COMPARISON OF TECHNIQUES FOR THE 3D MODELING AND THERMAL ANALYSIS

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Abstract
In this research paper, the comparison of the techniques for the 3D modeling and thermal analysis is done. The 3D modeling is done with the help of the 3D laser scanner, total station and DesignBuilder. So that the 3D model of the building can be compared on the basis of these techniques. To obtain an accurate estimate of the geometry of the vaults, 3D-laser scanning was performed. Based on the 3D-point cloud, a 3D-model of the vault sallow’s determining the lines of thrust in the structure. Thermal analysis and energy analysis are also performed on the 3D model by the different techniques like Thermograms, Designbuilder and Contours. So the comparisons of these techniques are also done in this research paper. The use of thermal infrared(IR) imaging is a valuable tool for inspecting and performing non-destructive testing of building elements, detecting where and how energy is leaking from a building’s envelop, collecting data for clarifying the operating conditions of hard to reach heating, ventilating and air-conditioning (HVAC) installations, identifying with the electrical and mechanical installations under full-load operating conditions. The resultant model is enriched with many points in space like coordinates, temperature, and humidity for the analysis. The aim is to get a comparison results.

Keywords: 3D Modeling, Laser Scanning, Theromography, DesignBuilder.

1. Introduction
In 3D computer graphics, 3D modeling is the process of developing a mathematical representation of any three-dimensional surface of object (either inanimate or living) via specialized software. The building of the urban area is selected to do the modeling on that. This study discusses the application of the visualization capabilities of IR in conjunction with three-dimensional models of buildings. Three-dimensional modeling is a powerful tool for visualizing and representing building conditions that is used by architects, builders, and contractors. Also, a three-dimensional model is better understandable than a more abstract two-dimensional representation (like a floor plan or an image). 3D modeling is done to have the following aspects in mind:
- Flexibility, ability to change angles or animate images with quicker rendering of the changes;
- Ease of rendering, automatic calculation and rendering photorealistic effects rather than mentally visualizing or estimating;
• Accurate photorealism, less chance of human error in misplacing, overdoing, or forgetting to include a visual effect.
• High Quality, Reduction in cost, Quick Turnaround Time, Edge on the competition -- without capital investment.

The goal of building inspections with thermographic systems is to get a fast and reliable objective statement about the condition of a building's thermal insulation. In order to detect covered, structural and architectural weak points early during the construction and to be able to repair it immediately, a building analysis with modern high-resolution thermographic systems by experts is necessary. The infrared thermography tests the surface temperature with the use of infrared detector according to infrared radiation law.

\[ E = \varepsilon \sigma T^4 \]

Where
\( E \) — radiometric force, \( \text{W/m}^2 \)
\( \varepsilon \) — emissivity
\( \sigma \) — the constant of radiation =5.67×10⁻⁸, \( \text{W/(m}^2\text{K}^4 \) 
\( T \) — the absolute temperature of the surface, K

With very clear and significant pseudo-colour visualization, the thermal image evaluation enables the fast detection of insulation faults and avoids expensive damages and loss of energy, which could occur at a later stage.

2. Need of the problem

Proper insulation, durability, air and moisture tightness are key elements for a comfortable and energy efficient building. As a result, it is important to have a continuous, stable, and integral boundary between the conditioned interior spaces and the unconditioned outdoors spaces. It is common today for many professional home inspectors and energy auditors to use infrared imaging technology to evaluate the performance of this “thermal envelope” in the process of conducting energy auditing of homes and buildings.

Common drawbacks of the current application of infrared thermography are that while it provides usable temperature data and renders false-color images, these images are only two-dimensional and in most cases of a very low resolution. In presenting the thermography images to a client, they can be confusing to an untrained eye. Also, the three-dimensionality of a building cannot fully be captured by individual images.

3. Related Work

In cultural heritage documentation, choosing the appropriate technology (sensor, hardware, software), the appropriate procedures, designing the workflow and assuring that the final output is in accordance with the set of technical specifications is always a challenging matter (Patias et al., 2008). The leading parameters are the size and the complexity of the object and the level of accuracy required. These are some of the major factors which may influence the procedure to be adopted. Result from photogrammetry based studies (Grussenmeyer et al., 2002) and guidance to users on laser scanning in archaeology and architecture (English Heritage, 2007) promote the use of these techniques appropriately and successfully.

Generally, 3D data acquisition as well as 3D modeling of cultural heritage monuments can be performed by different approaches, such as analysis of existing plans and elevation drawings, surveying, laser scanning, photogrammetry or computer vision methods (Gonzo et al., 2004). Indeed, whereas several authors advise the use of photogrammetry as an image based method (e.g. Hanke and Oberschneider, 2002; Mayer et al. 2004; Kersten, 2006; El- Hakim et al. 2007), others recommend laser scanning (e.g. Allen et al., 2003).

Advantages of imaging methods are their level of details, economic aspects, portability, handling in spatial limited environment and a short data collection time. Disadvantages remain in the post processing when the texture of the object is poor. Advantages by using an active sensor system like terrestrial laser scanners are 3D survey capacities and the 3D surface acquisition. Nevertheless, this technology is not optimal for capturing linear elements and produces a large amount of data which implies to be reduced for further processing. Consequently, in most cases a combination of the above mentioned methods regarding their benefits may be the best solution (e.g. Fuchs et al., 2004, Gonzo et al., 2004).

Due to the complex structures of medieval castles, commonly used assumptions made on standard architecture, like parallelism, perpendicularity or symmetry are not applicable. Thus, the recording of
such sites results in a huge amount of data and consequently the question of automation comes up. Whereas classical photogrammetry implies a heavy amount of manual and very time consuming interaction (e.g. Hanke and Oberschneider, 2002; Grussenmeyer and Yasmine, 2003), unfortunately the automation around laser scanning acquisition and data processing is really developed. Several parameters effect thermographic measurements namely emissivity, reflectivity, environmental conditions, colour, etc. To evaluate the influence of some of these parameters, simple tests are carried out using the LFCs thermography equipment, both in laboratory and “in situ”. One of the laboratory test consists of partially immersing two identical specimens of cellular concrete in water followed by a drying period. The tests are performed under steady-state conditions, in two climatic chambers with different temperatures and relative humidity. Thermal images were obtained during each test, using four different values of emissivity: 0.62, 0.85, 0.91 and 0.95.

4. Methodology

Fig. 1. Flow chart of the Methodology
The methodology is very simple. In this methodology, the 3D modeling is done with the help of the three techniques is shown in the appendix I. It is done with the help of 3D laser scanner, AutoCAD and Designbuilder. 3D laser scanner used is HDS 6100 Leica. The parameters that are input into the scanner are horizontal and vertical angles. It takes all the points around itself horizontally but in vertical it has some limit, it can take 270° only. So six stations have been made to cover two buildings and also three artificial points with each station. Six stations are the known GPS control points. The software used is Cyclone for the post processing and also to export the data to the AutoCAD format but it can be processed in the add-on of the AutoCAD i.e. Cloudworx. In the Cloudworx, the polyline can be drawn to get the 3D model of the buildings.

Geographical Positional System is used to get the co-ordinates of the some prominent points. By using these control points, the position of the total station is found out. The points on the building are taken with the help of the total station. Then the Decatop software is used to find all the points with respect to the ellipsoid. Then the points are exported to the AutoCAD to make a 3D model of the building. Hygrometer and thermometer is used to find the humidity and the temperature of the points in the building at a distance of 1 meter distance. The MNT is created with these points in the AutoCAD to find the thermal analysis of the building. It is like contours which show the difference of the temperature with the distance.

The laser distance meter is used to draw a 2D map of the building. The 2D map is transferred to the Designbuilder software. The heights of the objects are calculated with the help of the laser meter and the 3D model is created in the Designbuilder. Designbuilder shows the results in the form of 3D model, heating and cooling calculations and simulation results. Thermal analysis is done with the help of the FLIR E series camera. The photos are clicked with this camera. Then the analysis is done on the thermograms to find the defects and leakages in the building. As liquids evaporate they draw heat from their surroundings. Therefore wet/ damp spots are typically colder than their surroundings. The thermal imager sees those temperatures differences, even if it is less than 0.1°Celsius. Cold air can contain less moisture than warm air. Moisture always condenses on the coldest place/ spot. A cold spot will be an indicator that damp might be present. When the water dries in a wet piece of clothing the piece becomes colder than the ambient around it from where it takes the energy for the evaporation process to takes place.

The 3D model is created with the thermal and energy analysis. This model contains the temperature at each point. So it can be used for the analysis purpose. Now the 3D model is enriched with many points in space and temperature and humidity also. The temperature points are like contours, it is MNT of temperature and humidity for the analysis.

### 5. Limitations of every Recording Instrument

#### 5.1. Limitations of the involved Terrestrial Laser Scanning

The biggest part of the building as well as the surrounding gaps and the main parts of the fortifications have been captured by TLS via 6 stations. The scanner has been set up and oriented over known geodetic points belonging to a 3D network of about 25 points. Therefore, the point clouds were directly geo-referenced and can already be visualized in the field.

<table>
<thead>
<tr>
<th>Data</th>
<th>Instrument</th>
<th>Amount Of Data</th>
<th>Accuracy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Laser Scanner</td>
<td>HDS 6100 Leica</td>
<td>25 million points all around the building</td>
<td>5 mm, 1 m to 25 m 9 mm to 50 m range</td>
</tr>
<tr>
<td>Total Station &amp; GPS</td>
<td>Trimble M3 3° DR</td>
<td>100 points (1 day); Eastern façade (windows), Doors</td>
<td>2°Prism ±(2+2 ppm × D) mm 2°Reflectorless ±(3+2 ppm × D) mm 3°,5° Prism ±(3+2 ppm × D) mm 3°,5° Reflectorless ±(3+2 ppm × D) mm</td>
</tr>
<tr>
<td>Leica GPS 1200+</td>
<td>30 Control Points</td>
<td>6/7 mm in E,N and 15 mm in h</td>
<td></td>
</tr>
<tr>
<td>Designbuilder Laser Meter Leica DISTO A5</td>
<td>-</td>
<td>Range 5cm-200m. Accuracy ±2mm.</td>
<td></td>
</tr>
<tr>
<td>Thermohygrometer Testo 625</td>
<td>-</td>
<td>Meas. Range -10 to +60 °C Accuracy ±1 digit ±0.5 °C</td>
<td></td>
</tr>
</tbody>
</table>

Table 1. Overview of the instruments used for acquisition and summary of the amount of data recorded.
5.2. Limitations of the surveying data

Of course tacheometric measurements were indispensable not only for providing a geodetic network, but also for acquiring control points on the façade. Moreover, especially the windows have been captured by this technique, in order to provide a skeleton plan representing the outlines of significant objects or contours (windows, doors, etc.).

6. Energy analysis

To be operated to maintain user comfort and functionality, a building needs a defined amount of energy that has to be supplied. In order to estimate the amount of energy that is needed, an energy balance has to be set up. The demand side is calculated, cumulating energy losses such as transmission and ventilation heat losses of the building envelope. These losses can be fully or partly compensated by the energy gains. Different sources of energy gains can be utilized. Internal energy gains caused by appliances and users as well as solar gains through openings diminish the amount of heating energy that has to be supplied. Additional energy input is needed for lighting, ventilation and for the operation of building systems. Deducting gains from the overall losses results in the overall energy demand which has to be delivered.

![Fig. 2. Implemented energy mode](image)

Six key performance indices are calculated to display the energy performance of the building. These indices serve as an estimate to show the energy performance of the specific building design at the maximum temperature difference on a specified location. Most of the necessary input parameters such as geometry and masses, component properties and dependencies are automatically taken from the building information model. The parameters for the design of the heating system are defined in the tool interface. To simplify user input, some parameters of lesser impact on the overall performance are defined as static parameters. Contrasting to the underlying regulation, the heating energy demand is calculated for steady state conditions. The focus is on the energy demand at a maximum temperature necessary to layout the heating system, not on the annual energy demand the regulation aims for. Also contrasting to the regulation, the energy demand for domestic hot water is neglected. Following key performance indices are calculated:

6.1. Transmission heat losses of the envelope

All information about the geometry of windows, walls, roofs and floors is taken directly from the building model as well as the specific u-values of wall and window objects. Indoor ($\theta_i$) and outdoor ($\theta_o$) temperatures to layout the heating systems are defined by the location of the building. The total transmission heat loss is the sum of the heat losses of all envelope surfaces. Heat bridges are not considered.

\[
q_T = \sum (F_{kl} \cdot u_k \cdot A_k) \cdot (\theta_i - \theta_o) \text{ [W]}
\]

The temperature correlation factor $F_{kl}$ enables using the same design temperature difference for the calculation of parts facing different environmental conditions. This factor is set according to the regulations to 1.0 for exterior walls and roofs and to 0.6 for walls and floors facing the ground. Winter gardens, attics and unheated rooms are neglected.
6.2. Ventilation heat losses

A simplified formula captures the ventilation heat losses. The overall volume V is taken from the building model and multiplied by the air exchange rate \( n_{el} \). The specific heat capacity of air (0.34 W h/\( \text{m}^2 \text{K} \)) is taken into account.

\[
\dot{Q}_v = (0.34 \cdot n_{el} \cdot V) \cdot (\theta_1 - \theta_2) \quad \text{[W]}
\]

6.3. Solar heat gains through windows

The maximum amount of solar radiation is defined by the geographic location of the building and orientation of the opening. In dependency to opening surfaces \( A_{wind} \), the solar radiation heating up the building inside is calculated for every window. The g-value (total solar transmittance) of the windows defines the energy input of solar radiation passing through a specific glass.

\[
\dot{Q}_s = \sum (I_{ej} \cdot A_{wind} \cdot g_{Lj} \cdot F_{Gj} \cdot F_{W,j} \cdot F_{C,j} \cdot F_{S,j}) \quad \text{[W]}
\]

Four correction factors consider possible shading by shading devices \( F_c \), shading by surrounding buildings \( F_b \), non-orthogonal solar radiation \( F_{W,j} \) and window framing \( F_{C,j} \). To simplify parameter input, these factors are set to standard values according to the regulations, resulting in a cumulated correction factor of 0.567.

6.4. Internal heat gains

Internal heat gains caused by humans are stored as static parameter within the occupancy parameter \( n_{oc} \) of the room. In this approach, the heat gain per person \( \dot{Q}_{i,\text{h}} \) was set to a mean value of 80 W. It is multiplied by the statistic number of occupants. In order to simplify parameter input, the specific heat gain by electrical appliances \( \dot{Q}_{i,\text{a}} \) was set as static value for all rooms. It is multiplied with the room area. To capture different building types, this static value can be adapted.

\[
\dot{Q}_{i,\text{h}} = \dot{Q}_{i,\text{h}} \cdot A_{\text{r}} \quad \text{[W]}
\]

\[
\dot{Q}_{i,\text{a}} = \dot{Q}_{i,\text{a}} \cdot n_{\text{a}} \quad \text{[W]}
\]

6.5. Specific lighting power/lighting power

The calculation of the specific lighting power is taken from the Swiss regulation SIA 380/4. The necessary illuminance \( E_{\text{ne}} \) of each room defines the specific lighting power. In relation to the type of artificial lighting and its specific light efficiency \( \eta_{\text{fl}} \), the specific lighting power is calculated. The calculation includes factors of usage and aging \( \eta_{\text{a}} \), for the efficiency of the lamp \( \eta_{\text{el}} \) and specific room characteristics such as reflectivity and room geometry. These factors are set to standard values dependent on the type of artificial lighting in accordance to the regulations.

\[
P_{\text{fl}} = \frac{E_{\text{ne}} \cdot \eta_{\text{fl}}}{(1 + \eta_{\text{a}} \cdot \eta_{\text{el}})} \quad \text{[W/m}^2\text{]}\]

Resulting, the necessary lighting power is

\[
\dot{Q}_{i,\text{fl}} = P_{\text{fl}} \cdot A_{\text{r}} \quad \text{[W]}
\]

The specific lighting power is also added to the internal heat gains. Additionally, the auxiliary electrical energy for ventilation based on the internal volume is calculated and added to the total electrical energy consumption.

6.6. Resulting heat demand

All heat flows including gains and losses are summed up to create the heating energy balance:

heat demand = sum of heat losses-sum of heat gains

\[
\dot{Q}_{\text{e}} = (\dot{Q}_v + \dot{Q}_s) - (\dot{Q}_{i,\text{h}} + \dot{Q}_{i,\text{a}} + \dot{Q}_{i,\text{fl}} + \dot{Q}_{i,\text{f}}) \quad \text{[W]}
\]
6.7 Exergy

The common definition of energy utilization refers to the first law of thermodynamics which states that energy is stored in every device and process and can neither be consumed nor destroyed; it can only be transformed. For a more detailed analysis of energy flows in buildings, this concept is “inadequate for depicting some important aspects of energy resource utilization”

7. Comparison and quality assessment

Aim of this section is to compare the models derived from the different techniques. For comparing laser and surveying data, a point to point comparison makes no sense, since laser scanning technique does not allow choosing the point to be measured.

7.1. Comparison of the three techniques based on wireframes

Each wireframe is composed of 19 windows which contour lines have been digitized on each data set. Thus, a wireframe produced by point cloud digitizing has been compared to tacheometric data. In the same way, the photogrammetric model has been compared to laser scanning model and to surveying model.

Then, the 3D distances between each wireframe have been computed and analyzed. Results showed that the detection quality or the similarity between models must be related to the type of window. More particularly, laser scanning and survey models show the lowest deviations for rectangular reveal windows.

The main reason is the difficulty to measure the circular and chamfered parts of that kind of windows by tacheometry. On the other hand, the laser scanning enables to acquire each little detail, like for instance the sandstone linings of the windows. Globally, the absolute accuracy of every model is in agreement with the inherent accuracy of the geodetic network, i.e. +/- 5cm. Additionally six object edges have been analyzed to compare photogrammetric and laser scan recording.
To derive the edges from the TLS point cloud, adjusted planes had to be estimated in a local area left and right of the edge. By intersection of these two planes the particular edge can be determined and compared to the corresponding edge in the photogrammetric restitution. To determine the deviations, the mean distance between the photogrammetric edge points and the laser derived edge has been calculated. Dependent on the regularity of the edge the mean distances vary between ± 2.0 cm and ± 3.7 cm. Due to the typical characteristic of the edges of a medieval building the photogrammetric edge points lie closer to the object than the laser derived edges which lie slightly outside the building. Globally the 3D distances calculated between the three models are similar with respect to the tolerances fixed by the specifications (± 5 cm in X, Y, Z). So, the results of this wireframes comparison confirm that the 3 techniques – conventional surveying, laser scanning, photogrammetry are in accordance to the accuracy required for the documentation of the building.

7.2. Comparison of the three techniques on Thermography

The measurement of temperature remotely and assigning a colour based on the temperature. Thermal imaging is a science of seeing temperature patterns using special electronic cameras. Rather than seeing light, these remarkable instruments create pictures of heat and cold. They measure infrared (IR) energy and convert to data to images corresponding to the temperature.

After partial renovation, this home still consumes too much electricity for heating. Among other defects embodiment, the thermal imager detects immediately the absence of insulation on the full height of the room. It is a defect with absence of voluntary control over the site.

Pavilion Concrete beams. Vertical wall isolation. The right side of the ceiling is topped by a terrace (no insulation) and presence of a little winter sun, which one benefits while he is there. The left side of the cap includes a heated room. The beam directly on the outside edge and creates a thermal-time, which would be in "hot" thermography from outside.
Thermography from inside shows that air penetrates between the masonry and the frame (detail right) – natural ventilation – and the window is not in question. Silicone sealant to correct the structural deficiency: non compliance with DTU. This problem is extremely common.

Salon nine (in the extension of a flag) heated, but not yet occupied. Failure classic made by the electrician entry of cold air through an outlet. The door did not show such a failure while this is more than one would expect to see from air intakes natural ventilation.

This finding need for housing depression by the technique of “blower door” became a classic control habitat for awarding the label “low-energy building. The air intake under the front door is important, but more surprising is the air intake under the wall itself.

Designbuilder also gave us many results like heating and coolings calculations and simulation results. The heating calculation is done by considering 12 march 2010. Determine the size of heating equipment required to meet the coldest winter design weather conditions.

The cooling calculation is done by considering 12 march 2010. To determine the capacity of mechanical cooling equipment required to meet the hottest summer design weather conditions. Weather data comes from Hourly weather data file. Includes consideration of heat conduction and convection between zones of different temperatures. Includes solar gain through windows.
one or more ‘warm-up’ days to ensure correct distribution of heat in building thermal mass and the start of the simulation. Warm-up continues until temperatures/heat flows in each zone have converged.

The MNT’s are created with the Covadis 3D. It shows the variation of the temperature inside with the help of the contours. It shows the defect in the building if it is present in it. In the MNTs the contour line are drawn with the interval of .2°C. After each 5°C, there is one different colour line of contour. So if there is irregular line of contours it shows the fault. This can be seen in the conference hall of the ground floor in Figure 19.

In the Figure 20, the fault can be seen in the laboratory area. It is just in the left most cabin.

This is the 3D model of a building with surface temperature. It is used for finding different defects in the building.

8. Conclusions and Future Challenges

In this research paper, the thermal analysis of the buildings is done; we have come to know about the various defects which are still present there. These defects are represented by the analysis of the thermograms. Thermal analysis can be best done with the help of thermograms. 3D view has given us different views to analyze the building. The temperature of all the points can be find out by these techniques. In the model, the laser scanning method is very fast and accurate. The other method like Total Station and Designbuilder are also very fast but it is very quick to get the models. In the thermal analyses, Designbuilder, given a very accurate results with the accuracy of 0.5°C. The Thermohygrometer is also used to draw MNT of the temperature and it shows the same results as from designbuilder.

Many future challenges exist, e.g., a safety analysis system based on four dimensional(4D) technology will be developed for dynamically safety analysis during the entire process of construction, improving the accuracy and efficiency when generating a structural model from complicated architectural model. Analysis of support system and automatic alteration of construction plan according to the results are also expected in the future.
9. Bibliographical References


