The use of 3D laser scanning technology in buildings archaeology:

the case of Måketorpsboden in Kulturen museum, Lund

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Master Thesis in Historical Archaeology

Spring 2013

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1. Abstract

This thesis is a project developed with Kulturen Museum in Lund for the documentation of a timber building from the end of the 18ᵗʰ century. The technology applied is 3D laser scanning. The project wanted to answer several theoretical questions through the study and to conduct a practical case analysis, which lead to the production of a 3D textured model of part of the building.

The work has been developed discussing in the beginning the state of the art of building archaeology, describing the different stages of study of buildings through history, from Renaissance to the seventeenth century and with an overlook of the approach of this discipline in the Nordic countries. Subsequently it has analysed the different kind of surveys for a proper archaeological building investigation: the direct survey and the indirect survey, explaining the differences and the technological innovation applied to this field especially during the last 20 years.

A detailed paragraph about method of building investigation with the most recent laser scanning technologies illustrates the "pros and cons" of the utilization of 3D laser scanning for archaeological purposes; specific case studies are described. A final comment about the rising problem of handling and storing of data coming from the utilization of those new technologies has been taken in consideration.

The last part of the paper is focused on the explanation of the background history of the typology of timber building I have been studying and the detailed explanation of all the steps done for the actual project, from the acquisition campaign to the post processing of the data. An analysis of the data I got from the creation of the model of a single room has been performed with the examination of the possibility of future developments of the same project.

Key words: 3D laser scanning, laser scanner, digital acquisition, buildings archaeology

2. Introduction

The last twenty years have seen an exponential development in the application of technology to the cultural heritage, especially for the protection, study and handling of archaeological sites and cultural landscapes[1]. The utilisation of such instruments with high performances increased the possibility to record an incredible large amount of data with such ease that a single operator can easily perform a survey alone in a short time.

This thesis investigates benefits and limits in the application of Laser scanning technology in the field of Building Archaeology. In specific this work is focused on the use of such instrument for documentation and analysis.

Documentation is one of the main duties of an archaeologist; the new technologies help to record, analyse and display research's results in such way that the perception of the archaeological data has changed for both scholars and the great public.

3. Research questions

In my work I will focus on the use of 3D laser scanning technology for the documentation of an historical building. The aim of this work is to understand in which way this new technology can be used in archaeology for interpreting and analysing historical buildings, how these data can affect the understanding of the building and in which way the production of this type of data can be used for sharing and communicating results to a broad public and museums.

The questions I am going to answer in my work, therefore, are:

- *How the introductions of digital technologies are changing the process of interpretation in archaeology?*
- *How the uses of different instruments of documentation are affecting the perception of archaeological material?*

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[1] Haddad, N. A. 2011. From ground surveying to 3D laser scanner: A review of techniques used for spatial documentation of historic sites. In *Journal of King Saud University – Engineering Sciences*, vol. 23, n. 2. P. 110. Available from: http://www.sciencedirect.com/science/article/pii/S1018363911000250 (20130524).

- *How researchers can use 3D documentation to a deeper understanding of an historical building?*
- *How the production of such type of documentation is affecting the public communication?*

I am going to study a historical wooden building from the end of the 18th century, owned by Kulturen Museum in Lund.

4. State of the art

Archaeology´s main tool for discovering information about the past is the excavation, but in reality the process, called the "irreversible process"[2] is not the only possibility we have for understanding and discovering the past; a huge amount of information can be extracted also from not buried features such as ancient buildings, houses and castles that are still standing in the landscape.

The study of buildings from an archaeological perspective is called "building archaeology" and it focuses on the analysis of still standing structures using different methodologies from the excavations, allowing us to record and understand the history of a building without destroying irreversibly the archaeological context we are analysing.

The interest for the study of ancient buildings has seen an interesting revival since the Renaissance, when descriptions of ancient monuments were done not only for a mere study, but was fundamental for planning the reuse of ancient marble and stones in new constructions such as villas and residences for the nobility and for the religious court[3]. The interest for the study and graphic recording of ancient monuments continues under the 17th century, even if the focus of the study were concentrated on more noble remains, not the peasant farms[4].

The discipline of building archaeology deals with several different research fields, for example history of art, history of architecture (for obvious reason it is strictly connected

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[2] Barker, P. 2003. *Tecniche dello scavo archeologico*. Milano. P. 27.
[3] Barker, G. 1999. *Companion Encyclopaedia of Archaeology*. Vol. 1. London. P. 8.
[4] Morris, R. 1994. Buildings Archaeology. In Wood, J. (ed.). *Buildings Archaeology – Applications in Practice*. Oxford. P. 14.

with it) and not least ethnology and cultural history. In Nordic countries, the discipline of building archaeology experienced several changes during its history. For example, in the 19th century the research about historical building was strictly connected with history of art studies; it was mainly their stylistic features that gave to the monument historical artistic value and importance. The prevalent aim for the study of ancient buildings at that time was, anyway, to achieve a convincing restoration of the monuments; for achieving this goal then, it was necessary to start studying the material, technique and style of the monuments[5]. Soon it was clear that studying just the stylistic features of a particular building was not enough to understand clearly the historical perspective. This lead to a crescent interest in studying even a building in an archaeological perspective, starting to look for disappeared parts of the building using archaeological excavations.

Not only art historians but even ethnologists played an important role in the recording and study of standing buildings, especially buildings in a farmer landscape. In Sweden, one of the most prominent figures that left a big amount of descriptions and drawings of cities, landscape and historical buildings was Nils Månsson Mandelgren. Born in Ingelsträde in Scania in the year 1813, he became an artist, antiquarian and teacher. He studied art in Stockholm and Copenhagen. From 1842 he undertook several journeys in Europe and Sweden. According to his own words, the main aim for these travels was "to learn more about the restoration of ruined and neglected piece of art"[6]. In 1846 he took intensive trips around Sweden as well, where he depicted in details churches and ancient monuments that lead to the publication of *Monuments scandinaves du moyen âge avec les peintures et autres ornements qui les décorent*, 1-5, 1855-62[7]. He was interested also in the study of material culture in a broader sense (*Samlingar till svenska konst- och odlingshistorien*, 1–2, 1866–68; *Atlas till Sveriges odlingshistoria*, 1–4, 1877–84)[8]. He recorded, described and drew huge amount of historical buildings and farmer buildings that allow us today to know how they looked. His contribution was extremely important for our understanding of buildings that are nowadays missing or heavily modified. Today,

[5] Eriksdotter, G. 1998. Byggnadsarkeologiska synsätt. In Eriksdotter, G., Gardelin, G. and Wallin, P. *Från byggnad till dokument: en byggnadsarkeologisk pilotstudie i Malmöhus län.* University of Lund. Institute of Archaeology, Report Series n. 61. Lund. Pp. 69-70.
[6] Jacobsson, B. 1983. *Nils Månsson Mandelgren: en resande konstnär i 1800-talets Sverige*. Lund. P. 11.
[7] Ibid, p. 18.
[8] Nils Månsson Mandelgren. *Nationalencyklopedin*. Available from: http://www.ne.se.ludwig.lub.lu.se/lang/nils-månsson-mandelgren (20130330).

Lund University own a huge collection of his pictures, drawings, watercolour and photographs[9].

Another interesting figure in the preservation of the knowledge of ancient building techniques is August Holmberg. Born in Blekinge in 1860, he became an interesting case of carpenter that worked also as "permanent informant" for the Nordiska Museet about the traditional techniques of building timber houses[10]. The Nordiska Museet started in 1928 a series of "survey" for recording tradition, especially the peasant culture, with the aid of questionnaires. The people interested were pushed to explain as much as possible all the details involved in building techniques and more generally all information connected with the traditional rural building culture. August Holmberg was one of the most prominent contributors to the recording of this kind of information, especially for the buildings located in the southern and western part of Sweden. His personal experience in the building techniques was learned from the father and his capability of drawing and describing gave to the museum a fundamental source of information about the building techniques of wooden edifices[11].

These kinds of sources are of valuable importance for us today, but they do not follow a strict archaeological methodology in the study of buildings. In the 1950-1960 we have the first important work about building archaeology in Sweden, considered as the "milestone" of the study of ancient buildings under an archaeological perspective. In Erik Cinthio´s dissertation *Lunds domkyrka under romansk tid* the analysis of the underground remains of the building is amalgamated with a building archaeological survey of the parts of edifice still standing[12].

A building archaeological survey has mainly two aims: to understand the history of a particular building and to preserve the building itself with its historical qualities as close as possible to the original[13]. It gives not only historical and archaeological information but also a basis for the decisions that they will eventually be taken for a restoration[14]. The documentation in a building archaeology survey must be planned according to the aim of

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[9] Jacobsson 1983. P. 214.
[10] Palmqvist, L., Sjömar, P. and Wall, M. (eds.). 2006. *August Holmbergs byggnadslära*. Stockholm. P. 6.
[11] Palmqvist and al. 2006. Pp. 38-42.
[12] Eriksdotter 1998. P. 70.
[13] Andersson, K. and Hildebrand, A. 1988. *Byggnadsarkeologisk undersökning: det murade huset*. Stockholm. P. 9.
[14] Wallin, P. 1998. Byggnadsdokumentationen och den antikvariska verksamheten. In Eriksdotter and al. 1998. P. 35.

the research. Generally the methods for the documentation comprehend archive studies (previous restorations, old pictures or drawings) and literature research about the building or the kind of building we are going to study. Depending of the aim of the survey, it is generally done a sketch of the building by hand under the first survey. Subsequently the archaeologist will measure carefully the parts of the building (façade, windows, any important feature that is going to be drawn) and reproduce it in scale on the paper. This way of recording buildings started during the Renaissance and continued to be used in architecture. During the 1970s these kinds of survey, called *direct survey*, enter as part of the teaching of archaeological methodology[15]. This method is the classic way of surveying an ancient building. There is also another survey method, the *indirect survey*, which allow us to measure the archaeological features with optical and mechanical instruments (and more recently informatics instruments) allowing us to transform complex calculations in a graphical result inside a specific coordinate system. The first mechanical aid to the survey was theodolites, which developed subsequently into the total station. Total station, first available around 1998, is an instrument that calculates the position in space of one point, knowing the distance and the angle of that point in respect to the device[16]. Practically it is an electronic theodolite with the ability of measuring distances using the EDM (Electromagnetic Distance Measurements)[17]. With developing of the technology archaeologists could use more precise instruments such as cameras. Close range photogrammetry is another important *indirect survey* method. Photogrammetry is, on the most basic definition, *the technique of measuring from photographs*[18]. This method is used mostly for the survey of façade or other plain surface, for example. It has been developed since the middle of the 19th century, with the progress of photography[19] and it continues to develop with the refining of the computer science. This method has been considered for a long time a sophisticated technology that needs a skilful trained operator[20].

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[15] Bianchini, M. 2008. *Manuale di rilievo e di documentazione digitale in archeologia*. Roma. P. 71.

[16] Warden, R. 2009. Towards a New Era of Cultural-Heritage Recording and Documentation. In *APT Bulletin*, vol. 40, n. 3/4. P.6.

[17] Bradley, M. 2005. Archaeological survey in a Digital world. In Evans, T. L. and Daly, P. (eds.). *Digital archaeology: bridging method and theory*. New York. P. 31.

[18] Fussell, A. 1982. Terrestrial Photogrammetry in Archaeology. In *World Archaeology*, vol. 14, n. 2. Pp. 157-172.

[19] Boehler, W. and Marbs, A. 2004. 3D scanning and Photogrammetry for heritage recording: a comparison. In *Proc. 12th Int. Conf. on Geoinformatics − Geospatial Information Research: Bridging the Pacific and Atlantic*. University of Gävle, Sweden, 7-9 June 2004. P. 294.

[20] Xiao, Y., Zhan, Q. and Pang, Q. 2007. 3D Data Acquisition by Terrestrial Laser Scanning for Protection of Historical Buildings. In *Wireless Communications, Networking and Mobile Computing, 2007*. WiCom 2007. International Conference on. 21-25 Sept. 2007. Pp. 5971- 5974.

With the increase of development of laser scanning technology the 3D laser scan starts to be used also in cultural heritage environment. Since the 1970 the laser scanner technology has been used in several industries (especially into the engineering field for reverse engineering but also for surveying industrial facilities and other equipment)[21] but its employment into cultural heritage projects has been started only from the second half of 1990s. One of the first experiments of the use of terrestrial laser scanner technology applied to cultural heritage is the scanning of the "Sala Ottagonale" in the Domus Aurea in Rome and the St. Giovanni´s Baptistery in Florence. This survey, done in the 1997, used a Quarryman MDL LaserAce time of flight scanner, which allowed registering up to 3600 point per hour[22]. In both cases it has been produced a Digital Surface Model (DSM). The conclusion of this survey was that *laser shows great possibilities in surveying* and *the instrument is suitable mainly for vaulted surfaces like cupolas, where traditional methods like photogrammetry are difficult and time consuming to use*[23]. This is one of the first attempts to use laser scanning technology so it is clear that the operators encountered a lot of difficulties, but it was shown already the potentiality of such survey method. The costs of this kind of equipment in the end of the 1990s was around 200.000 dollars, while today is decreased exponentially and a good terrestrial laser scanner can be bought for 40.000 dollars. Documenting a historical building with the "classical" methods of survey (drawing and measuring by hand and, later, using theodolites and total station) is a fundamental part of the interpretation and study of an historical and archaeological feature, central for subsequently decision concerning restoration and care. The technological develop of the last two decades allow us archaeologists to record and process a quantity of data that was impossible to handle before; in the specific case of the 3D laser scanner, the raw data that we get can be post- processed in several different ways depending on which kind of information we want to extract from the building itself. This kind of technology speeds up the acquisition campaign and give the possibility to always go back to the raw data in order to analyse different aspects of the same case. Moreover, the data we post-process from a 3D laser scanner survey can be used also to create 3D

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[21] Hughes, K. E. and Louden, E. I. 2005. Bridging the Gap: Using 3-D Laser Scanning in Historic-Building Documentation. In *APT Bulletin*, vol. 36, n. 2/3. P. 37.

[22] Fangi, G. and Nardinocchi, C. 1999. Experiences of Laser Autoscanning for Architecture: The Domus Aurea in Rome and the San Giovanni's Baptistery in Florence. In *Proceedings for CIPA International Symposium 1999*. Available from: http://cipa.icomos.org/fileadmin/template/doc/olinda/99c606.pdf (20133103).

[23] Ibid.

models for a better understanding of the feature from a broad public[24]. Technology helps research and promulgates knowledge to the public.

5. Method and theory

The last decades have seen an exponential increase in the utilization of technology in several fields, from entertaining to daily life. We are completely surrounded by technological devices that allow us to be connected with an infinite flow of information; internet, one of the biggest technological and, in my opinion, cultural revolutions in human history. This availability of knowledge has shaped the perception of the world around us, and the interaction between us, humans, and the environment. In all this, archaeology is not left to the side. The utilization of digital resources has entered even this field, bringing new ways to analyse and document the archaeological feature but, in the same time, to create and influence the theoretical approach to archaeological problems. *Digital archaeology* is the name of this new approach to archaeological research[25].

A new approach to a discipline brings up new problems, and new problems must be solved with new solutions[26]. The utilization of digital technologies to archaeology has divided the researchers in two main currents; the ones stating that digital archaeology is just a method for solving problems in the archaeological process, and the ones saying that actually digital archaeology is going to create or influence the creation of theoretical approach[27]. In my opinion both statements are true. Technology is a tool that can be used to increase the computing power and the processing of big amount of data in a way that was simply not possible until some years ago, but in the same time the digital tools allow us to study in a deepened way the artefacts, archaeological features and landscapes bringing up hidden information that are simply not visible to the naked eye. For example, the study of satellite remote sensing images (RADAR) combined with other techniques such as aerial photography and 3D modelling helps to understand and discover new features on large areas. The temple of Angkor Wat in Cambodia, for instance, has been

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[24] Hughes and al. 2005. P. 39.
[25] Evans, T. L. and Daly, P. 2005. Archaeological theory and digital pasts. In Evans and al. 2005. P. 2.
[26] Zubrow, E. B. W. 2010. From Archaeology to I-archaeology: cyberarchaeology, paradigms, and the end of the twentieth century. In Forte, M. (ed.). *Cyber-Archaeology*. Oxford. Pp. 1-2.
[27] Zubrow, E. B. W. 2005. Digital archaeology. A historical context. In Evans and al. 2005. P. 9.

surveyed with such technology. The analysis of the data revealed the extension of the archaeological area of the temple, which was much broader than previously thought, revealing an intricate network of artificial watering system, fields, canals that were completely hidden before[28] (figures 1-2).

Figure 1. Landsat image of Angkor Wat, Cambodia. Source: Parcak 2009. P. 152.
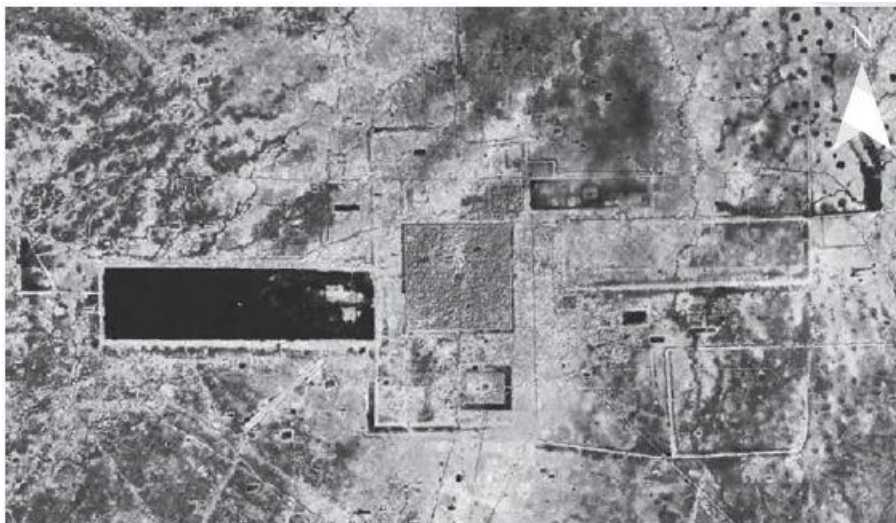

Figure 2. Landsat pseudocolor image of Angkor Wat, Cambodia. Source: Parcak 2009. P. 153.

The work I am going to present is the digital acquisition with 3D laser scanner of a timber gallery house from the end of the 18th century for the elaboration of a high resolute 3D model. The timber house, a storage building originally located in Småland, is now part of

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[28] Parcak, S. H. 2009. *Satellite remote sensing for archaeology*. London. Pp. 152-153.

the collection at Kulturen in Lund and it is located in the garden of the museum, along with other historical buildings from all over Sweden[29]. An acquisition campaign has been performed using a *phase shift laser scanner* and a virtual model, for the analysis and the documentation of the monument, has been realized.

3D scanning, which comprehends a series of different technologies is *a form of automatic measurements of geometric properties of objects*[30]. It allows creating a 3D model of a particular feature (historical building, archaeological artefact or even a big scale survey with LIDAR – SLR satellites) that can be transferred to other platforms for several purposes, from the computer aid restoration to the help of the process of analyse, interpretation and study of an archaeological feature to the display for the public.

Laser scanner is an instrument able to measure the position of thousands of points in the space that will define the surface of the scanned feature. As a result of the scanning process we get what it is called "cloud point", a very dense group of points placed in the space according with XYZ coordinates that will subsequently be aligned in specific software to recreate the three-dimensional model[31]. One of the main merits of laser scanning is that we can gather high quantity of measures in a relative short period of time without having direct contact with the object we are measuring; another merit is that we can have a high quality virtual replica of any artefact or feature that allow researchers to study, modify, perform quality control or the so called "reverse engineering", which is the process that allow us to understand how a building, an artefact or another device was constructed[32].

Laser scanning is then a way to create a model that can help the process of investigating and analysing a feature, not only in the archaeological field but even in architecture and engineering[33]. In the book "3D laser scanning for Heritage"[34] the author presents a list of tasks suitable for the laser scanner, which could be summarised in:

- *Make a record of the aspect of a particular feature and monitoring the condition of a structure (for example, the façade of an historical building) before the*

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[29] See p. 21.
[30] Source: http://vcg.isti.cnr.it/index.php.
[31] Bianchini 2008. P. 159.
[32] Melvin, J. W. and Basiliki, V. K. 2009. 3D scanning and replication for museum and cultural heritage applications. In *Journal of the American Institute for Conservation*, vol. 48, n. 2. P. 143.
[33] Hughes and al. 2005. Pp. 37-46.
[34] Jones, D. (ed.). 2007. *3D Laser Scanning for Heritage*. English Heritage, Swindon. Pp. 4-5.

renovation. In 2010 the Alnwick Estate, responsible for the maintenance of Alnwick Castle in England, commissioned a survey to English Heritage before the restoration that was planned. Considering the size of the castle the team decided to use 3D scanning to produce the data needed. The scanner used was a Leica Scan Station 2 and, in addition to the raw data produced by the scanning of the building, photographs with a fish-eye lens were taken, to add eventual architectonical information that was not possible to capture with the scanner. More than a billion points were collected for this project, and the colour images were integrated onto the model[35]. The use of 3D scanner was preferred because it was a fast, more precise, less invasive survey technique, avoiding the need to build scaffoldings to get the data from the highest parts of the building[36].

- *Record of a feature in risk of damage or loss.* In 2009 the Polo Museale Fiorentino asked the ISTI-CNR to perform a digital sampling of some lesion in the base of the Michelangelo´s David. The fractures affected the back of the left leg and the log situated on the back of the right leg. Considering the dimensions of the cracks, a photographic acquisition of high resolution images was done along the 3D scanning. The team integrated the shape of the statue (3D model) and the images into a single digital model; the colour data were projected onto the geometry of the digital model in order to achieve a 3D model that was suitable for accurate analysis from the restoration staff. The possibility to change light settings and shadows and to measure gives the possibility to understand the gravity of the cracks in the marble and, in a virtual environment, attempt to simulate the restoration[37].

- *3D Model to create mould for copies[38].* An interesting application of a 3D scanner and a 3D printer for making a copy of an artefact was done by the Weston Discovery Centre, World Museum Liverpool. The museum wanted to have an exact copy of an Anglo-Saxon square-headed brooch dated around 400 – 500 AC. The artefact was sensitive and fragile to mould so it was required a non-contact

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[35] To see the final result: http://www.youtube.com/watch?v=sTSsjWmTc7I (20130312).

[36] Jones 2007. Pp. 21-22.

[37] Bathow, C., Breuckmann, B., Callieri, M., Corsini, M., Dellepiane, M., Dercks, U., Scopigno, R. and Sigismondi, R. 2010. Documenting and Monitoring Small Fractures on Michelangelo's David. In Fco. Melero, J. & Cano, P. (eds.). *Computer Applications and Quantitative Methods in Archaeology – CAA 2010*. Available from: http://vcg.isti.cnr.it/~corsini/publications/caa2010.pdf (20130521).

[38] As an example, in Italy is not allowed by law to make a mould for copying an artefact, so the 3D scanning can help to perform a semi-automatic reproduction of a particular artefact. Source: http://vcg.isti.cnr.it/index.php.

approach. The brooch was scanned and a 3D model was created. The details of the artefact forced the researchers to spend several hours in post processing the raw data in order to get a high quality polygon mesh for being able to capture all the fine details and inlay work of the surface. When the virtual model was completed a "copy" of it was printed out with a 3D printer and used as model for the mould. Later, a replica was casted in bronze[39].

- *The models can be used as an efficient medium for showing results to a broad public, in museum exhibitions and on the web[40].* The digital reconstruction of the funerary complex of Arrigo VII shows the potentiality of the application of 3D models as a medium for showing the result of a scientific research to a broad audience. The funerary complex, one of the most famous monuments of the 14th century in Italy, has been dismantled shortly after its construction and the different parts that formed it were scattered into the Cathedral of Pisa. The aim of the research conducted by the University of Pisa, Florence and CNR was to acquire digitally the parts of the monument, to create a virtual reconstruction of the apse of the Cathedral where the monument was originally placed and to "reconstruct" the monument as it could have looked in its environment. The device used for acquiring the data was a Konica Minolta Vivid 910, a triangulation-based laser scanner. At a later stage, the models were put into a visualization system called "Virtual Inspector" which gives the possibility to the audience to inspect, rotate and observe on a standard the 3D models PC of the statues of the monument. The museum audience could then observe through the virtual reconstruction how the mausoleum had looked like[41].

- *3D models can help to understand archaeological features and to discover hidden structures not visible to the "naked eye".* A remarkable example of the potentiality in discovering hidden features is described in the Stonehenge Laser scan project, funded by English Heritage. The research was carried out between May – August 2012 by ArcHeritage using laser-scanner and photogrammetric data in order to study the stone circles. The data collected were 0.5 mm resolution across the entire

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[39] Jones 2007. P. 27.
[40] Source: http://vcg.isti.cnr.it/index.php.
[41] Baracchini, C., Brogi, A., Callieri, M., Capitani, L., Cignoni, P., Fasano, A., Montani, C., Nenci, C., Novello, R. P., Pingi, P., Ponchio, F. and Scopigno, R. 2004. Digital reconstruction of the Arrigo VII funerary complex. In *VAST 2004: The 5th International Symposium on Virtual Reality, Archaeology and Cultural Heritage*. Available from: http://vcg.isti.cnr.it/Publications/2004/BBCCCFMNNPS04/arrigo_final.pdf (20130521).

stone circles; the surface analysis was conducted on all the stones. The result of this survey was astonishing: along the carving that already has been studied, the study of the models in 3D environment revealed the presence of 71 new axe-head carvings. Moreover, the analysis of carvings and tools signs on the stones, enhanced by the possibilities of increasing the light on particular direction in the virtual environment, revealed new information about how and possibly when the carvings were made. Despite the fact that Stonehenge is one of the most studied archaeological sites in England, the use of "cutting edge technologies" allow discovering new information and deepen our understanding of the site[42].

- *A 3D model gives a more complete and intuitive understanding and perception of the space, which is valuable in learning process and public visualizations[43]*. The scanning of the tomb M27, one of the Western Han Mural Tomb in Xi´an, dated between 206 BC and 9 AD, is a good example how the 3D scanning can be used to create a model for understanding the disposition of the mural painting according to the position of the observer. Tomb M27 was excavated in 2004 and in 2008 members of the University of California Merced with the Italian CNR ITABC, Virtual Heritage Lab made a survey to collect raw data of the tomb, which is closed to the public. The team created a 3D model of the tomb in which the mural paintings, at risk of loss, were recorded and inserted into a "cyber map"[44]; a three dimensional map that shows the spatial connection between the different paintings. More important, the cybermap is always in relation to the position of the watcher[45]. Creating a 3D environment that can be navigated by the user with this kind of data helps the spectator to understand the complex relations between space and decoration, as in this case[46].

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[42] Abbott, M. and Anderson-Whymark, H. with contributions from Aspden, D., Badcock, A., Davies, T., Felter, M., Ixer, R., Pearson, M. and Richards, C. 2012. *Stonehenge laser scan: archaeological analysis report*. Research Report Series 32-2012. English Heritage. Portsmouth. See also http://archpro.lbg.ac.at/case-studies/united-kingdom/stonehenge (20130312).

[43] Peloso, D. 2005. Tecniche laser scanner per il rilievo dei beni culturali. In *Archeologia e Calcolatori*, n. 16. Firenze. P. 199.

[44] A cybermap is a graphic rendering that shows the relation between the images and the context in which they are displayed. Galeazzi, F., Di Giuseppantonio Di Franco, P. and Dell´Unto, N. 2010. 3D Cybermaps of Western Han Mural Tombs. In Forte 2010. P. 103.

[45] Gloor, P. A. 1991. Cybermap: yet another way of navigating in hyperspace. In *Proceedings of the third annual ACM conference on Hypertext*. Pp. 107 – 121. Available from: http://delivery.acm.org/10.1145/130000/122985/p107-gloor.pdf?ip=194.47.218.159&acc=ACTIVE%20SERVICE&CFID=85358516&CFTOKEN=36555586&__acm__=1338385328_3fdbb6cf12673148c9d7696fe09cde08 (20130312).

[46] Galeazzi and al. 2010. Pp. 97-107.

On the other hand, the laser scanning does not provide unlimited geometrical accurateness; the procedure of data post processing can be very long and technical knowledge to handle both the instrument and the data is required. Moreover, depending on the quantity of data we want to register and deliver the laser scanner could be a device excessively accurate; according with the time we have for a project or the costs we can effort, a laser scanner survey is sometimes too expensive to use, or it gives data that are too detailed for the aspect we want to study. Other technical issues can be that the scanned feature must be in the line of sight of the instrument because it doesn´t capture information behind corners or if the feature is hidden. Finally, the scanners can have troubles in detecting points on particular surfaces (the reflectance can be an obstacle) and it is not recommended to record corners[47].

 Another problem that is relatively new in the field is the handling and storing of the data that archaeologists gather with the new technologies. The possibility of recording a big amount of data with the most modern technological devices must be taken in high consideration, because we have the responsibility as archaeologists not only to record and make it accessible to other academics and the big public, but also to organize the data in a way that it will be possible for future scholars to have access to it and being able to use it for other studies. If compared with the most common medium of recording data (such as paper, vellum paper, or stone) the longevity of the data is shorter. The paradox that emerges from using such new recording methods is, on one side, to have the possibility of digitalizing the cultural heritage and giving visibility to it in a way that it has never been possible before in history, but on the other side this new way of storing data gives rise to the possibility of losing information that could not be replaced due to lack of organization in terms of storing, accessibility and maintenance of servers. Other issues are connected with the copyright of the data. A solution could be to establish an international agreement of "copy left"[48] concerning the digital heritage community, for example[49]. The fundamental thing to do is to share and let as much scholars and people as possible have access to the data; the more the knowledge is shared the more likely the

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[47] Jones 2007. P. 7.

[48] Is a method for making a program or a work accessible for free to everyone, provided that all the changes or implementations that the users make are free to share with the entire community as well. Source: http://www.gnu.org/copyleft/ (20130318).

[49] Addison, A. C. 2008. The vanishing virtual. Safeguarding heritage´s endangered digital record. In Kalay, E. Y., Kvan, T. and Affleck, J. (eds.). *New Heritage. New media and cultural heritage*. New York. Pp. 32-39.

data will be preserved, analysed, adjusted and even contested, creating eventually new interpretations and new approaches to the data itself[50].

An interesting project started recently and is moving towards this direction is called Ariadne. The name is an acronym standing for *Advanced Research Infrastructure for Archaeological Dataset Networking in Europe* which mission is to create an international research infrastructure for the connection of European digital archives with archaeological data. In this way scholars and researchers can have access to scattered data that otherwise would be hard or impossible to consult. This project was launched the 7th February 2013 in Rome and it is funded by the European Commission 7th Framework Programme. Its coordinator are PIN (Italy) and the Archaeology Data Service at York University (UK)[51].

6. Introduction of the activities

The Kulturen museum is going to perform a restoration of a historical wooden building, Måketorpsboden. My master thesis project is developed with the intent of digitally acquire the building in order to create a 3D model and understand which kind of archaeological information we can get from this type of digital acquisition and how it can be useful for the planning of a restoration.

7. Farmer building under the medieval period

Medieval farms consisted of several buildings. Generally, every building had a specific function: some were used as dormitory; some others had the function of bathroom and kitchen, others were used as working spaces, storage rooms, stables, huts. It was possible even to find more than one buildings with the same function at the same farm. Moreover, buildings might have a symbolic function for the family which could establish a sort of "social position" related to the number and the size of the storage houses that a farm owned[52]. At farms in Dalarna, during the 16th and 17th centuries it was possible to find up

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[50] Clack, T. and Brittain, M. 2007. Introduction: Archaeology and the Media. In Clack, T. and Brittain, M. (eds.). *Archaeology and the Media*. California. P. 60.
[51] Source: www.ariadne-infrastructure.eu/News/Press-release (20130422).
[52] Skötsel av kulturvärden i odlingslandskapet – Loftbodar. Available from: http://old.raa.se/cms/showdocument/documents/extern_webbplats/landskapsvard/kulturvarden_i_odlingslandskap et/b_byggnader/b4c_loftbodar.pdf (20121205).

to five timber buildings; during the Middle Ages we could find from ten to fifteen buildings. From the 17th century the farms and the land has been divided into smaller units, which led to a decrease in the number of storage buildings[53].

There are similarities in the construction techniques between all the different kinds of buildings; however, the decorations and the look were different in a way so that it was possible to recognize the real house, the storage house and the barn. Besides, the material, and the experience of the carpenter influenced the construction and the look of the above mentioned buildings, giving a personal appearance to every farm.

The oldest preserved timber houses in Sweden are different kinds of storage buildings, from which we can experience a lot on the knowledge of timber techniques dated back to the 13th and 14th centuries[54]. Considering that this kind of edifice is the one I am interested in for my research, I will focus on this kind of architecture.

Storage buildings in Sweden were used mainly to store the farm supplies; that´s why they were built and kept with great care. Those constructions had a range of different names; one old name is *bur* (literally: a room with barred walls; generally a minor building in the farm, a small storage room or a bedroom[55]). Another name was *loft* (which means literally "floor above" or attic; this name is more connected with the design of the building). The oldest kinds of storage buildings were found in Dalarna and were called *härbrena*[56] (or stolpboden). The word "härbre" is an old Swedish word indicating a storehouse; it comes from the word "härbärgera", which means to keep something or somebody. This kind of storage room, commonly used since the medieval period, was organized in one or two rooms on the ground floor (sometimes they could have more than one floor). Its primary use was to store corn, fish, meat, sometimes bred, all things that need a dry storage. That´s why the entire construction was lifted up on four poles, to keep the goods far from the wet floor, rats and other small predators[57].

The *loft* is the kind of storage building that I will study and document. *Loftbodarna*, "attic storage buildings" trace their presence in the document since the 15th century and they

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[53] Sjömar, P. 1988. *Byggnadsteknik och timmermanskonst: en studie med exempel på några knuttimrade kyrkor och allmogehus*. Göteborg. P. 31.
[54] Sjömar 1988. P. 41.
[55] Erixon, S. 1952. *Byggnadskultur. Nordisk kultur XVII*. Oslo. P. 330.
[56] Sjömar 1988. P. 42.
[57] Skötsel av kulturvärden i odlingslandskapet – Härbren. Available from: http://old.raa.se/cms/showdocument/documents/extern_webbplats/landskapsvard/kulturvarden_i_odlingslandskapet/b_byggnader/b4g_harben.pdf (20130107).

have been used until the 19th century[58]; the oldest preserved *loft* in Uppland and Dalarna date back to the end of the 15th century – beginning of the 16[th][59]. They present three main forms that we can see being of some importance: the one with vertical, not interrupted frontal wall, the one with a part of the building that extrudes from the main body and the one with an outdoor gallery on the second floor[60]. Each of them is generally organized in two floors, with two rooms in each floor[61] even if bigger construction could contain three rooms for each floor[62]; usually there were no doors between the walls of the rooms. The first two types presented an inner ladder to reach the second floor, one for each room; when there was just one inner ladder a door was open between the two rooms upstairs, while the third type has an external ladder connected with the gallery on the second floor[63]. Måketorpsboden belongs to the third type described, which is generally known in Swedish literature as *loftbod med svalgång* (gallery house in English, figure 3).
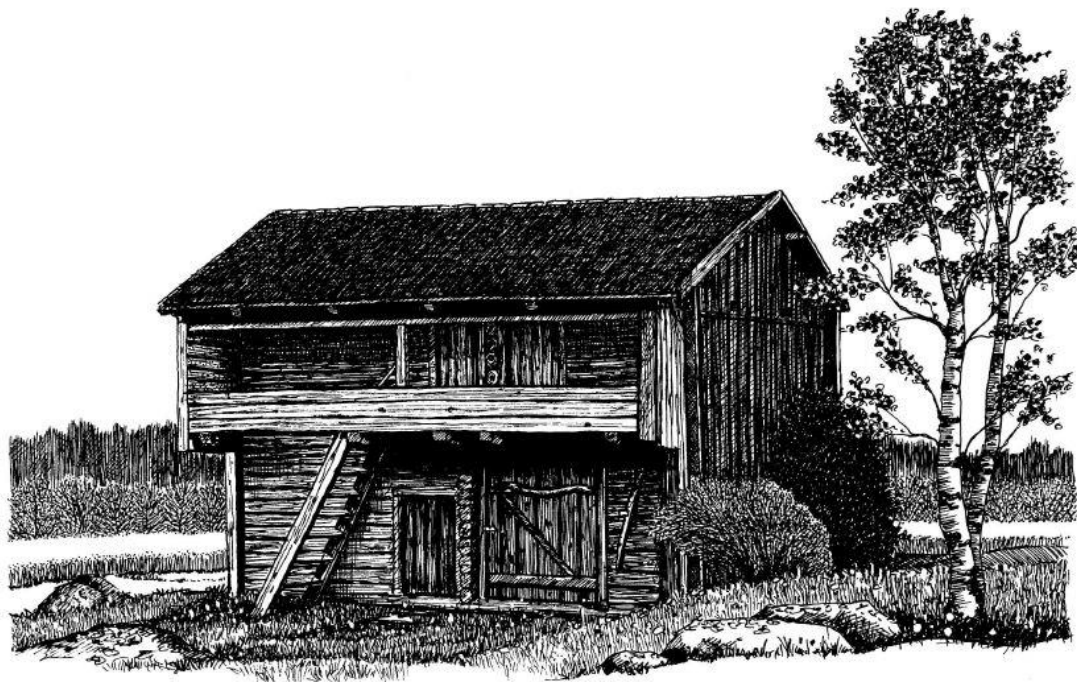
Figure 3. An example of "loftbod med svalgång". Source: Skötsel av kulturvärden i odlingslandskapet – Loftbodar. Source: http://old.raa.se/cms/showdocument/documents/extern_webbplats/landskapsvard/kulturvarden_i_odlingslandskapet/b_byggnader/b4c_loftbodar.pdf (20121205).

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[58] Skötsel av kulturvärden i odlingslandskapet – Loftbodar. Available from: http://old.raa.se/cms/showdocument/documents/extern_webbplats/landskapsvard/kulturvarden_i_odlingslandskapet/b_byggnader/b4c_loftbodar.pdf (20121205).

[59] Sjömar 1988. P. 42.

[60] Erixon, S. 1947. *Svensk byggnadskultur. Studier och skildringar belysande den svenska byggnadskulturens historia*. Stockholm. P. 610.

[61] Sjömar 1988. P. 42.

[62] Erixon 1947. P. 613.

[63] Erixon 1952. P. 337.

According to records, the oldest preserved building of this kind in Sweden is the one located in Ornäs, Torsångs parish, Dalarna, famous because Gustav Vasa spent some nights there in 1520 during Christmas, when he was fleeing from men loyal to the Danish king[64]. In this kind of edifice, the second floor is reachable through an external ladder and a covered outdoor gallery. It is clear that this kind of storage building presents a more complicate structure than the others storage constructions. The *loftbod* was probably the first to have not only storage rooms, but bedrooms as well, used by the young adult working in the farm, such as maids and normal workers during summertime[65]. The food goods were stored on the first floor while clothes, textiles and other household goods were located on the second floor, along with the bedroom[66]. Often the two-rooms building has half of the ground floor open in a way that a wagon could pass under it[67].

7.1 Building method

Our knowledge about the medieval farmer building techniques is not so broad; the problem is that there are not so many preserved buildings from that period that would allow us to study the building techniques. Our hypothesis are based on the few exemplars from earlier periods still standing today, assuming that these techniques did not change radically from medieval times[68].

A fundamental factor for the construction of timber buildings is the availability of timber, the system of transport, the knowledge of the craftsman and the tools used. The building techniques were strictly correlated with the presence or not of timber. In Scandinavia, which has always been a well wooded region, the *corner timber* technique has been used continuously for almost one thousand years up to the 19th century. The only tool needed for the corner timber technique is an axe: a log is put horizontally on another and they are locked together by some cut into the corners that made possible to join the far end of the trunks without the use of nails[69] (figures 4-5).

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[64] Erixon 1952. P. 338.
[65] Jacobsson 1983. P. 57.
[66] Sjömar 1988. P. 44.
[67] Erixon 1947. P. 626.
[68] Dolby, C., Hammer, A. and Jeppsson, K. 1988. *Rural Constructions in timber*. Lund. P. 2-4.
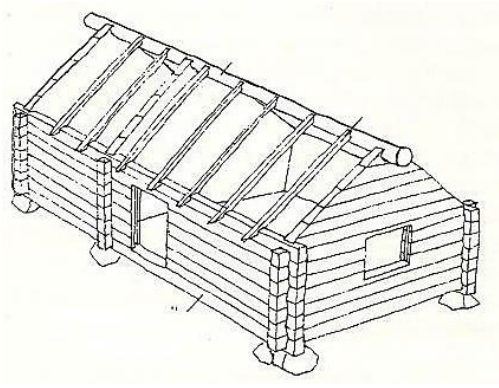[69] Ibid, p. 2-5.

Figure 4. Example of building with the corner timbering technique. Source: Dolby and al. 1988. P. 2-5.
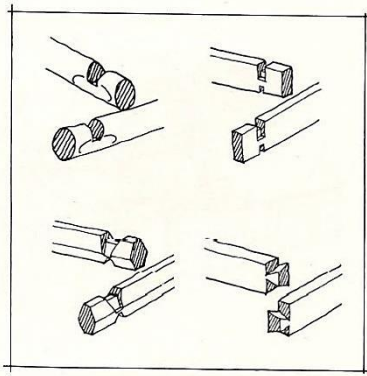

Figure 5. Joints of the corner timbering technique. Source: Dolby and al. 1988. P. 2-5.

7.2 Måketorpsboden

Previously it was thought that Måketorpsboden was built in the 1650s, but a dendrochronological analysis made in 2012 and not yet published shows that the house was built in the late 18th century with timber felled during the winter 1793/94[70]. The farm Måketorp 1:2 is located in Åseda parish, Uppvidinge District, Kronoberg (Småland). Måketorp was only a single farm, but in 1856 it was divided into two farms. The two rooms on the first floor were used as storage rooms for food and farmer tools while the two rooms on the second floor were used as "summer house" and even used as guest room.

The shed, which is quite large for this kind of building, is constructed with the *corner timbering* technique: the joints are visible on the outside of the hen house to the north-west corner (figure 6).

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[70] Information from Gunilla Gardelin, curator at Kulturen museum.

Figure 6. The "hen house" corner on the front of the house. The technique used is the *corner timber*. The picture shows the cut in the logs used to connect the end of the trunks. To the left of the picture it is possible to see the far end of the logs extruding from the wall. (Picture: Linda Nesi, 2013).

Måketorpsboden was bought by Kulturen in 1892; it was dismantled and transported by rail from Småland to Lund where it was rebuilt[71].

8. Aim of the investigation

The project developed during this work of thesis is about the acquisition of a timber house located in Kulturen Museum, Lund with a 3D laser scanner. The aim of this work was to acquire several range maps (point clouds) of the building and to reconstruct the geometry and colour information in order to create a 3D model able to perform a deeper analysis of the structures.

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[71] Wahlöö, C. 2003. *Vägledning till Kulturen Lund och Östarp. Drottens arkeologiska museum, Tegnérmuseet, Borgeby slott samt Bosjöklosters mölla*. Kulturhistoriska föreningen för Södra Sverige. Kulturen. Lund.

9. Acquisition campaign

The acquisition campaign was realized the 4th March 2013. The scanning of the timber house has been performed with a *Phase Shift* laser scanner from Faro industry, *Faro Focus 3D*. The *Phase Shift* laser scanner belongs to the family of *Time of Flight* laser scanner (ToF). This typology of instrument calculates the time needed for a pulse of laser to reach the object and being reflected back to the scanner for calculating the position in the space of points that defines the surface of the scanned feature[72]. This kind of scanner can collect several thousands of points each minute and are usually employed to perform acquisition of large areas or complex of buildings. The *Phase Shift* laser scanner is a particular kind of 3D scanner that belongs to the family of the ToF scanners. It uses a similar technology but, in addition, this scanner modulate the power of the laser emitted by the device[73] and bases the calculations on the differences of the emanate and returning laser pulse[74]. This kind of scanner can capture millions of point per minute, giving a denser and accurate point cloud in a shorter time and with a lower noise of point's distribution[75].

The scanner employed during this acquisition campaign was a *Faro Focus 3D* (figure 7). The performance specifications are:

Distance accuracy up to ±2mm

Range from 0.6 m up to 120 m

Measurement rate up to 976,000 points/sec[76]

Vertical field of view (vertical/horizontal): 305° / 360°[77]

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[72] Jones 2007. P. 8.
[73] Source: http://www.rapidform.com/3d-scanners/ (20130409).
[74] Jones 2007. P. 8.
[75] Source: http://www.rapidform.com/3d-scanners/ (20130409).
[76] Source: http://www.faro.com/products/3d-surveying/laserscanner-faro-focus-3d/overview (20130409).
[77] *Faro Focus 3D – Features, benefits & technical specifications*. Available from: www.faro.com (20130326).

Figure 7. *Faro Focus 3D* scanner on the field. (Picture: Linda Nesi, 2013).

With the initial assistance of Stefan Lindgren, research engineer at the Humanities Lab in Lund University[78], the scan´s plans have been organized in three separate acquisition groups: *outside scans*, *first floor scans* and *second floor scans*.

The acquisition procedure is completely automatic; the user creates a project scan, setting all the scan parameters (resolution and camera acquisition settings) and at the end establishes how to name the single scans.

In order to document the building outside, 14 scans has been produced, the first floor required 12 and the second floor 13 scans for a total of 39 scans. Each scan has been taken with a resolution of 7 million points. The specifications of the positions of the scans are shown in the plans (figures 11-12).

The entire acquisition campaign took a day, from 10 to 16 with a single operator.

Starting from the right corner of the façade, I performed the acquisition covering as much as possible the geometrical details that describe the external surface, positioning the scan in a way to cover the corner of the building. On the back I decided to perform three scans, one for each section of the façade and one in order to get the entire building from a more

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[78] Humanities Lab: http://www.humlab.lu.se/.

distant position. The last three scans have been realized with the purpose of acquiring the area under the gallery and the "hen house" (the room outside on the ground floor, figure 8).

Figure 8. Screenshot of the point cloud showing the area scanned under the gallery and the "hen house". Three scans (12, 13 and 14) have been performed to cover this part, as showed in figure 11.

The second group of scans marked with red numbers in figure 11 have been acquired to document the ground floor of the building. Those particular groups of acquisitions have been particularly complicated. In fact the presence of beams extruding from the ceiling imposed the acquisition of a larger number of scans (figure 11). In order to perform an efficient acquisition campaign a scan under each inter space between the beams has been performed.

Figure 9. Position of the instrument for the scan number 15. (Picture: Linda Nesi, 2013).

As shown in figure 9, the scan number 15 has been taken exactly on the doorstep for creating a cloud point that would be useful to align the first group of scans (outside) with the ground floor scan's group. Scan number 24 has been taken to provide a complete description of the walls; for safety reasons the beam keeping up the ceiling on that area has been shored up with two logs, creating a "shadow area" for the scanner. Scan number 26 has been taken in order to connect the outside scan's group with the second floor scan's group.

The third group of scans, showed in figure 12, have been acquired considering the presence of the beams used for support of the new roof recently built in order to cover and protect the shed (figure 10). Scan 38 cover the inside of a small room on the gallery.

Figure 10. The protective roof built above the shed. It has been demanding to clean all the point clouds of the second floor to remove those features but it is crucial for obtaining a good model. (Picture: Matteo Dellepiane, 2013).
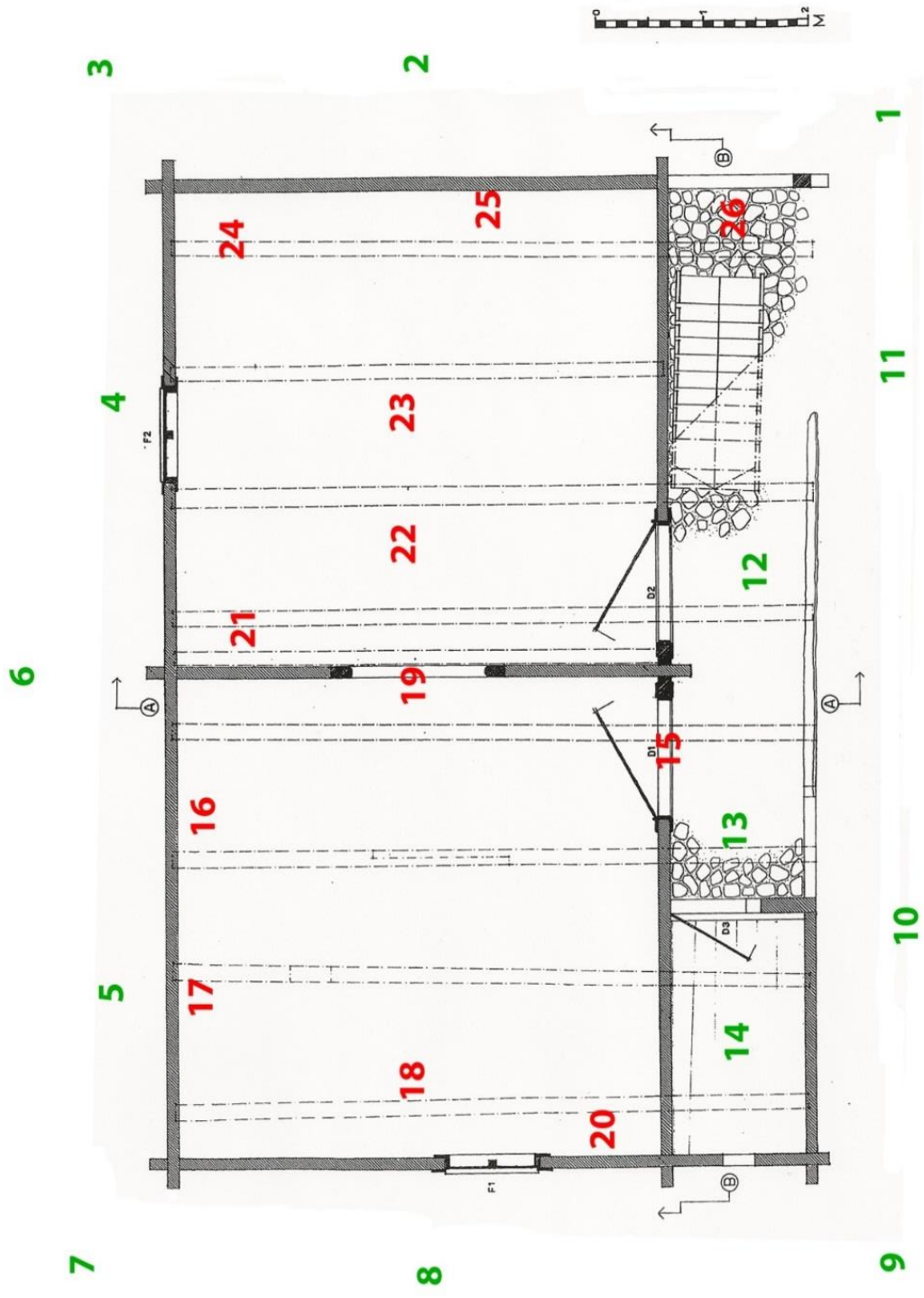
Figure 11. Scans plan for the outside and the ground floor. The numbers in green indicate the scans taken outside, the numbers in red the scans taken inside. Image: Plans made for Kulturen by the architect Heinz Werner in 1998. Kulturen archive.
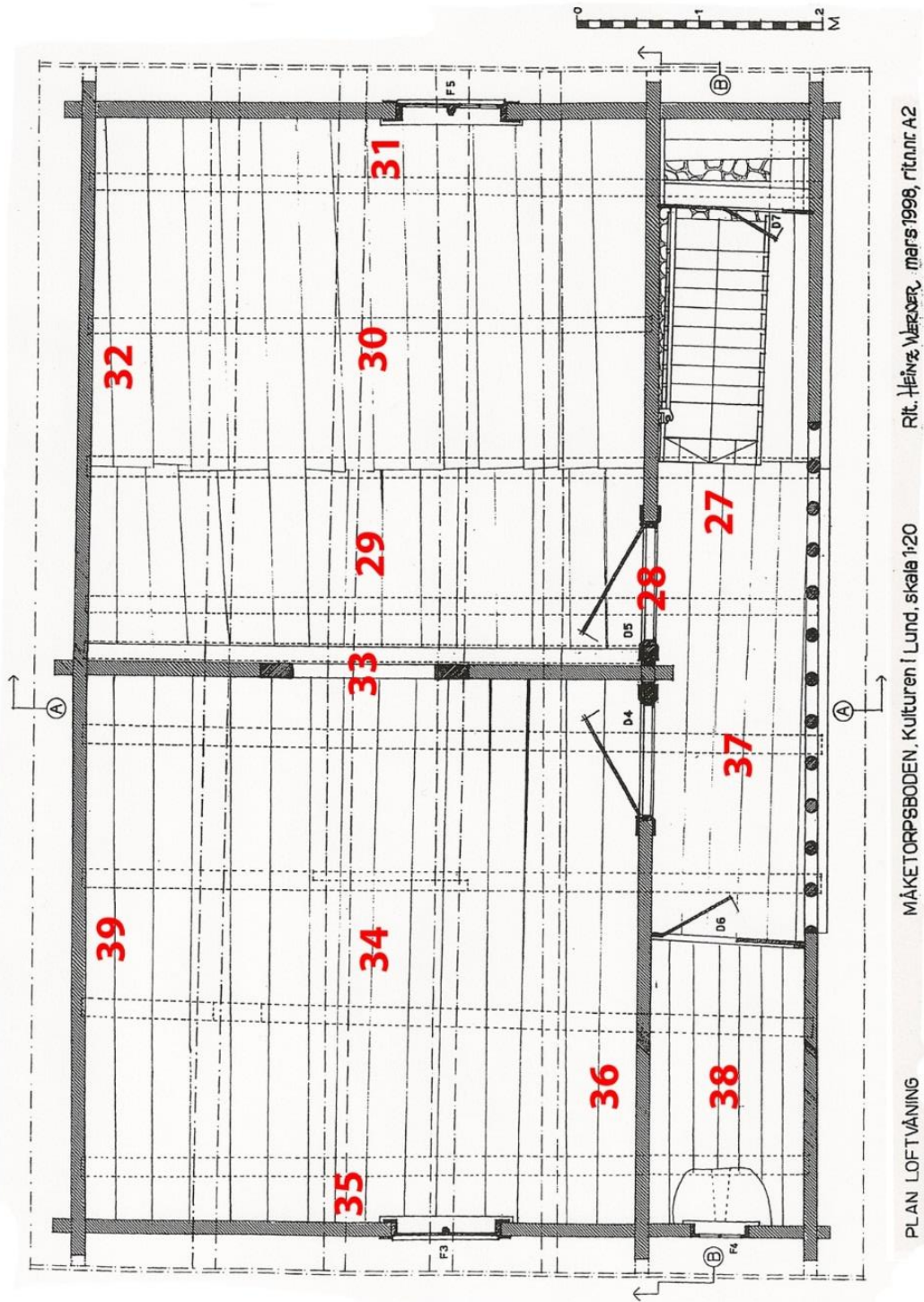
Figure 12. Scans plan for the second floor. Image: Plans made for Kulturen by the architect Heinz Werner in 1998. Kulturen archive.

9. 1 Acquisition of pictures for the projection of colour on the model

The projection of the colour information on the mesh represents the final part of the 3D pipeline. This is the hardest part of the entire process; while the geometry is relatively easy to acquire with the scanner because it is a feature that it is not susceptible to light, the colour is a component changing according to the light of the environment and the sensitivity of the camera used for the acquisition. The scanner itself uses a camera to project the colour directly on the point cloud produced during the acquisition, but the quality of the pictures are very low, and this make the operation of colour transfer not sufficient to perform analysis on the materials.

The 17th April 2013 together with Matteo Dellepiane from the visual computing Lab, ISTI (National research council of Italy) I performed a photographic acquisition campaign. To properly acquire the images we used a Nikon D80 and a hand-made "beauty dish" for enhancing the flash of the camera (figure 13).

Figure 13. Matteo Dellepiane from the Visual Computing Lab (http://vcg.isti.cnr.it/index.php) using the camera with the hand made "beauty dish". Sometimes the most efficient tools are the cheapest. (Picture: Linda Nesi, 2013).

At the end of the campaign we chose 46 pictures, each one with a size of nearly 4 MB.

10. Post processing

After the acquisition campaign the data has been processed using an ASUS laptop G74SX-91111V, Intel® Core™ i7-2630QM, 16GB RAM.

The program used for the post processing is *MeshLab*, a multiplatform open source program for the *processing and editing of unstructured 3D triangular meshes*[79]. The program, developed by the Visual Computing Lab, ISTI - CNR, Pisa (Italy) allows managing the alignment of scans and subsequently their cleaning, editing and rendering. The meshes so created can also be converted in 3D models. MeshLab is relatively easy to use even for people without almost any 3D modelling experience and it presents a depth of use that allow experienced users to change parameters and other advanced settings in order to achieve a more professional result[80].

At the end of the acquisition campaign 19 GB of data have been acquired. The total amount of scans (39) has been extracted in raw format (.ptx). Each scan had a size of 300MB with a number of collected points of approximately: 60 million for the first floor, 42 million for the outside and 88 million for the second floor. The scans have been optimized using a tool available in MeshLab called "subsampling" in order to be more manageable during the alignment process. The subsampling is an instrument that allows decreasing the number of points in a single mesh using a complex mathematical algorithm, generating a "uniformly random distributions of points"[81].

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[79] A mesh is a group of triangles that approximately recreate a surface. Source: http://meshlab.sourceforge.net/ (20130414).

[80] Cignoni, P., Callieri, M., Corsini, M., Dellepiane, M., Ganovelli, F. and Ranzuglia, G. 2008. MeshLab: an Open-Source Mesh Processing Tool. In Scarano, V., De Chiara, R. and Erra, U. (eds.). *Eurographics Italian Chapter Conference 2008*. Available from: http://vcg.isti.cnr.it/~corsini/publications/meshlab_egit.pdf (20130418).

[81] Corsini, M., Cignoni, B. and Scopigno, R. 2012. Efficient and flexible sampling with blue noise properties of triangular meshes. In *IEEE Transaction on Visualization and Computer Graphics*, vol. 18, n. 6. Pp. 914-924.

10. 1 Alignment of the scans

The alignment process is fundamental for the creation of the model; the program allows us to overlap each range map in order to organize them in a single constant aligned space[82].

After the alignment in order to edit the points 'cloud in MeshLab I transformed the .ptx files in .ply and I started removing from the scans all the excessive features. Considering that every single scan describes the entire surrounding, it has been necessary to remove the groups of point that are not of any interest for the reconstruction. Using the *select vertexes* function of MeshLab the operator is able to choose the points that must be removed.

Once aligned the entire model I decided to focus my attention on the first room of the second floor of the shed; this part of the building is the most affected by the restoration work, and the acquisition of such element will allow in the future a direct comparison with the restored part.

I started isolating the area that I wanted to further develop, flattening all the scans concerning the second floor (28, 29, 30, 31, 32 and 33). The amount of points at this stage of the process was too high to build a surface (nearly 28 million), which is the reason why before proceeding with the constructions of the polygons I optimized the points cloud up to 3.2 million points.

The areas closer to the scanner have a higher density of points while the other part of the scan presents a less density; this can cause noise in the data (figure 14). The *Poisson disk sampling* is a filter that creates a new layer with a point sampling of the current mesh; this tool deletes the excessive number of point in areas where there is a higher density of points.
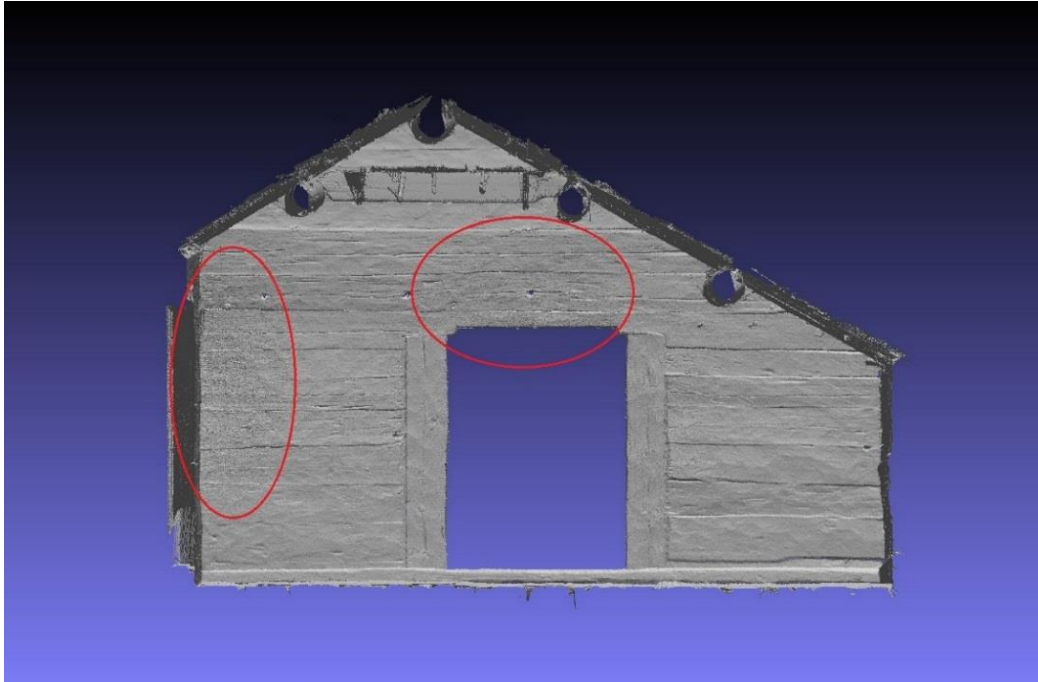
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[82] Cignoni et al. 2008.

Figure 14. Screenshot of the 28 million point cloud. The noise is visible due to the vicinity of the scanner to the walls (underlined in the red circles). Despite this is only a point cloud with no geometry it is possible to appreciate the carving on the timber.

On this stage of the process we have only vertexes; the next step is to reconstruct the geometrical surface from the aligned range maps. In MeshLab there are mainly two filters that allow performing this operation: the *Surface Reconstruction, Poisson* and the *Surface Reconstruction, VCG.* Both these methods use the points and normal of the range maps in order to build a geometrical surface. The main difference is that the Poisson creates a closed mesh while the VCG does not reconstruct any geometry if there are no points defining an area. For this case I used the Poisson reconstruction. The result is a mesh formed by 2.2 million vertexes and 4.5 million faces that can be further optimized first of all by removing the part of meshes that have been created by the algorithm for filling the holes and then using other filters such as *remove duplicated faces*, *remove duplicate vertex*, *remove zero area face* (a special filter that remove the faces presenting an area equivalent to zero) and *remove unreferenced vertex.*

In order to make the 3D model lighter and easier to manage, I applied also the *quadric edge collapse decimation* filter which simplifies the current mesh, decreasing the number of faces in the model (figure 15). This instrument allow to manually inserting the desired number of faces.

Figure 15. Snapshot of the model created with the Poisson Reconstruction after the cleaning.

10.2 Projection of the colour on the mesh

The projection of the colour on the mesh has been achieved through the use of three different software: TexAlign, TexAlignSuite 2012 and MeshLab.

The first step was to clean the pictures from unwanted features. As shown in the previous paragraphs, the second floor is covered with a new roof that has been removed from the final model; the same thing has been done with the images. In Photoshop I used digital masks to cover the parts with the new roof with the aim of removing these unwanted features.

I imported the model of the room into TexAlign Software (figure 16) and aligned each image to the model, with a similar procedure used for the alignment of the range maps in MeshLab.
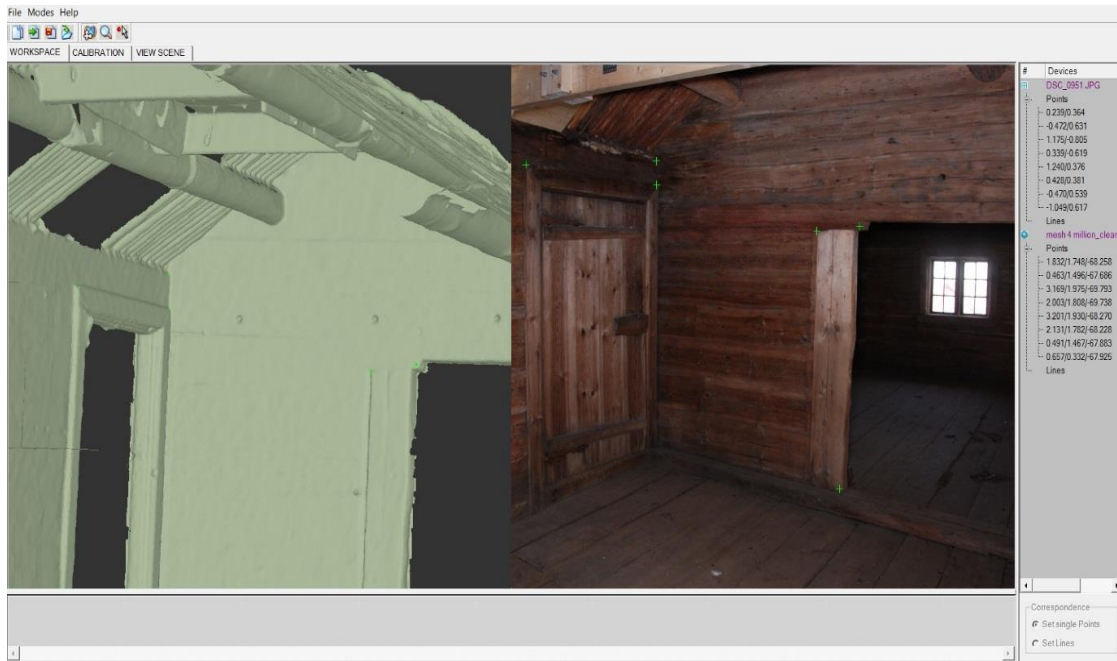
Figure 16. TexAlign 2. The program that allow aligning the image to the model.

TexAlign is software that allows the alignment of 2D images onto 3D models[83]. Due to the difficulty of the case study, it has been necessary to use this kind of program in order to align the images onto the model.

I then imported the projection file from TexAlign to TexAlignSuite 2012 (figure 17) for the optimization of the alignment. With this software is possible to optimize the alignment the pictures with more accuracy.

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[83] Franken, T., Dellepiane, M., Ganovelli, F., Cignoni, P., Montani, C. and Scopigno, R. 2005. Minimizing user intervention in registering 2D images to 3D models. In *The Visual Computer*, vol. 21, n. 8/10. Pp. 619-628.
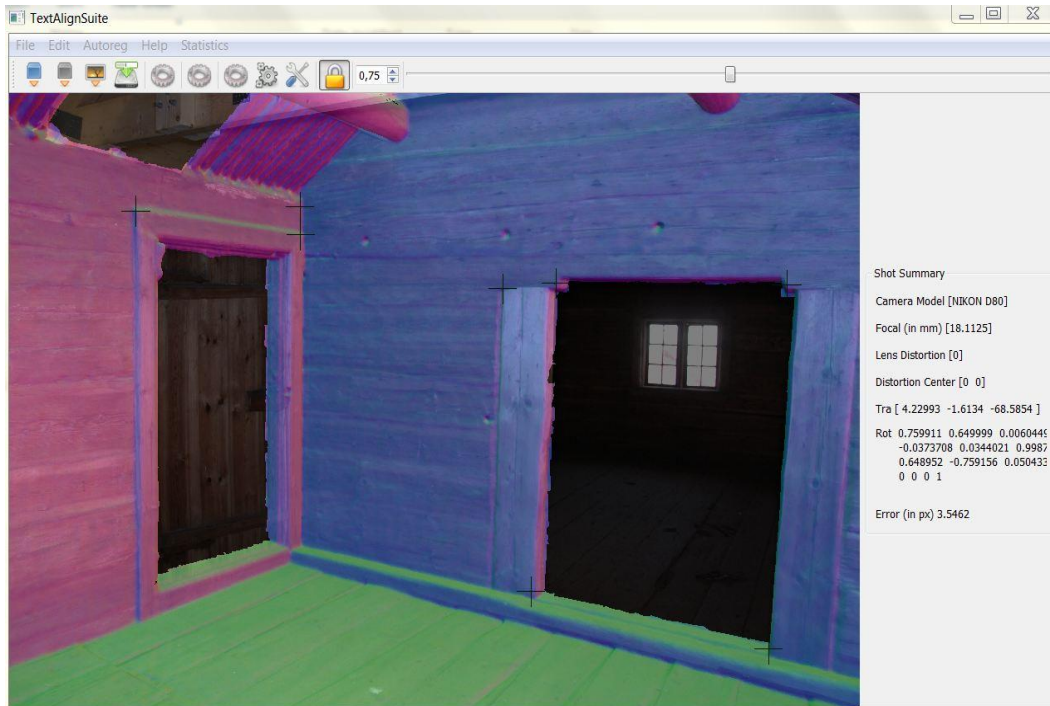
Figure 17. TexAlign Suite 2012. The program used for optimizing the alignment of the image onto the model.

At the end of the process I saved the result as an .mlp file in order to be edited and visualize into MeshLab (figure 18). With the filters *Image alignment Info* MeshLab allows registering the raster image onto the 3D model, performing a mathematical projection of the colour information directly on the meshes. This operation has been achieved using the *Project Active Raster Colour to current mesh* filter.
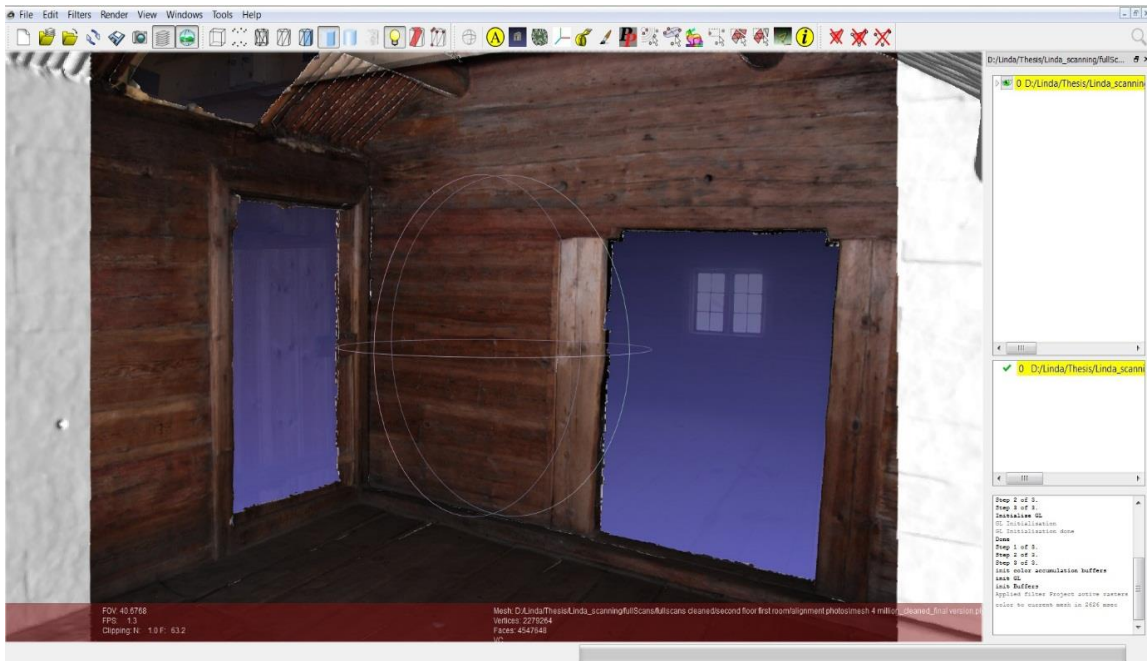
Figure 18. MeshLab allows projecting a 2D raster image onto the 3D model. This is the result of the processing of one image through three different programs.

11. Analysis

Once post processed the data have been used to analyze the historical building. In order to perform a complete evaluation and analysis of this methodology I decided to focus my work on a small part of the building, in specific the first room to the right on the second floor (figure 19). The room presents a window to the short side of the wall and a platform with wooden hooks on the ceiling, used probably for hanging food or other supplies. However this part is not original. A door has been opened in more recent time to connect the two rooms from inside.
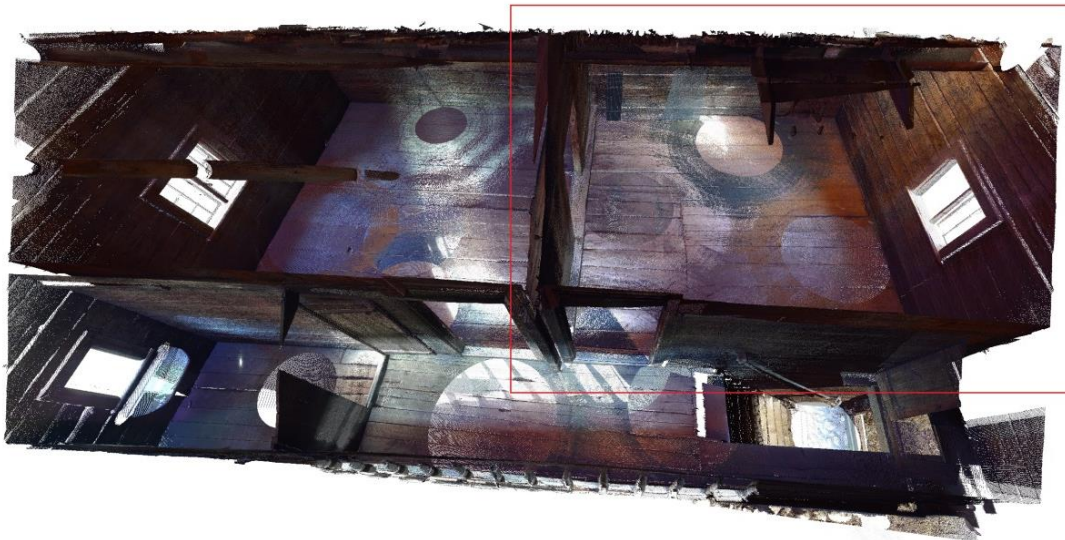
Figure 19. The room I analysed is underlined in red. Screenshot over the second floor of a point cloud.

The model has been processed into MeshLab and several shaders have been applied to the mesh. A shader is a virtual material that allow simulating the aspect of the virtual surface, creating different final visual effects that improve the visualization of the geometry that are not so visible otherwise with the naked eye.

MeshLab gives the possibility to take pictures of a portion of model in orthoview, which I imported into AutoCAD for drawing and underlining specific areas that I judged interesting.

AutoCAD® is software belonging to the Autodesk® family for *computer-aided design* (CAD). It is used for drawing into several fields such as architecture, engineering, design and nowadays is used also into archaeological documentation[84]. Its characteristics make it a perfect tool for archaeological drawings because it allows working in layers and importing 2D images that can be used as a base for drawings. The limits of the precision of the drawing, due to the utilizations of scaled drawings have been removed by using this program[85]. In this case, the geometry of the walls has been described in a way that it is possible to appreciate the carving and the curvatures of the timber directly on the model.

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[84] Source: http://www.autodesk.com/products/autodesk-autocad/overview (20130503).
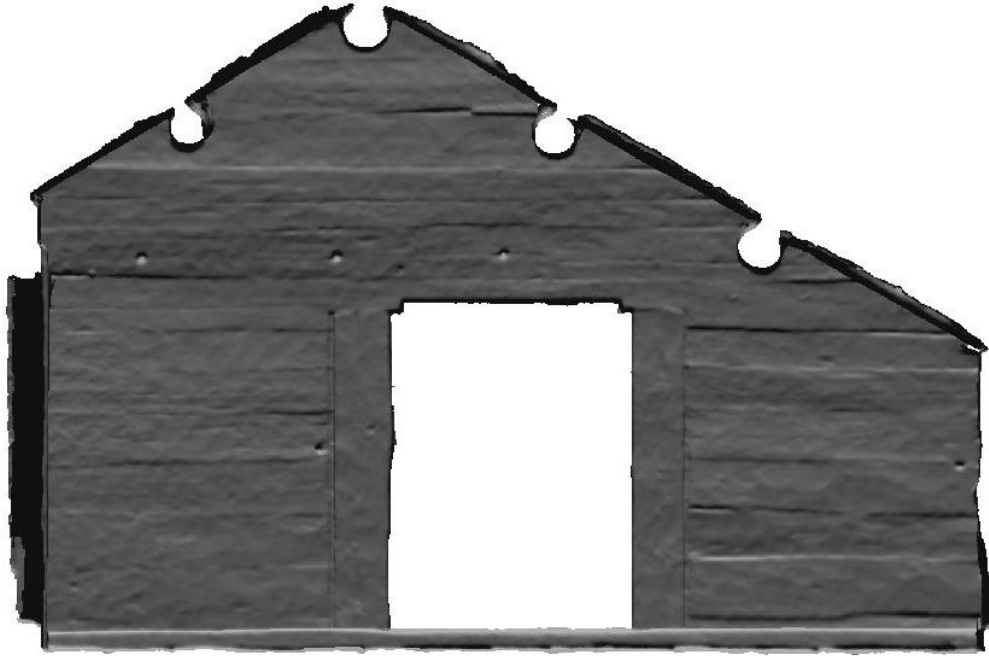[85] Haddad 2011. P. 112.

Figure 20. Orthoview of the dividing wall on the second floor without colour information.

Figure 20 shows the model without any colour information The use of MeshLab to examine the model allow to see clearly the carvings left on the wall during the construction phase of the building. Moreover MeshLab allows controlling an artificial light through which is possible underlining the differences on the surface´s geometry. The environment, due to the presence of a little light source can be dark; the construction of a virtual model allows the researcher to lighter up the environment simulating different light conditions such as intensity and direction. The use of such instrument makes it possible to notice details that would be hard to see in the "real" environment. Moreover, the possibility to focus only on the geometrical surface of the timber, avoiding the colour, makes the observer concentrating only on the shape of the object, which in many cases is the most interesting feature of an architectonical object

3D scanning helps, in this regard, to acquire a big amount of data that can be further processed as a whole or just as a part of it, depending on the goal of the study.
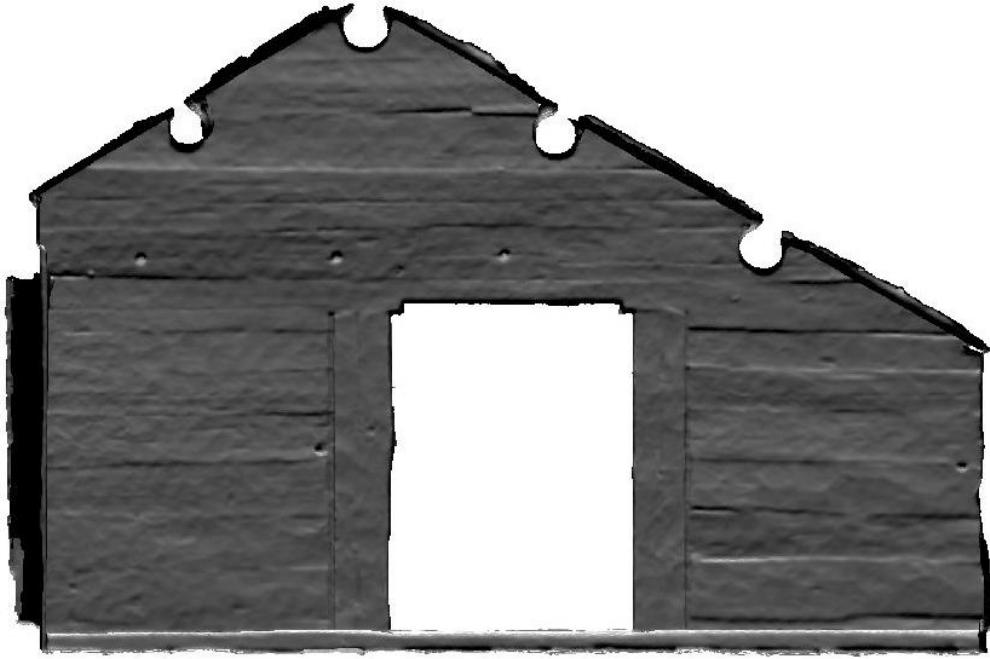
Figure 21. Radiance scaling filter applied to the mesh.

The *Radiance Scaling* shader heightens directly on the model the differences between light and shadow zones. There is the possibility to increase the enhancement of the shader; in this way it is easy to stress the differences between flat areas and more steep zones. It is very useful for noticing the eventual carving pattern on a timber surface. The darker areas indicate a deeper depression in the timber, as it is possible to notice in the figure 21. The five holes on the wall are immediately visible, which would not be so clear if we had a normal digital image. It is possible to compare this image with the coloured model to appreciate the different perception of the geometry with and without colour projected.

Figure 22. Discrete Curvature – mean curvature filter.

The *Discrete Curvature – mean curvature filter* is very useful rendering effect for enhancing the surface shading of an object (figure 22). It is used to have an immediate overview of the tendency of the surface of the wall, underlining with different colours the depth of an area. The green areas are plainer, the blue areas indicate steep areas and the red zones presents an even deeper step. From this image we can understand that this wall presents not so strong differences in the height of the surface, except for the holes and the cut in the middle of the wall that has been made for opening a door between the rooms. The holes on the wall are easily recognizable.

Figure 23. Discrete Curvature – ABS filter.

There is another filter called *Discrete curvature – ABS* (figure 23) which allow highlighting the differences in height of the surface through the application of different colours. From red to blue the differences in height of the surface are underlined with those colours, where red indicate a flat surface and blue indicate a steeper zone.

As seen in figure 23, the yellow curvatures shows with high detail the orientation of the carving in the timber. This type of visualization allows recognizing if these kind of carvings have been performed using a new tool or a more ancient axe[86]. This kind of analysis can be used for understand which part of the timber has been carved more recently, pointing out possibly parts of the building that are not original, or have been replaced in recent times.

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[86] For more information regarding the types of tools and technique used for cutting and building timber houses: Henriksson, G. 1996. *Skiftesverk i Sverige: ett tusenårigt byggnadssätt*. Stockholm. Pp. 7-64.
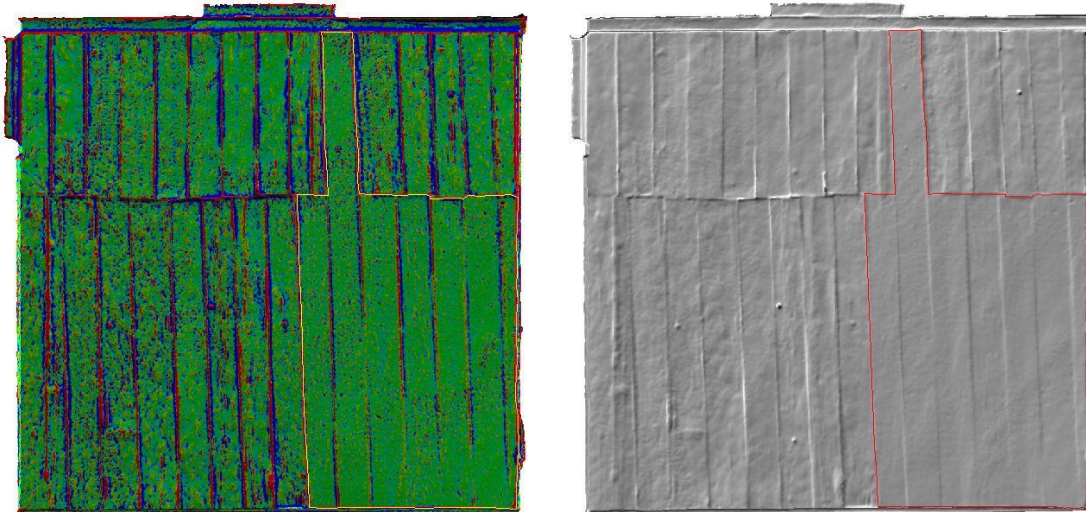
Figure 24. Floors of the first room in the second floor analysed with the *Discrete curvature* filter (to the left) and the normal model without any filter (to the right).

The observation of the floor with the aid of filter shows the differences in the carving on the surface of the wood. It is possible to see the differences in the area on the right part of the floor, underlined respectively in yellow and red (figure 24). According to the colour information from the first image, the surface of the timber in that area appears to be smoother in comparison to the rest of the floor; the same information can be deduced from the other image. It appears as if the timber has been carved in a different way, or with different tools. Talking with Gunilla Gardelin, curator at Kulturen and building archaeologist, it appears that the area I described has been remade in more recent times (under the 1930s) with modern tools and with different timber.

The model shows clearly the geometry of the surface and the application of different filters and different lights enhance features of the timber, depressions, cuts that would be very hard to identify in a dark environment such as this one.

The 3D model is a reproduction in a virtual environment of a real archaeological feature that can be studied, analysed, measured without the need of being in front of the feature itself. The application of this kind of technology to the archaeological research gives the possibility to recreate a measurable model in a virtual environment to be analysed and used in support of a direct inspection of the monument. The virtual model gives the

possibility to apply the so called "reverse engineering"[87], taking some parts of the object away and simulating different environmental situation (such as light) to see how this affect the object. Moreover, the process is totally reversible and not destructive. The possibility of studying some characteristic of the object and being able, in the same moment, to eclipse other features (such as the colour of the timber in the project I have done) gives the possibility to focus only on one feature without being affected and "distracted" by other characteristics.

In this specific case, the scanning of the entire building allows to reconstruct the entire model for both research and public communication purposes; recreating a part or the entire building gives the possibility to measure, analyse, take orthographic images of a wall or a façade and export those data onto other programs for further study or to the web, for increasing the visibility of a particular historical building or for scientific publication.

12. Future development

The amount of data acquired during the scanning campaign allows building the entire model of the shed. Due to the size of the project and the limited time to develop it, it was not possible to create the entire mesh from the point cloud, but I aligned all the scans obtaining an initial idea of how the complete model will look like. Figure 25 is a screenshot of the point cloud made with all the 39 scans.

The entire model, especially the model of the second floor, can be used for showing the interior of the shed to an audience with disability. The model can be loaded onto the net and everyone can visualize and explore the different parts of the shed from everywhere in the world. In this regard, there are already several websites showing cultural heritage models; for example the Visionary Cross Project[88] is a project for visualizing a group of Anglo-Saxon crosses giving access to the full 3D models of the objects worldwide.

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[87] An interesting book on the reverse engineering is: Eilam, E. 2005. *Reversing. Secrets of reverse engineering*. Indianapolis. Another article talking about reverse engineering applied to historical building is: Cheng, X. J. and Jin, W. 2006. Study on Reverse Engineering of Historical Architecture Based on 3D Laser Scanner. In *Journal of Physics: Conference Series*, n. 48. Pp. 843–849. Available from: http://iopscience.iop.org/1742-6596/48/1/160 (20130503).
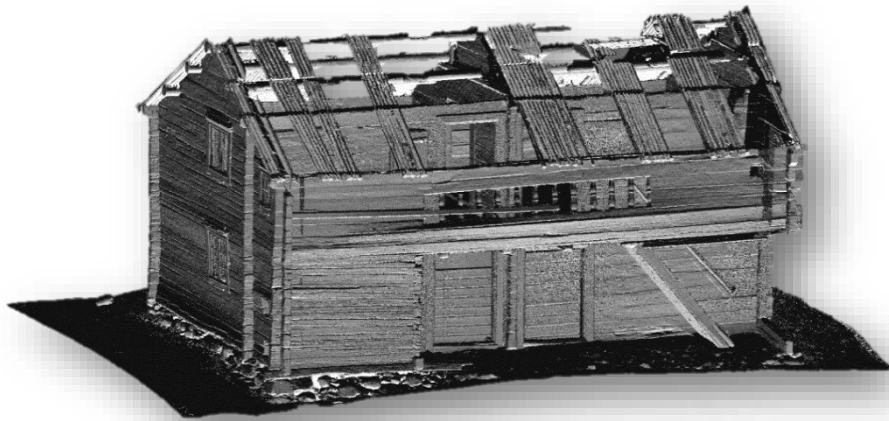[88] Source: http://visionarycross.org/ (20130503).

Figure 25. Point cloud of the entire model.

Another interesting example for showing how the 3D model could be used for web visualization is Cenobium[89], a presentation of Romanesque cloister capitals from south Europe. The website provides both 2D images of the capitals and 3D models that users can navigate freely.

The high detailed models that are done with such an amount of data can be used for a complete survey of all the walls, ceilings and floors of the shed, allowing drawing and recording all the characteristic of it in less time than a more traditional survey and drawing process.

Figure 26 shows the texturing of a part of the room. The main goal for a complete reconstruction of the shed is to create the entire model with the complete texturing.
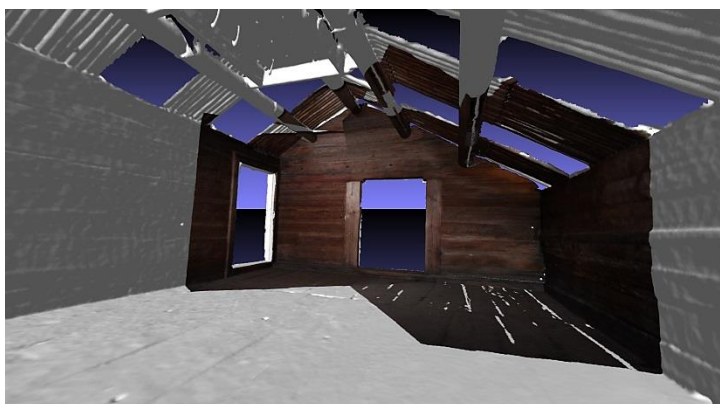

Figure 26. Part of the model of the room textured.

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[89] Source: http://cenobium.isti.cnr.it (20130503).

13. Conclusion

3D Scanning has been used in cultural heritage since the end of the 1990s and it has been a precious technology for helping archaeologists and cultural heritage workers to study and preserve historical and archaeological features all over the world.

The introduction of such technology brought, as we have seen, a new perception of the archaeological feature and the space around it; before the documentation was performed and visualized in two dimensions, while today we can have also the perception of the space around (or inside) a building or another feature. This allow us to experience a new perception of the archaeological feature and open new horizons on both the study and the preservation of the cultural heritage all around the world; the creation of 3D models of historical evidences in danger, for example, gives the possibility to record and share information that most likely could be lost in the near future. Moreover, the storing of those data help scientists to eventually recreate the lost artifact, giving to the posterity the possibility of experiencing if not in the real world, in a virtual environment some lost archaeological objects. Technology and cultural heritage is a combination that is giving, and will give the possibility to increase the interest for the wide public into our past and help the preservation and study of our history.

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