Conclusion

The first two chapters characterize the instruments used. Fortunately, we can state that when comparing the instruments with each other, the LR proved to measure the tolling balls as well as the laser tracker can measure the SMR, making the comparison successful.

When verifying the laser radar's resolution, we confirmed that the instrument's resolution stated by the fabricators specifications at ambient conditions was not only ~20µm, but ~10µm for a 2.5 meter distance away from the instrument. This indicated that both instruments have high resolution and are comparable to each other.

We were also able to prove that the hole feature can be measured equally as well as tolling ball. This is important because many times it is much easier to measure the hardware directly rather than locating a TB on it.

After we have discussed the results presented in Chapters 1 and 2, let us now discuss the results obtained in Chapter 4. As we mentioned previously, in section 4.3, there is an obviously noticeable disagreement in every comparison plot in this section, between the measured data and the Zemax numerical simulation.

In the case of the axial shift plots, the measured data shows a disagreement that ranges from 0.4mm to 0.5mm from the Zemax simulation. The simulation indicates that the targets apparent position reaches a maximum displacement of 12.984mm, but we measured a maximum target shift of 13.515mm. We measured a longer optical path length than what the simulation indicates. The model values indicate an apparent axial target shift of 12.716mm when measuring with the laser radar, and 12.984 when measuring with the laser tracker. However the measured data in both cases varied by a few hundred microns, measuring an average of 13.106mm with the LR and 13.515mm with the LT.

For the transverse shift comparison, the Zemax simulation showed a smaller slope compared to that of the measured data. For the LT data, even when scattering was present we managed to obtain a determination coefficient of $R^2 = 0.9011$ which is distinctly better than the factors calculated for the LR data which were $R^2 = 0.553$ and $R^2 = 0.5223$ for the LR TB and hole measurement respectively. These low coefficient values signify that there is a low association between the variables (x and y axis), indicating that the equation can easily change by adding or eliminating data points. We could attempt to improve the coefficient value by collecting more repeatable data that would show less dispersion, which would be easier to fit. This would be useful for future work.

Returning to the disagreement between the measured data and Zemax simulated data, we still do not have a clear understanding of why this occurred. There is a possibility that the difference in temperature in the room caused the laser beam to refract, even thought this would be unlikely if we do not take it into account in the simulation, we cannot disregard this theory.

There could have also been a polarization effect occurring in the window that again, was not taken into consideration when creating the Zemax simulation. It is also possible, as we mentioned in section 3.3, that the window material was not BK7. However, we did create other Zemax simulations using different window materials and the difference between the simulations and the measured data increased.

In addition to this, there could have been some wedge associated with the window that was not measured by the theodolite but that could have been measured with an interferometer, which we did not do, but we do recommend it for future tests.

Without a doubt, the instruments represent the biggest questioning when talking about the data disagreement. Since the instruments are not aware that they are measuring through a window, there might be a misreading of some kind when reading the light return. We attribute the disagreement mainly to the instruments. At the beginning of this thesis, during Chapters 1 and 2 we attempted to characterize the instruments and quantify their resolution; compare their capacities to one another, to better understand how they work and how they would impact the tests; however further testing and more in depth modeling are recommended for finding a better agreement. It is also possible that the window apparent shift would be better understood if more tests were done where the distance between the window and the instrument and the window and the plate, changed.

We are certain that the Zemax simulation is incomplete and further development with it is required to find an agreement.

It is important to mention that the physical effect of a lightbeam propagating through a window, also called plane parallel plates (see section 3.2) has been known for many years, as John Strong explains in 1958 in his book the *Concepts of Classical Optics*; nevertheless there are new technologies, like the laser radar and the laser tracker that make calculating d more complicated than we expected.

We are aware that the work presented in this thesis is simply preliminary testing. In the future, the targets will be in vacuum and later, in cryogenic conditions, making the window behave in an unusual manner, as we had mentioned previously, in section 3.2. When we reach that point, the Zemax simulation will be more complex and so will the testing.