans, but in this case, it was employed solely to verify point cloud quality in the post-processing softwares.

The test was intended to try how different environmental conditions influence the scanning process. Particular attention was given to performance in a dark indoor space, in a hall with windows admitting natural light, and in bright outdoor conditions. In addition, the effect of varying distances was tested both indoors and outdoors to evaluate how range impacts point cloud quality under different lightning scenarios.

Figure 8. Checkerboard reference target paper.

3.3.1 Indoor tests

The reference target was mounted at a height of approximately 1.8 meters from the floor, and the scanner was positioned 10 meters away from the wall. The scanner was positioned on a tripod at a height of approximately 0.8 meters. The full setup can be seen in Figure 9. Predefined indoor profiles are specifically designed for this distance, making it a suitable setup for the test. Inside the hall, lightning conditions varied between dim and bright areas, as sunlight entered through large doors and windows. One darker corner of the hall provided a suitable setting for evaluating color representation and the overall quality of the point cloud. All predefined and custom settings were scanned under these conditions, after which the outdoor tests were carried out.

Figure 9. Scanner setup.

3.3.2 Outdoor tests

The outdoor test was carried out on a July evening with clear skies and direct sunlight. The evening was considered optimal for the experiment, as the light conditions were even and not overexposed, which could otherwise have affected the comparability of the results. Laser scanning itself is not significantly disturbed by bright or dim environments, but the captured images may influence the point cloud by causing slight variations in color representation. The selected test site was the western wall of a building, where the reference target was attached, and the scanner was positioned at a distance of 20 meters from the wall. The surrounding area contained a considerable amount of vegetation.

3.4 Point cloud quality observations

This section examines the quality of the scans and finally makes an assessment using an Excel-based tool. The examination of the point clouds began by importing and naming each scan as a separate project in Faro Scene, where the data was visually inspected and notes were taken. After this initial review, the projects were exported in .rcp format and opened in Autodesk ReCap, which provides an even clearer view of the color data.

3.4.1 Indoor

Indoor 10m far: The point cloud remains of high quality even at longer distances, showing significantly better results than the 10m close setting. The reference paper is clearly readable, and the colors appear acceptable even in low-light conditions.

Indoor 10m close: With the resolution set to 1/8, the lighting conditions caused overexposure, resulting in a coarse and pixelated outcome. The reference paper appeared blurred, and the overall point cloud was very grainy, with acceptable quality only within a radius of about 5m. This setting is not recommended for use in normal conditions or standard projects.

Indoor HDR: Colors were superior to the 10 m far setting, with significantly greater depth and improved readability in low-light areas. The scanning time was long, and the file size was very large at approximately 1GB. The reference paper was clearly readable, and the overall point cloud quality was high.

Outdoor 20m far: The quality and color were slightly better than in the 10 m far setting. The scanning time was long, and the reference was clearly readable. The point cloud remained highly accurate even at long distances. The results were comparable to indoor HDR, with a bit weaker colors. This setting offers a high-quality outcome, but the long scanning time reduces efficiency.

Outdoor HDR: The point cloud quality was excellent, with accurate and rich color representation as can be seen in Figure 10 and in Figure 11. The quality remained high even in low-light conditions, and the reference paper was sharply visible. The main drawback was the scanning time and the file size of approximately 1.5GB.

Fast 1 (Custom): The overall quality was coarse, and the reference paper appeared blurred. While the result was acceptable in relation to the short scanning time, the point cloud was grainy and the colors appeared dark and muted. This setting is not recommended for use. The speed setting reduced the scanning time slightly.

Fast 2 (Custom): The quality was coarse, similar to the previous custom setting, but the scanning time was slightly shorter than with the indoor 10m close profile. Colors and point cloud structure were acceptable considering the reduced time, with reasonable quality within a 5 m radius. Beyond that distance the data appeared blurry, and the reference paper was also a bit unclear.

Figure 10. Indoor scan with Outdoor HDR setting.

Figure 11. Indoor scan with Outdoor HDR setting from other point of view.

3.4.2 Outdoor

Outdoor 20m: The scan captured almost the entire side of the building. From this distance, the point cloud quality was adequate, but the colors and structural details appeared slightly rough. Reference paper was visible but appeared blurry.

Outdoor 20m far: The point cloud quality was acceptable, producing a clearer overall result in which the building was well captured as a continuous point cloud. The reference paper appeared sharper compared to the outdoor 20 m setting, and the colors were slightly improved.

Outdoor HDR: The point cloud quality was comparable to the outdoor 20 m far setting, but with significantly better colors. The reference paper was clearly readable. This profile is particularly suitable in situations where color accuracy is important, or the weather conditions are challenging.

Fast 1 (Custom): The point cloud quality was acceptable, but the images were completely overexposed, rendering the entire wall white. The reference paper was not visible at all. The speed setting which shortens the exposure time was not useful for this profile.

Fast 2 (Custom): The point cloud quality was poor and overexposed, with the automatic motion removal reducing the number of captured points significantly, even on the walls. The data was unusable, and the reference paper was not distinguishable.

When importing the outdoor scans, it became immediately clear that the automatic motion removal had eliminated almost all vegetation near the building, and it can be seen in Figure 12. This feature is typically intended to filter out moving objects such as people, vehicles and also vegetation. In this case, removing the plants was actually a positive 'issue,' as only the building remained visible in the scans. This was beneficial since the vegetation was not needed, and the file size was significantly reduced. It was observed that with lower quality settings the number of points decreased approximately 30% and with higher quality the reduction was around 60%.

Figure 12. Outdoor scan point cloud.

3.4.3 Comparison table

An Excel comparison table was created to provide a simple overview of all profiles and their settings. The table includes the number of points in millions, file sizes in megabytes, and scanning times in minutes. The final column records the quality of the reference paper. The table was designed to be simple to make comparison easier and to support the overall analysis.

The raw data size of the 12 scans amounted to 2.22GB, which provides an indication of the expected scale of raw data in larger scanning projects involving tens of scan positions. This underlines the importance of considering both storage capacity and processing performance when planning extensive scanning projects. Table 5 presents the outcomes of the comparison, where both time and quality were considered.

Table 5. Scan profile comparison table.

INDOOR TEST	Resolution	Quality	Points (million)	File size (MB)	Scan time (min)	Ref. paper
Indoor 10 far	1/5	4x	20.51	664	7	3
Indoor 10 close	1/8	3x	7.61	293	4	4
Indoor HDR	1/5	4x	20.51	1060	10	2
Outdoor 20m far	1/4	4x	32.61	980	10	2
Outdoor HDR	1/4	4x	32.61	1580	11	1
Fast 1	1/5	2x + speed	7.50	295	3	5
Fast 2	1/8	2x	7.50	295	3	4
OUTDOOR TEST						
Outdoor 20m	1/5	4x	6.51	358	7	3
Outdoor 20m far	1/4	4x	10.52	524	10	2
Outdoor HDR	1/4	4x	10.53	1180	12	1
Fast 1	1/5	2x	6.47	315	4	4
Fast 2	1/8	2x	2.36	173	3	5

3.5 Scanner profile selection

The selection of scanning profiles was based on the results of the testing. The final selection of recommended profiles is shown in Table 6.

Table 6. Profile selection.

	Purpose	Resolution	Quality	HDR	Time
Outdoor 20m close	Regular	1/5	4x	-	07:49
Outdoor 20m Far	High quality	1/4	4x	-	10:24
Outdoor HDR	High quality + Wide range of colors	1/4	4x	3x	12:44
Fast (Custom)	In case time is concern	1/8	4x	-	04:23

For general indoor and outdoor use, the Outdoor 20 m close profile is recommended. With a scanning time of under 8 minutes, it provides stable quality and a sufficient number of points. The Outdoor 20 m far profile can be applied when more detailed capture is required, as it offers higher resolution than the close setting, with a scanning time of just over 10 minutes. In cases where weather conditions are challenging or when capturing accurate color data is a priority, the Outdoor HDR profile can be applied. Using HDR 3x ensures high-quality colors and precise results, even though the scanning time increases more than 12 minutes. The fourth standard option, a custom profile was developed where the resolution was reduced to shorten the scanning time, while quality was kept at 4x to maintain reliable color reproduction. With a scanning time of around 4 minutes, this profile can be used in situations where scans need to be performed quickly, for example to generate extra registration points.

Together, these three profiles plus one custom profile provide a balanced set of options that can be used to carry out the majority of scanning projects. They enable scans to be performed with consistently high quality while keeping scanning times reasonable, ensuring both technical reliability and efficient use of resources in future projects.

4 Expert interviews

This chapter is for expert interviews which was chosen as a research method for this thesis. It begins by introducing the semi-structured interview as the primary data collection method. The following sections present the collected interview material, include the researcher's own contribution, and summarize the key point that emerged from the interviews.

4.1 Interview method and material

A semi-structured interview, or themed interview, is a qualitative data collection method where the interviewer follows the predetermined set of questions but also allows room for open discussion (Hirsjärvi & Hurme, 2001). It allows all participants to respond to the same core questions while also enabling the discussion to expand into other relevant perspectives related to the topic.

Five experts were interviewed, and each of them has been involved in the 3D scanning process in different ways or has used point cloud data in their work. The semi-structured interview included a set of open-ended questions designed to explore the participants' experiences with 3D scanning and the use of point cloud data in their work. The questions focused on topics such as workflow, challenges, benefits, and development suggestions. The full list of questions can be found in Appendix 1.

The interview questions were prepared in advance and distributed to the participants prior to the actual interview sessions. This gave them the opportunity to prepare and reflect on their responses beforehand. The interviews were conducted in a shared discussion format, either in person or via Microsoft Teams, during which the questions were addressed systematically one by one. The conversation progressed in a free-form manner, and both the participants' actual responses and additional observations that emerged during the discussion were recorded.

4.1.1 Interviewee 1

A senior design engineer with over 20 years of experience in the field shared insights on the use of point clouds in daily engineering tasks, particularly in pipe modeling. According to the interviewee, point clouds provide a significant advantage when modeling both existing and new piping systems or modules. One of the key benefits is the ability to measure space reservations directly in a digital environment, which offers far more information than traditional tools like measuring tapes and photographs. This leads to improved accuracy and efficiency in the design process.

The use of point clouds also comes with challenges. The engineer noted that point clouds often contain ghost points and reflections that have not been properly cleaned or filtered out, resulting in messy or unclear models. There have been instances where scans were corrupted, leading to missing sections in the final point cloud data.

In terms of development, the interviewee emphasized the need for higher quality scan results and suggested that 3D scanning should be used more extensively in existing projects. Utilizing point clouds from the beginning can significantly accelerate the design of new components, making the overall process faster and more reliable.
The interviewee also gave an example from a local project, where the design team had to revisit the site multiple times to take additional photographs and measurements because certain details were not documented during the initial visit. According to the engineer, using 3D scanning in that case would have saved several working hours that were otherwise spent on travelling and manual measuring.

4.1.2 Interviewee 2

A senior design engineer with over 15 years of experience has been actively involved in several 3D scanning projects from start to finish as part of a dedicated scanning team. Based on this experience, the interviewee sees significant potential in further integrating

3D scanning into the design process, while also highlighting several areas for development.

One of the key issues raised is the limited access to design software, such as Navisworks and E3D. This lack of access prevents certain team members from reviewing completed point clouds effectively. The interviewee noted that having access to these tools would improve the overall workflow, particularly during the early stages of project planning and design. To support broader adoption, local training could be offered to both the design team and other employees who are interested in learning how to utilize point clouds more effectively.

According to the interviewee, more scanning projects should be initiated, and 3D scanning should be treated as a standard part of project budgeting rather than offered as an optional service. He emphasized that the use of 3D scanning should begin as early as the offer or tendering phase, especially in projects where little or no initial site data is available. This would enable more accurate cost estimation and better-informed planning decisions from the outset.

The interviewee also pointed out that overall awareness of the benefits of 3D scanning is currently insufficient among designers. As a recommendation, he suggests that 3D scanning should be required as input data for all projects involving structures that are more than five years old, particularly when modifications or additions are planned. This would ensure that design work is based on current and reliable information.

In addition to improving efficiency, the use of point clouds significantly enhances the quality of design. Existing models are often outdated or inaccurate due to undocumented changes and deviations from the original plans. By basing new designs on accurate and up-to-date scan data, such issues can be identified and addressed early in the process, reducing the risk of errors later in the project.

The interviewee clearly advocates for the broader adoption of 3D scanning in design work and actively promotes its benefits within the organization. He considers 3D scanning not only as a tool for improving accuracy and efficiency but also as a strategic asset that should be fully integrated into standard project workflows.

4.1.3 Interviewee 3

A senior design engineer with six years of industry experience, including four years working directly with 3D scanning and point cloud management, shared detailed insights into the practical use of these technologies in engineering projects. According to the interviewee, the overall efficiency of 3D scanning depends greatly on several factors, including the scope of work, the on-site conditions, and the type of scanning equipment used.

For instance, if a coordinate system is not required, the process can be relatively straightforward: the scanning can be done on site and the data registered later in the office. However, if a coordinating system must be used, additional preparation works such as creating or measuring GPD tags may be needed before scanning begins. Similarly, the required level of accuracy significantly influences the equipment choice and the scanning strategy. High-accuracy projects typically require terrestrial scanners, and in environments where access is limited, the number of necessary scan positions can increase dramatically. This, in turn, reduces the overall efficiency of the process.

In terms of reliability, the interviewee reported that terrestrial scanners used for their purposes consistently deliver high accuracy, even in challenging conditions involving vibrations or background noise. For most objects within a few meters, millimeter-level precision can be expected. However, for very small components less than 10 centimeters in size, other types of scanners might be more suitable. The interviewee also emphasized the importance of correcting rotation and tilt, especially in scans covering vertical distances of 10 to 15 meters or more, or when extremely precise alignment is required.

From a functional perspective, one of the most important benefits of using point clouds is the ability to visualize how new components, such as pumps or tanks, fit into existing layouts. This allows for better planning of modifications, including pipe rerouting and platform design, and ensures that there is enough space for future maintenance activities.

While challenges in scanning vary by project, common bottlenecks include issues such as poor accessibility, limited lighting, vibrations, water vapor, and time constraints. However, the interviewee pointed out that with proper planning, most of these challenges can be overcome effectively.

Regarding software compatibility, point clouds can be used in most 3D engineering programs. If native support is not available, the data can still be combined with 3D models in common viewing platforms such as Navisworks or Encore. According to the interviewee, the quality of point clouds is generally sufficient for a wide range of applications, from entire buildings spanning several hundred meters to small components requiring high-detail modelling.

The interviewee sees several key areas for improvement in the current 3D scanning workflow. These include selecting the right scanning equipment for each project, improving the planning and data cleaning processes, and advancing the transition from point clouds to mesh models. In addition, there is a need for increased education, both within the scanning team and in departments such as sales, to raise awareness of what 3D scanning can offer.

Looking ahead, the interviewee believes that 3D scanning and point cloud data should be utilized in all engineering projects. He emphasizes that widespread adoption across all phases of design and planning would significantly enhance both project efficiency and the accuracy of engineering outcomes.

4.1.4 Interviewee 4

A chief design engineer with over seven years of experience shared his views on the current state and future development of 3D scanning and point cloud utilization in engineering design. The interviewee has both theoretical and practical experience with 3D scanning. Earlier in his career, he used point clouds for positioning in Navisworks and for direct pipe modelling in E3D. In his current role, he supervises point cloud work and 3D modelling, and he has also managed customer-specific requests related to scanning projects.

When describing the current 3D scanning process, the interviewee highlighted both strengths and shortcomings. While scan quality is generally considered sufficient for most modelling purposes, quality issues and poorly defined customer requirements are frequently encountered. Scans often contain blind spots or lack key components, typically due to time constraints or insufficient planning. These issues occasionally lead to repeated site visits for manual measurements or re-scanning, resulting in avoidable inefficiencies.

Despite these challenges, the interviewee sees significant benefits in using point clouds, particularly in brownfield projects involving existing plants. Point clouds allow designers to attach new components directly to existing infrastructure, even when accurate models are unavailable. They also offer notable time savings during reference modelling. In as-built projects, point clouds support precise model updates and enable designers to perform verification checks, ensuring alignment with the actual physical conditions. Additionally, they are valuable for reopening older projects, as they help identify space constraints and undocumented changes resulting from equipment replacements or plant modifications over time.

The interviewee noted that although point clouds can be used in most design software, their practical application varies. In E3D, working with point clouds can be slow, especially when precise alignment is needed. Locating individual components often requires manual rotation of the model from multiple angles. In contrast, programs like Navisworks are better suited for visualizing mesh and graphical data, offering smoother handling of point cloud information.

Regarding quality, the interviewee confirmed that point clouds are generally sufficient for a wide range of uses, provided that the scanning is conducted with the right setup and an adequate number of scan points. However, there is considerable room for improvement in current workflows and tools. Suggestions include standardizing working methods for different environments (such as indoor, outdoor, cramped, or open spaces), developing clear usage guides, improving tool efficiency for post-processing, and evaluating whether current viewing platforms like Navisworks or Encore are optimal. He also mentioned the potential of automated object generation for space reservation, though current solutions are often prohibitively expensive.

The interviewee emphasized that internal awareness of 3D scanning remains low within the organization, both in terms of its potential and in understanding when it should be offered to clients. He advocates for broader accessibility of scanning tools and knowledge across teams and regions within the company.

Looking toward the future, the interviewee envisions an ideal situation where 3D scans are consistently available for all brownfield and as-built projects. This would enable designers to connect new structures accurately to existing ones and perform effective clash checks. In his view, this would significantly improve design quality, efficiency, and the overall coordination of engineering work.

4.1.5 Interviewee 5

A systems engineer with over eight years of experience in various engineering roles, most of which as a design engineer, provided valuable insights into the practical use and development needs of 3D scanning and point cloud management. The interviewee has both academic and professional background in 3D scanning, having studied it at university and participated in several scanning projects abroad as part of the company's 3D scanning team.

According to the interviewee, the Finnish team is still in the early stages of gaining proficiency in 3D scanning workflows, which affects both travel planning and the efficiency of scan processing. One of the key challenges is ensuring that enough scan data is collected on site. To mitigate the risk of scan failures or corrupted files, extra scanning points and sufficient overlap between scans should be ensured. If overlap is lacking, the process of stitching the point cloud together becomes slow and error prone. The large file sizes also pose challenges in terms of handling and sharing the data efficiently.

Reliable time estimates for scanning projects are currently difficult to provide due to limited experience. The interviewee emphasized the need for improved planning before arriving on site. This includes identifying the exact areas to be scanned, preparing scanning clusters in advance, and reviewing all available materials such as existing drawings and satellite images. It is recommended to allocate one or two extra working days during site visits. One day should be reserved for performing additional scans if needed, and another for verifying scan quality and beginning the initial processing. In the case of remote sites, this verification could also be done locally before leaving the location.

The main strength of point clouds, according to the interviewee, lies in their ability to provide accurate and comprehensive digital representations of existing facilities, particularly in older service projects where drawings may be outdated or entirely missing. In such cases, 3D scanning is often the only way to obtain a reliable basis for new design work. Traditional methods such as manual measurements and photographs cannot match the level of accuracy required for precise integration with existing systems.

Regarding software compatibility, the interviewee noted that point clouds can be utilized in most used engineering tools. Navisworks Manage is effective for viewing and manipulating point cloud files, and it allows merging and transforming multiple scans. Point cloud files can also be used as references in AutoCAD, and support is available in both E3D and Revit. Therefore, point clouds can be integrated into most design environments as needed. In terms of quality, the data is generally more than sufficient for use in design tasks involving modifications to existing structures. Point density and precision can be adjusted based on project needs, and the results are typically accurate enough for high-quality design work.

There are several areas where the interviewee sees room for improvement. These include building internal expertise in software such as Faro Scene and Autodesk Recap to reduce processing time and errors. Additionally, the scanning process on site should be made more systematic. For example, by predefining clusters during scanning, post-processing can be significantly streamlined. Increased collaboration and training from more experienced teams, such as the one in Sweden, would also help improve overall efficiency and consistency.

The interviewee also observed that awareness of 3D scanning activities within the company is still limited, likely because relatively few projects have included scanning so far. However, most engineers working with plant-related projects have encountered point clouds at some point, usually provided by external consultants, and therefore generally understand their value.

In the future, 3D scanning should be prioritized especially in service projects, where the benefit is greatest. Accurate modelling of existing facilities enables reliable design work and helps avoid clashes or misalignments. The interviewee emphasized that manual methods cannot match the precision achieved through scanning, especially in complex or undocumented environments.

As additional development ideas, the interviewee noted that vibrations in areas such as engine halls, particularly when scanning from elevated platforms, can negatively affect scan quality. Solutions such as vibration-dampening tripods could help address this issue.

Finally, standardizing the on-site scanning process through detailed checklists and ensuring that safety procedures are always followed were highlighted as practical steps to improve reliability and professionalism in scanning operations.

4.2 Personal contribution

My role at the company spanned two years as a design engineer, during which time my work was closely tied to the 3D scanning team. My experience covers the entire scanning workflow, from practical scanning tasks and theoretical understanding to data processing, cleaning, and finalizing point cloud files.

The division of responsibilities within the scanning team was typically arranged so that a expert handled the data import and registration into a unified model, after which my tasks included cleaning the data, placing it accurately, and submitting the finalized point cloud file to the administrator responsible for integrating it into the 3D model environment in E3D.

Point cloud data, both from my own scans and those produced by others, was regularly used in my daily work, which focused on piping design. The idea for this thesis also partially originated from my initiative, as the company recognized the need for internal documentation and clearer guidelines to support future processes. Since my employment at the company has ended, ensuring the transfer and preservation of this knowledge became an important motivation behind the thesis.

The scanning process has been developed collaboratively by the team, although no clear or standardized procedure has been formally established. As 3D scanning was a new addition to the company’s operations, efforts were made to develop the process as effectively as possible through practical experience. Since scanning projects have been relatively limited in number, each project has served as a learning opportunity to refine the workflow and gain insights for future improvements.

Challenges have arisen during the process, but they have also been successfully resolved. The current scanning device does not allow for on-site verification of whether all scan points have been successfully captured. This can only be confirmed later at the office. Some members of the team have performed scanning work abroad, but it has not always been possible to review the files at the hotel due to scheduling constraints or limited internet access.

Overall, the quality of the scans has been sufficient, but more attention should be paid to the placement and number of scan points to increase overlap. This would also help mitigate the impact of corrupted files by reducing the risk of blind spots in the scanned area.

My work has included modeling piping systems based solely on scan data, as well as modifying existing project models using point clouds. In one of the most recent projects, certain pipe runs had been “corrected” based on photographs and manual measurements, but despite these efforts, the pipes in the model were still misaligned by approximately 150 mm. With the help of the point cloud, adjusting the piping was straightforward. The only significant challenge was the limited number of scan points, which slightly slowed down the modeling process.

This was an as-built project, where the piping had been roughly designed beforehand, but was installed on site in a way that made practical sense during construction. The point cloud was used to adjust the model according to the actual installation. Although site visits were not part of my responsibilities in this case, all necessary modifications were completed successfully using only the point cloud. This advantage was also noted by several interview participants, who pointed out that the ability to work remotely with point cloud data is a major benefit in older or undocumented projects.

One of the main challenges from my perspective has been the limited number of scanning projects, which makes learning through hands-on experience less effective. In some earlier cases, certain working methods proved to be successful, but because they were not documented, those practices were forgotten by the time the next similar project came along. Sometimes this occurred several months later or even after half a year. One of the aims of this thesis is therefore to help establish a functional handbook for the scanning team to support continuity and consistency.

Another challenge has been the lack of available expertise within the company, which has made it difficult to obtain support when needed. While valuable assistance has been received from the Swedish team, the nature of their projects often differs from those handled by the Finnish team, which limits direct applicability.

Expanding the size of the scanning team would also help to avoid resource bottlenecks. In addition, planning the scanning process for brownfield projects has presented its own difficulties. When existing layout data or other reference information is missing, rough estimations must be made during the quotation and planning phase. This must be done carefully to avoid exceeding the budget, making the situation a double-edged sword.

In domestic projects within Finland, travel costs are generally not a major issue. However, when traveling abroad, the trip must be carefully planned in advance. There is rarely room in the schedule for extra days, even though it would always be advisable to include some buffer time for unexpected delays.

Based on my experience, the software used in the workflow performs reliably. Sharing point cloud data with other stakeholders is straightforward, and Navisworks is commonly used for reviewing point clouds due to its ease of use and ability to visualize both point clouds and 3D models effectively.

One of the development goals of this thesis is to establish a clear way of working and define scanner settings that help streamline both the scanning process and the planning phase. Setting realistic daily scanning targets is essential, as transferring data to a computer after scanning can take several additional hours and must be considered when planning project schedules.

4.3 Summary of Interviews

The expert interviews conducted for this thesis provided valuable insights into the current use, challenges, and development needs related to 3D scanning and point cloud data in engineering design projects. The interviewees, who represented a range of roles from senior design engineers to systems and chief design engineers, shared both practical and strategic perspectives based on their experience in real-world projects.

A shared understanding emerged regarding the usefulness of 3D scanning, particularly in brownfield and as-built projects where up-to-date reference data is often unavailable. Point cloud data allows for the accurate integration of new structures into existing environments, early detection of potential clashes, and reduced reliance on outdated documentation. These strengths were consistently highlighted across interviews and are also reflected in my own experience. In one recent project, the point cloud enabled me to correct major inaccuracies caused by traditional measurement methods, even without visiting the site in person.

At the same time, the interviews revealed recurring challenges in both planning and execution. Participants reported that incomplete scans, poor initial coordination, and unclear customer expectations often led to errors or delays. In several cases, missing scan data resulted in costly return visits. Similar challenges were also evident in my own work, where scan completeness could only be verified afterward at the office. The inability to check scan coverage on-site was seen as a significant limitation in both the interviews and my own experience.

Lack of internal expertise in scanning practices and software was another common subject. Many participants noted that project teams still lack experience in planning and executing scans, and in processing data using tools such as Faro Scene and Autodesk

Recap. While external support was sometimes available, particularly from the Swedish team, differences in project types and working practices often limited the direct applicability of their methods. This issue also surfaced in my own projects, where the absence of clearly defined roles and limited prior knowledge within the team made implementation more difficult.

Regarding software usability, interviewees reported mixed experiences. Although point cloud data can be used in tools such as E3D, AutoCAD, Revit, and Navisworks, not all platforms offer the same level of usability. Navisworks was widely recommended for reviewing point clouds due to its intuitive interface and strong visualization capabilities. This aligns with my own practice, where Navisworks proved to be the most efficient tool for communicating spatial information across the team.

Another issue identified in the interviews was the lack of documentation. Several participants stated that valuable working methods were developed during projects but often forgotten or lost between assignments. This concern is familiar from my own work as well, where useful practices were not retained or shared. One of the main goals of this thesis is to help address this problem by supporting the creation of consistent internal guidelines and scanning workflows.

Many participants also emphasized that 3D scanning should be included in project planning and budgeting from the start, rather than treated as an optional addition. They stressed the importance of early-phase preparation, including checking available reference materials, setting scanning targets, and allocating time for data handling and verification. From my perspective, this planning phase is essential, especially since scanning generates a large amount of data that requires time and attention after fieldwork. Without realistic planning, post-processing can cause delays, even if the scanning itself proceeds on schedule.

The interviews and my own experience show strong agreement on both the benefits and challenges of 3D scanning in engineering projects. While technology offers clear advantages in terms of accuracy, efficiency, and adaptability, its successful application requires better planning, clearer internal processes, and stronger knowledge sharing. With targeted development and internal investment, 3D scanning can become a routine and reliable part of the design workflow.

5 Results from pre-tests and interviews

This chapter presents the main findings of the thesis, and the results are divided into two parts: Pre-tests with the Faro Focus S350 scanner, and insights gathered through semi-structured interviews. These findings form the basis for the development of internal company guidelines.

5.1 Pre-test results

A series of test scans were taken to evaluate both predefined and custom scanner profiles. The tests were performed in indoor and outdoor environments, with variations in resolution, quality settings, HDR use and Speed setting.

The quality of each scan was analyzed visually in Faro Scene and Autodesk Recap. The evaluation criteria included point cloud density and clarity, color representation, file size, scanning time, and readability of the reference target paper. Observations were systematically recorded in an Excel table, which was also used as a support tool in scanning profile selection.

The pre-tests showed that the scan quality setting should always be set to at least 3x, and preferably 4x, as lower settings consistently resulted in overexposure, especially in outdoor conditions. HDR 2x or 3x was found to be highly effective in challenging lighting conditions, producing stable colors and clear point clouds in both bright and darker indoor corners.

The results also highlighted the balance between resolution and efficiency. Higher resolution profiles produced more detailed point clouds but significantly increased file sizes and scan durations. Lower resolution profiles shortened scanning time but often resulted in grainy or overexposured outputs that were not suitable for engineering use. HDR settings improved color depth but came with large file sizes. For the company, it is more practical in large-scale projects to scan the most critical areas at higher quality, while using moderate settings for the rest of the environment, as this ensures both efficiency and sufficient accuracy for design purposes.

Based on this evaluation, four profiles were selected as standard configurations for future projects:

- Outdoor 20m Close – 1/5 Resolution, 4x Quality
- Outdoor 20m Far – 1/4 Resolution, 4x Quality
- Outdoor HDR – 1/4 Resolution, 4x Quality, 3x HDR
- Custom Fast – 1/8 Resolution, 4x Quality

These profiles provide a practical balance between quality and efficiency, making them suitable for the company's project conditions.

5.2 Interview results

The interviews with experts provided both practical and strategic perspectives on the use of 3D scanning and point clouds.

Benefits:

- Strong value in brownfield projects where up-to-date documentation is lacking.
- Establishing a long-term digital reference for future modifications or expansions.
- Early clash detection and improved coordination between different engineering disciplines.
- The ability to create reliable as-built reference data, reducing the risk of dimensional errors.

Challenges:

- Corrupted scan files in several projects in the past, the reason for this is still a mystery
- Limited internal expertise in processing tools such as Faro Scene and Autodesk Recap.

- Vibrations in the engine room can affect the scanner during prolonged scan durations and may potentially degrade the final scan quality
- Overlap between scan points was emphasized as crucial to ensure reliable registration and to avoid coverage gaps.

Development:

- 3D scanning should be included in project planning and sales phases rather than treated as an optional addition.
- More structured documentation and knowledge sharing are required to retain good practices between projects.
- Internal training and closer collaboration with experienced team in Sweden would strengthen the competence.

The interviews confirmed that 3D scanning is a powerful tool when properly planned and executed. Its value lies not only in reducing errors and rework but also in supporting collaboration and long-term project documentation.

6 Development of company guidelines

This chapter describes the development of the internal company guidelines for 3D scanning. The complete guideline document is confidential and intended solely for internal company use. This chapter presents the reasons for creating the guidelines, the method used in their development, and their overall structure.

6.1 Purpose of the guidelines

The purpose of the guidelines is to establish a standardized approach to 3D scanning that can be applied consistently across all projects. Without clear instructions, scanning practices may vary between operators, leading to differences in data quality, a higher risk of errors and longer post-processing times. The guidelines aim to eliminate this variation by defining a common workflow that ensures reliable and repeatable results.

Another important objective is to clarify the scanning process for employees throughout the company. While many are familiar with the concept of 3D scanning, fewer understand in detail how the process is carried out, what equipment and settings are required, and how the data is ultimately used in design. By describing the workflow step by step, the guidelines raise overall awareness of how scanning supports projects and how each phase contributes to the outcome. The guidelines are based on the Faro Focus S350 currently in use, but their principles have been defined to remain valid if the company upgrades to a newer scanner model in the future.

The guidelines also serve a practical role in project execution. They provide clear instruction for equipment setup, project planning, on-site scanning, and data handling, making the process more predictable and easier to manage. This reduces the need for repeated site visits and helps optimize both scheduling and resource allocation.

The guidelines are intended for use by all employees involved in scanning projects, regardless of their level of experience. For new team members, they provide step by step instructions that shorten the learning curve while for experienced users they serve as a reference that helps maintain standardized practices across the company.

6.2 Development method

The development of the company guidelines was based on a combination of literature, manufacturer documentation, PSK standards, experimental testing and practical experience from both experts and the researcher. This approach ensures that the final document is not only technically accurate but also directly applicable to the company's daily work.

The process began with a review of the manufacturer's documentation, which provides technical descriptions of device settings and best practice recommendations. These materials together with relevant PSK standards gave the theoretical foundation for understanding how parameters such as resolution, quality and color capture affect the outcome. Prior experience with the scanner in earlier projects provided an additional practical basis, helping to interpret the documentation and adapt it to the company's specific needs.

Further insights were gained through experimental testing of the scanner settings. Both indoor and outdoor environments were used to evaluate the performance of predefined and custom profiles. The tests analyzed point cloud quality, color representation and scan time duration under different conditions. The results made it possible to identify the most suitable settings for common project scenarios and to optimize standard profiles for future use.

Discussions with experts provided valuable input, particularly by highlighting common challenges such as incomplete scans, coordination issues and limited internal expertise. This feedback ensured that the guidelines reflect actual project needs while remaining clear and straightforward to apply.

6.3 Guideline structure and benefits

The company guidelines are organized to follow the typical workflow of a scanning project. They begin with an Introduction, which explains the purpose and scope of the document.

Equipment and Settings Overview presents the scanner hardware, its main settings, and the standard profiles defined for company projects, ensuring that operators know which configurations to apply in different situations.

Planning a Scanning Project provides instructions for preparing fieldwork. It includes guidance on estimating the number of scan positions, dividing large areas into regions and subregions, and managing logistics such as travel and accommodation in international projects.

Data Handling and Storage explains how raw data should be transferred, organized, registered, and post processed to meet customer requirements and deliverables.

Storing Point Cloud Data defines long-term data management practices, including storage locations, responsibilities for maintaining access, and ensuring traceability and deliverables.

Useful Links offers quick access to manufacturers' documentation, internal templates, and other resources that support project execution.

The step-by-step workflow improves efficiency, reduces the need for repeated site visits, and ensures reliable outcomes. Documented practices support knowledge sharing, making it easier to train new team members and for experienced operators to maintain uniform standards. The guidelines also provide clear overview of the entire scanning process, enabling both operators and stakeholders to understand how each phase contributes to projects success.

7 Conclusions

This thesis demonstrates that 3D scanning provides benefits for industrial projects, particularly in brownfield environments where up-to-date documentation is often missing. By producing reliable as-built reference data, scanning enables new components to be integrated with reduced risk of dimensional errors. The technology also supports early clash detection and better coordination between engineering disciplines, while simultaneously establishing a digital reference that can be used for future modifications or expansions.

Despite the benefits, several challenges remain. In earlier projects, corrupted scan files have occurred, although the root cause is still unknown. Internal expertise in data processing tools such as Faro Scene and Autodesk Recap is limited, which increases dependence on a few specialists. Interview feedback also revealed that vibrations in engine rooms can affect scanning by prolonging the scan time and by degrading the final point cloud. Another recurring issue was the importance of overlap between scan positions, which is critical for reliable registration and for avoiding corrupted files.

The development of internal company guidelines addressed many of these issues by defining standardized workflows for equipment use, project planning, data handling and storage. These guidelines ensure consistent quality, support onboarding of new team members, and reduce the risk of repeated site visits. Testing confirmed a limited number of optimized profiles that balance data quality and scanning time, making them suitable for most project conditions.

For future development, 3D scanning should be systematically integrated into both project planning and sales phase rather than considered an optional addition. Expanding internal training and strengthening collaboration with the experienced team in Sweden will enhance competence and ensure that 3D scanning becomes a reliable and efficient tool in the company’s daily operations.

8 Summary

The thesis was carried out at the request of Cyient Oy, to support execution of power plant projects. Its objective was to study the role of 3D scanning in engineering design and to develop standardized internal guidelines for its use.

The research combined pre-tests with the Faro Focus S350 scanner and semi-structured interviews with five experts. The tests provided practical insight into the performance of predefined and custom profiles under different conditions, while the interviews revealed the current strengths, challenges and development needs of scanning practices. These results formed the basis for creating clear and structured company guidelines.

The guidelines define step-by-step workflow covering equipment setup, project planning, scanning execution, and data management. They help ensure consistent quality, reduce rework, and improve knowledge sharing within the company. By adopting these practices, 3D scanning can be used more systematically to support design projects.

The results show that with the right profiles, structured workflows and stronger expertise, the benefits of 3D scanning can be reinforced by making it a reliable and efficient tool for the company.

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Appendices

Appendix 1. Interview Questions

Interview Questions

1. Background info
- Role and work experience
- Experience with 3D scanning/point cloud usage

2. User experience
- How would you describe the current 3D scanning process (efficiency, reliability, etc.)
- What are the biggest strengths/benefits of using a point cloud?
- What are the biggest challenges/bottlenecks?

3. Processes and workflow
- How well can point clouds be utilized in our programs?
- Is the point cloud quality sufficient for different uses?

4. Development and Improvement Ideas
- Where do you see the most room for improvement in the current scanning process?
- Is there sufficient awareness of 3D scanning in the company?
- How should 3D scanning and point clouds be utilized in the future?
- Any other development ideas related to the topic?

5. Feedback

Data of this interview will be used anonymously in the finished thesis. Personal data and collected material will be treated confidentially and privacy will be considered.

Haastattelukysymykset

1. Taustatiedot

- Rooli ja työkokemus
- Kokemus 3D skannauksen/pistepilven käytöstä

2. Käyttökokemus

- Miten kuvailisit nykyistä 3D-skannausprosessia (tehokkuus, luotettavuus yms.)
- Mitkä ovat suurimmat vahvuudet/hyödyt pistepilven käytöstä
- Mitkä ovat suurimmat haasteet/pullonkaulat

3. Prosessit ja työnkulku

- Kuinka hyvin pistepilveä pystytään hyödyntämään ohjelmissa?
- Onko pistepilven tuottama tieto laadultaan riittävää eri käyttötarkoituksiin?

4. Kehitys- ja parannusehdotukset

- Missä näet eniten kehitettävää nykyisessä skannausprosessissa?
- Onko tietoisuus 3D skannaamisesta riittävää yrityksessä?
- Miten 3D skannausta ja pistepilveä tulisi hyödyntää tulevaisuudessa?
- Muita kehitysideoita aiheeseen liittyen?

5. Palaute

Tämän haastattelun aineistoa käytetään nimettömästi valmiissa opinnäytetyössä. Henkilötietoja ja kerättyä aineistoa käsitellään luottamuksellisesti ja yksityisyyden suojaa kunnioitetaan.