Evaluation of the Microsoft HoloLens for the Mapping of Indoor Building Environments

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Abstract: Mobile augmented reality devices like the Microsoft HoloLens are capable of simultaneously tracking the device location and mapping its environment in real-time. Thus, they offer potential for acquiring at least coarse point clouds and meshes of single rooms or even complete building structures that can be used in the context of building information modelling (BIM) in the future instead of manually modelling existing buildings based on 2D floor plans or manual measurements with laser scanners or computationally expensive image-based 3D reconstruction techniques. For this reason, we provide an extensive quantitative evaluation of the mapping results of the Microsoft HoloLens against terrestrial laser scanning (TLS) ground truth. We show that while the geometry of single rooms can be mapped quite accurately with the HoloLens, deviations may occur in the spatial arrangement of multiple rooms relative to each other.

1 Introduction

Mobile augmented reality (AR) devices like the Microsoft HoloLens (MICROSOFT 2018) that are capable of accurate real-time inside-out tracking offer potential for the in situ visualization of building information modelling (BIM) data, e.g. in the domains of facility management (GHEISARI & IRIZARRY 2016), cultural heritage (BARAZZETTI & BANFI 2017) or education (ARASHPOUR & ARANDA-MENA 2017). This of course implies the availability of building model data for the building environments to be augmented.

While, in recent years, building construction projects are increasingly conducted with the aid of BIM techniques (GHAFFARIANHOSEINI et al. 2017) which results in building models arising together with their corresponding physical buildings, there are many existing buildings for which building model data does not exist. As manually modelling existing buildings based on two-dimensional floor plans or manual in situ measurements is a laborious and costly endeavor, the automatic or semi-automatic acquisition of three-dimensional building model geometry is currently an active field of research (LU & LEE 2017; MA & LIU 2018). In this context, the acquisition of indoor building geometry is mostly done by specialized highly accurate active sensors like laser scanners or computationally expensive image-based 3D reconstruction techniques (DAI et al. 2013).

On the other hand, the HoloLens is not only capable of augmenting indoor environments with corresponding building model data (HÜBNER et al. 2018), but it is also equipped with four cameras and a depth sensor for simultaneously mapping the environment and tracking the movements of the device. The geometric information captured by moving around within an indoor environment are accessible to the user as sparse triangle meshes. While the geometric accuracy and resolution

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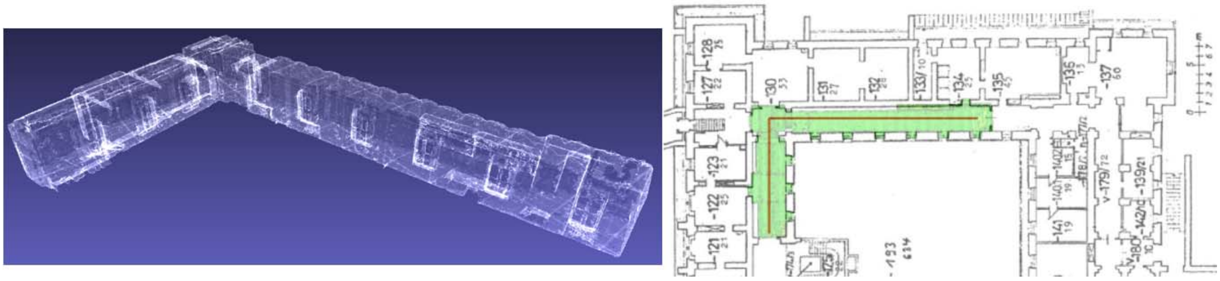

Fig. 1: Overlaying the 2D floor plan (right) with the corresponding mesh (left) captured with the HoloLens shows that the overall geometry of the hallway can be captured without noticeable distortions (LANDGRAF 2018)

of these meshes can certainly not compete with the accuracy of laser scanners, derived building models should principally be sufficient for the task of visualizing building-related information with mobile AR devices like the HoloLens itself.

Compared to laser scanners, the HoloLens as a mapping device enables comfortable and time-efficient indoor mapping. A mesh of a hallway of approximately 30 meters as depicted in Figure 1(left) for example can be captured in a matter of few minutes just by casually walking through it with the device and looking around. Overlaying a 2D floor plan with the derived mesh as depicted in Figure 1(right) shows that its overall geometry is quite accurate. Furthermore, the HoloLens can be considered as a comparatively low-cost mapping device in relation to laser scanners.

In this paper, we evaluate the indoor mapping capacity of the Microsoft HoloLens. While evaluation in terms of the accuracy of various distances measured within indoor data captured with the HoloLens has been done e.g. by LIU et al. (2018) or HUANG et al. (2018), we provide an extensive, quantitative evaluation of the mapping accuracy of complete room-scale meshes against a ground truth provided by a terrestrial laser scanner (TLS). As test environment, an empty apartment consisting of five rooms of different size and a hallway was selected.

The focus of this paper lies on the evaluation of the indoor mapping capacity of the HoloLens with respect to the mapping of coarse indoor building geometries. Our use-case is the mapping of the building geometry itself - i.e. the dimensions of rooms and walls including windows and door openings - and not the mapping of fine geometric details. For this reason, an empty apartment without furniture was chosen as test environment.

Anyhow even finer geometric details can be captured up to a certain degree by the HoloLens device. Figure 2 for example shows various views on a mesh captured with the HoloLens for a stairwell that has interior window casement frames with a width of about 10 cm and handrail rods with a diameter of about 2 cm. The views on the mesh in the Figure 2 show, that enough of these fine geometric details could be captured to at least allow an easy visual interpretation of the scene represented by the mesh. However, especially the detail view in Figure 2(right) demonstrates that the window frames and handrail bars are not captured geometrically complete or accurate.

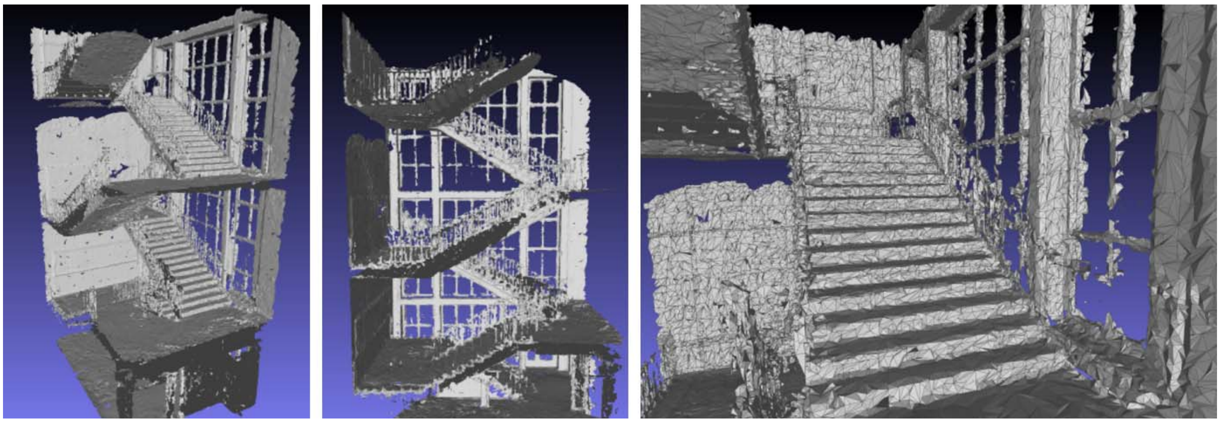

Fig. 2: Different views on the mesh of a stairwell captured with the HoloLens (LANDGRAF 2018)

The key contributions of this paper are:

- We provide an extensive quantitative evaluation of the mapping results of the Microsoft HoloLens against TLS ground truth.
- We show that while the geometry of single rooms can be mapped quite accurately with the HoloLens, deviations may occur in the spatial arrangement of multiple rooms relative to each other.
- We show that drift effects can occur when mapping large indoor spaces.
- We show that the mapping results of the Microsoft HoloLens are affected by a constant scale factor.

2 Evaluation Method

For the purpose of evaluating the capacity of the Microsoft HoloLens as a device for the rapid and easy-to-use mapping of indoor building geometry, an empty apartment consisting of five rooms of different size and one central hallway was used as test environment. An overview of this apartment is provided in Figure 3.

For acquiring ground truth data to evaluate the HoloLens meshes against, a terrestrial laser scanner (Leica HDS 6000) was used. The obtained point clouds from the different positions of the laser scanner visible as circles in the plan view in Figure 3(left) were registered in a common coordinate system by means of artificial planar and spherical markers placed in the apartment. The complete point cloud of the whole apartment was consecutively cleaned, thinned to an average point distance of 1 cm and meshed with the Poisson surface reconstruction algorithm (KAZHDAN et al. 2006) implemented in the software MeshLab (CIGNONI et al. 2008). The resulting triangle mesh is depicted in Figure 3.

This complete apartment was mapped five times with the HoloLens for obtaining evaluation data. Between each consecutive mapping, all environment data on the device was deleted to ensure five independent measurements. For this mapping process, the commercially available HoloLens App SpaceCatcher (SPACECATCHER 2018) was used for recording the triangle mesh data of the apartment.

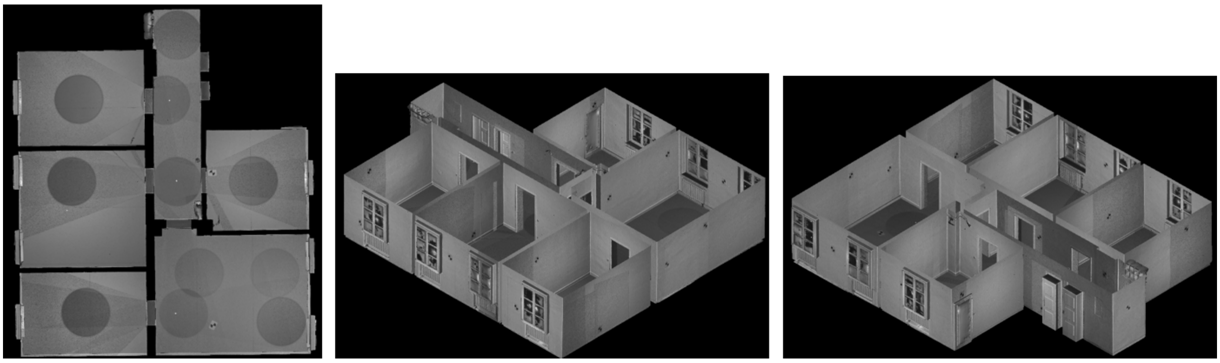

Fig. 3: Ground truth data acquired with a terrestrial laser scanner for the test environment

Although the HoloLens device always measures the geometry of the environment via its depth sensor to assist its tracking and the resulting triangle meshes can be obtained via the web interface of the device, it is advantageous to use an app for the cause of recording triangle meshes, because this allows for configuring a desired spatial resolution of the obtained triangle meshes. Furthermore, with suchlike apps, triangle meshes are directly visible for the operator while they get recorded as depicted in Figure 4. In the standard using mode of the HoloLens device, this is not possible in such a comfortable way. Furthermore, the spatial resolution cannot be set by the user outside custom apps that make use of the respective HoloLens SDK functionality. Therefore, the triangle meshes obtainable with apps like the SpaceCatcher as depicted in Figure 4(c) are much smoother and more complete in comparison to meshes recorded without the use of an app depicted in Figure 4(b).

For comparison of the resulting HoloLens meshes against a respective reference mesh, each HoloLens mesh was registered on the reference mesh via the software CloudCompare (CLOUDCOMPARE 2018) by means of manually selected pass points and subsequent fine registration via the Iterative Closest Point (ICP) algorithm (BESL & MCKAY 1992; ZHANG 1994). The registered

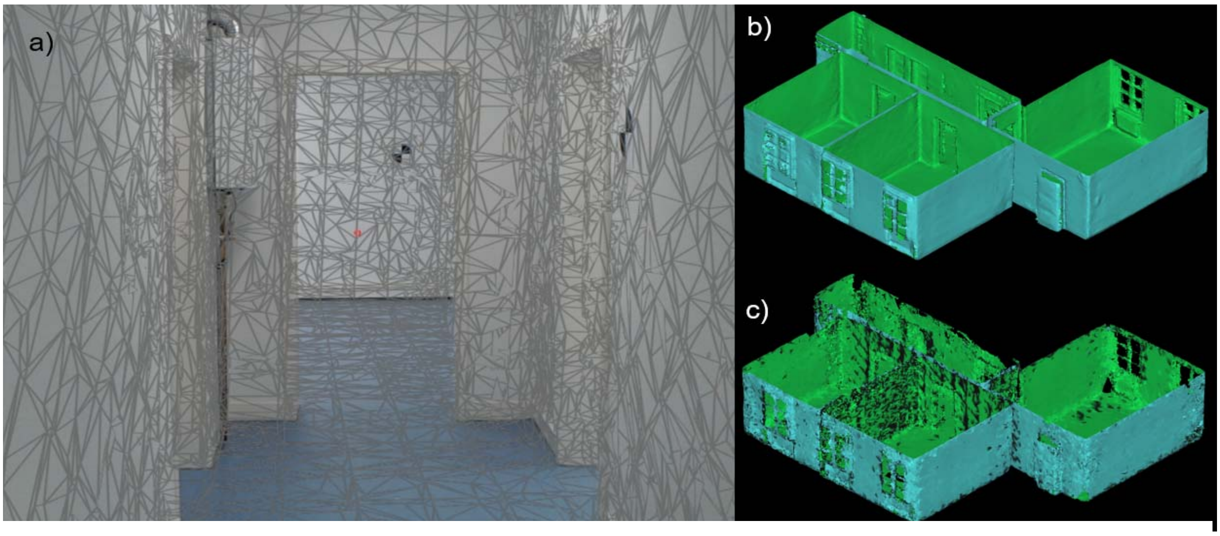

Fig. 4: View of a corridor (a) overlaid with the triangle mesh captured by the HoloLens app SpaceCapture (b) or without scanning app (c)

meshes were then compared via the Hausdorff distance (CIGNONI et al. 1998) in MeshLab (CIGNONI et al. 2008).

Firstly, the results of these five mappings of the apartment with the HoloLens Device were compared to each other in the above described manner to get an impression of the variability of indoor mapping results acquired with the HoloLens. Furthermore, the HoloLens meshes were also evaluated against the ground truth data acquired by terrestrial laser scanner.

3 Results and Discussion

An averaged mesh color-coded with the averaged Hausdorff distances across all 10 possible combinations for comparing the five meshes recorded with the HoloLens device with each other is depicted in Figure 5.

It is clearly visible, that the deviations between the compared HoloLens meshes are in the range of few centimeters for most parts of the apartment. They only reach higher values near the ceiling, where some of the meshes have holes (the ceiling itself was not scanned in the course of all experiments in this work). It can thus be concluded that the HoloLens device performs spatial mapping of indoor environments with a low level of variance between independent measurements even for indoor environments consisting of multiple rooms.

Furthermore, while registering the HoloLens meshes on each other, the scale was kept fixed. So, larger non-constant scale errors can be excluded for the HoloLens. While registering the HoloLens

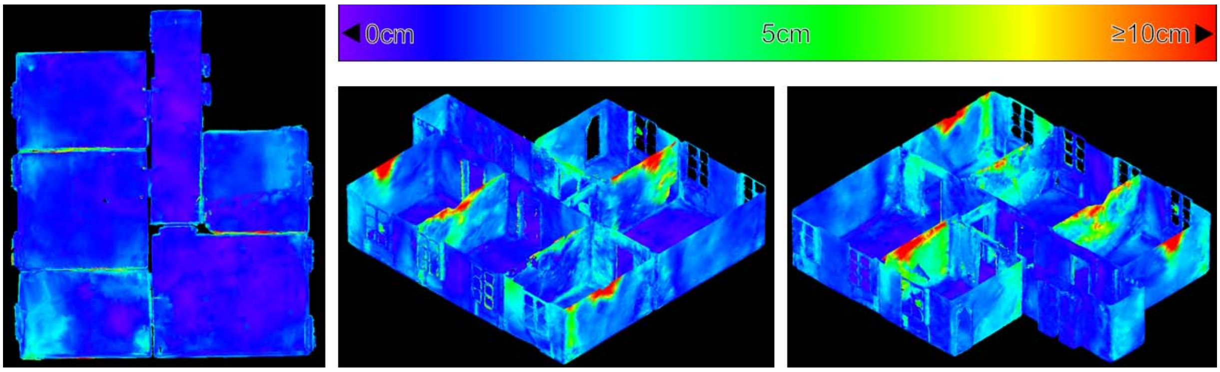

Fig. 5: Mean Hausdorff distances of all five HoloLens meshes compared with each other

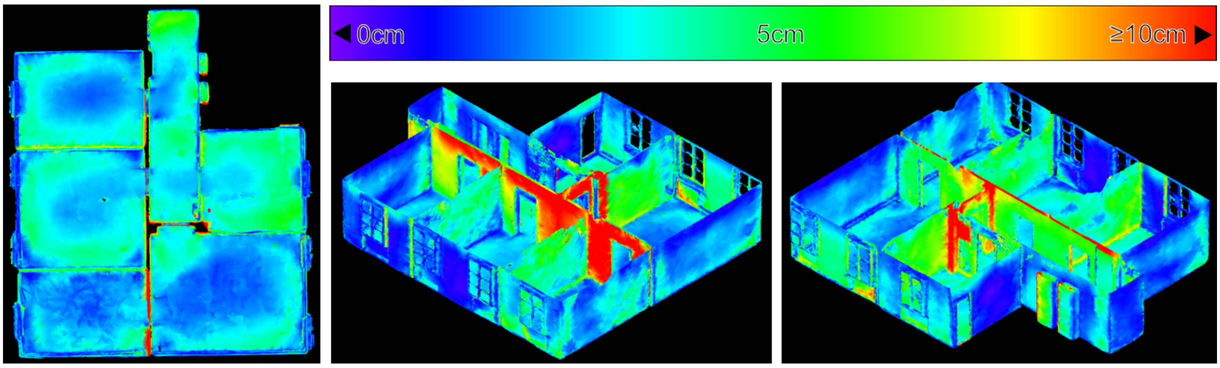

Fig. 6: Mean Hausdorff distances of all five HoloLens meshes compared with the TLS ground truth

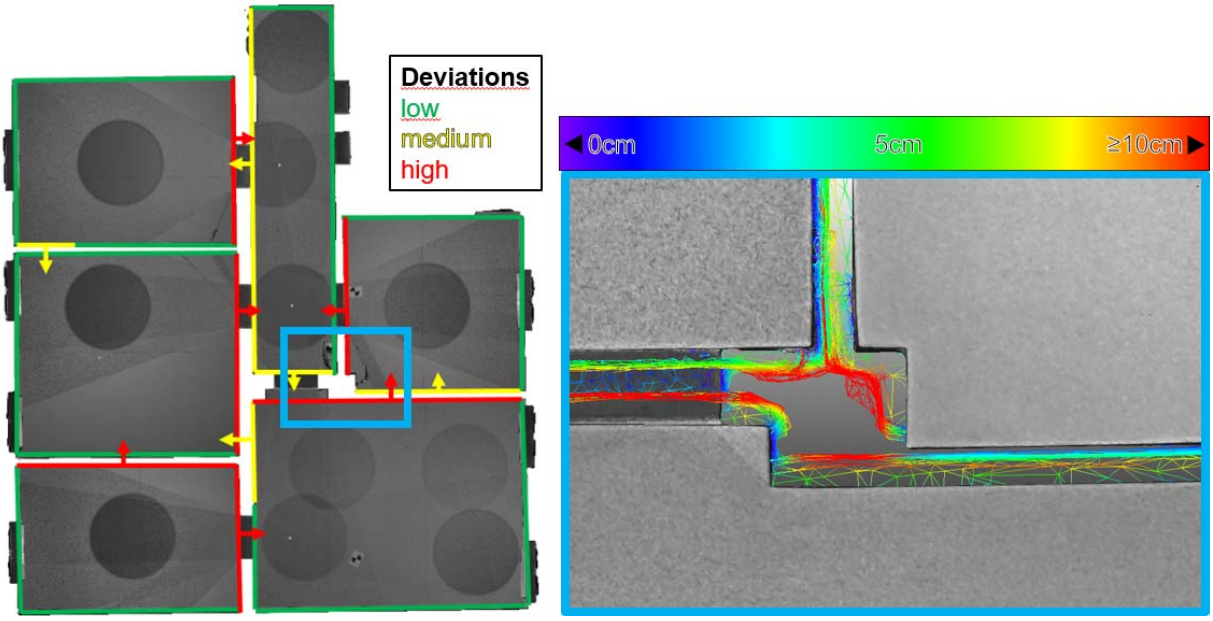

Fig. 7: Schematic overview (left) of devations between the rooms of the test environment that are hidden in Figure 6 because of the situation depicted on the right

meshes on the TLS ground truth mesh however, there proved to exist a significant scale factor. In our experiments, this scale factor was estimated to 1.0120 ± 0.002 across 18 tested meshes in total. The averaged point clouds color-coded with averaged Hausdorff distances across all five HoloLens meshes compared to the TLS ground truth mesh are depicted in Figure 6.

Here, the deviations are again comparatively low on the floor and on the outer walls of the mapped apartment. Especially on the inner walls, however, larger deviations between the HoloLens meshes and the ground truth data are visible. In this case, the situation is in fact even worse than indicated by the color-coded Hausdorff distance values. As exemplified on the right-hand side in Figure 7, it can happen that the deviated mesh of the wall of one room is compared to the ground truth mesh of the wall of a bordering room instead of comparing it to the ground truth mesh of the same respective wall if the deviation is large enough in relation to the space between both wall surfaces. So for this use-case of evaluating meshes from indoor building geometry where the spatial deviations can lie in the same range as the distance between wall surfaces of neighboring rooms, the Hausdorff distance as presented by CIGNONI et al. (1998) is not directly applicable. Here, an evaluation procedure is needed that takes into account the topology of indoor building structures and ensures that wall meshes only get compared to meshes of corresponding walls even if there are walls of neighboring rooms with a lower distance.

The schematic overview on the left-hand side of Figure 7 depicts the actual deviations of the HoloLens meshes in comparison to the TLS ground truth data. Here, walls where the HoloLens meshes fit well to the ground truth data are indicated in green, regions of medium differences are indicated in yellow and walls with strong deviations from the ground truth meshes are indicated in red. The arrows indicate the direction in which the respective wall mesh from the HoloLens is shifted in relation to the wall in the ground truth data. The length of the arrow is only chosen for reasons of visibility and does not indicate the amount of deviation.

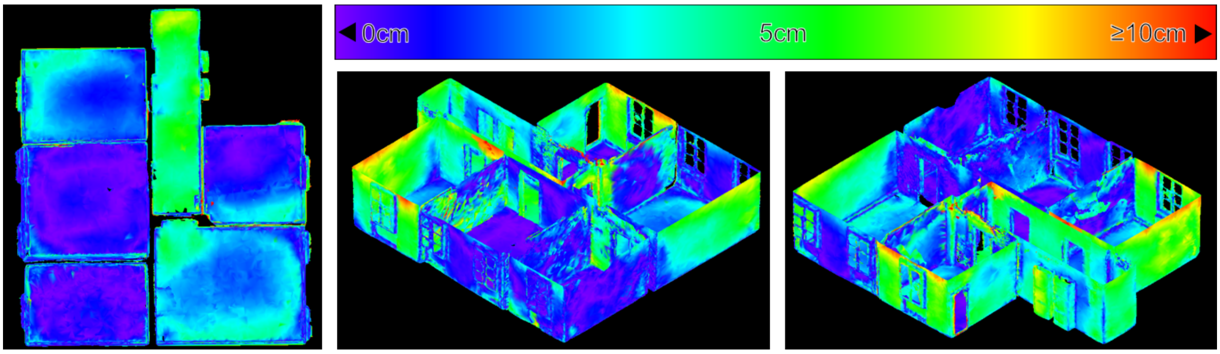

Fig. 8: Registration of every single room independently registered against ground truth with same scale factor

Figure 7 shows that deviations from the ground truth data mainly occur on inner walls parallel to the doors connecting the rooms of the apartment with each other. In fact, the transitions from one room to another through doors are weak spots in the tracking of the HoloLens device and thus the spatial correctness of its mapping data. So it can be assumed that, while the geometry of the respective rooms by themselves is captured well, the overall correctness of the whole measured apartment suffers from weak accuracy in the spatial connection between the respective rooms.

To demonstrate that this is in fact the case, the single rooms from the averaged HoloLens mesh of the apartment have been extracted. Those single-room meshes were then registered separately on the respective ground truth room from the TLS data while keeping the scale fixed to the scale factor that was estimated when registering the HoloLens mesh of the whole apartment on the TLS ground truth. As shown in Figure 8, the resulting single-room meshes fit the ground truth room meshes well.

So it can be concluded, that the high deviations in the walls of the apartment interior in Figure 7 do not result from the scale factor of the HoloLens not being constant but merely from the fact that spatial connections between the rooms that are all mapped quite correctly by themselves are captured with large errors.

Anyhow there definitely are situations where drift in the spatial mapping with the HoloLens is occurring. The left part of Figure 9 for example shows the mesh of a large loop of a hallway with a total length of over 200 m. On the right, the same mesh is mapped on a floor plan. In this case, large deviations contrasting the good results from Figure 1 are clearly visible, and loop closure is not appropriately achieved.

4 Conclusion and Outlook

In this paper, we have presented a first look on the quantitative evaluation of the Microsoft HoloLens in the context of the mapping of indoor building geometry. It shows that the HoloLens allows the scanning of the basic geometry of single rooms consisting of walls with windows and door openings with an accuracy of few centimeters. In the case of indoor environments consisting

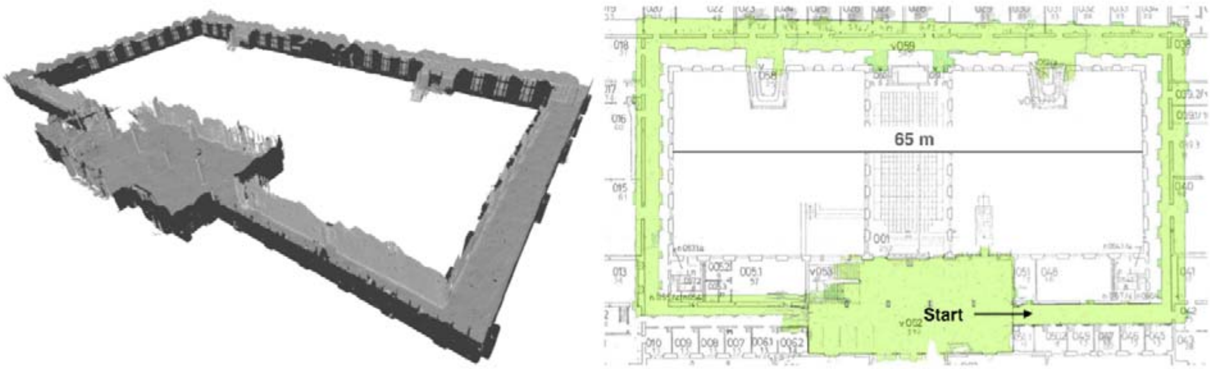

Fig. 9: Overlaying the 2D floor plan (right) with the mesh on the left shows that there exist drift effects in the mapping of large-scale spaces with the HoloLens (LANDGRAF 2018)

of multiple rooms connected by narrow passages like doors, there occur larger deviations of the resulting meshes relative to ground truth building geometry. However we have shown, that the respective rooms constituting the indoor environment by themselves still are captured with sufficient accuracy. Nonetheless we also have shown, that in very large, continuous indoor spaces there can also occur drift effects.

In conclusion, the HoloLens reveals high potential for rapid, easy-to-use mapping of basic indoor building geometry. This is of interest, especially in the field of the automated creation of as-built BIM models of existing buildings, which in turn can provide a valuable source for spatially located information to be visualized in augmented reality applications on devices like the HoloLens itself. However, getting from the triangle meshes recorded by the HoloLens device to semantically enriched, topologically correct building models is still challenging and holds much potential for further research.

Also the specific topic of evaluating the indoor mapping capacity of mobile self-tracking mapping devices like the HoloLens still holds open research questions to be addressed in future work. The spatial mapping process of the HoloLens can still be considered as a black-box system, whose exact inner workings are not publicly known and well understood. Furthermore, there is a need for a suited evaluation metric for evaluation scenarios like the one discussed in this work, where there is the need to ensure, that meshes representing specific walls are only compared to ground truth meshes representing the same wall and not other walls nearby, even if those are situated in closer proximity because of the inaccuracy of the meshes to be evaluated. This again presupposes a high level of semantic and topological information to be extracted from the basic triangle meshes delivered by a device like the HoloLens.

5 Literature

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