Markerless BIM Registration for Mobile Augmented Reality Based Inspection

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Abstract:

On-site construction inspection requires extensive data extraction from paper or digital drawings and/or databases. This is time consuming and labour intensive. One of the potentially viable solutions to this problem is providing easier access to such data through mobile augmented reality (AR) systems. Such systems can facilitate simpler, faster and more accurate inspection processes by allowing users to have instant access to better visualisations of the Building Information Model (BIM) for the location they inspect. One of the main problems of current AR systems is in having an accurate alignment of the BIM on the user's view. In order to solve this problem, researchers have proposed solutions that either use tags, restrict the user to specific spots, or rely on Global Positioning Systems (GPS) and compasses that are unable to be used in an indoor environment. This paper presents an alternative, markerless solution based on the Kinect Fusion, since new mobile augmented reality devices are equipped with similar RGB and depth sensors. This solution combines the registration of the camera pose provided by Kinect Fusion with the registration achieved using the Iterative Closest Point (ICP) algorithm on the 3D reconstruction generated by Kinect Fusion. The results indicate the potential for maintaining a stable registration while traversing indoors, while generating 3D data that can be used to sense the user's surroundings.

Keywords: Markerless Augmented Reality, BIM, Inspection, Kinect.

1. INTRODUCTION

Only 16% of construction projects manage to meet all of the following criteria: a) on-time completion, b) within budgeted cost, and c) within quality standards (Frame, 1997). Another study has shown that approximately 60% of construction project organisations in the UK face time and cost overruns on more that 10% of their projects (Olawale & Sun, 2010). One major site management related factor that causes time and cost overruns is inadequate monitoring and control (Memon et al., 2012). Good progress monitoring practices can reduce execution schedule slip by 15% (IBC, 2000), improve cost by more than 10% (CEC, 1999), and decrease the cost of reworks, disputes and claims (Yates & Epstein, 2006). However, current practices are still manual (Navon, 2005), since they are based on visual inspections (Zavadskas et al., 2014), and labour intensive (Navon, 2007). The problem is amplified when the inspector has to deal with more complicated works such as in an interior environment (Koo & Fischer, 2000). Inspectors have now started to implement web-based technologies on site in order to improve the way they fill and keep their reports.

Recent research efforts have aimed to automate project monitoring in the construction industry and facilitate the inspection process with the use of commercial inspection software packages such as LATISTA, Autodesk BIM 360 Field, Field 3D, xBIM, etc. These software packages offer the inspector the capability of using a mobile device (e.g. Tablet PC) on site that loads a Building Information Model (BIM) instead of using paper drawings and databases. Although the aforementioned packages improve document management, navigation in the BIM model remains manual while the inspector inspects the building. BIManywhere is a similar software that gives the user instant access to the current BIM view, however it depends on the pre-installation and maintenance of QR codes, which renders it inappropriate for the construction environment that constantly changes and evolves. A survey has shown that inspectors favour mobile-based augmented reality systems for simpler and faster inspections compared to the current manual practice (Gheisari et al., 2014). Although the above survey was conducted for facility management purposes, it shows the tendency towards implementation of augmented reality technology for facility inspection.

2. BACKGROUND

The introduction of several augmented reality platforms such as AMIRE, ARVIKA, StudierStube, DWARF, DART, etc. (Izkara et al., 2007) illustrates the gradual increase in augmented reality applications in recent years. The major problem holding back wider implementation of augmented reality is the difficulty in obtaining an accurate alignment between the virtual and real world data (Azuma, 1997; Koller et al., 1997), which is based on the accurate pose estimation of the user.

Shin and Dunston (2008) searched possible applications of augmented reality (AR) in construction that could improve activities' performance. Lee & Peña-Mora (2006) and Golparvar-Fard & Peña-Mora (2007) examined the implementation of augmented reality progress monitoring. Golparvar-Fard & Peña-Mora (2007), Golparvar-Fard et al. (2009, 2012) aligned the as-planned 3D model and as-built data in a semi-automated way where the user must first manually choose a set of initial points. This solution, though, does not use mobile Augmented Reality and cannot be implemented on site in teal time but shows the potential of using augmented reality for automating Progress Monitoring.

Other AR-based approaches for inspection (Cote et al. 2013; Shin & Dunston, 2009; 2010) used equipment that is bulky, heavy, and mounted on a tripod placed at fixed positions. These systems provide accurate registration between the virtual model and real world data, but they are not easily portable. Other AR systems that either provide information regarding onsite activities (Wang et al., 2014) or support a defect management system for reinforced concrete (Kwon et al., 2014) used fiducial markers. However, these systems require additional time and cost for the installation and maintenance of the markers. In order to overcome this deficiency, Irizarry et al. (2013) presented a different mobile AR system for facility management purposes that uses a three-axis gyroscope, accelerometer, Wi-Fi, and a digital compass in order to display information from the BIM file. The researchers used the BIM2MAR application (Williams et al., 2014a; 2014b) to optimise visualisation of the information. The user, though, has to be located at a specific spot and needs a Wi-Fi network which renders the on-site implementation of this method inefficient. Additional mobile AR systems use Global Positioning Systems (GPS) (Meža et al., 2014) and compasses for the user's pose estimation (Woodward et al., 2010), but they are not accurate enough and are not able to be used for indoor applications (Wing et al., 2005).

Additional methods for markerless augmented reality were introduced in computer vision literature. These methods allow alignment of real and virtual objects, but have not yet been employed for BIM models nor tested on a construction site. In the past years, new camera systems (e.g. Kinect) were introduced that could provide both colour and depth images. These systems created new possibilities for marker-free augmented reality applications by offering a 3D perception of the world and facilitating detection of the position and orientation of the user. Because of these new possibilities, new mobile devices have emerged that are equipped with both camera and depth sensors such as Microsoft Hololens, Project Tango, etc. Besides the potential that all these new devices offer, there are several limitations. First of all, they were designed for indoor applications, and thus their use is constrained to such environments. Additionally, the drift error in the tracking has not been eliminated, meaning error increases when there is no depth variation, and the movements have to be relatively small and slow (Newcombe et al., 2011). The registration of local meshes to reconstruct the whole scene can contain errors, and the processing of data in real time on the device is also an issue.

3. PROPOSED SOLUTION

The objective of this paper is to suggest a markerless mobile-based augmented reality framework for building inspection purposes focusing on interior environments that supplements the view of the inspector with the 3D as-planned BIM model. As mentioned above, the majority of emerging mobile augmented reality systems can capture RGBD data. Thus, the authors decided to leverage these 3D perceptions of the scene for the purposes of their research. Since the research is focused mainly on interior inspection, where the construction activities tend to be more complicated, the inefficiency of those systems used in outdoor environments does not affect the implementation of the current framework. Thus, the first step of the framework is to capture the RGB and depth data.

Using the Kinect Fusion algorithm (Newcombe et al., 2011), the 6 degrees of freedom (DOF) pose estimation of the camera and 3D reconstruction of the view's scene are captured. Kinect Fusion currently is able to reconstruct only local volumes of the scene. Then the BIM file is loaded and manually moved to match the view given by the Kinect camera. The next step is to connect the pose estimated by the Kinect Fusion algorithm to the BIM viewer for the augmented reality implementation so the camera of the BIM viewer follows the movement of the Kinect camera. The movement of the Kinect sensor has to be relative slow, as mentioned in section 2 of the paper, to avoid loss of tracking. This step can contain errors, and in order to correct the alignment of the BIM model to the real scene view, the Iterative Closest Point (ICP) algorithm is used. The ICP algorithm minimises the difference between the 3D reconstruction of the real scene and the 3D as-planned BIM model. The proposed framework is depicted in Figure 1.

Since, Kinect Fusion can only reconstruct a specific volume of the scene, a method is needed to reset the reconstruction when the camera nears the borders of the previously-reconstructed volume. A volume of the new scene must then be reconstructed. Subsequently, the ICP algorithm is applied again to match the 3D as-planned model to the new reconstructed volume of the scene. The reconstructed volumes are also registered to each other using the ICP algorithm, resulting in a map of the reconstructed as-built scene.

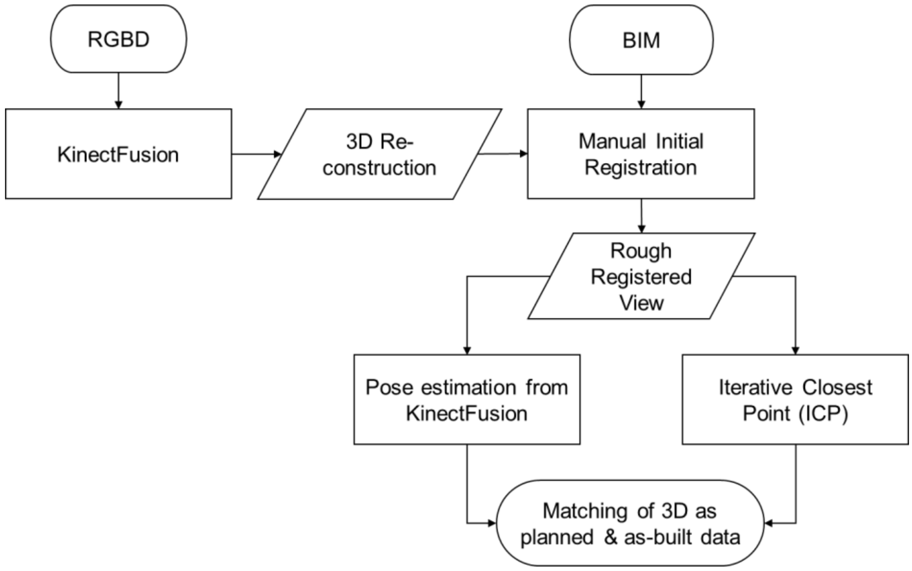

Figure 1. Proposed framework

4. EXPERIMENTS AND RESULTS

This section includes the steps we followed to implement and test the proposed approach. First, we built an AR-based platform that supports BIM files and RGBD data acquisition and processing. For this purpose, XbimXplorer was chosen as the core of the platform, which is an open source BIM viewer written in C# and WPF (Figure 2). For visualisation of the BIM file, XbimXplorer uses the HelixToolkit library. Windows 8.1, Visual Studio 2013, and .NET Framework 4.5 were used for development. Kinect v2 was chosen for the RGBD data acquisition. The next step was integration of the Kinect Fusion Explorer – WPF, as provided from the SDK Browser (Kinect for Windows) v2.0 (Figure 2), with the XbimXplorer (Figure 4). Figure 3 shows an exploded view of the different elements within the platform. A BIM file of the Construction Information Technology (CIT) Lab at Cambridge University was designed using SketchUp 2015. The BIM model was then displayed transparently for the augmented reality implementation, as depicted in Figure 4. More specifically, Figure 4 illustrates the visualisation of the 3D reconstruction of a part of a wall in real time using Kinect Fusion, overlaid with the corresponding BIM file displayed transparently. The BIM is manually placed in a way that matches the Kinect camera's view.

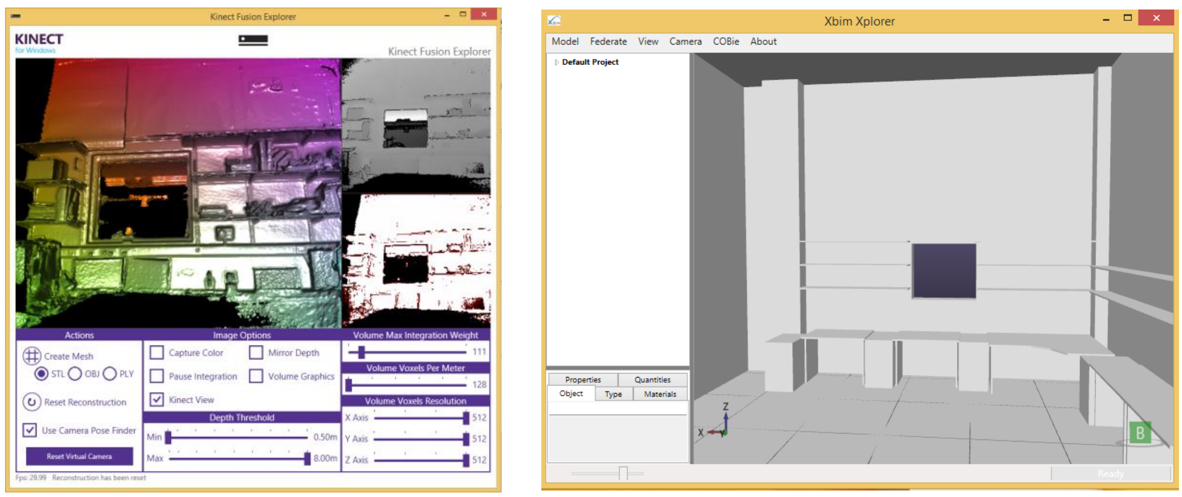

Figure 2. Kinect Fusion Explorer – WPF from SDK Browser (Kinect for Windows) v2.0 (left) and a display of a BIM model using XbimXplorer (right).

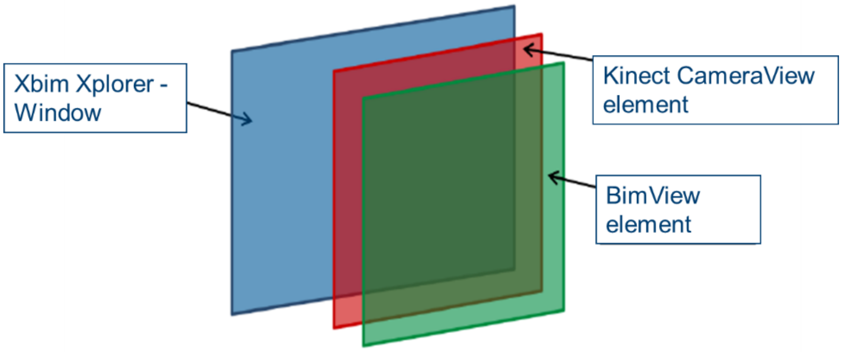

Figure 3. View of elements of the platform.

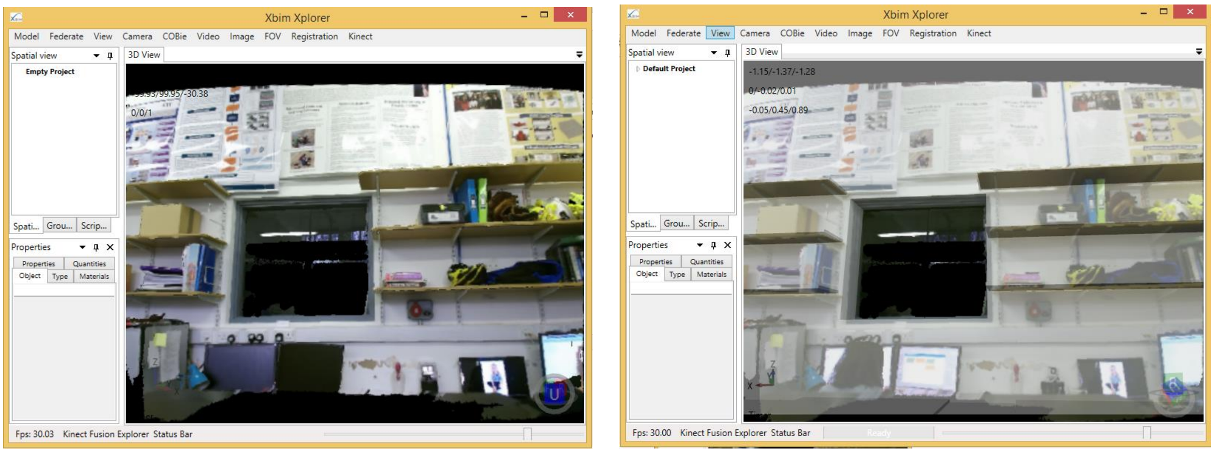

Figure 4. Integration of Kinect Fusion to XbimXplorer (left). Full augmented reality implementation of GUI – transparent BIM model on top of 3D as-built reconstruction on XbimXplorer (right).

The final step was connection of the Kinect camera's movement (rotation and translation) with the BIM viewer camera. Kinect Fusion Explorer includes a class that provides quaternion coordinates of the camera. These were linked and translated into XbimXplorer's camera direction as given from the HelixToolkit library. So far, the proposed framework and the tracking of the camera was tested within scenes that have sufficient depth variation. The ICP algorithm was then implemented to match the 3D as-planned model and the 3D as-built scene (Figure 5). The reconstruction volume voxel resolution was chosen to be 512x512x512.

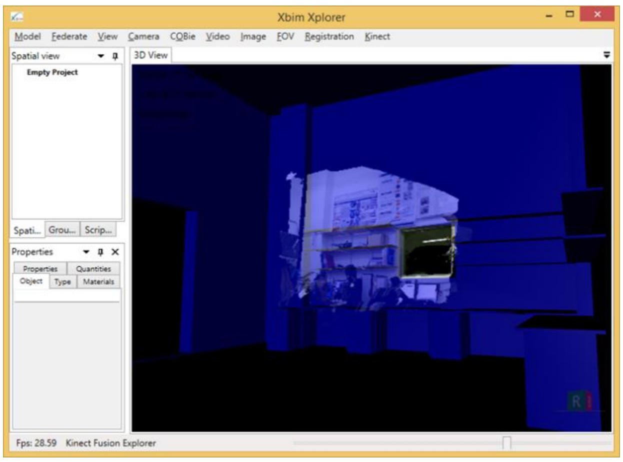

Figure 5. Implementation of the ICP algorithm

5. CONCLUSIONS

Most mobile augmented reality inspection systems in current practice are limited by their use of markers, by restricting the user to specific spots for using BIM information, and by requiring the use of Wi-Fi. All these systems cannot be efficiently implemented on a construction site, which is a dynamic and constantly evolving environment. Other methods for markerless mobile augmented reality applications were introduced in computer vision literature, but have not yet been tested on site nor used with BIM models. This paper presented a solution for markerless registration for mobile augmented reality based inspection that displays the BIM model and its information on top of the user's mobile camera view. First, a platform was built that supports the augmented reality implementation and can display the BIM model transparently. The proposed solution uses the Kinect v2 sensor that acquires RGBD data and the Kinect Fusion algorithm to reconstruct the as-build scene. The pose estimation given from Kinect Fusion is used in the BIM viewer to move the BIM view accordingly. The ICP algorithm is implemented to correct errors in the alignment of the BIM model with the view of the Kinect camera. The ICP algorithm is also used to register the local meshes obtained by Kinect in order to create the map of the as-built scene. This 3D as-built map can be used further for additional applications such as progress or quality control.

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REFERENCES

Azuma, R. T. (1997). A Survey of Augmented Reality. *Presence-Teleoperators and Virtual Environments* 6, 4(August), 355–385.

Côté, S., Trudel, P., Desbiens, M., Giguère, M., & Snyder, R. (2013). Live mobile panoramic high accuracy augmented reality for engineering and construction. *Proceedings of the Construction Applications of Virtual Reality (CONVR)*, London, England.

Frame, J. D. (1997). Establishing project risk assessment teams. *Managing risks in projects*, K. Kahkonen and K. A. Artto, Eds.: E & FN Spon, London.

Gheisari, M., Williams, G., Walker, B. N., & Irizarry, J. (2014). Locating Building Components in a Facility Using Augmented Reality Vs. Paper-based Methods: A User-centered Experimental Comparison. *Proceedings of International Conference on Computing in Civil and Building Engineering* (pp. 850–857).

Golparvar-Fard, M., Peña-Mora, F. (2007). Application of Visualization Techniques for Construction Progress Monitoring. *Computing in Civil Engineering* (pp. 216–223). Reston, VA: American Society of Civil Engineers. Golparvar-fard, M., Peña-mora, F., & Savarese, S. (2011). Integrated Sequential As-Built and As-Planned Representation with D 4 AR Tools in Support of Decision-Making Tasks in the AEC / FM Industry, (December), 1099–1116. doi:10.1061/(ASCE)CO.1943-7862.0000371.

Golparvar-Fard, M., Peña-Mora, F., & Savarese, S. (2009). Monitoring of construction performance using daily progress photograph logs and 4d as-planned models. *In ASCE International Workshop on Computing in Civil Engineering*.

Golparvar-Fard, M., Peña-Mora, F., & Savarese, S. (2012). Automated Progress Monitoring Using Unordered Daily Construction Photographs and IFC-Based Building Information Models. *Journal of Computing in Civil Engineering*, 04014025. doi:10.1061/(ASCE)CP.1943-5487.0000205

IBC 2000 Project Control Best Practice Study by IPA

IBC Cost Engineering Committee (CEC)

Irizarry, J., Gheisari, M., Williams, G., & Walker, B. N. (2013). InfoSPOT: A mobile Augmented Reality method for accessing building information through a situation awareness approach. *Automation in Construction*, 33, 11–23.

Koller, D., Klinker, G., Rose, E., Breen, D., Whitaker, R., & Tuceryan, M. (1997). Real-time vision-based camera tracking for augmented reality applications. *Proceedings of the ACM symposium on Virtual reality software and technology* - VRST '97 (pp. 87–94). NY, USA.

Koo, B., & Fischer, M. (2000). Feasibility study of 4D CAD in commercial construction. *Journal of construction engineering and management*, 126(4), 251-260.

Kwon, O.-S., Park, C.-S., & Lim, C.-R. (2014). A defect management system for reinforced concrete work utilizing BIM, image-matching and augmented reality. *Automation in Construction*.

Lee, S., & Pena-Mora, F. (2006). Visualization of Construction Progress Monitoring. *In Joint International Conference on Computing and Decision Making in Civil and Building Engineering* (pp. 2527–2533).

Memon, A. H., Rahman, I. A., Aziz, A. A. A. (2012). The cause factors of large project's cost overrun: a survey in the southern part of peninsular Malaysia. *International Journal of Real Estate Studies*. 7(2).

Meža, S., Turk, Ž, Dolenc, M. (2014). Component based engineering of a mobile BIM-based augmented reality system. *Automation in Construction*, 42, 1-12.

Navon, R. (2005). Automated project performance control of construction projects. *Automation in Construction*, 14(4), 467–476.

Navon, R. (2007). Research in automated measurement of project performance indicators. *Automation in Construction*, 16(2), 176–188.

Newcombe, R. A., Izadi, S., Hilliges, O., Molyneaux, D., Kim, D., Davison, A.J., Kohli, P., Shotton, J., Hodges, S., Fitzgibbon, A. (2011). KinectFusion: Real-time dense surface mapping and tracking. *Proceedings of the 2011 10th IEEE International Symposium on Mixed and Augmented Reality*, p.127-136, October 26-29, doi 10.1109/ISMAR.2011.6092378.

Olawale, Y. and Sun M. (2010). Cost and time control of construction projects: Inhibiting factors and mitigating measures in practice. *Construction Management and Economics*. 28 (5), 509-526.

Shin, D. H., and Dunston, P. S. (2008). Identification of application areas for augmented reality in industrial construction based on technology suitability. *Automation in Construction*. 17(7), 882–894.

Shin, D. H., & Dunston, P. S. (2009). Evaluation of augmented reality in steel column inspection. *Automation in Construction*, 18(2), 118-129.

Shin, D. H., & Dunston, P. S. (2010). Technology development needs for advancing Augmented Reality-based inspection. *Automation in Construction*, 19(2), 169-182.

Wang, X., Truijens, M., Hou, L., Wang, Y., & Zhou, Y. (2014). Integrating Augmented Reality with Building Information Modeling: Onsite construction process controlling for liquefied natural gas industry. *Automation in Construction*, 40, 96–105.

Williams, G., Gheisari, M., Chen, P., and Irizarry, J. (2014a). BIM2MAR: An Efficient BIM Translation to Mobile Augmented Reality Applications. *Journal of Management in Engineering*, 10.1061/(ASCE)ME.1943-5479.0000315, A4014009.

Williams, G., Gheisari, M., and Irizarry, J. (2014b). Issues of Translating BIM for Mobile Augmented Reality (MAR) Environments. *Construction Research Congress* 2014: pp. 100-109. doi: 10.1061/9780784413517.011

Wing, M. G., Eklund, A., & Kellogg, L. D. (2005). Consumer-grade global positioning system (GPS) accuracy and reliability. *Journal of Forestry*, 103(4), 169-173.

Woodward, C., Hakkarainen, M., & Rainio, K. (2010). Mobile augmented reality for building and construction. *VTT Technical Research Centre of Finland*. Mobile AR Summit MWC 2010.

Yates, J. K., & Epstein, A. (2006). Avoiding and minimizing construction delay claim disputes in relational contracting. *Journal of Professional Issues in Engineering Education and Practice*, 132(2), 168-179.

Zavadskas, E.K., Vilutienė, T., Turskis, Z., Šaparauskas, J. (2014). Multi-criteria analysis of Projects' performance in construction. *Archives of Civil and Mechanical Engineering*, 14(1), 114-121.