3D BUILDING MODELS DEVELOPMENT BASED ON DATA FUSION – CURRENT STATUS

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ABSTRACT

For the past years, a better and complete 3D building model has been intensely studied. To get a 3D building model as desired, it is known to use data fusion which is a technique of 3D dataset combination. Data fusion is conducted to overcome the limitations of each measurement technique in obtaining data. This paper aims to show the status of 3D building models development that is generated from two or more datasets by using data fusion technique. From several works of data fusion, it is observed the development of data fusion related things like various technologies, methods, and accuracy. The technology used varies for data fusion, for both air and ground based measurements. Technologies such as Terrestrial Laser Scanning (TLS) and close-range photogrammetry are the most appropriate surveying methods to generate accurate and high-resolution models. Meanwhile, recent technology of mobile laser scanning makes scans more quickly and offers more convenience to obtain data in a difficult area. Furthermore, mobile laser scanning has higher completeness data than photogrammetry data. For future work, mobile laser scanning data is be considered to use in data fusion. In term of accuracy, several works agreed that data fusion is a better way to have more complete 3D building models with high accuracy. Related to data processing of data fusion, most of algorithms have disadvantage in accelerating the data fusion time. Therefore, an algorithm to shorten the processing time needs to be created.

KEY WORDS: 3D Building Models, Data Fusion, Point Cloud, Image Data.

1. INTRODUCTION

A better and complete 3D modelling has been intensely studied for years. In this case, preferable results of 3D model are expected to have higher accuracy and complete 3D models imply that there is no data or data lost in modelling. The works were conducted to gain a more complete 3D model by combining multi-sensor data (Chhatkuli et al., 2015; Zhen et al., 2019; Maset et al., 2022). They produced a 3D model of the entire area including terrain, buildings, and other details. The other study by Bouziani et al. (2021) assessed and confirmed the high accuracy of data from LiDAR (Light Detection and Ranging) drone and photogrammetric drone. Based on this work, it is possible to get high-accuracy fusion-based 3D model from these technologies. The combination data of multi-sensor was also developed to generate specific 3D model of building (Kwak et al., 2012; Kedzierski and Fryskowska, 2014; Du et al., 2017). A building has a complex structure including interior and exterior, moreover, heritage buildings have more complex architectural structure. In relation with cultural heritage field, there is no satisfactory documentation for whole area (Ramos and Remondino, 2015). Thus, more complete data is expected to obtain the detail of 3D building models using data fusion technique.

Data fusion in 3D building modelling is a data combination technique to obtain a complete 3D building model. By using this method, 3D building models could be generated by integrating two or more datasets (Fryskowska et al., 2015; Luhmann et al., 2019; Abdelazeem et al., 2021), including images and point cloud data. This fusion data was carried out to overcome limitations of each sensor in measuring objects. For example, terrestrial measurement for buildings cannot properly record the top or the roof of the buildings. Moreover, terrestrial measurement technique such as Terrestrial Laser Scanning (TLS) has area coverage limitations because of the sensor's line of sight (Abdelazeem et al, 2021). Otherwise, the use of technology for measurements from the air has limitations in measuring the side of the building such as walls. The use of unmanned aerial system also has limitation resulting in blurred texture 3D models. Fusion methodology in addressing the limitations of each of these technologies will result in a complete 3D building model.

A better and complete 3D building model is widely used for heritage building documentation (Bonora et al., 2005; Guarnieri et al., 2006; Nex and Rinaudo, 2010; Fryskowska et al., 2015; Luhmann et al., 2019; Jaber and Abed, 2020) and building reconstruction (Khoshelham, 2004; Lee and Choi, 2004; Du et al., 2017). Thus, data fusion from several datasets is continuously evolving. This paper aims to present the status of 3D building models development by using data fusion technique. Several studies for the last two decades were observed in the aspect of data fusion. The next section, generally explains the development of data fusion which includes technologies, accuracy, and methods. Section 3, the conclusions of the paper.

2. CURRENT STATUS OF 3D BUILDING MODELLING FROM DATA FUSION

This section addresses the development of various technologies which are used in data fusion. This section also outlines some developed methods and the accuracy of several data fusion.

LiDAR and photogrammetry are technologies that can be used to obtain spatial data of a building. LiDAR produces point clouds data and photogrammetry captures images data. These technologies can be applied based on both aerial and terrestrial measurement principles that lead to the introduction of airborne LiDAR, TLS, aerial photogrammetry, and terrestrial photogrammetry. In 2001, the work of Vosselman and Djikman was indicated to carry out data combination. They reconstructed a 3D building model from combination of airborne laser altimetry data (point clouds) and ground plans. Other works that integrated point clouds and images are conducted by Rottensteiner & Jansa (2002), Khoshelham (2004), Lee & Choi (2004), and Guarnieri et al. (2006). This data combination of LiDAR and photogrammetry evolves and is continuously inspected for the last 20 years including by the works of Nex and Rinaudo (2010), Altuntas et al. (2016), Luhmann et al. (2019), Abdelazeem et al. (2021), and Li et al. (2021). Furthermore, data combination of close-range photogrammetry and TLS are the most appropriate surveying methods to generate accurate and high-resolution models (Maset et. al, 2022).

Development in technology lies on the use of measurement platform and sensor. Since drone is utilized to carry measurement sensor (camera or LiDAR), several works began to generate 3D building model using data fusion method (Luhmann et al, 2019; Hua et al., 2020; Abdelazeem et al, 2021). LiDAR technology is also developed for mobile mapping and applied to measure building. Comparison between mobile laser scanning (using iPhone 13 Pro) and TLS in acquiring data was conducted by Jakovljević et al. (2022). Another comparison work was conducted by Costantino et. al. (2022) by using Android and iOS smartphone to produce 3D point clouds. Those two mentioned works did not fuse the data. Meanwhile, Maset et al. (2002) used mobile mapping technology and photogrammetry data to generate 3D building model. They said that mobile mapping technology scanning has higher completeness than photogrammetric data. However, the point clouds from mobile mapping measurement have a significantly higher noise.

Previously, data combination of laser scanning and photogrammetry was applied in two ways: (1) images were used as texture of the meshed model of laser scanning, (2) Digital Elevation Model (DEM) from point clouds was used to generate orthophoto. Then, the utilization of point clouds and image data changes to different ways as reported by Guarnieri et. al. (2006), Nex and Rinaudo (2010), Chhatkuli et. al. (2015), and Luhmann et. al. (2019). The first work made 3D building models based on photogrammetry and laser scanning data then merged the two 3D models into a unified 3D model. The second work extracted points and edges from images (by using image-matching) to ease the point clouds segmentation and modelling. However, the third and fourth works conducted data fusion at a point cloud level (image-based and laser scanning point clouds). The third used Triangulated Irregular Network (TIN) model meanwhile the fourth used Structure-from-Motion (SfM) program to convert image data to point clouds.

To join two sets of point clouds from different measurements, Iterative Closest Point (ICP) algorithm is commonly used. In this algorithm, there is a transformation process to orient the data into one common system. Two works developed methods related to transformation in selecting precise reference points and refining sensor parameters. First work by Kedzierski and Fryskowska (2014) fused multiple data (TLS and Aerial Laser Scanning/ALS point clouds) by using wavelet analysis to increase data accuracy (ALS) and precision of determining reference points. The result showed that the point clouds integration increased. However, the wavelet method is quite time consuming. Second work by Zhen et. al (2019) proposed a joint optimization approach which was an offline method of data combination to solve problems in bundle adjustment and a cloud registration. They fused the data (from LiDAR and camera) along with restoring the extrinsic calibration. The results showed that the method was able to generate dense 3D model and restore accurately camera-LiDAR extrinsic transform. The disadvantages of this offline method were that it took a lot of time to carry out the measurement and became inconvenient when reaching difficult area. Recently, another work by Li et. al. (2021) proposed Laplacian fusion approach to enhance details of 3D building model. In this work, they proposed an automatic approach in detecting holes and repairing holes by using Laplacian approach. The result showed that the Laplacian method completed details of 3D model up to 82% without human interventions and had errors less than 4 cm. Evaluation of this method showed that the method performance surpassed the state-of-the-art approach (volumetric fusion). However, this approach limitation did not address holes with complex geometric forms which were sensitive to the qualities of the point clouds.

In term of accuracy, the works of Luhmann et al. (2019), Abdelazeem et al. (2021), and Maset et al. (2002) indicated that fusion 3D building model has high accuracy. The first work analysed two datasets based on TLS measurement (FARO and Leica) by using cloud-by-cloud comparison method to know the match between the two datasets. The result of the analysis stated that the point cloud matches each other at distance of 5-10 mm. After adjustment with ICP, the combination of two datasets had a maximum deviation of 4 mm. They also analysed image combination (Unmanned Aerial Vehicle/UAV and terrestrial images) as meshed surface model that was processed in both Agisoft and RealityCapture software. The results showed that the fusion 3D model mean deviation were 8 mm and 5 mm point spacing respectively in both software. These values indicated that the fusion data error was within the high TLS accuracy range. The second work evaluated point clouds combination from terrestrial close-range camera (Sony) and Unmanned Aerial System (UAS) images. A 3D model based on close-range camera point clouds was generated and said have high accuracy while UAS point clouds generated a complete 3D model but in low resolution. That fusion 3D model was then investigated using multiscale model-to-model cloud comparison (M3C2). The result showed that the data fusion was able to reduce the registration error about 12.75% (from 0.149 to 0.130 m). The relative precision of fusion 3D models from denoised point clouds also increased about 52.4% and 30.6% respectively in comparison with original and subsampled point clouds. The third work evaluated the data fusion of photogrammetry (UAV and terrestrial) images and mobile laser scanning point clouds. The UAV and terrestrial data fusion reported to have 0.5 cm of average 3D error. Meanwhile, the mean 3D error of point clouds fusion (photogrammetry and mobile laser scanning) was 1.3 cm. They concluded, fusion data from photogrammetry and mobile laser scanning has high accuracy although they said point clouds from mobile mapping have higher noise. Furthermore, works by and Hua et al. (2020) confirmed Li et al. and (2021) that data fusion can produce a more complete 3D building model. The 3D building model completeness was said including the upper parts of the building and the hole repair of the objects respectively for both works.

3. CONCLUSIONS

Based on Section 1 and Section 2, data fusion is a way of data combination to complete the lack of data from each measurement technique for a better and complete 3D model. Recent technologies are supported to generate 3D building models by using fusion method. In terms of methods, data fusion is successfully done although they have their own

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limitations. Several works also confirmed a better accuracy of fusion data. However, data fusion has some issues and challenges based on description above.

TLS is the most accurate method to increase data accuracy. As it is known, the most appropriate methods in data fusion to get high accuracy 3D model are TLS and close-range photogrammetry. However, current LiDAR technology platform such as mobile mapping offers rapid way, more convenience measurement and more complete data. By using these platform, measurement of building object can reach difficult area or building part. It also can complete TLS coverage limitation. Furthermore, compared to photogrammetry, mobile laser scanning produces more complete data. Based on this, mobile laser scanning can be explored for future work of data fusion with the most accurate data from TLS.

Each fusion data method described at Section 2 was successfully fuse the multi-sensor data, but it had limitations. A lot of time consuming is the main limitation of almost proposed methods. It can be concluded that determination of point clouds to produce 3D building model from a huge amount of data from two or more measurement techniques in data fusion is a challenge. Generating a performance-enhanced algorithm to overcome the limitations of current approaches in data fusion can be considered for the future work. The algorithm should be fast in processing data and produce a complete and high accuracy 3D building model.

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