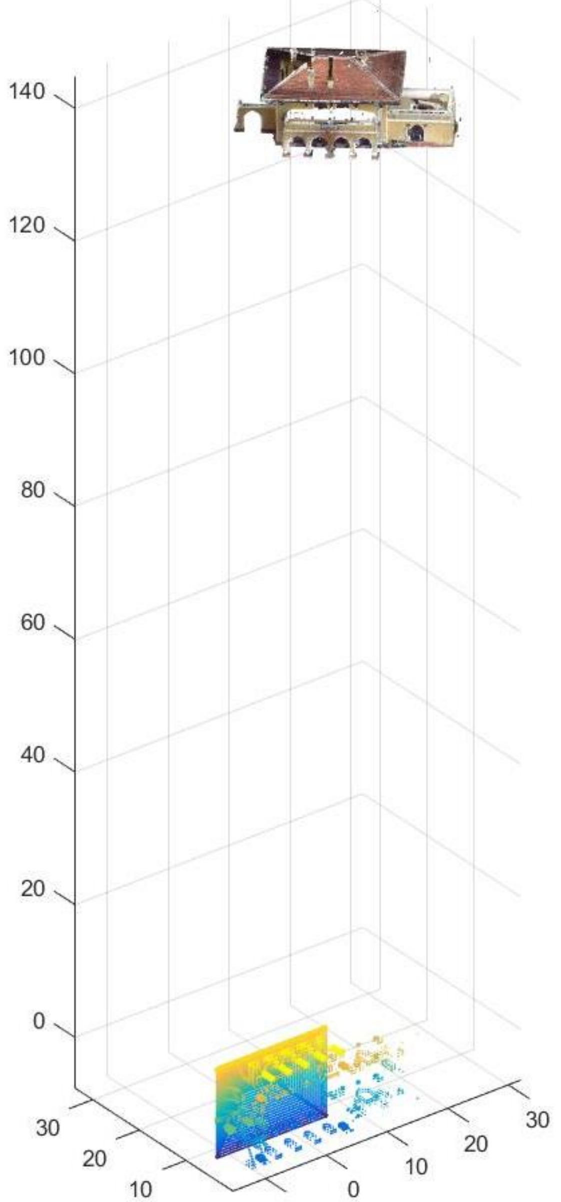
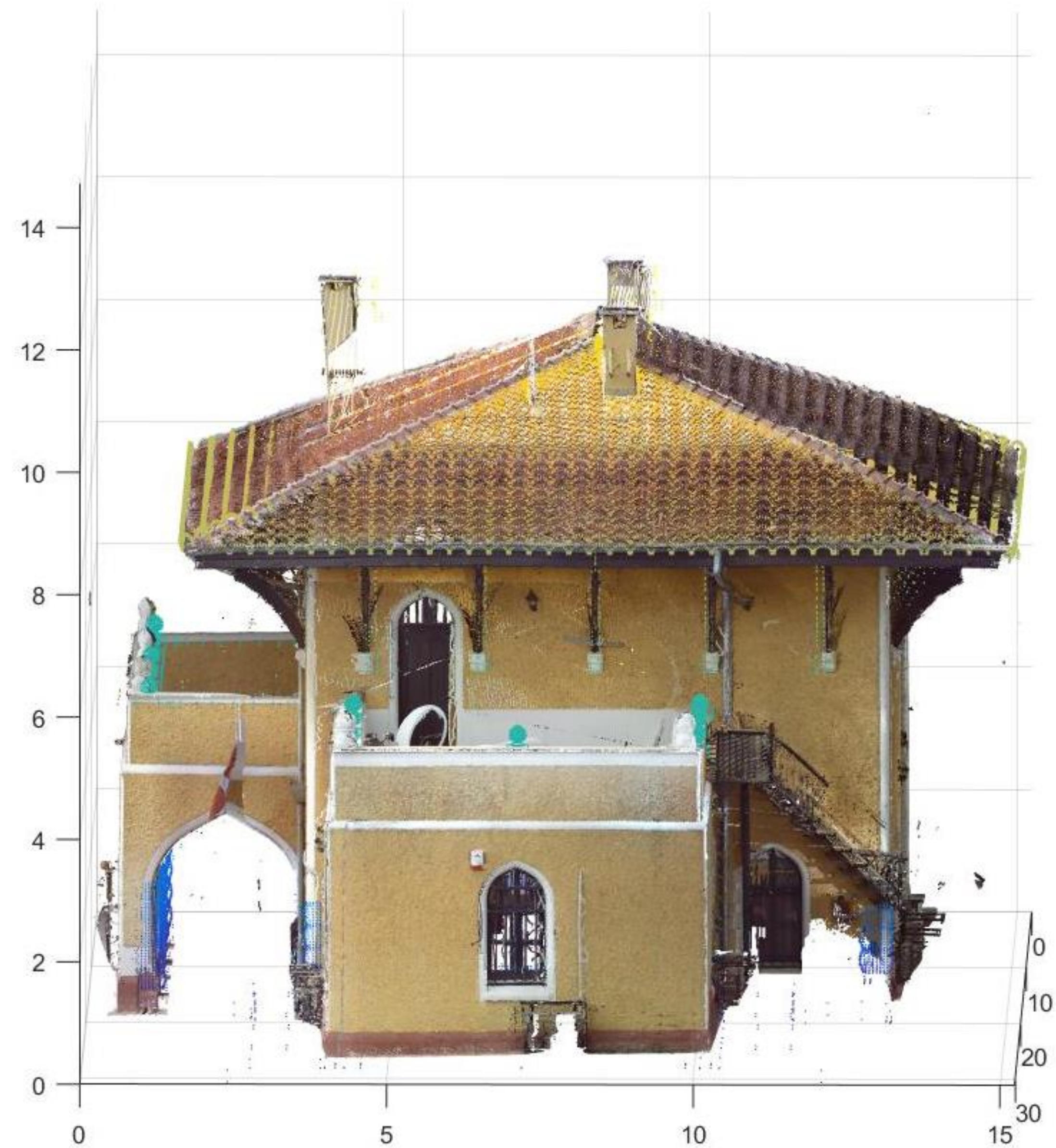
Data Auralization of 3D Point Clouds

The University of Rochester's Architectural Biometrics team initiated a collaborative effort with the AME department to sonically interpret massive datasets produced in their 3D scans with the FARO Focus^{3D} Laser Scanner. The initial effort consisted of a comparison between two scanned models in an attempt to identify differences between the structures. However, after some deliberation it was decided that perhaps a more effective method (or one that could yield more interesting results) would be to compare a scanned model with a platonic model, designed directly from the original blueprints, constructed in 3D architecture software and converted to the relevant point cloud format. Some initial questions and challenges that arose dealt mainly with the normalization of the data – the essential problem seemed to be determining a method of interpretation and auralization that didn't result in random noise signals. Other smaller issues manifested themselves throughout the project and will be explored in more detail but ultimately, the goal of formulating a comprehensive sonic representation of the differences between a scanned point cloud and the original architectural drawing was achieved.



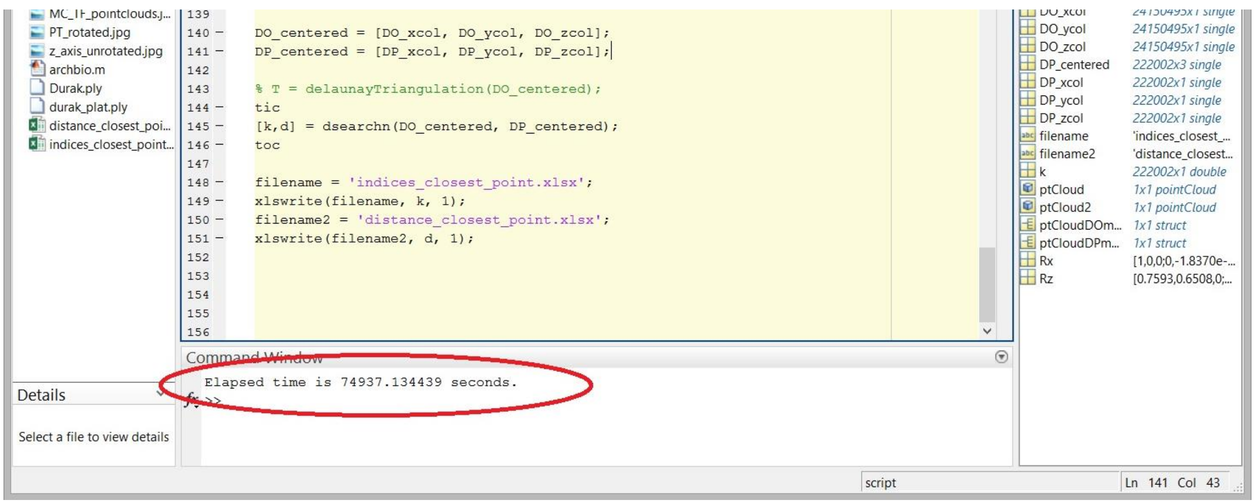
The figure on the left demonstrates one of the first hurdles encountered in the project. Many of the models, when imported into Matlab, had different orientations and relative positions. In order to effectively measure the differences between models, it is necessary to first ensure that they are on the same plane and aligned properly with one another. In order to achieve this, the x, y, and z components of each model's point data are isolated and operated on individually. Figure (2) of the appendix shows the translation of the z components of the original Durak train station scan in order to bring it within range of the platonic model. Figure (3) shows the result of a rotation matrix being applied to all points of the platonic model in order to rotate it 90° about the x-axis so that it is oriented "upright" according to the original scan. Lastly, figure (4) shows a rotation matrix applied to the original scan in order to align it with the platonic model. In this figure, both models have been translated such that they are in the first quadrant of the x-y plane.

The next step involved aligning the models so that they sat one atop the other, in order to take accurate measurements to determine the differences between the two. To achieve this, the center of mass of each model was calculated and then the original scan was translated so that its center of mass corresponded to the center of mass of the platonic model, thus ensuring both were aligned. The figure below shows the "eastern" face of the models (looking from the first quadrant into the second quadrant). Here we can already see some ways in which construction differs noticeably from the architectural drawings. Figures (5), (6), and (8) of the appendix further show some interesting deviations from the blueprint.

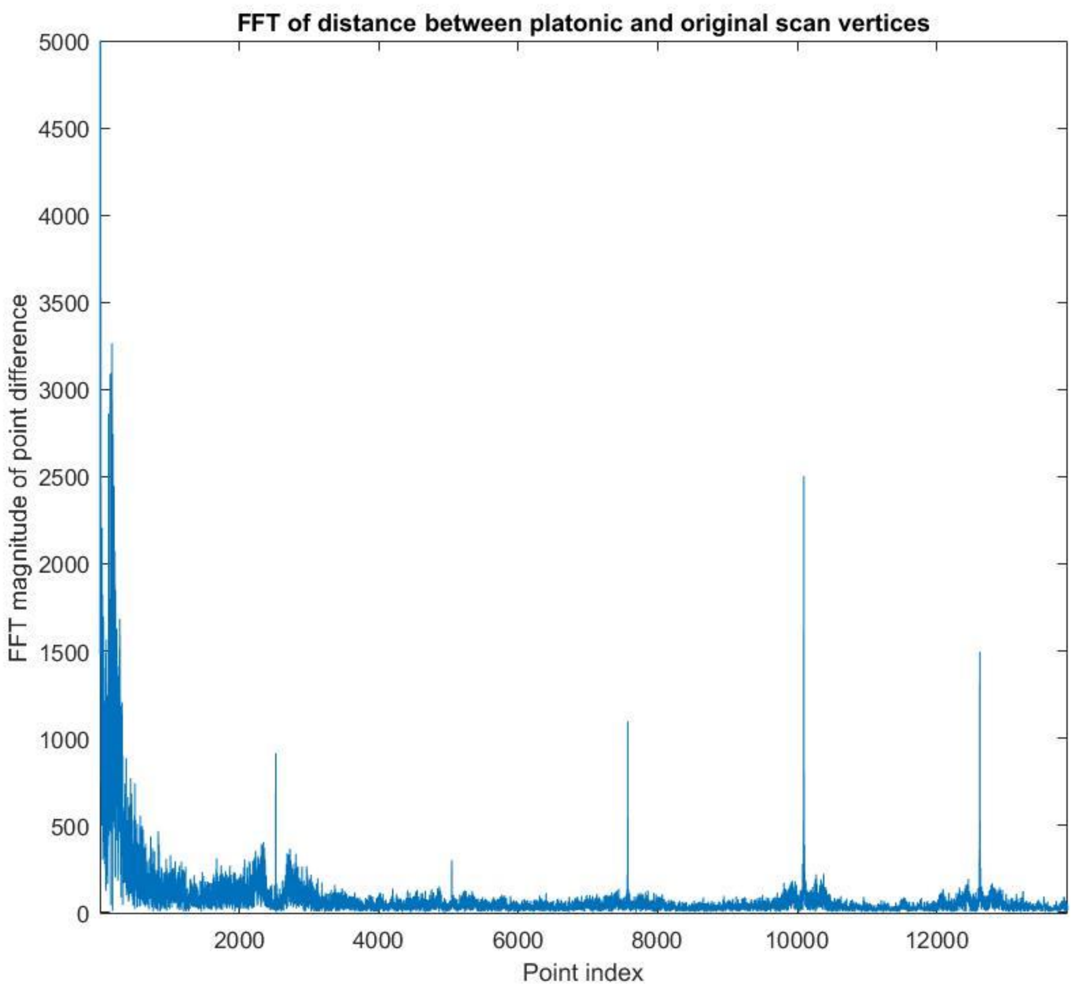


With these challenges addressed and the models properly aligned and centered, all that was left was to determine a set of criteria for measuring differences between the models and auralizing the results. The first issue encountered was the method for measuring differences – the platonic model was created in Blendr, but upon being exported to .ply format lost its point cloud population for faces so that only the vertices in the model were represented, which ruled out an idea for auralization that had depended on the presence of data for the faces of the models. There is also the presence of “shadow regions” on the original scan; there are regions in the roof and balcony that are missing data simply because the orientation of the camera did not permit a comprehensive scan. Naturally, the difference calculations in these areas will produce drastic results, when in fact the deviation from the original design may not have been so noticeable, or even not present at all. Lastly, Matlab seems to assign arbitrary scaling units to the .ply files, so that it is difficult to say whether the graphs show units of meters or feet (neither seems likely when taking into account the dimensions of the building) and thus the “distance” measurements are simply scalars.

Since it would have taken more time than was available to attempt to populate the missing regions with point cloud data, the erroneous measurements would be included in the final comparison, if only to demonstrate the capabilities of the auralization criteria. In a scenario in which it becomes necessary to have highly accurate measurements, it is possible to isolate and ignore the cases in which there are missing regions of data. Thus, the next stage consisted of measuring the distance from each point in the platonic model to the nearest point in the original scan and storing the matrix index. Considering the fact that the smaller model contains 222002 points of 3D data, and that the larger model is two degrees of magnitude greater in size, it isn’t surprising that this stage of the code took nearly 21 hours to execute (74937.134439 seconds according to Matlab’s internal timer).

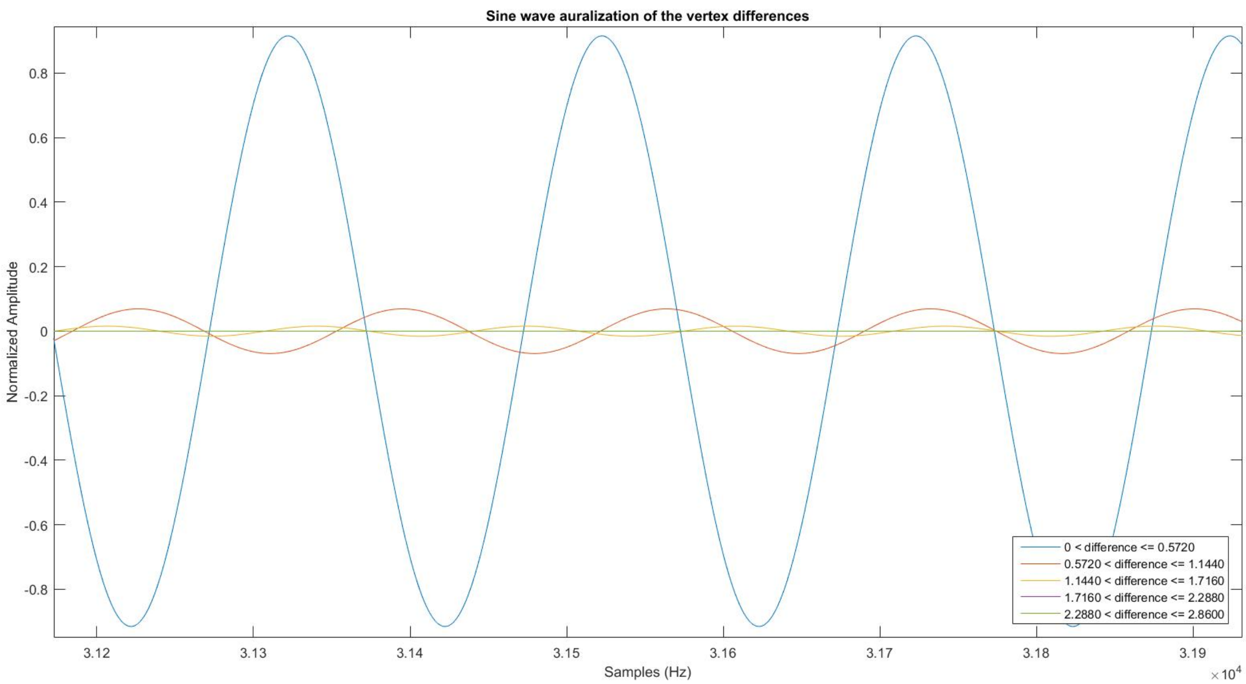


The final decision for the auralization was that the difference measurements would be grouped according to some pattern in the Fourier transform and assigned a particular frequency in a stack of minor thirds. The idea is that, if the Fourier transform had seven peaks, each peak region would be assigned a note in a minor 11th chord such that the greater the distance was between the points, the more dissonant the resulting chord would be. Once the differences between the vertices of the platonic model and the nearest points of the original scan had been calculated, a Fourier transform was performed on the data in order to determine how many regions should be calculated for the resulting chord.



A brief inspection shows 5 peaks, which corresponds to a minor 9th chord according to the criteria. The maximum calculated difference between the models was 2.8542 and thus the matrix of difference measurements is sorted such that the values fall into bands of equal $\frac{2.8542}{5} = 0.572$ unit width. The chosen key was A minor (A3 base) simply because it starts at 220 Hz; the second frequency is 261.63 Hz, the third is 329.63, the fourth 392, and the fifth 493.88. These frequencies were represented as pure sine tones, and the amplitude of each tone was determined by the number of points which fell into a specific band divided by the total number of points.

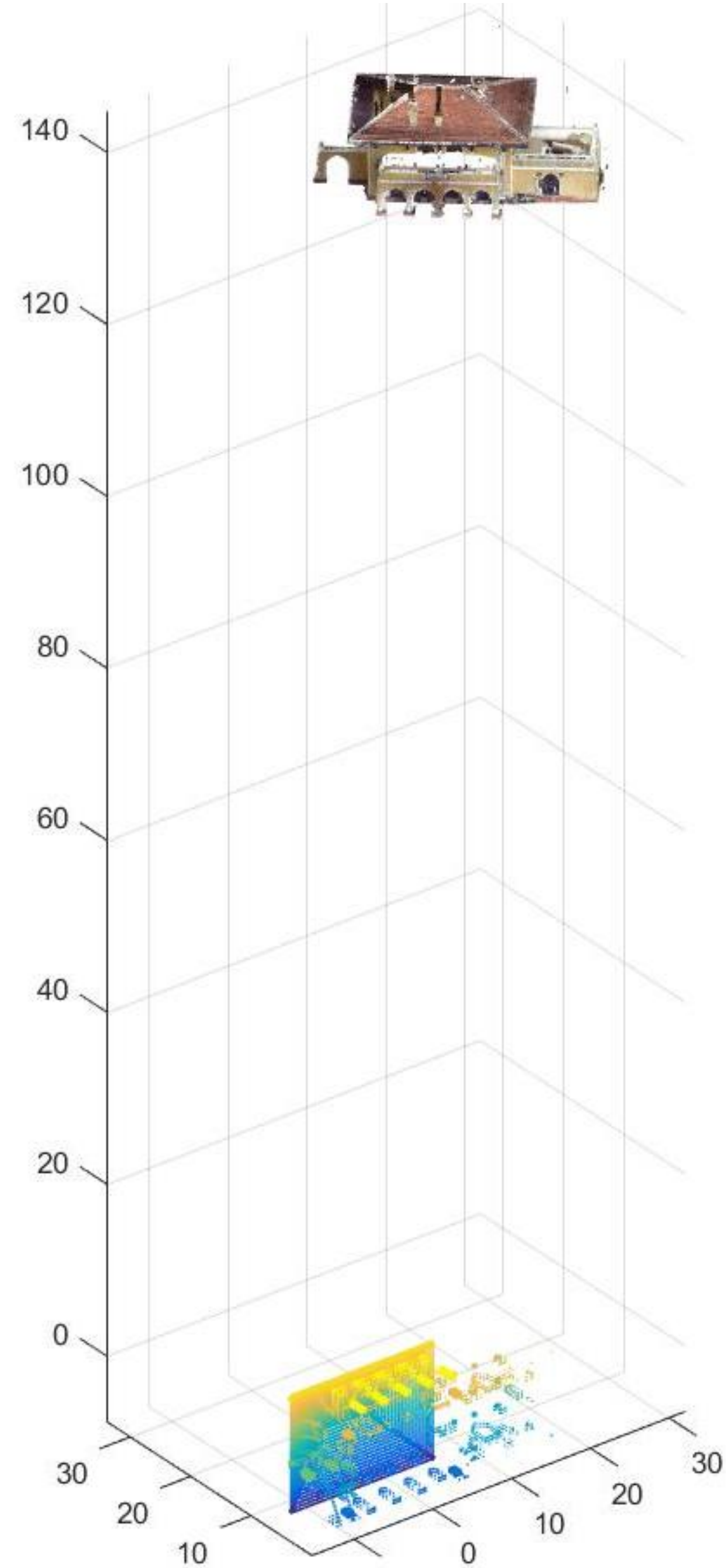
Thus, the lowest band (difference measurements from 0 to .572) correspond to the first note in the chord, A3 (220 Hz). The next band (difference measurements from .572 to 1.440) correspond to C4 (261.63 Hz), and so on, thus making the chord more dissonant the bigger the differences are. Below is a graphical representation of the sine waves as they appear individually. Notice that the fourth band (difference measurement 1.7160 to 2.2880) has no signal; this is because the amplitude for this band (the ratio of the number of elements per band to the number of total elements) was almost 0.



From the figure it is clear that most of the measurements fell in the first band (difference of 0 to .5720). Had we decided to ignore the missing data regions on the roofs and balconies, we may have had a more nuanced representation and possibly more peaks in the FFT, thus changing the distribution of the difference measurements and yielding a more dissonant chord. Overall, the criteria and method used to auralize the data seem to be comprehensive enough, though the lack of efficiency in dealing with massive point clouds means that this will probably not be a widely practiced application for some time.

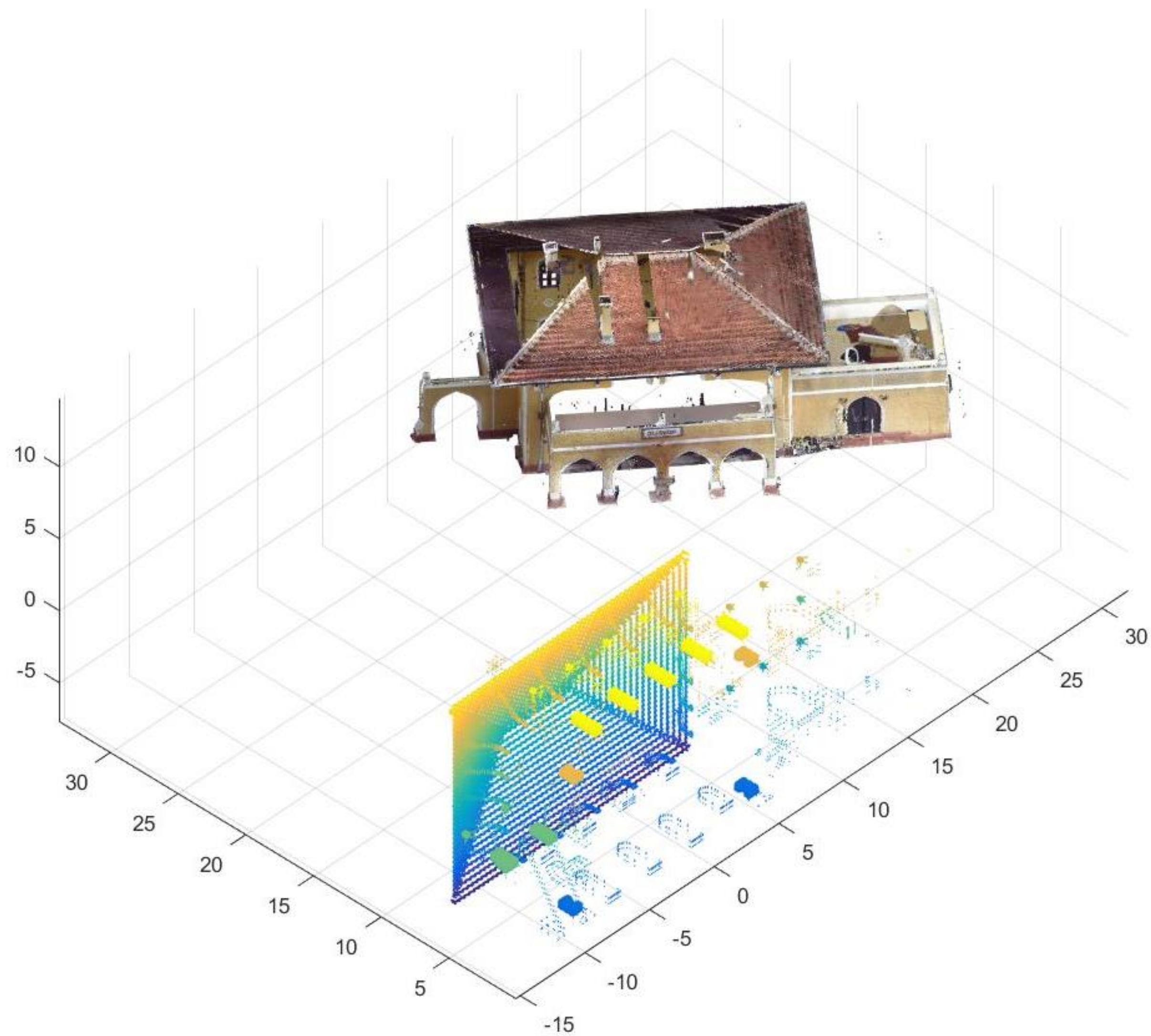
Appendix

Figure (1)



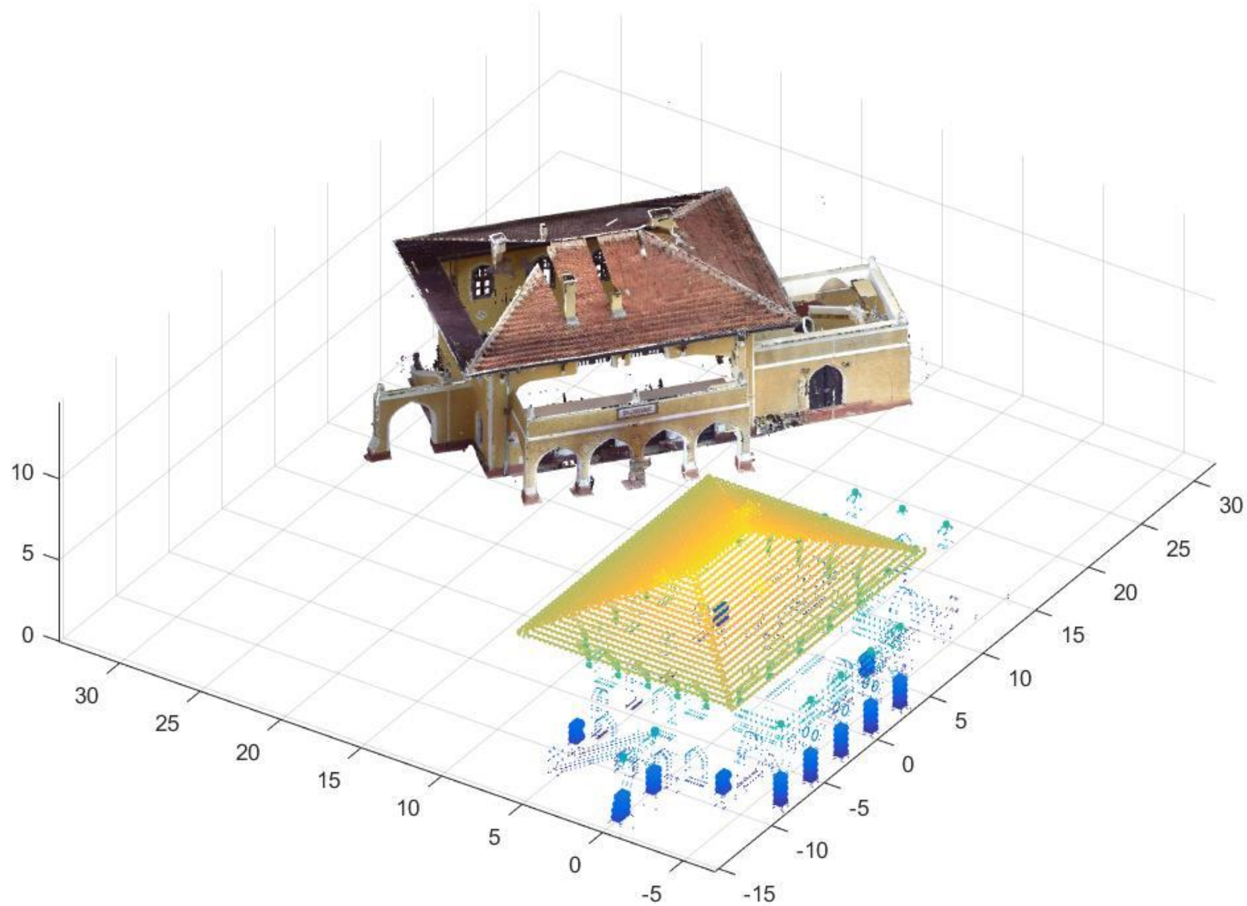
The models as they are imported

Figure (2)



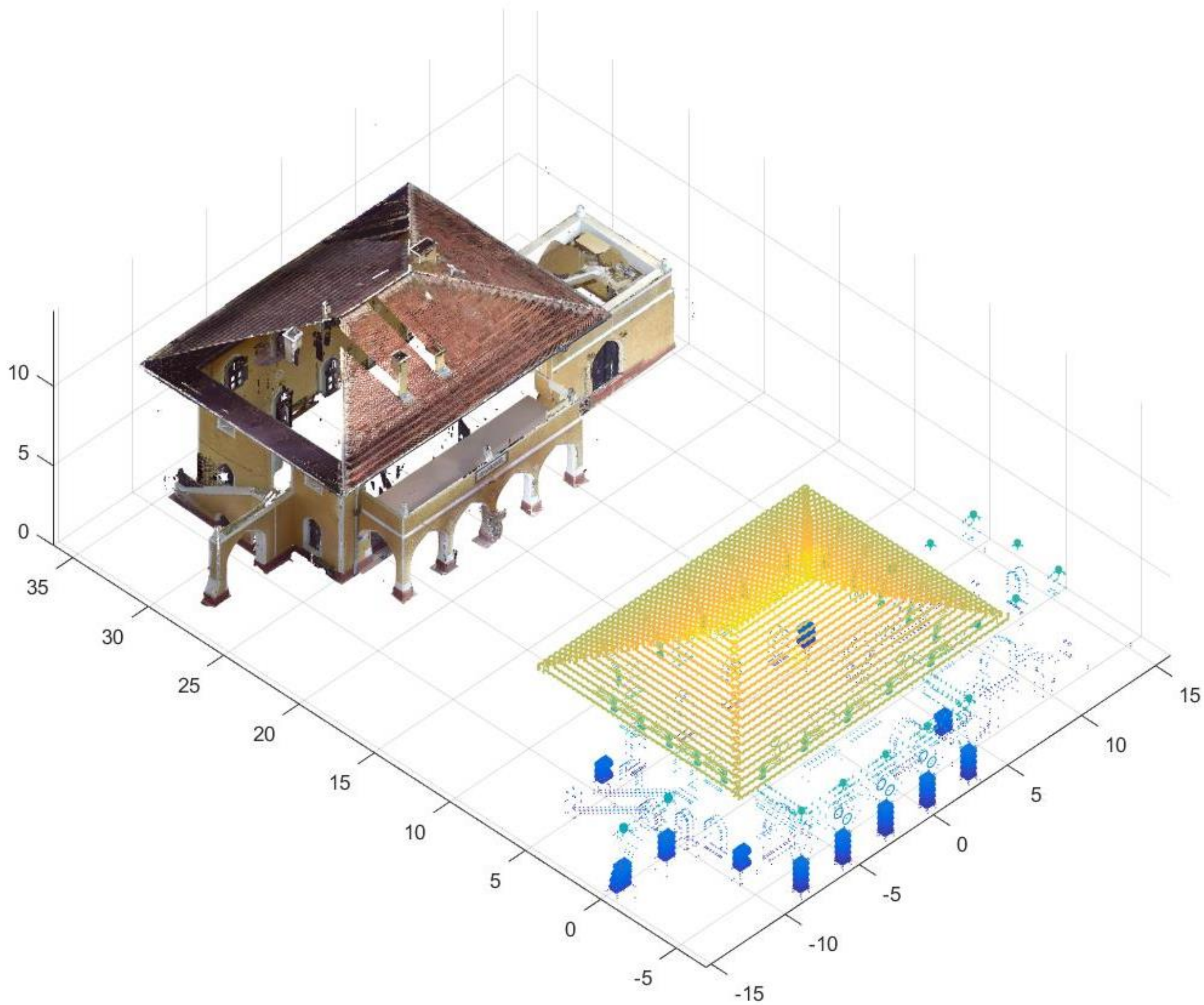
Constraints applied to the original scan in order to orient it to the same x-y plane as the platonic model

Figure (3)



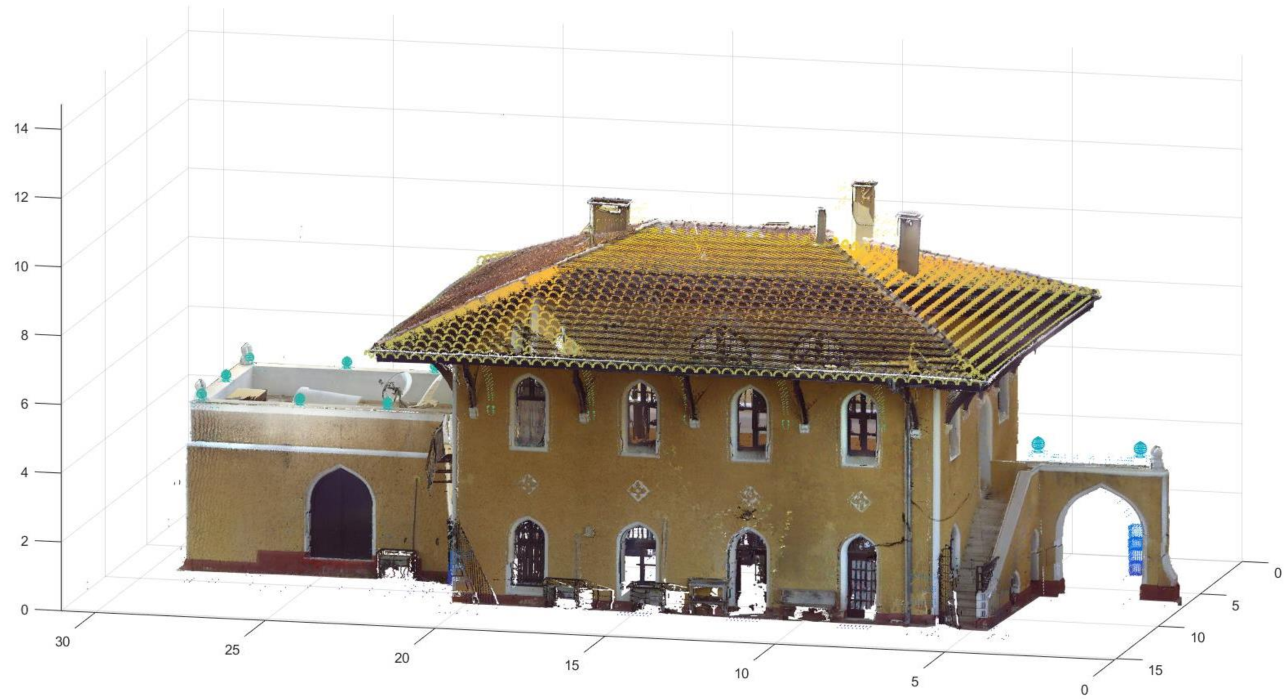
Rotation matrix applied to the platonic model in order to orient it "upright" with respect to the original scan

Figure (4)



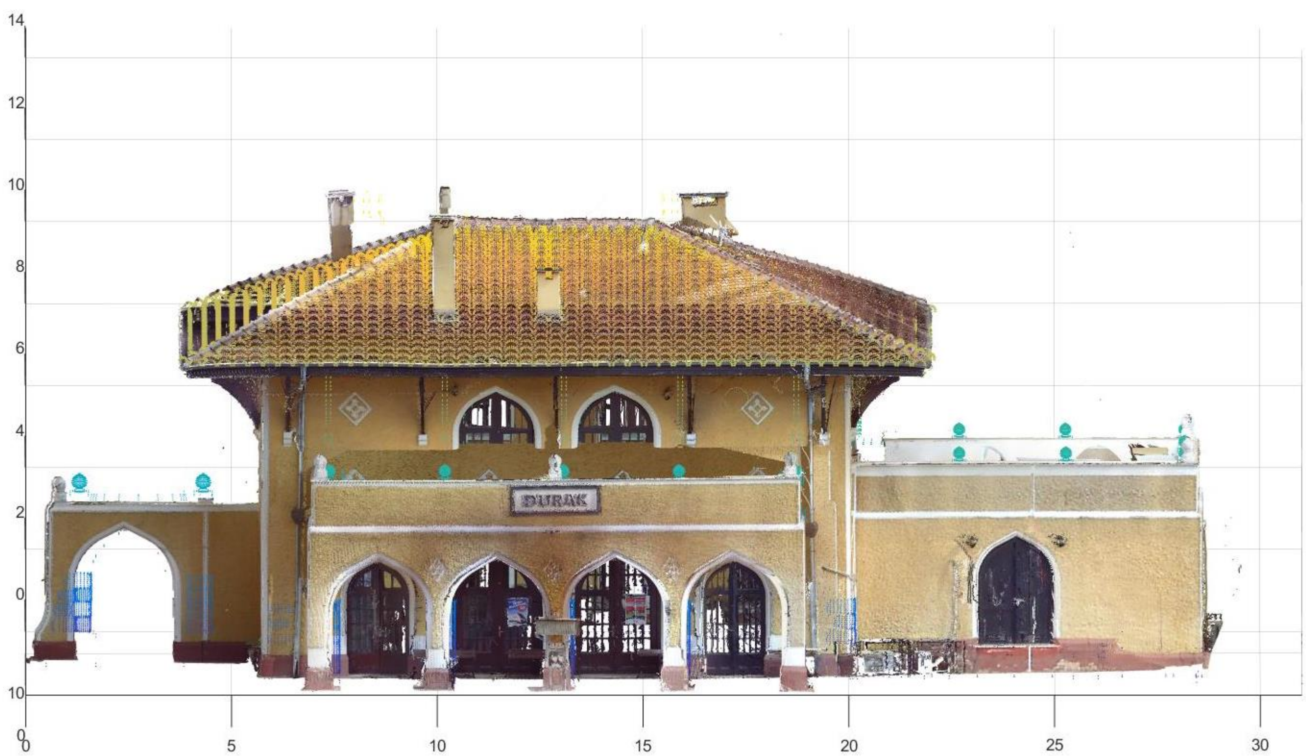
Rotation matrix applied to the original scan in order to align it with the platonic model

Figure (5)



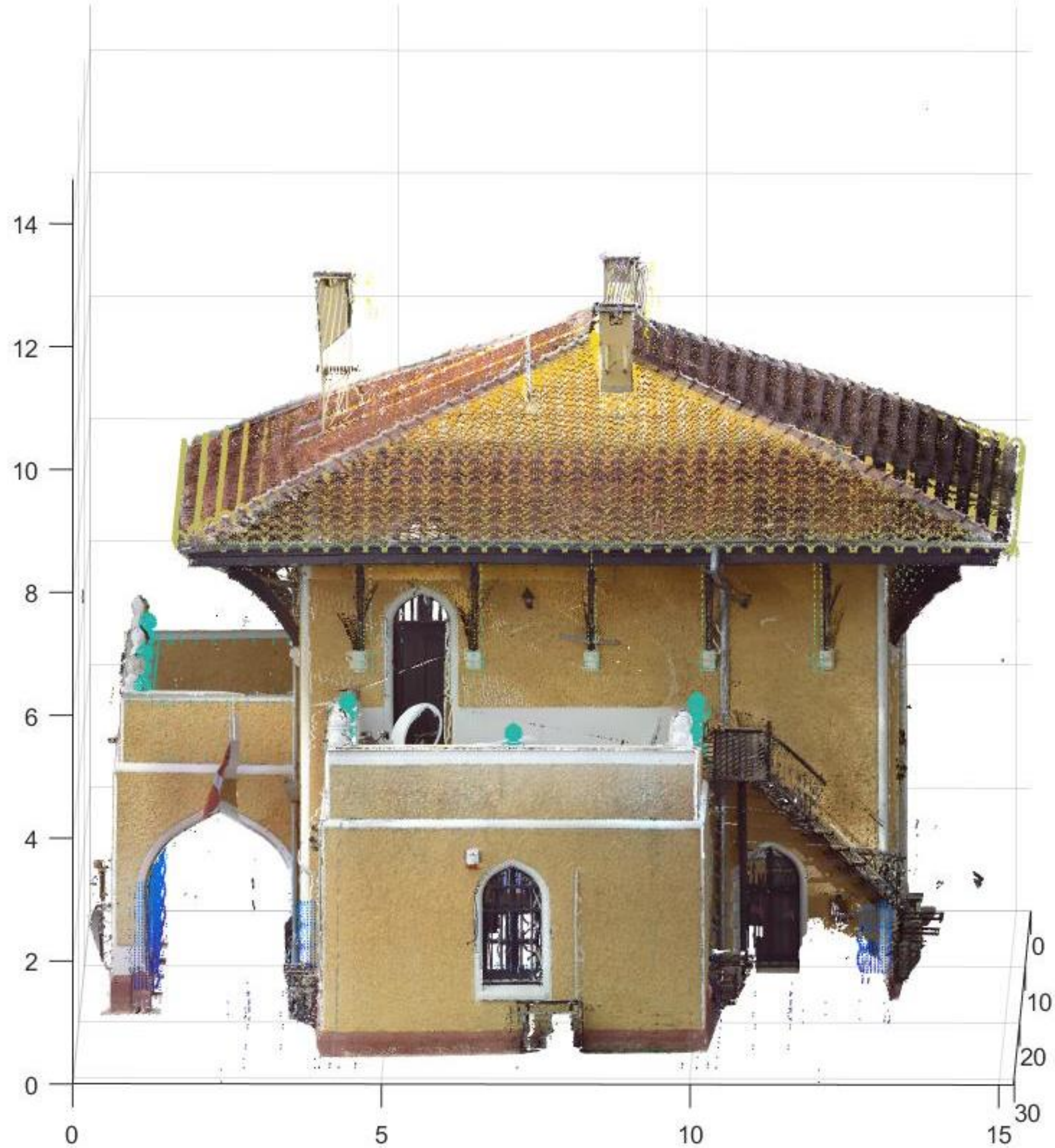
The “northern” face of the centered models (looking from quadrant 1 into quadrant 4)

Figure (6)



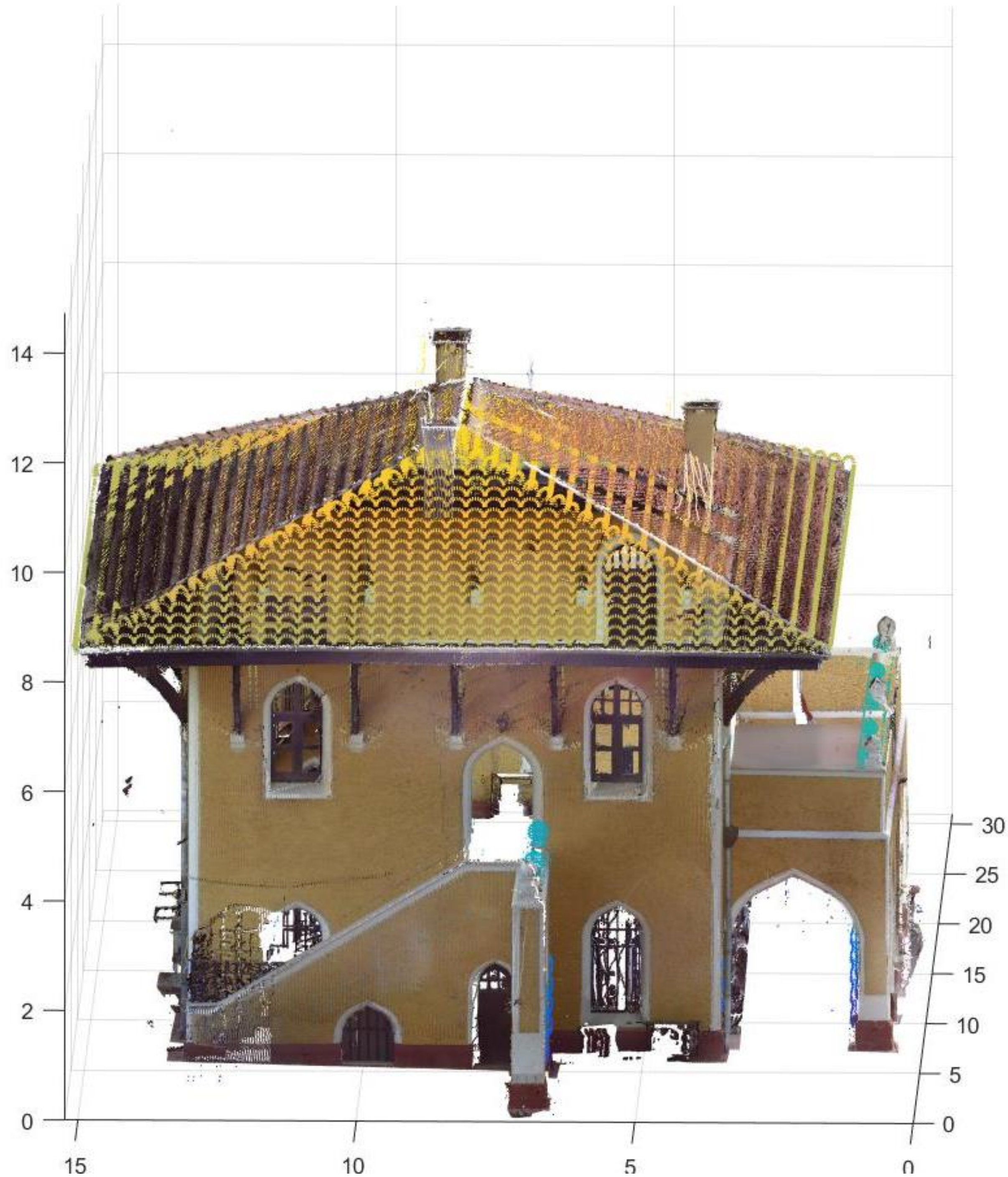
The “southern” face of the centered models (looking from quadrant 4 into quadrant 1)

Figure (7)



The “eastern” face of the centered models (looking from quadrant 1 into quadrant 2)

Figure (8)



The “western” face of the centered models (looking from quadrant 2 into quadrant 1)

Figure (9)

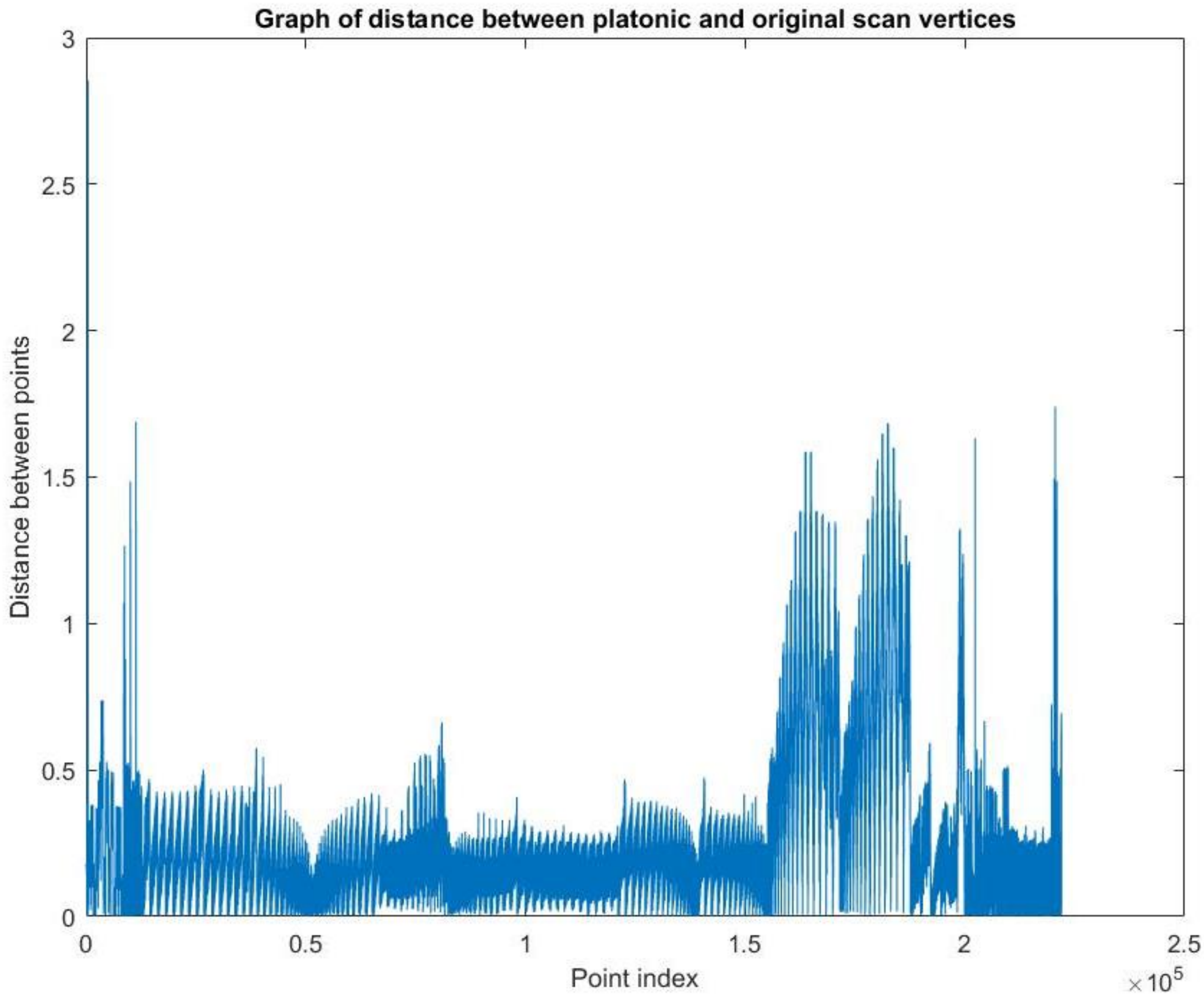

Graph of distance between platonic and original scan vertices
Distance between points
Point index
× 10^5
0
0.5
1
1.5
2
2.5
3

Figure (10)

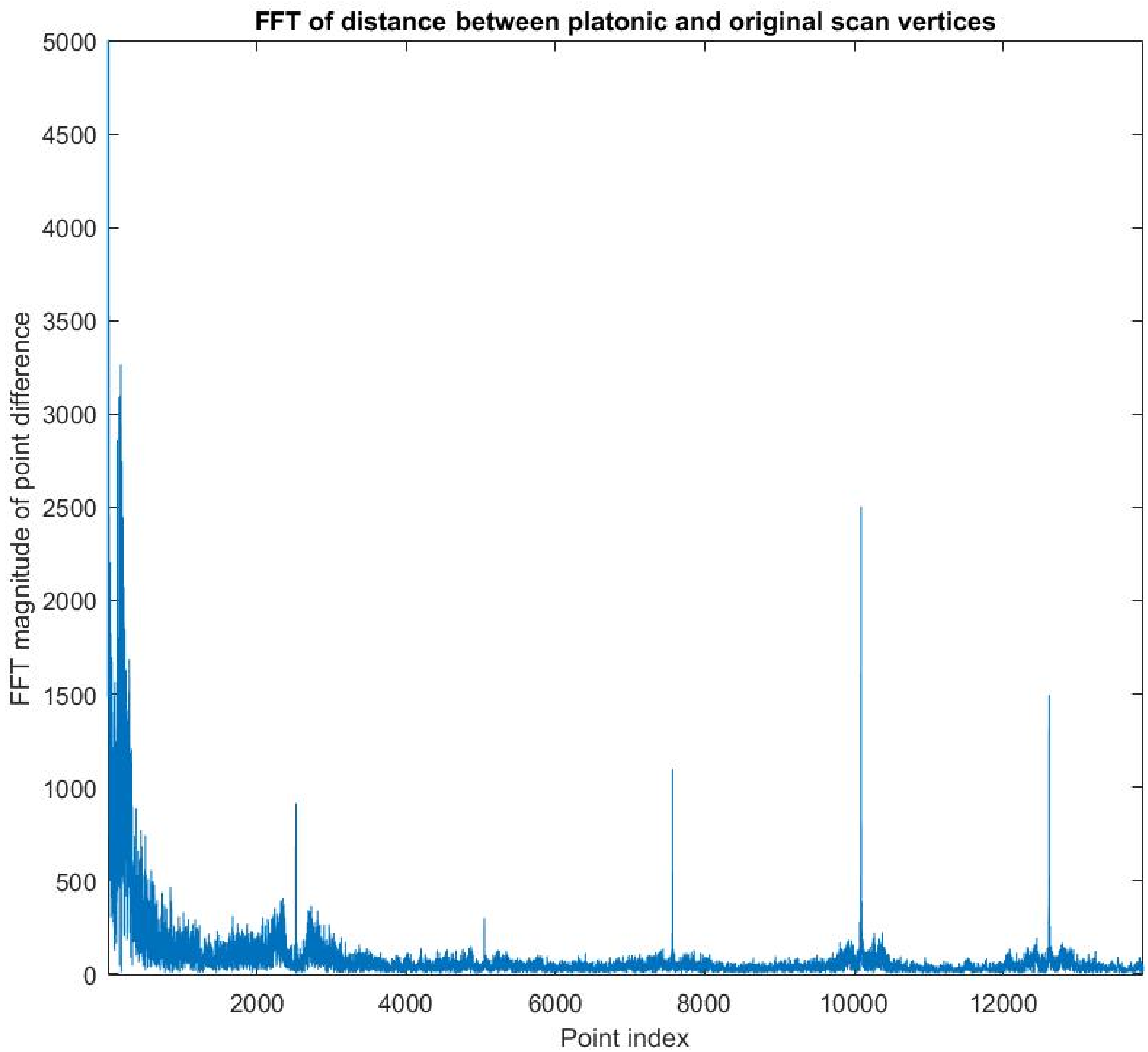
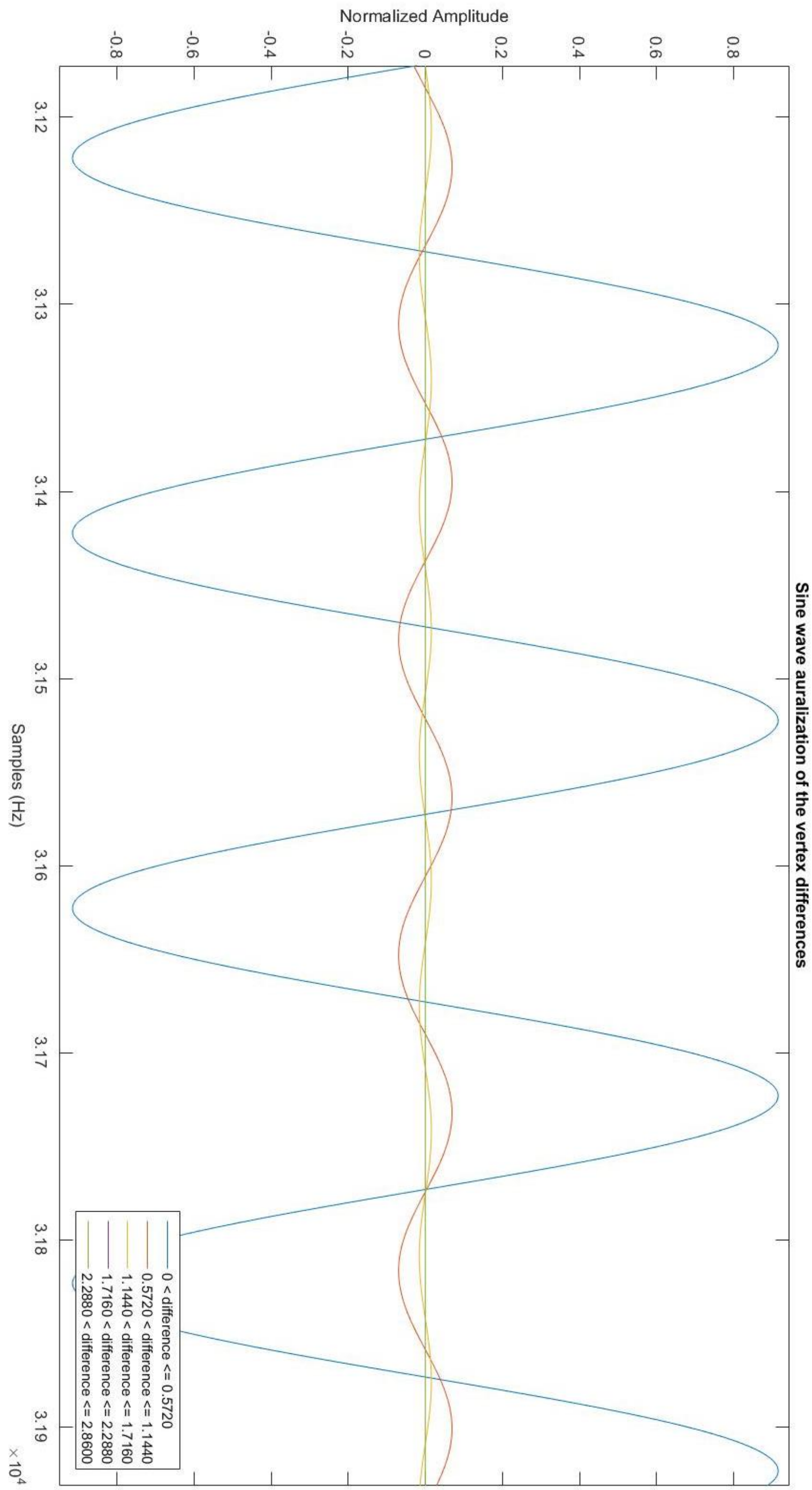

FFT of distance between platonic and original scan vertices
FFT magnitude of point difference
Point index
0
500
1000
1500
2000
2500
3000
3500
4000
4500
5000
2000
4000
6000
8000
10000
12000

Figure (11)


Sine wave auralization of the vertex differences
Normalized Amplitude
-0.8
-0.6
-0.4
-0.2
0
0.2
0.4
0.6
0.8
Samples (Hz)
3.12
3.13
3.14
3.15
3.16
3.17
3.18
3.19
×10^4
0 < difference <= 0.5720
0.5720 < difference <= 1.1440
1.1440 < difference <= 1.7160
1.7160 < difference <= 2.2880
2.2880 < difference <= 2.8600