A Systematic Review of the Benefits of Automation Inspection Tools for Quality Housing Delivery

T D Nena¹*, I Musonda¹ and C S Okoro²

¹. Department of Construction Management and Quantity Surveying, University of Johannesburg, South Africa
². Department of Finance and Investment Management, College of Business and Economics, University of Johannesburg, South Africa

*tholangdavid@yahoo.co.uk

Abstract. Efficient and effective inspection is vital for the quality delivery of housing construction. Houses are being inspected less frequently due to incapacitated inspectorates, high cost, and the long duration of the current inspection process. Furthermore, traditional inspection processes often contribute to poor quality housing delivery are inspector dependent and complex and unsafe working environment is exposed to inspectors. Automated inspection technologies play a vital role in the inspection of housing construction. Automation-assisted technologies such as laser scanners, drones and Augmented Reality (AR)-based inspection equipped with multiple imaging and sensing systems have been developed to mitigate some of these issues with the traditional method of inspection processes. This paper reviews relevant peer-reviewed articles to explore automation inspection process tools and technologies and highlight their benefits in the housing construction process. Following the systematic literature assessment methodology, five (5) databases were queried, based on the specific search string. Specifically, 26 journal articles satisfying a set of inclusion criteria were reviewed, its results highlighting the benefits of adopting an automated inspection process for quality housing delivery. The review of the journal articles revealed that the automation inspection process is available with several benefits demonstrating the potential to improve the quality housing delivery with the aid of tools and technologies like Augmented Reality (AR)-based inspection, 3D laser scanning, Drones, and BIM-based inspection. Benefits such as time-saving, limited human intervention during the construction process, inspection accuracy, reduced resource requirements, and improved collaboration between stakeholders. This study also revealed that while new technologies are evolving with benefits to improve the inspection process, there is still a gap in the practical application of these automated inspection process technologies during housing construction. The outcome of this study would benefit both the housing owners (clients), building inspection entities, building construction researchers, and the industry professionals to realise the potential of the automation inspection process and understand the requirements and benefits for their successful implementation.

1. Introduction

Construction industry productivity has declined over the last decades compared to the manufacturing industry which doubled its productivity over the same period [1]. The benefits of automation in the manufacturing industry could be the reasons for high productivity. In manufacturing, it has been observed that, automation helps reduce the rate of production errors, does not compromise production quality for speed, drastically reduces production time, and increased workers' safety [2]. Furthermore, automation recorded a sustainable reduced cost on labour spending, and increased labour productivity also cut down manual tasks [3]. These immense benefits have led to the emergence of research in applying automation to construction processes. Concurrent with this is the need to automate the processes vital to enabling rapid delivery of quality housing infrastructure [4]. Principal to these processes is the housing inspection process which enables the compliance of construction projects with acceptable government standards and guidelines.
The use of automation for housing inspection is increasingly being adopted in the construction industry. The use of an automated inspection process offers the benefit of carrying out inspections of houses without being on the actual construction site [4]. For instance, automated technologies such as drones, laser scanners improve upon traditional methods of inspecting which are human reliant [5]. However, while research in automation inspection is an emerging area, it is imperative to establish an outlook of relevant previous studies and their impact in furthering research in automation during housing construction inspection. The review is also pivotal in identifying areas that are lacking and areas that need further research to avail a seamless automation inspection adoption across the AEC sector.

Accordingly, the systematic review reported here aims to explore the benefits of the automated inspection process for construction of houses following the Preferred Reporting Items for Systematic Review and Meta-Analysis (PRISMA) statement for systematic review reporting format [6,7]. To explore the recent automated inspection processes with their benefits, peer-reviewed journal articles published from 2012 to 2020 were reviewed. The specific objectives were to 1) determine the tools and technologies used for the automation-enabled inspection process, 2) to determine the benefits of the automation inspection process for quality housing construction, and finally, 3) to identify the gap in the literature and propose future research agenda.

2. Methodology

Systematic reviews are important in summarising the empirical evidence related to technology or method that helps in suggesting feasibilities for further research in the same area. Sometimes, contradiction or support of the hypothesis can be achieved through a systematic review. First, a protocol to select studies and extract necessary information from the data set along with the proper justifiable need for the review needs to be identified and later take efforts to synthesise the selected data and report the overall review properly [8]. Hence, the studies related to automation in the housing construction domain were systematically reviewed to explore the benefits of the automation inspection process. For the development of theory, a systematic literature review plays a vital role in the development of theory and also helps in fulfilling the possible gaps in research. Moreover, it highlights the areas where further research is needed within the available literature [8]. The main objective of the paper was to provide a systematic review and the benefits of the automation inspection process in housing construction within the last nine years. For that purpose, a systematic review was done following the PRISMA template presented below [6].

2.1 Search strategy

A systematic search strategy was used to identify relevant literature available on the automated inspection process methods for housing construction. This strategy was tailored to five databases: Scopus, Ebscohost, Google scholar, African Journals (Formerly: SA ePublications), American Society of Civil Engineers (ASCE), and the terms used as search string were the following: “inspection process” OR “inspection systems”, “inspection technology” AND benefits, “housing” OR “building infrastructure” AND delivery, as advised by the Boolean operator [9]. Keywords used were automation, inspection, technology, housing construction, benefits, and the search span was from the year 2012 to 2020.

2.2 Quality assessment

The study is based on peer-reviewed journal articles. A thorough check of duplicated articles was carried out on Microsoft excel [10] to maintain the quality of the review and 4 duplicate articles were removed. Also, the abstract and conclusion of articles were thoroughly checked to ensure the quality and relevance of academic literature included in the review process [11] at the later stage, the careful evaluation of each research paper was carried out. The next was to consider exclusion and inclusion criteria where the study was only limited to English-written articles. For exclusion criterion, only four (4) articles were
written in non-English language and were excluded from the study. The literature search is also explained in the PRISMA flowchart below.

2.3 Studies included in the qualitative synthesis
The final 26 journal articles are used after assessing each article based on the above-mentioned exclusion and inclusion criteria. These articles are used for the final process based on different steps. In the first step, the corresponding of Microsoft excel to a descriptive analysis of the literature published on automation inspection process in the field of housing construction like the distribution of year, distribution of countries, distribution of the citations, and journal area identifications. In the other step, the content analysis was done to identify and analyse the main direction and research done by the researchers in the year 2012 to 2020 as well as mentioning the benefits and reporting on the future opportunities to research [10].

Figure 1: Study selection results using PRISMA chart

3. Results

3.1 Journal article year-wise publications
The journal year-wise publications focusing only on automation-enabled inspection process are shown in figure 2 below with 2012 and 2015 selected papers being the lowest with one (1) paper respectively, followed by 2013 with only two (2) papers. The year 2016, 2017, 2019, and 2020 were high with three
(3) papers, respectively. 2014 selected publications were higher with four (4) papers while 2018 was the highest number of selected papers with six (6) papers. The Journal article year is imperative in gauging the evolution of research in the field of discourse [12]. The low number of publications in 2019 and 2020 could be due to the Coronavirus pandemic which shut down numerous countries across the globe and therefore prevented, amongst other activities, research, and academics. However, the high number of publications gotten from 2018 signifies a degree of enlarging awareness amongst researchers in the area. The finding also instructs that the emergence is slow, and much effort is needed between researchers to advance this important discourse.

![Year-wise publications per year between 2012 and 2020](Figure 2)

### Figure 2: Year-wise publications per year between 2012 and 2020

### 3.2 Journal based publications

The other important assessment that was made for the study is article journal area identification of the study. Most of the papers were selected from the automation in construction with eleven (11) papers. The second journal area identification is the journal of infrastructure systems and Proceedings of the Creative Construction Conference with two (2) papers, respectively. And finally, one (1) paper was selected from each remaining journal area identification contributed to the study. The results are shown in figure 3 below. The high rate of publications from Automation in Construction could be due to the focus of the Journal on Industry 4.0 technologies; however, it also raises the need for more Journals reviewing and accepting publications more importantly as research in Industry 4.0 currently dominates the academic discourse. As the publication is pivotal to research drive, journals as stakeholders in the research process must encourage more publication in this discourse to further expand the body of knowledge on automation of the inspection process.

![Journal area identification](Figure 3)

### Figure 3: Journal based publication

### 4. Classification of literature

#### 4.1 Automated inspection tools application and their benefits

The application of automation in inspection processes is wide-ranging. As stated by [13], UAV/Drones could help in accurate inspections, improved time efficiency, reduced paperwork, and enabling safety of labour on site. While with robotics, they could aid with the flexibility of the inspection process [14].
Furthermore, they can be integrated with BIM to automatically generate inspection lots, improve quality supervision of projects, and also avail a safe, efficient, and cost-effective platform. Other applications and benefits include; Automated document management & data collection [15,16] in Augmented reality platforms and 3D laser scanning, [17,18].

Table 1: Table of classifications

| ID | Automated inspection tools and technology | Benefits of the automated inspection process | Sources |
|----|------------------------------------------|---------------------------------------------|---------|
| 1. | UAV/Drone-based inspection                | • Effectiveness and more robust in automated navigation and visual data collection  
• accurate inspections  
• Improve time efficiency  
• reduce paperwork | [5,13,19,20,21,22] |
| 2. | Robotic – Based inspection                | • Cost-effective, robust, and flexible enough to be employed in a variety of inspection scenarios. | [3,14,23,24,25] |
| 3. | BIM-based inspection                      | • Automatically generate inspection lots, items, and points.  
• The system makes it easier for inspectors to learn the inspection object intuitively and comprehensively before the construction phase  
• More effective to fill out the customized forms without worrying about omission and negligence  
• More convenient to input the data in the original records into computers without second input to reduce huge workload and data falsification. | [26,27,28,29,30,31,32] |
| 4. | Augmented Reality (AR)                    | • Automated document management & data collection,  
• Minimal set-up required  
• No need for training to operate the tool | [15,16,33,34] |
| 5. | 3D laser scanning                         | • Automated document management & data analysis  
• Improved accuracy | [17,18,35,36] |

4.2 Time saving
Time-saving is one of the benefits of the automation inspection process where more houses are being inspected effectively and efficiently. According to [14] robotic inspection system was proven to being an effective and efficient tool for inspection without time-consumming where defects during the construction process are detected without the involvement of human inspectors. Also, the study conducted by [16] developed an inspection system that does not save time only but also reduces construction reworks related costs on site. These studies present the possibility of improving the inspection process by automation in the construction of housing.

4.3 Reduced resource requirements
Daily site visits to conduct inspection can cause fatigue to humans, as a result, more errors could be encountered during decision making. The study conducted by [20] emphasised that utilising and implementing new technologies such as drones can be useful in improving efficiency, reduce paperwork and automate the entire process of inspection process. The study found that the ability for drones to use the on-board processor to receive the location information of the scheduled inspection visits makes it
easy for inspectorates not to drive around searching for a location and reduce the unnecessary site visits, with the use of images and data collected with the help of drone from site to detect any non-compliance then inspectorates use the mobile application to issue out non-compliance if detected during the inspection process. This is supported by [14] who suggest the use of robots to assist with housing inspection with the argument that it reduces labor while improving efficiency and effectiveness during the inspection process. Another study by [3] designed the robotic inspection tool to assist human inspectors to reduce the need for more labor to conduct an inspection task of housing construction. These studies present the possibility of adopting the use of automated tools for housing inspection under construction where it was found to be more beneficial than the use of traditional tools of inspecting.

4.4 Improved collaboration

The collaboration of all construction stakeholders plays a vital role in ensuring quality housing delivery [37]. Currently, structural damage results from compromised construction quality standards [38]. For effective and efficient inspections, builders and inspectors should work together for a better quality of construction work [39]. Also, transforming construction into a technology-driven industry could improve quality, collaboration between stakeholders, productivity, and efficiency [40]. According to [27], this technology could be Building Information Model (BIM) which will improve inspection efficiency where collaboration work among inspectors and builders is improved leading to improved quality housing delivery. For better collaboration, multiple mobile robots can also work simultaneously and send the inspection data to a cloud server and the results can be reviewed by multiple inspectors retrieved from the cloud server at the same time [41]. The BIM-based inspection makes it easier for housing inspectors to collaborate during the inspection process.

5. Conclusion and future work

Research trends indicate that in recent years automation in housing construction is receiving more attention. An automation inspection process is a key to efficient and effective quality housing delivery. A systematic search and the literature screening procedures in this research were used following the PRISMA statement template to identify relevant research studies on the topic. After the literature selection procedure, 26 articles were selected for further analysis. The results show that more of the research activities are done in developed countries where the benefits of the automation inspection process are realised. The most proposed tools and technologies used to enable the automation inspection process are 3D laser scanners, Drones, BIM-based inspection, Robotic–based inspection, and Augmented Reality (AR). While some of these tools and technologies are evolving and tested mostly in laboratories with mock-ups, the main existing gap is the implementation of these tools and technologies to the actual housing construction and monitor their benefits. The existing research shows that the main challenge is to adopt and implement these automation tools and technologies which can collect data effectively and efficiently. Automation tools and technologies are usually complicated to use and expensive to acquire. In addition to the use of these tools and technologies, experienced inspectors are required. Future studies should test the use of automated inspection tools and technologies on the actual construction of houses. Future research should also look at developing an automated inspection process framework for housing construction projects focusing on developing countries.

6. References

[1] Oesterreich T D and Teuteberg F 2016 Understanding the implications of digitisation and automation in the context of Industry 4.0: A triangulation approach and elements of a research agenda for the construction industry *Computers in industry* 83 pp 121-139

[2] Gregori F, Papetti A, Pandolfi M, Peruzzini M and Germani M 2017 Digital manufacturing systems: a framework to improve social sustainability of a production site. *Procedia CIRP*, 63 pp 436-442
[3] Yan R J, Kayacan E, Chen I M, Tiong L K and Wu J 2018 QuicaBot: Quality inspection and assessment robot *IEEE Transactions on Automation Science and Engineering* 16 pp 506-517

[4] Elshafey A, Saar C C, Aminudin E B, Gheisari M and Usmani A 2020 Technology acceptance model for Augmented Reality and Building Information Modeling integration in the construction industry *J. Inf. Technol. Constr.* 25 pp 161-172

[5] Rakha T and Gorodetsky A 2018 Review of Unmanned Aerial System (UAS) applications in the built environment: Towards automated building inspection procedures using drones *Automation in Construction* 93 pp 252-264

[6] Moher D, Liberati A, Tetzlaff J and Altman D G 2009 Preferred Reporting Items for Systematic Reviews and Meta-Analyses: The PRISMA Statement *PLoS Med* 6 pp 1-6

[7] Albeaino G, Gheisari M and Franz B W 2019 A systematic review of unmanned aerial vehicle application areas and technologies in the AEC domain *J. Inf. Technol. Constr.* 24 pp 381-405

[8] Abideen A Z, Mohamad F B and Fernando Y 2020 Lean simulations in production and operations management–a systematic literature review and bibliometric analysis. *Journal of Modelling in Management*.

[9] Aghajafari F, Nagulesapillai T, Ronksley P E, Tough S C, O’Beirne M and Rabi D M 2013 Association between maternal serum 25-hydroxyvitamin D level and pregnancy and neonatal outcomes: systematic review and meta-analysis of observational studies. *Bmj*, 346

[10] Khan N and Qureshi M 2020 A systematic literature review on online medical services in Malaysia

[11] Olawumi T O, Chan D W and Wong J K 2017 Evolution in the intellectual structure of BIM research: A bibliometric analysis *Journal of Civil Engineering and Management*, 23 pp 1060-1081

[12] Saka A B and Chan D W 2019 A scientometric review and metasynthesis of building information modelling (BIM) research in Africa *Buildings* 9 p 85

[13] Greenwood W W, Lynch J P and Zekkos D 2019 Applications of UAVs in civil infrastructure *Journal of infrastructure systems*, 25 p 04019002

[14] Wang J and Luo C 2019 Automatic Wall Defect Detection Using an Autonomous Robot: A Focus on Data Collection In *Computing in Civil Engineering 2019: Data, Sensing, and Analytics* pp 312-319

[15] Kopsida M, Brilakis I and Vela P A 2015 A review of automated construction progress monitoring and inspection methods In *Proc. of the 32nd CIB W78 Conference 2015* pp 421-431

[16] Kwon O S, Park C S and Lim C R 2014 A defect management system for reinforced concrete work utilizing BIM, image-matching and augmented reality *Automation in construction* 46 pp 74-81

[17] Maalek R, Ruwanpura J and Ranaweera K 2014 Evaluation of the state-of-the-art automated construction progress monitoring and control systems In *Construction Research Congress 2014: Construction in a Global Network* pp 1023-1032

[18] Liu D, Lu W and Niu Y 2018 Extended technology-acceptance model to make smart construction systems successful *Journal of Construction Engineering and Management* 144 p 04018035

[19] Freimuth H and König M 2018 Planning and executing construction inspections with unmanned aerial vehicles *Automation in Construction* 96 pp 540-553

[20] Ashour R, Taha T, Mohamed F, Hableel E, Kheil Y A, Elsalamouny M, Kadadha M, Rangan K, Dias J, Seneviratne L and Cai G 2016 Site inspection drone: A solution for inspecting and regulating construction sites In *2016 IEEE 59th International Midwest Symposium on Circuits and Systems (MWSCAS)* pp 1-4

[21] Asadi K, Suresh A K, Ender A, Gotad S, Maniyyar S, Anand S, Noghabaei M, Han K, Lobaton E and Wu T 2020 An integrated UGV-UAV system for construction site data collection *Automation in Construction* 112 p 103068
[22] Musonda I and Pillay N 2019 Using UAV’s and BIM integration to improve infrastructure delivery--A case of Gauteng department of Infrastructure Development, South Africa In Creative Construction Conference 2019 pp 922-928

[23] Lattanzi D and Miller G 2017 Review of robotic infrastructure inspection systems Journal of Infrastructure Systems 23 p 04017004

[24] Yan R J, Kayacan E, Chen I M and Tiong L K 2017 A novel building post-construction quality assessment robot: Design and prototyping In 2017 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS) pp 6020-6023

[25] Cai S, Ma Z, Skibniewski M J, Bao S and Wang H 2020 Construction Automation and Robotics for High-Rise Buildings: Development Priorities and Key Challenges Journal of Construction Engineering and Management 146 p 04020096

[26] Ma Z, Cai S, Mao N, Yang Q, Feng J and Wang P 2018 Construction quality management based on a collaborative system using BIM and indoor positioning. Automation in Construction 92 pp 35-45

[27] Ma Z, Mao N and Yang Q 2016 A BIM based approach for quality supervision of construction projects In Creative Construction Conference, 25-28 June 2016, Budapest, Hungary pp 644-649

[28] Hamledari H, Davari S, Azar E R, McCabe B, Flager F and Fischer M 2017 UAV-enabled site-to-BIM automation: Aerial robotic-and computer vision-based development of as-built/as-is BIMs and quality control In Construction research congress pp 336-346

[29] Ding L, Li K, Zhou Y and Love P E 2017 An IFC-inspection process model for infrastructure projects: Enabling real-time quality monitoring and control Automation in Construction 84 pp 96-110

[30] Tsai Y H, Hsieh S H and Kang S C 2014 A BIM-enabled approach for construction inspection In Computing in Civil and Building Engineering (2014) pp 721-728

[31] Tsai Y H and Hsieh S H 2016 Process modeling of a BIM-enabled construction inspection approach with BPMN In Proceedings of the International Conference on Innovative Production and Construction, Darwin, Australia pp 3-5

[32] Chen L and Luo H 2014 A BIM-based construction quality management model and its applications Automation in construction 46 pp 64-73

[33] Lee J Y, Kwon O S, Choi J S and Park C S 2012 A study on construction defect management using augmented reality technology In 2012 International Conference on Information Science and Applications pp 1-6

[34] Park C S, Lee, D Y, Kwon O S and Wang X 2013 A framework for proactive construction defect management using BIM, augmented reality and ontology-based data collection template Automation in construction 33 pp 61-71

[35] Anil E B, Tang P, Akinci B and Huber D 2013 Deviation analysis method for the assessment of the quality of the as-is Building Information Models generated from point cloud data Automation in construction 35 pp 507-516

[36] Kim M K, Thejdja J P P and Wang Q 2020 Automated dimensional quality assessment for formwork and rebar of reinforced concrete components using 3D point cloud data Automation in Construction 112 p 103077

[37] Akinyeke I J, Fapohunda J A and Haldwang R 2017 Evaluation of Critical Factors for Achieving Quality Housing Delivery within Budget In International Conference on Sustainable Infrastructure 2017 pp 153-164

[38] Adenuga O A 2013 Factors affecting quality in the delivery of public housing projects in Lagos State, Nigeria

[39] Fore S 2015 An Analysis of Factors Influencing the Quality of Housing Construction Projects in the Western Cape, South Africa International Journal of Science and Technology 1 pp 195-211

[40] Aripin I D M, Zawawi E M A and Ismail Z 2019 Factors influencing the implementation of technologies behind industry 4.0 in the Malaysian construction industry In Matec Web of Conferences 266 p 01006
[41] Liu L, Chen I M, Kayacan E, Tiong L K and Maruvanchery 2015 Automated construction quality assessment: A review In 2015 10th International Symposium on Mechatronics and its Applications (ISMA) pp 1-6