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QUALITY MANAGEMENT PLATFORM INSPIRED DURING COVID-19 PANDEMIC FOR USE BY SUBCONTRACTORS IN PRIVATE HOUSING PROJECTS

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Abstract. Due to the COVID-19 pandemic in Taiwan, many construction sites must limit the number of people on the jobsite or conduct work independently to avoid the spread of COVID-19. The quality of construction may be in doubt with unclear job handover, especially when workers have COVID-19 infection that should be isolated immediately. On top of that, first-level subcontractor self-inspections are crucial parts of construction process management, and neglecting inspection processes can lead to construction errors and poor quality. To improve current quality inspection methods for private projects, a literature analysis was conducted to identify construction quality management issues that are faced in private housing projects. In-depth interviews with small and medium-sized subcontractors of private housing projects were performed to understand the quality management methods that they use in practice. Next, improvement measures for quality management were formulated and a simplified checklist for private project subcontractors, based on the practical feedback obtained, was created. Finally, the AppSheet platform was used to develop an inspection application for construction, and a subcontractor was invited to confirm its feasibility. The paperless design avoids redundant human contact, and the results of this study greatly facilitate construction practice, particularly during the pandemic. The main contribution of this study is its investigation of the procedures that are used by private project subcontractors to inspect their work for quality management; its results can serve as a reference for academics in evaluating construction quality management levels and improving the management of work by subcontractors to promote safety and health.

Keywords: private housing project, subcontractor management, construction quality management, construction inspection checklist, mobile device application.

Introduction

Owing to the COVID-19 pandemic in Taiwan, many construction sites are either being required to limit the number of people on the jobsite or executing individual tasks on their own to limit the spread of COVID-19. It causes longer construction times with only one or two items being allowed to work on a project at a time to maintain social distancing among workers. The quality of construction may be in doubt because of unclear job handover, especially when workers are infected with COVID-19, and self-quarantine is mandatory immediately.

Apart from this, the construction quality of private residences has a direct impact on the quality of life of their residents. Severe cases of poor construction quality can pose a threat to life and property. Neglecting quality management during construction can lead to construction accidents, water leakage, the falling of tiles in the future, or even insufficient overall structural strength, which can reduce the service life of the building.

Proper quality management should therefore be implemented during construction to prevent poor quality from resulting in future hazards. To manage and enhance construction quality, the Public Construction Commission of the Executive Yuan promulgated the Public Construction Quality Management System in 1993. However, no mandatory regulations govern inspection management by subcontractors, leading to variable quality of construction in private housing projects. Poor subcontractor performance impacts the quality of projects and the outcomes of assets,

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as well as reflecting on contractors, other subcontractors, and clients, further leading to project delays and overruns (Arantes & Ferreira, 2021; Doloi et al., 2012).

To ensure that construction is executed in accordance with design specifications, inspections by construction subcontractors of their own work are critical. Negligence during inspection processes can cause construction errors, poor quality, or additional expenses in the future (Al-Adhami et al., 2019). Checklists are an important inspection device. In public construction quality management systems, most inspections of work are performed by construction companies.

However, the key links in construction process management are the first-level subcontractors (Hernández et al., 2018), who often regard checklist-based checks as a formality and do not properly perform them. Applying checklists in public construction to private projects is cumbersome and over-standardized; a simpler checklist would facilitate implementation. In addition, information management systems should be introduced to replace conventional handwritten inspection methods, which are time-consuming and inefficient to prevent possible writing errors or omissions (Rolfsen & Lassen, 2020) and to increase work efficiency.

With small and medium-sized subcontractors in private housing projects as the target of this study, a literature review, on-site inspections of construction projects, and in-depth interviews with project managers were conducted to investigate construction quality management methods and discrepancies between quality management theory and practice and to propose improvements to inspections for quality management. These improvements can be promulgated as part of the continued education of construction operators to improve the quality of construction by private housing project subcontractors.

Finally, an application was developed using a cloud system for use by subcontractors in conducting on-site inspections of their own work, based on quality management knowledge systems and interviewees' feedback on construction practices, in the hope of resolving issues around conventional handwritten inspections and properly recording and managing construction documents. The results of this study will greatly benefit private project subcontractors in overcoming challenges that have been posed by COVID-19. The proposed quality management platform reduces the need for human contact, provides safer working conditions, and supports workers both mentally and physically.

This paper is organized as follows. Section 1 reviews the relevant literature. Section 2 describes the methodology that is used herein. Section 3 discusses the current situation and analysis of private project subcontractor inspections for quality management. Section 4 elaborates on the application of mobile devices for subcontractor self-inspections. The last section summarizes the findings and limitations of the method and makes recommendations for future studies.

1. Literature review

This section first reviews the domestic and international construction quality management systems. Based on the literature review, inspection by subcontractors is a crucial link in quality management and control. Therefore, this work investigates the inspection procedures of subcontractors to lay a foundation for the subsequent development of a quality management platform for use by subcontractors in private housing projects. The literature review establishes the theoretical basis for this study to build the self-checking application and future prospects.

1.1. Public construction quality management

1.1.1. Domestic construction quality management system

The Public Construction Commission of the Executive Yuan promulgated the Public Construction Quality Management System in 1993. This system is a quality management framework that comprises three constituent systems, which are a contractor construction quality control system (Level 1), an authority-in-charge construction quality assurance system (Level 2), and an authority-in-charge construction quality inspection system (Level 3) as shown in Figure 1. The purpose of the overall system is to improve supervision, management, and construction quality.

Although public construction quality management in Taiwan already involves a relatively sound system and planning, inadequate implementation sometimes occurs and improvements are needed in some areas. The most fundamental and critical problem that affects construction quality is the lax use of checklists (Qiu, 2011), which makes inspections for quality management merely nominal and a formality (Zhang, 2021). Second only to this problem is the repetition of inspection tasks by supervisors, organizers, and contractors, which leads to low efficiency and increases the complexity of document reviews (Lin, 2005). This study will therefore create a simplified version of the standard checklist and promote it to private project subcontractors to improve construction quality and construction efficiency, while reducing the repetitiveness of relevant procedures.

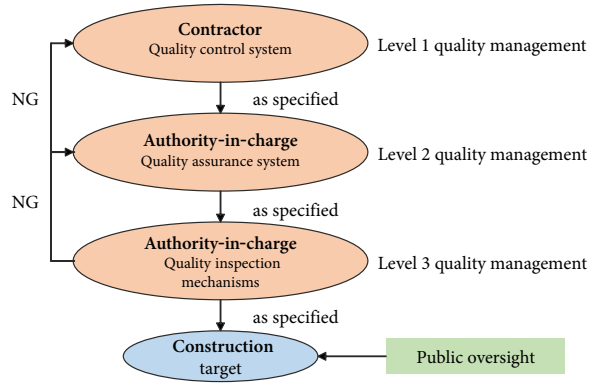


Figure 1. Framework of three-level quality management system for public construction

1.1.2. International construction quality management

To expand the knowledge of construction quality management, we examined the progress of public construction quality management in the US, the UK, Japan, Singapore, and China to support our subsequent revisions of management measures.

The construction industry in the US adopts Total Quality Management (TQM) in construction management to pursue high quality (Guo, 2006). The owners, designers, construction companies, and inspectors are all independent entities, and their responsibilities in relation to the quality inspection results are all very clear. Supervisory and management work is performed by inspectors sent by local governments.

Construction projects in the UK must be certified by Building Control Services (Zhang et al., 2006). Both supervisors from the local government and certified supervisors inspect the construction process and confirm that the construction meets building regulations.

The Great Hanshin earthquake in 1988 made Japan realize the importance of building safety; they established a new intermediate inspection system according to which third parties have the power to inspect construction and request that construction supervision units and contractors provide reports on their construction management process and inspections, so as to ensure construction quality (Xie & Ren, 2016).

Singapore promulgated the Construction Quality Assessment System (CONQUAS), which uses consistent quality management standards to evaluate construction quality (He & Li, 2018). Owners can choose construction companies that provide good construction quality based on their CONQUAS score, thereby promoting healthy competition among construction companies.

In China, the State Council promulgated the Regulations on the Quality Management of Construction Projects, which refer to three levels of oversight; these involve government departments on the first level, owners and supervision units on the second level, and construction units and survey and design units on the third level (Na et al., 2014).

A review of foreign public construction quality management and inspection systems reveals that construction quality is mostly managed by supervision units, with little mention of subcontractors' performing their own quality inspections. Based on our literature review, inspection by subcontractors is a crucial link in quality management and control. This work, therefore, investigates the inspection procedures of subcontractors to lay a foundation for the subsequent development of a quality management platform for use by subcontractors in private housing projects.

1.2. Quality management in private housing projects

The Taiwan government established a three-level quality management system for public construction and required that construction companies follow and implement the system to ensure construction quality. However, no quality management system has been established for private housing projects. The private construction legal system is not as complete as the public one: no inspection mechanisms, rewards, or punishments, are in statute. Quality assessment is entirely based on experience and judgment, which do not guarantee construction quality (O'Connor & Koo, 2021).

Construction companies presently outsource the quality management of private housing projects to their affiliated construction companies to reduce management fees and control construction quality (Zheng, 2008). With management models that integrate various operations, they have a more flexible decision-making system, but quality is determined by their operators (Xue, 2001). However, the production rating of the subcontractors is the key to the project quality, and supervisors may have to re-instruct subcontractors' workers on operations, leading to mistakes owing to insufficient manpower (Wu, 2019). Therefore, this investigation will identify quality management issues that private housing project subcontractors encounter and propose improvements to promote their implementation of inspections for quality management.

1.3. Applications of mobile devices in construction

A review of the foreign and domestic literature revealed an increase in the use of mobile devices in construction in recent years; such devices make the management of documents more convenient and increase construction efficiency. Ochoa et al. (2011) developed COIN (Construction Inspector), a document-sharing workspace with functions that include the management of inspection tasks associated with various construction tasks, the viewing and marking of construction drawings, and synchronous construction data messaging. Nguyen et al. (2015) created the InSite Inspector application, whose functions include recording information that is associated with construction errors, the automatic GPS-based location of such errors, and reporting the results of inspections.

Likewise, Liao (2016) developed a quality inspection information gathering system for small and medium-sized construction companies that digitizes construction checklists on paper. The system includes material quality checklists, occupational safety and health checklists, and construction item checklists for use by contractors. Its functions include adding, revising, and deleting forms, uploading construction photos/videos, and reviewing checklists. Tsai (2017) created mobile software to digitize daily construction project reports on paper; its functions include completing/revising daily construction logs and supervision reports, uploading and creating data files to save, and viewing historical reports.

The present review revealed that both foreign and domestic researchers have been incorporating information management systems into construction management and eliminating conventional paper-based operations. The use of mobile devices on construction sites can reduce

manual errors, increase document transmission efficiency, and make construction management more convenient and economical (Amici et al., 2022). Accordingly, making construction paperless and digital, with the storage of information on a cloud, is already a trend (Shin & Choi, 2022). However, the developed applications vary widely and have complex interfaces; no template for construction subcontractors is yet available. This study therefore uses a no-code friendly app platform to create a simple checklist and establishes an inspection application for use by subcontractors to enhance construction quality in private projects.

2. Research methods

This section introduces the research methods that are adopted in this study, including the use of the method of literature analysis that is used to summarize construction quality management theories, in-depth interviews with construction personnel, and surveys of construction quality management practices. Based on quality management knowledge systems and feedback on construction practices, a quality inspection application is developed using the AppSheet platform and the created checklist to enable digital documents to be stored on a cloud. Figure 2 presents the flowchart of the research methodology.

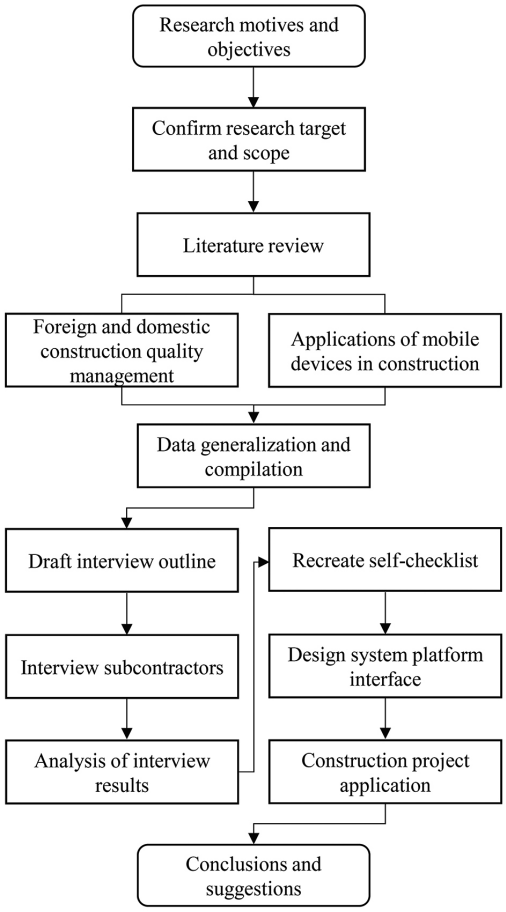


Figure 2. Flowchart of research methodology

2.1. Literature analysis

Literature analysis is a research approach that involves collecting market information, survey research reports, and industry information on a given topic; analyzing, generalizing, and integrating the information; and then objectively describing and analyzing the literature (Niu et al., 2019). The literature includes government agency reports, industrial studies, library books, academic journal papers, media news, newspapers, or magazines. The four major steps of this approach are reading and organizing, describing, classifying, and interpreting.

Consistent with the aforementioned method, foreign and domestic academic journals, research papers, government publications, and the websites of government and private institutions were read and organized to describe quality management methods in foreign and domestic construction and the characteristics of quality management in domestic private projects. The characteristics of those methods were classified as pros and cons and the issues and challenges that are encountered in construction quality management in private projects were identified to provide references for questions in subsequently conducted interviews.

2.2. In-depth interviews

In-depth interviews are frequently used to collect data in qualitative research (Whang et al., 2022). Conversations between interviewers and interviewees lead to an exchange of opinions and ideas (Shoar & Banaitis, 2019). An interview implicitly places value on the uniqueness of an interviewee's experiences and their feelings (Abu Adi et al., 2021). An understanding of interviewees' social phenomena and facts of interest can be gained, and their opinions and perspectives offered will be influenced by environment or background (Al-Janabi et al., 2020). During long interviews, interviewees can express their thoughts or personal feelings about, and experiences of, the subject of interest, and they can delve deep into the main points of related problem. As an interviewee expresses ideas, the interviewer obtains answers to questions of interest.

Interviews can be structured, semi-structured, or unstructured. Semi-structured interviews were used herein to investigate the quality management practices of small and medium-sized subcontractors in private housing projects. The interviewers set the topic and questions in advance to guide the interview. However, the interviewer did not have to follow the questions and could adjust flexibly depending on the responses. This approach gave the interviewees more room to express their opinions.

2.3. AppSheet design platform

AppSheet is a no-code development platform that was developed by the AppSheet software company (now Google AppSheet), which was founded in Seattle, Washington, in the USA. It extracts data from databases, such as forms or spreadsheets, and uses column names or fields in those

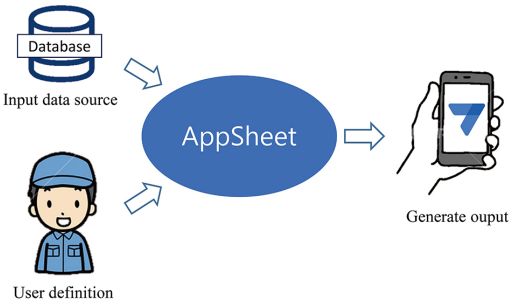


Figure 3. Work process of AppSheet platform

forms or spreadsheets as the basis of application construction. It manages input data using a user-defined interface and then finally generates the electronic apps with no code (as shown in Figure 3).

The advantages of this platform are that it can construct an application without the writing of code; no additional database server is required, and no website has to be set up as the editing console. It can link to multiple data sources and can be used on computers or mobile devices such as smartphones or tablet computers. It is compatible with both Android and iOS systems and only requires the user to download and install the client end software that was created by AppSheet and then create and sign into an account.

AppSheet has been used in numerous fields. For instance, in field of health and safety, Petrović et al. (2020a) developed an indoor safety monitoring security app for COVID-19 and a city resource planning app for managing epidemic crises. In the field of medicine, Wijesekara et al. (2020) designed an electronic database management system for disease management. In the field of education, Ariyanti (2021) constructed a system that can be used by teachers to manage student attendance. In the field of commerce, Kistiyanti (2021) created a daily monitoring system for power companies in Indonesia. In the field of energy management, Petrović et al. (2020b) invented an app for the management of energy consumption at home.

The platform has not, however, been used in construction, so in this study, it is used to develop a quality management interface and interviewees are invited to use it in the field and provide feedback. The goal is that construction personnel will use it intuitively to perform onsite construction quality inspections.

3. Current situation and analysis of private project subcontractor inspections for quality management

Based on the literature review and research methods, this section explains the interview questions, introduces the target interviewees of this study, and analyzes and discusses the interview results, with a view to formulating improvements to the inspections that are carried out by private project subcontractors for quality management. Finally, quality management theory is combined with feedback on construction practices to create a concise checklist to help subcontractors properly implement quality management.

3.1. Interview question outline

Based on foreign and domestic construction quality control systems and a review of the literature on quality management in private projects, the problems that are faced in construction quality management in private projects were sorted and an outline of interview questions was drafted (as shown in Table 1). The interview topic was the construction quality management practices of private housing project subcontractors and the interview questions were associated with three major outlines.

Question outline A targets the use of subcontractor checklists and related practices. This outline covered the frequency of use of checklists during the quality assessment of construction, reasons for their lack of use, needed improvements in their applicability to private projects due to the differences between the public and private construction projects, situations in which subjective judgment must be used to apply inspection standards, and construction quality management practices.

Question outline B concerns the establishment of quality management standards and inspection procedures. It examined whether the construction management practices of the interviewee follow set construction guidelines,

Table 1. Outline of interview questions

Topic	Outline	Interview content
A	Use of checklists and associated practices	A1. Frequency of checklist usage and reasons why they are not used A2. Improvements needed when checklists are applied to private projects A3. Situations where subjective judgment is to apply and comply with inspection standards A4. Current construction quality management practices
B	Establishment of quality management standards and inspection procedures	B1. Construction guidelines B2. Quality management standards B3. Material and construction inspection procedures B4. Nonconforming product control procedures B5. Corrective and preventive procedures (to identify which first-level quality management items must be incorporated into private projects)
C	Construction document management	C1. Essential construction documents C2. Construction document management methods C3. Attitudes toward applying mobile devices to construction quality management inspections

quality management standards, material and construction inspection procedures, nonconforming product control procedures, and corrective and preventive procedures. The objective was to identify which first-level quality management items must be considered in private housing projects.

Question outline C concerns construction document management. It addresses relevant documents essential to private projects, the ways in which construction documents are currently managed, and attitudes toward the future use of mobile devices in construction quality management inspections.

3.2. Interviewees

We invited small and medium-sized subcontractors of private housing projects to be interviewed for this study. Following a review of the studies that were conducted by Jones and Taylor (2018), Pyo and Baek (2019), Leeuw et al. (2020), and Ljungblad et al. (2021) in commerce, education, healthcare, and engineering, in each of which 10–12 individuals were interviewed, we chose to interview ten subcontractors. Owing to the COVID-19 pandemic, all of the interviews were conducted by telephone.

All interviews were recorded in their entirety. Each interview took about 30 minutes, adjusted flexibly depending on the interviewee's responses. Although we had originally planned to interview ten people, while searching for interviewees, we found two construction companies that were willing to give an interview. In construction, an owner hires a contractor to complete a building project, and that contractor may hire subcontractors to perform specific jobs as part of the overall project. Therefore, to obtain more opinions and ideas about the management of subcontractors, a total of 12 individuals from ten subcontractors and two construction companies in private housing projects were interviewed. With a larger number of subcontractors interviewed, it is valuable to include the views of contractors despite the main focus of this research is to propose a simplified checklist and app platform for the use of subcontractors. Table 2 presents the companies for which the interviewees worked, and their interview times.

Table 2. Interviewees

No.	Employment company name	Time of interview
1	Liangpeng Fire Engineering Co. Ltd.	2022/03/01 20:00–20:30
2	Lichiun Formwork Construction Co.	2022/03/02 17:20–17:50
3	N/A	2022/03/08 19:30–20:00
4	Yifeng Interior Decoration Construction Co.	2022/03/11 17:30–17:50
5	Changhung Construction Co.	2022/03/23 19:30–20:00
6	N/A	2022/03/24 20:30–21:20
7	Maoli Construction Engineering Co.	2022/04/05 12:30–13:00
8	Ruiji Co., Ltd.	2022/04/07 15:00–15:30
9	Chienhang Co., Ltd.	2022/04/07 16:00–16:30
10	Hanhsiang Construction Co.	2022/04/11 10:00–10:30
11	Lihsin Construction Co., Ltd.	2022/03/15 14:50–15:15
12	Reiju Construction Co., Ltd.	2022/04/10 20:00–20:30

3.3. Interview results and analysis

3.3.1. Analysis of basic information of interviewees

A total of 12 individuals, comprising ten subcontractors and two construction company employees, were interviewed. Table 3 displays their basic information. They ranged from 21 to 60 years old (as shown in Figure 4), and those aged between 31 and 40 years accounted for 50% of the interviewees.

Their work experience ranged from three years to over 20 years (as shown in Figure 5), and those with 10–20 years of work experience constituted 50% of the all interviewees. The highest levels of education that had been reached by the interviewee were junior college, senior or vocational high school, university, and graduate school (as shown in Figure 6), the largest single group (42%) had a senior or vocational high school degree.

With respect to job position, interviewees were either person in charge or a supervisor (as shown in Figure 7), supervisors represented 58% of the interviewees. The construction tasks that the subcontractors performed included rebar construction, formwork, light partitions, and electrical and mechanical works, with the proportions as shown in Figure 8. The subcontractor companies were all located in Central or Southern Taiwan, including in the cities of Taichung, Yunlin, Chiayi, Tainan, and Kaohsiung (as shown in Figure 9); the largest minority were in Taichung (33%).

3.3.2. Analysis of interview content

Through the interviews with the 12 interviewees, the construction experiences of practitioners and their perspectives on quality management were collected. The interview results were then analyzed to identify the difficulties that are currently faced by subcontractors in private housing projects. The management behavior of private project subcontractors indicates that only 10% use checklists to perform construction quality management; 50% had set construction guidelines; 60% had set quality management standards; 60% had set material and construction inspection procedures; 70% had set nonconforming product control procedures; 100% implemented corrective and preventive measures, and 60% approved of using mobile devices for inspections.

During the interviews with the construction personnel, they shared their opinions and experiences regarding construction quality management and clarified the difficulties and challenges that are currently faced in the management of private construction projects. The practices of private project subcontractors in relation to construction quality management are compiled below, with reference to the interview outlines A, B, and C.

Table 3. Basic information about interviewees

No.	Age	Work experience	Educational background	Job position	Construction task	Location
1	51–60	Over 20 years	Senior or vocational high school	Supervisor	Electrical and mechanical works	Kaohsiung
2	21–30	3–5 years	University	Person in charge	Formwork	Yunlin
3	51–60	Over 20 years	Junior college	Supervisor	Electrical and mechanical works	Kaohsiung
4	41–50	Over 20 years	Senior or vocational high school	Person in charge	Light partitions	Yunlin
5	31–40	10–20 years	Senior or vocational high school	Person in charge	Rebar construction	Tainan
6	31–40	10–20 years	Senior or vocational high school	Supervisor	Formwork	Yunlin
7	31–40	10–20 years	Junior college	Person in charge	Interior decor	Tainan
8	31–40	10–20 years	Graduate school	Supervisor	Light partitions	Taichung
9	31–40	5–10 years	University	Supervisor	Rebar construction	Taichung
10	21–30	10–20 years	Senior or vocational high school	Supervisor	Formwork	Taichung
11	31–40	10–20 years	University	Person in charge	Construction	Chiayi
12	41–50	Over 20 years	Junior college	Supervisor	Construction	Taichung

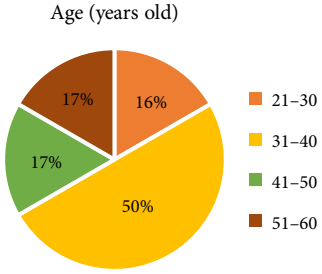


Figure 4. Interviewees by age

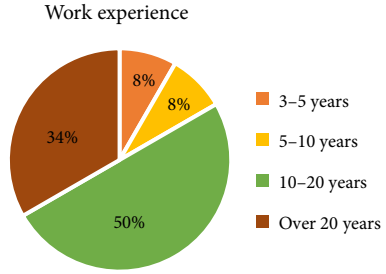


Figure 5. Interviewees by work experience

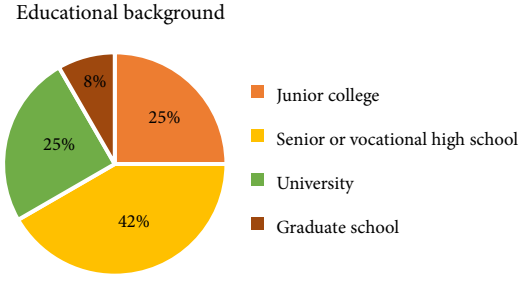


Figure 6. Interviewees by educational background

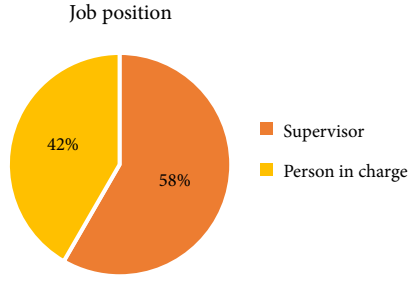


Figure 7. Interviewees by job position

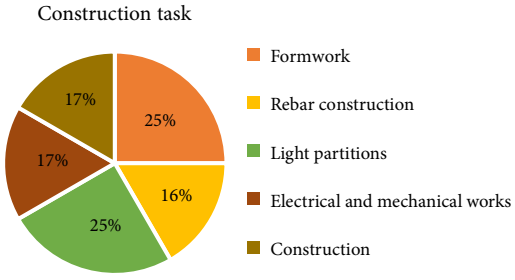


Figure 8. Interviewees by construction task

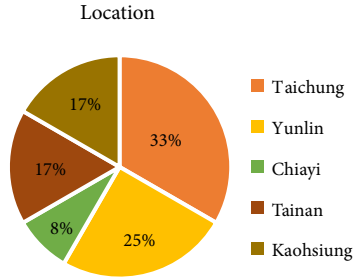


Figure 9. Subcontractors by location

A. Practical use of checklists

Only one of the ten subcontractors used checklists to confirm construction quality; the other nine subcontractors simply judged construction quality by external sight comparison with the construction drawings and based on personal experience. The subcontractors that did not use checklists felt that checklists cannot adapt to onsite conditions and that checking list items was time-consuming and retarded progress. Regarding tasks that required the application of subjective standards and judgment, the sub-

contractors felt that companies' standards varied and that any experienced worker would have enough work experience to make the necessary judgments, communicate and coordinate with the owner, or perform necessary tasks based on experience of construction practices and their feasibility.

With regard to how inspections are currently conducted in private construction projects, most were conducted directly by the construction company after the workers had completed their tasks, because even if the work was inspected and approved by the subcontractors, it may not necessarily pass the re-inspections by the construction companies. For smaller projects with no site directors, only the person in charge or a supervisor from the subcontractor company might perform an inspection based on the construction drawings after the workers have completed their work, and no third-party personnel were involved quality management. Furthermore, when workers have been asked to ensure construction quality in the past, they sometimes indicated that the applied standard differed from that applied previously.

The subcontractors indicated that to promote the use of checklists in private projects, government or academic units should more frequently emphasize construction quality. Worker quality should be improved, and inspections should be accompanied by illustrations and adjusted as requested by the owner. Additional will be needed and costs incurred to improve implementation.

B. Setting of quality management standards and inspection procedures

Among the ten subcontractors, five had set construction guidelines; however, they were executed by merely orally notifying the workers of relevant regulations and special requirements. The subcontractors believed that only reminders of the main points were needed since construction methods for each construction task were already established; variations were minor, and experienced workers already had a basic perception of the required construction quality.

Six of the subcontractors had set quality management standards that were executed in accordance with governmental stipulations or self-established error standards. The subcontractors that had not set these standards believed that quality standards should be set by the construction company because that is its prerogative and because the subcontractors' quality standards were the lowest allowed. Six of the subcontractors had established material and construction inspection procedures, all executed in their own ways. Generally, the person in charge or the supervisor performed inspections based on the construction drawings, and if they were passed, the construction company then performed another inspection. Those that had not set these procedures made judgments based on experience and inspected the construction work only upon completion.

Seven of the subcontractors had set nonconforming product control procedures. Of the ten subcontractors, four took photographs before and after improvements, and six kept no records as private projects place more emphasis on the outcomes following improvement. All of the subcontractors implemented corrective and preventive measures because they must bear the costs in time and money in the event that repairs are needed. These measures mostly involved orally reminding the workers to pay more attention next time and to use their experience to reduce the likelihood of failure to meet standards.

C. Management of construction documents

The private project subcontractors believed that, aside from contracts and construction drawings, the most important construction documents were daily construction photographs that serve as evidence in any future disputes and protect the rights of the workers. Four of the subcontractors felt that any other documents were unnecessary, whereas six subcontractors mentioned that construction meeting records, invoices, and health and safety educational documents were of secondary importance. Most of the subcontractors used WORD and EXCEL to manage construction documents. A few used clouds, Facebook, and Line to upload and save documents, and a few used the conventional method of managing paper documents and notes.

None of the subcontractors had used mobile devices to perform inspections, but most used smartphones or tablet computers to look at construction drawings onsite. They indicated that they rarely brought hard copies because carrying mobile devices into construction sites was already the norm. Three of the interviewees shared the applications that they were currently using to view construction drawings or record construction and indicated that assistive information products were already being applied to construction. A small number of subcontractors felt that incorporating information technology could be troublesome, naming issues such as internet connections, system costs, or the difficulty that elderly personnel may have in using it. However, six of the subcontractors felt that incorporating mobile cloud platforms into inspections would make quality records more consistent. Mobile devices are easy to carry, would increase the convenience of reporting back onsite, and would be favored by younger workers. The uptake would depend on how accepting are personnel and the philosophy of the construction operators with regard to construction quality.

Based on the above summary of the interview content, the following six issues concerning inspections and quality management by private project subcontractors delay progress in private projects:

- Most of the subcontractors judged construction quality by sight and experience, and workers responded that construction quality standards may vary: therefore, no uniformity or consensus exists with respect to construction quality management standards in private projects.
- Subcontractors worry that checking construction quality one item at a time would affect their progress

and they attach more importance to progress than to construction quality.
- Inspections were performed by the construction company (general contractor), revealing that the subcontractors were not focused on the quality of their own work but only wanted to pass inspections.
- In smaller projects, no third-party ensured quality, which was controlled by the subcontractors; in such projects the subcontractors are both player and referee.
- Analysis of the interview content revealed that the subcontractors set their own construction guidelines, quality management standards, material and construction inspection procedures, nonconforming product control procedures, and corrective and preventive procedures. Hence, a lack of mechanisms for reviewing current quality management standards and inspection procedures of subcontractors affects quality management.
- At present, labor shortages and experience gaps in the construction industry are making the improvement of construction quality by subcontractors difficult.

3.4. Improvements to inspections for quality management

To improve construction quality in private projects, in this investigation, measures for improving inspections for quality management were formulated, based on the practical feedback that was obtained through the interviews. The objective of continued education on inspections is self-management for construction quality and sustainability:
- *No uniformity or consensus regarding construction quality management standards in private projects*. When private project subcontractors check construction quality, using checklists instead of judging by sight and experience can help them to conform to government standards and solve the problem of lack of uniformity. Furthermore, inspections can enhance construction quality, reduce mistakes, and save time and money that would otherwise be spent on secondary repairs.
- *Subcontractors attach more importance to progress than construction quality*. Using checklists to check construction quality one item at a time, subcontractors can discover mistakes and immediately correct them. Doing so will prevent them from having to notice their mistakes by sight or experience when they have completed the associated construction tasks.
- *Subcontractors do not focus on the quality of their own work*. Construction companies should implement strict penalty systems for construction mistakes and require that subcontractors improve their own quality. The objective of inspections is not to inspect others' work but to self-manage and take responsibility for the quality of one's own work. If every subcontractor were to fulfill this duty, the construction quality of private projects would naturally improve.
- *Being both player and referee*. At present, the owners of private projects choose subcontractors chiefly because they are familiar with their team or because an acquaintance has introduced them, so no sound selection standards apply. For smaller projects, in which the construction site is not supervised by the construction company or any third party, the subcontractors should use checklists to record and photograph their processes. Inspection records give owners a clear idea of the process of construction.
- *Lack of mechanisms for reviewing the quality management standards and inspection procedures of subcontractors*. Subcontractors should set and perfect their construction guidelines, quality management standards, material and construction inspection procedures, nonconforming product control procedures, and corrective and preventive measures. However, these do not need to be as complex as those in public construction, which can be referred to and drawn upon, perhaps with the elimination of their formality.
- *Labor shortages and experience gaps*. Risk of accidents is one of the primary reasons why young people are not willing to go into the construction industry. Experience gaps arise as a result. The fatality rate in the construction industry in Taiwan is 0.105%, which is 4.77 times the national industrial average (0.022%) (Occupational Safety and Health Administration [OSHA], 2021). To address this issue, the incidence of safety accidents must be reduced. The government must promote construction quality and industrial safety, support education and training, and improve the quality management literacy of workers and their knowledge of safe behavior.

3.5. Creation of construction checklist

Our previous discussion reveals that inspections by subcontractors are of upmost importance to the management of construction quality processes. Based on quality management theory and practical feedback, we created a simple checklist, simplified from checklists that are used in public construction to suit private project subcontractors (as shown in Figure 10). It is easy to use during inspections, simple and clear; it can facilitate inspections for construction quality, and promote thorough quality management.

The purpose of checklists is to give onsite workers a clear idea of the inspection items and approval standards. They should be easy to use, and the inspection standards should be clear and concise so that workers can swiftly determine whether construction quality meets them. Based on a literature analysis and the interviews with management personnel, the use of checklists is presently limited. The interviewed private project subcontractors felt that checklists will only be adopted if they are easy to use and have content that can be flexibly adjusted to be effective

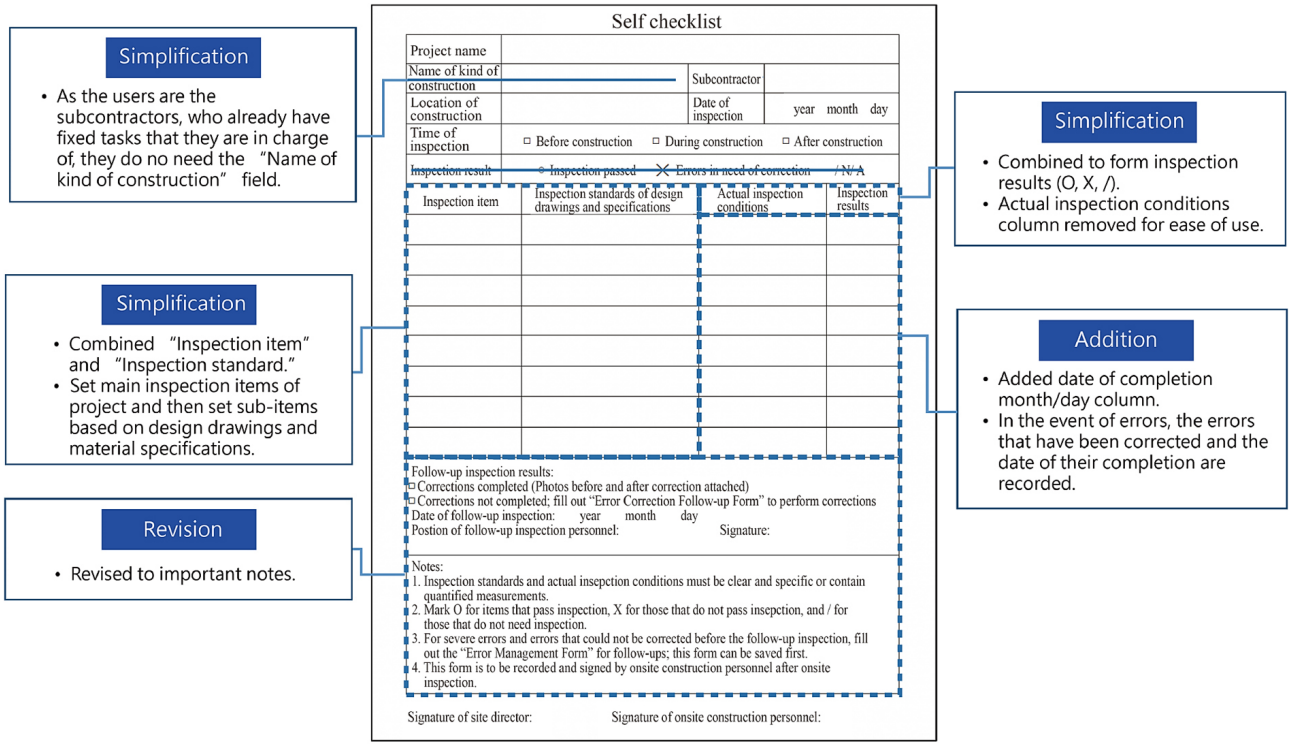


Figure 10. Example of refined checklist for private housing project subcontractors

without taking too much time. Accordingly, the following revisions were made to the Taiwan's public construction existing standard checklist.

- The users are subcontractors, who already are responsible for fixed tasks, so the "Kind of construction" field was removed.
- Based on the interviews with the private project subcontractors, who indicated that the checklist fields should be simple and straightforward, "Inspection item" and "Inspection standard" (quantification) columns were combined. When using the checklist, the subcontractors can firstly list the main inspection items of the project, set inspection standards according to quality management standards, and then revise the contents of the checklist to suit the project and owner requirements.
- Since the subcontractors need the checklist to be easy to use, "Actual inspection conditions" was combined with "Inspection results" to yield "Inspection results (O, X, /)", and the "Actual inspection conditions" column was eliminated. Subcontractors can swiftly respond with one of the three choices to indicate whether an item passes inspection; O means that it passes inspection; X means that errors need to be corrected, and / means that the inspection item does not exist.
- To make the results of a follow-up inspection easy to check, an "Error improvement" column was added to the right of the "Inspection results" column. In the event of an error, the user can simply tick the error that has been corrected, and record the date of completion of the correction. Whether errors have been corrected is thus easy to determine.
- Since the follow-up inspection results were moved, the "Follow-up inspection results" and "Notes" columns were combined to form the "Important notes".
- The construction tasks of subcontractors can be complex, so the columns in the checklist should be flexible and customizable. Thus, an app platform that is easy to use with a no-code design is required.

With the above revisions, the content and format of the simple checklist (as shown in Figure 11) are clear and simple. The inspection contents of contracts and specifications can be concisely listed in the table; whether an item meets standards can be swiftly determined. The construction process is converted into quantitative data to support construction management. The hope is that this simple self-checklist can be utilized on-site and that subcontractors will be willing to use it to conduct proper inspections of construction quality and thereby improve the overall quality of private construction projects.

4. Application of mobile devices for subcontractor self-inspections

Due to the ubiquity of information technology and smart mobile devices, subcontractors can use mobile devices to perform inspections for construction quality management and thereby increase their efficiency. An app with the above checklist was created using the AppSheet platform and used to manage construction quality data properly and increase the convenience and usage efficiency of inspections for construction quality.

Project name		Subcontractor	
Location of inspection		Date of inspection	
Inspection item and standard (quantification)		Inspection results (O, X, /)	Error improvement
Brands and quantities of waterproofing materials match construction drawing.			☐ Improvement done month day
Absence of pits, cracks, or impurities on the construction surface.			☐ Improvement done month day
Bottom coating is dry.			☐ Improvement done month day
Downspout is flat with proper waterproof reinforcement around it.			☐ Improvement done month day
Protection of piping outlets is sound.			☐ Improvement done month day
Amount and thickness of waterproofing agent used match construction drawing.			☐ Improvement done month day
Extra coatings are applied to a height of at least 20cm at all floor corners.			☐ Improvement done month day
Waterproofing is at least 20 cm wide around doors and windows.			☐ Improvement done month day
Waterproofing is dense and smooth.			☐ Improvement done month day
Waterproof layer has not expanded.			☐ Improvement done month day
Downspouts were sealed before waterproof test was conducted.			☐ Improvement done month day
Waterproof test lasted for 48 hours.			☐ Improvement done month day
During waterproof test, water was immediately added when water storage area contained too little water.			☐ Improvement done month day
If any leaks were found during waterproof test, water was drained, waterproofing was reinforced, and a local waterproof test was performed.			☐ Improvement done month day
Important notes:			

Figure 11. Prototype of designed checklist for private housing project quality management

4.1. AppSheet framework settings and interface planning

4.1.1. Platform framework settings

The framework of the AppSheet platform (shown in Figure 12) converts the established inspection content into a back-end Excel spreadsheet. Users can then go to the AppSheet website platform, link to Excel spreadsheets in Google Drive as a database, set the column names in the self-defined interface, and link spreadsheets to each other. The system will automatically generate the operating screen of the app, supporting inspection using a mobile device. When subcontractors conduct inspections for construction quality on the construction site, they can carry a mobile device instead of paper. The system automatically uploads the provided inspection content to the cloud server, and the user and any authorized personnel can view the results of the inspection in real time (as shown in Figure 13).

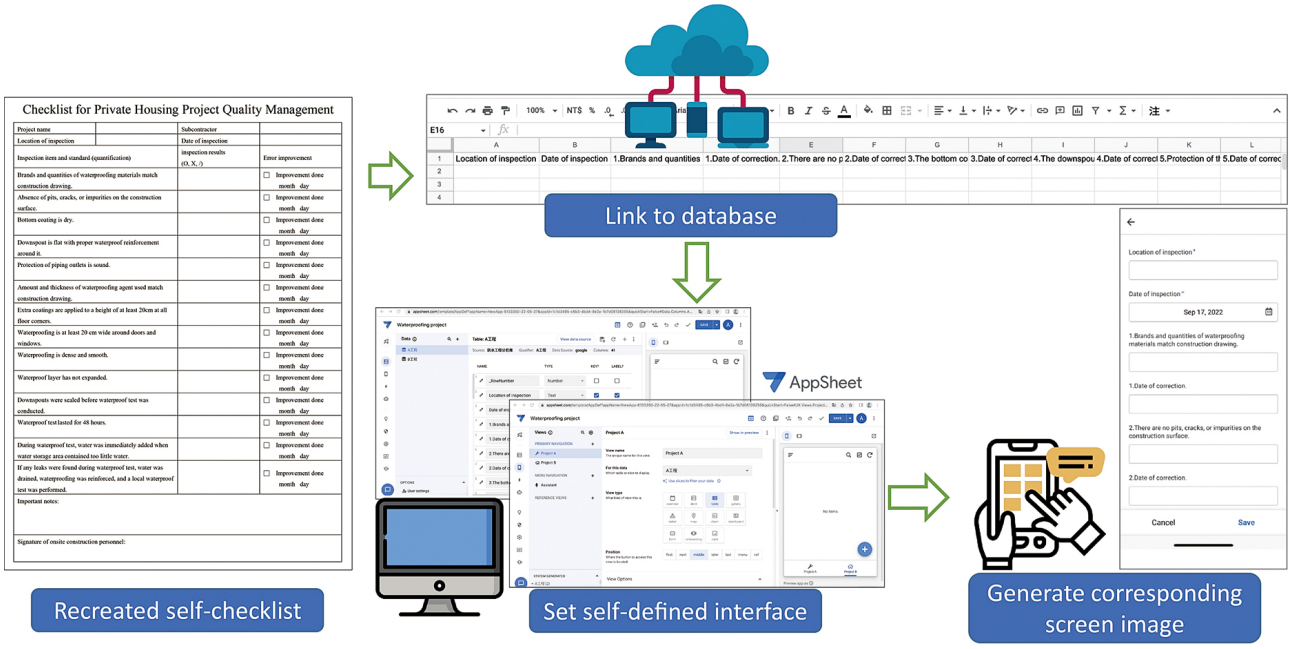


Figure 12. Platform framework

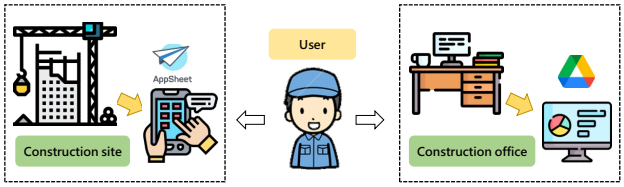


Figure 13. Application of mobile device for inspection

4.1.2. Database fields and interface planning

The AppSheet platform has various functions that can be used to construct various applications. Only those used herein will be described here. The platform uses webpage browsers in environments with an internet connection to construct apps on its official website. No software needs to be installed to load the database and perform the app development operations. The platform can be used with the AppSheet app itself.

On the official AppSheet website, a user can choose one among several sign-in methods. Once signed into an account, a user can create a new app or use already developed apps. and authorized apps. (as shown in Figure 14). A user who chooses to develop an app must select the database to be connected to. A single app can link to more than one file. A Google account was used herein to sign in and a cloud EXCEL spreadsheet was used as the database file. No data exchange or concatenation was involved; only the data from a single EXCEL file were accessed.

Once the database connections are established, users go to the user-defined screen. In the "Data" tab in the list on the left, data formats can be edited. In the "Tables" pane of "Data", a table can be selected, and the platform will automatically link to that table. To add new tables, the "New Table" option (as shown in Figure 15) must be selected. Next, in the "Columns" pane, the settings for each field (as shown in Figure 16) can be changed. The platform will automatically incorporate the name of the field. To add or remove fields, the original file must be revised before the name of the field in the platform is updated. The field format is an important item to be set. The formats that are used in this study included Text, Date, Enum, Image, and Signature, which are explained in detail below:

- Text: a single line of text;
- Date: a date (year/month/day);
- Enum: a drop-down list of items (defined by the user);
- Image: photographs (the platform automatically links to a fixed cloud folder);
- Signature: a signature (the platform automatically links to a fixed cloud folder).

The names of the fields in the app that is created in this study include Location of construction, Date of inspection, Inspection content, Inspection result, Date of error correction, Photo of construction error, Photo of corrected error, Important notes, and Signature of inspector. The format of each field was as follows:

- Location of construction: Text;
- Date of inspection: Date (TODAY) function applied, in which the system automatically captures the current date);
- Result corresponding to Inspection content: Enum (drop-down list including O, X, and /);
- Date of error correction: Date;
- Photo of construction error: Image;
- Photo of corrected error: Image;
- Important notes: Text;
- Signature of inspector: Signature.

After the data formats are set, the display interface of the app can be set in the "Views" pane of the "UX" tab on the left. First, in View name, the name that is displayed by the interface that corresponds to the table can be set. In View type, the way the results are displayed after inspection responses are given can be set. Position determines where the interface that corresponds to the table is located

(as shown in Figure 17). In Icon, the icon of the interface that corresponds to the table can be selected (as shown in Figure 18). Next, in the "Brand" pane of the "UX" tab, the theme, primary color, and logo of the app can be chosen (as shown in Figure 19). The contents of the app display interface in this study are as follows:

- View name: name of the project;
- View type: table;
- Position: center;
- Icon: an icon associated with the construction site;
- Theme: light;
- Primary color: blue;
- App logo: a house icon.

After the platform has been constructed, the user must download the AppSheet app to their smartphone (as shown in Figure 20), sign in with the account and password that are used to develop the app (as shown in Figure 21), and select the developed app (as shown in Figure 22) to use the established functions (as shown in Figure 23).

Once complete, the results of self-inspections are automatically uploaded by the system to a cloud for storage. However, the storage capacity of any cloud is limited, so users must pay attention to whether usage may exceed limits or pay for an adequate amount of storage to meet their needs. Furthermore, the user permission settings of the app can be adjusted on the official AppSheet website platform. Authorized accounts can be added (as shown in Figure 24), and their permissions can be set to one of the following; Use app, which means that the app can be used but not edited and no settings can be added in the app editor, View definition, which means that the app can be used and viewed but not edited in the app editor, and Edit definition, which means that the app and can be used and edited and the settings can be changed in the app editor.

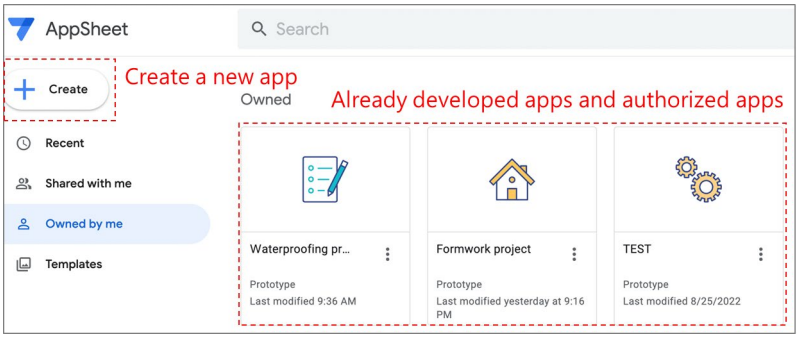


Figure 14. Screen image after sign-in

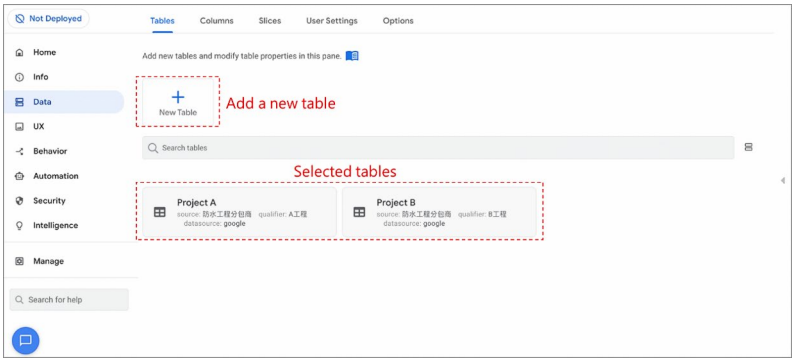


Figure 15. Table selection screen image

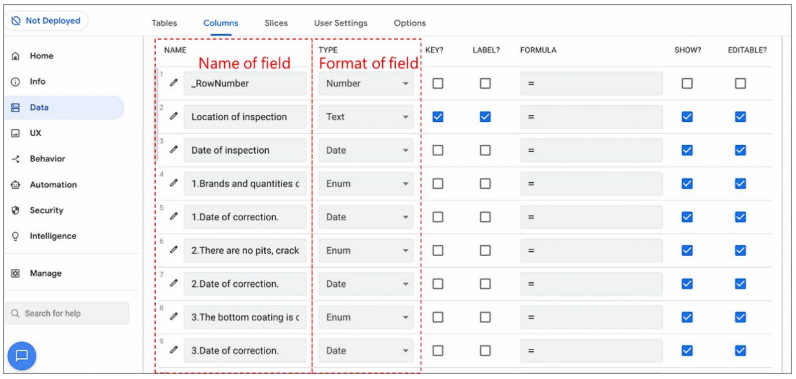


Figure 16. Field format setting screen image

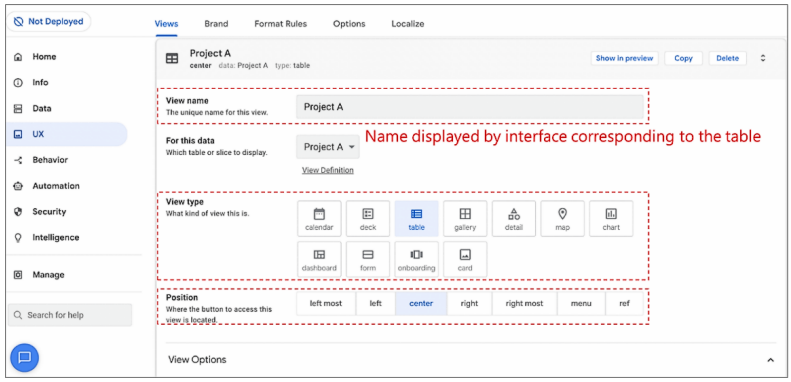


Figure 17. Screen image for design of interface corresponding to table

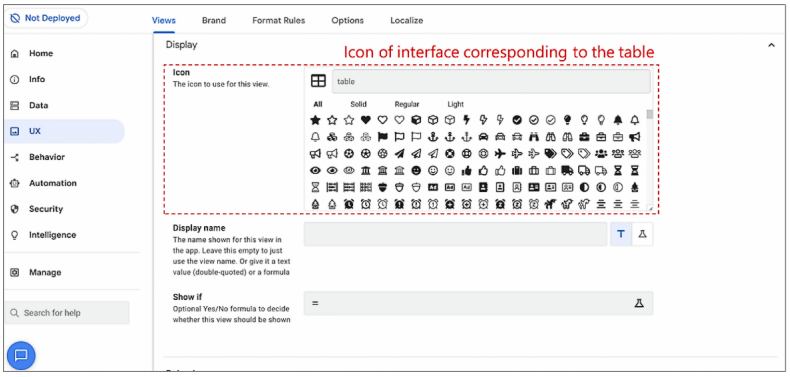


Figure 18. Screen image for design of icon corresponding to table

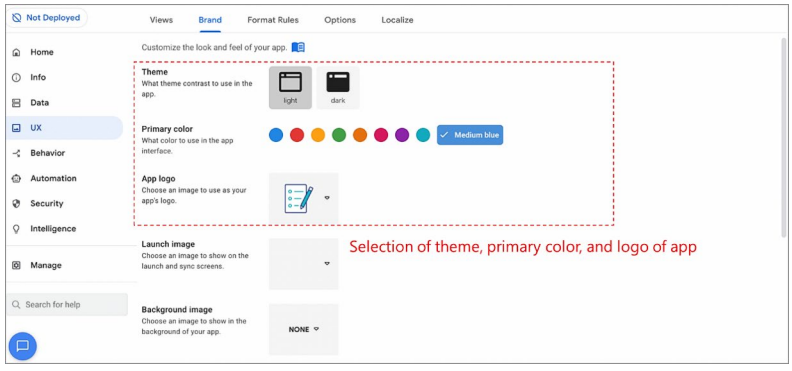


Figure 19. Screen image for design of app color and logo

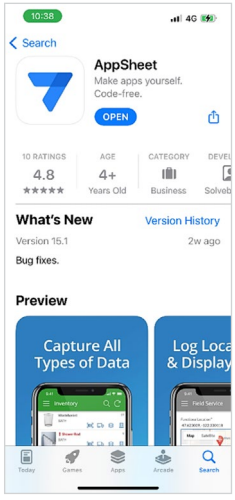


Figure 20. Downloading AppSheet app

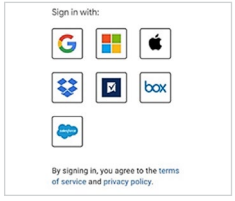


Figure 21. Sign-in screen image of app

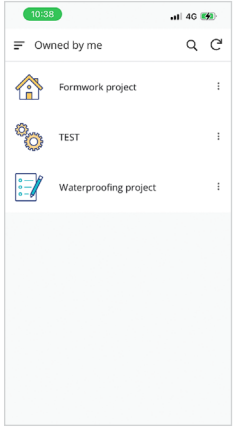


Figure 22. App selection screen image

4.2. Display of inspection app

To help subcontractor personnel more efficiently conduct inspections on construction sites, the simple created checklist was converted into an inspection interface using the AppSheet no-code development platform. Our example shows the inspection content from a subcontractor that is performing waterproofing (as shown in Figure 25), and a comparison is made with the paper form (as shown in Figure 26). The self-inspection app also includes fields to record photos of construction errors and their corrections to facilitate further documentation during construction processes. The goal of the overall design is ease of use and intuitive operation.

Figure 27 shows the operation flow chart of the self-inspection app. First, the user signs in with the account and password that was used when the app was created, selects the construction project to be inspected, selects + to enter the inspection form, and conducts the inspection according to the previously established inspection content. If all of the items pass inspection, then the inspector signs the form and stores the inspection results. If any errors are found, then the inspector takes photographs of them and uploads them. After the errors have been corrected, photographs of the corrected errors are taken and then uploaded. The inspector provides the data concerning the correction, signs the form, and then selects “Save”.

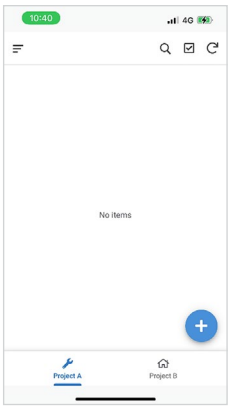


Figure 23. Screen image of developed app

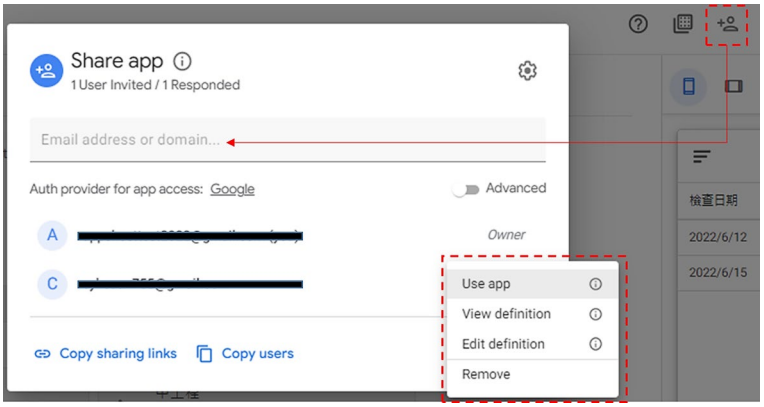
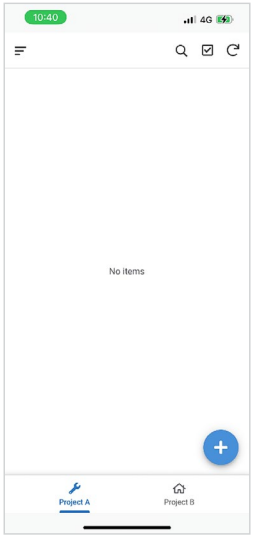
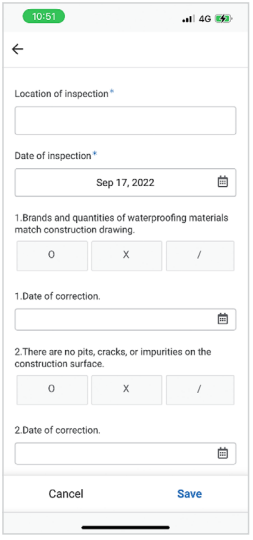


Figure 24. User permission settings

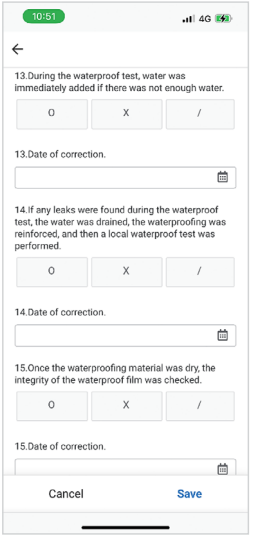
a) Main screen of app



b) Operation interface for inspection

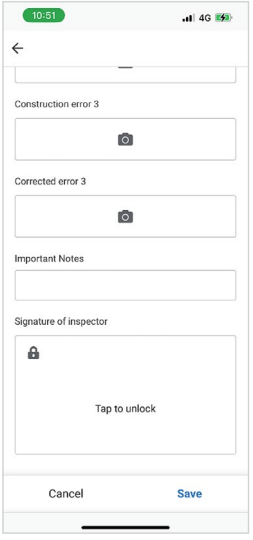


c) Operation interface for inspections



d) Operation interface for inspections

e) Operation interface for inspections



f) Interface for viewing inspection results

Figure 25. Display of self-inspection app

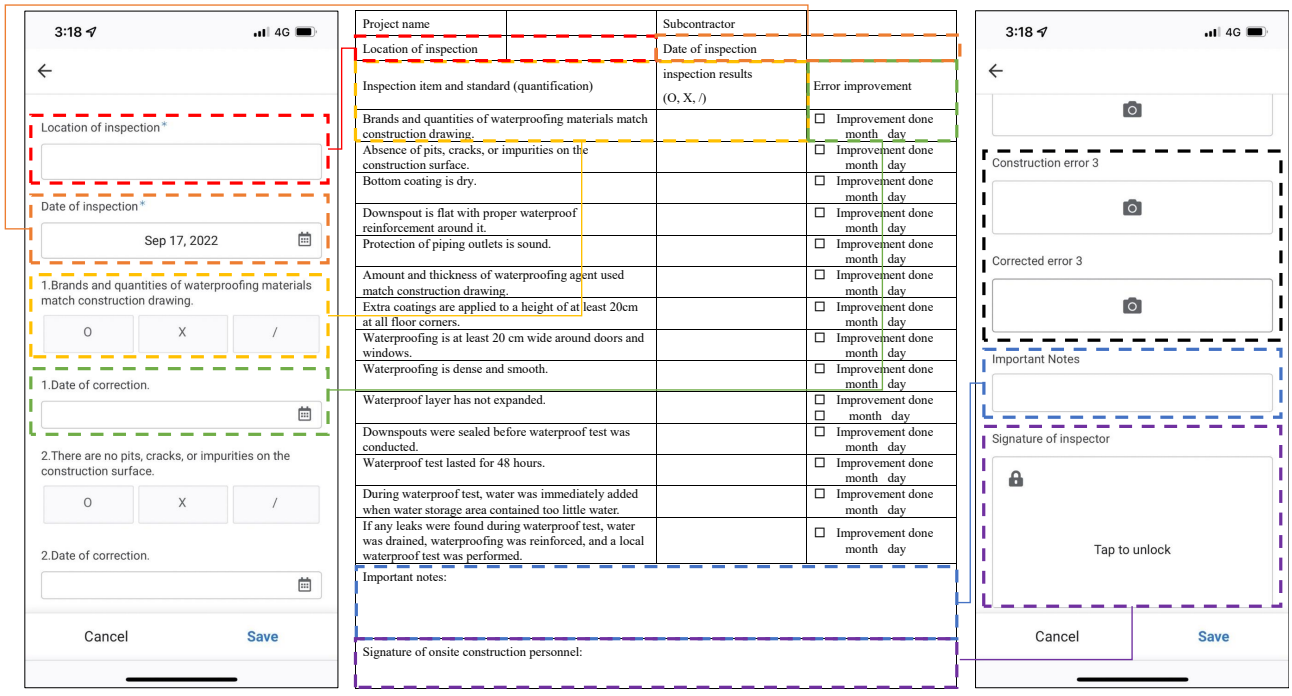


Figure 26. Comparison of simple paper checklist and operation interface in app

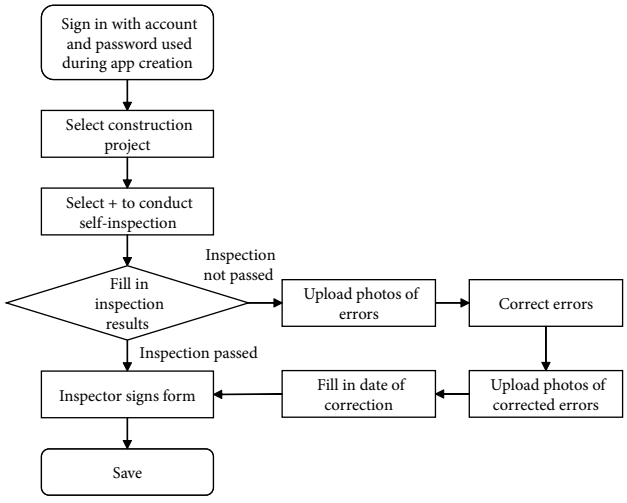


Figure 27. Flow chart of inspection app operations

Unlike existing quality management information systems most of which were created for general contractors, the inspection app in this study is aimed at subcontractors. The greatest feature of this app is that its design requires no code or database server. Subcontractors can flexibly adjust and customize the content to meet the needs of the project. Another difference between this app and other systems is that it can be used without connection to the internet; it can update data once an internet connection can be established again. It can therefore be used in a wider range of locations.

After the app was created, an interviewee was invited to use and assess it. A satisfaction survey was carried out and the suggestions provided were adopted to ensure that the app can facilitate construction quality inspections and improve the quality of private construction projects.

4.3. Application to construction management

Subcontractor Y, a formwork subcontractor, was invited to use the app because he had previously judged construction quality solely by sight and experience. He hoped to be able to handle the entire construction process using this app and to assess whether the app can help to improve construction quality. He therefore used the app that was developed in this study in conducting inspections. The example project was a new housing project in Huwei Township, Yunlin County, called Shui-An-Yan. It has a base area of 957 ping (3,163.3 m^2) and is designed with seven floors above ground and one floor underground. It includes eight buildings containing a total of 92 apartment units. Table 5 presents the relevant data of the project.

Using the inspection items and standards in the app, Subcontractor Y inspected his own work to maintain the standards for the assessment of quality. Figure 28 displays two sets of quality inspection results that Subcontractor Y recorded using our app. The location associated with the first set was the second floor of Building A, where the mounds of the building were not tightly fitted together, resulting in an error. The error was corrected on the spot, and the date of correction was noted. In the fields below, photographs of the error before and after correction were

Table 5. Project data

Name of project	Shui-An-Yan
Location of base	Huwei Township, Yunlin County
Area of base	957 ping (3,163.3 m^2)
Type of project	Apartment building
Planned floors	Seven floors above ground and one floor underground

recorded, and then the inspector signed the form (as shown in Figures 29 and 30). The construction location associated with the second set of inspection results was the first floor of Building B, where all items passed inspection (as shown in Figure 31). After using the simple-to-operate inspection app that was developed in this study, Subcontractor Y could easily handle the entire formwork process, find errors in time, thereby ensuring the work matched the construction drawing.

After using the app, Subcontractor Y was fairly satisfied with its design app and sufficiently satisfied with its positive effect on construction quality. He was very satisfied with its ease of use. The subcontractor self-inspection app that was developed in this study is already sufficiently convenient and efficient for practical use. More functions can be added to the operation interface in the future to make it even more effective in improving construction quality. The convenience of this app is hoped to induce subcontractors to conduct more inspections to save time and money spent on secondary repairs, reduce time spent by construction companies in performing re-inspections, make construction go more smoothly, and ensure construction quality.

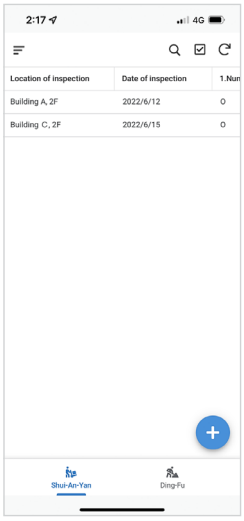


Figure 28. Results of inspection conducted by Subcontractor Y

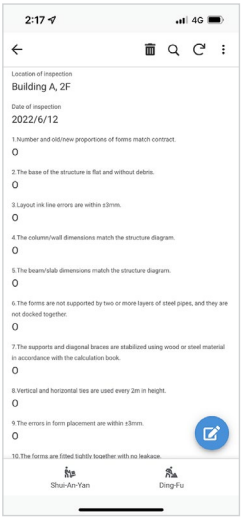
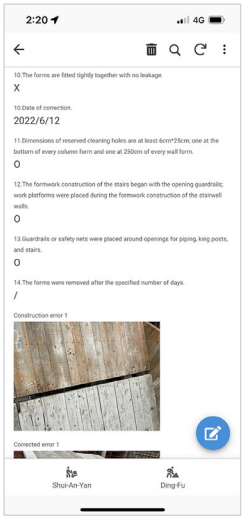


Figure 29. First set of inspection results



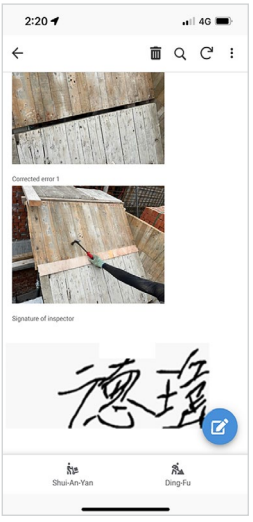
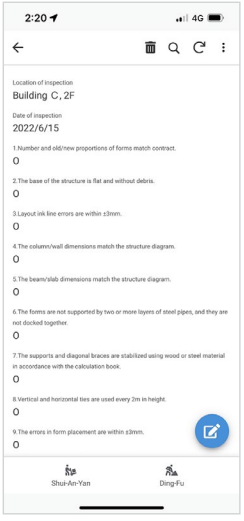


Figure 30. First set of inspection results



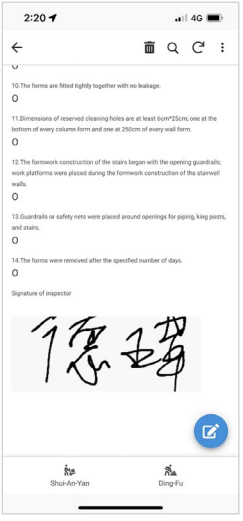


Figure 31. Second set of inspection results

Conclusions and suggestions

The construction quality of buildings has a direct impact on the quality of life of their residents, so good quality management should be implemented during construction. At present, an absence of mandatory regulations concerning inspection management control in private housing projects has led to variable quality across private housing projects. The literature has shown that first-level subcontractor inspections are essential in construction process management for construction quality and progress. Therefore, a self-inspection app for use by subcontractors was developed to help them implement construction quality management conveniently and efficiently. The main achievements of this study are as follows:

– A literature review and in-depth interviews with construction personnel revealed that with respect to construction quality management, private project subcontractors prioritize their construction progress and costs, slowing down quality management in private projects. Improvements were proposed; workers should continue to be taught that inspections are conducted not for the benefit of others but to support the managing of, and taking responsibility for, construction quality. Using checklists can support compliance with government standards, and keeping records during inspections supports a clear understanding of the construction process, reduces construction error rates and costs, and reduces the time that is needed to correct errors. Government and academic units should more frequently emphasize the importance of construction quality and industrial safety, improve worker philosophy regarding quality, and increase the willingness of young people to enter

the construction industry. Based on practical feedback, the need to save time and the need for simple planning, a simple checklist was created to encourage private project subcontractors to perform inspections and pursue supreme quality in private projects.

– In in-depth interviews, six subcontractors felt that incorporating mobile cloud platforms into inspections would make quality records more consistent. Mobile devices are easy to carry, would make report onsite conditions more convenient, and would be happily used by younger workers. AppSheet was used to create an app with the created checklist for the proper management of construction quality data. The app can automatically link to stored inspection results, and its greatest feature is that it requires no code, allowing construction personnel without a background in information technology to add or adjust self-inspection content and standards, depending on the construction task, reducing maintenance costs.
– Practical verification by Subcontractor Y, a formwork subcontractor, generated the following feedback: the structure of the app makes it easy to use; the inspection content is easy to adjust; it is easier to carry than paper; the automatic linking of the app to a cloud to upload inspection results saves the time that would otherwise be needed to upload the results again manually; and the error and correction photograph records are easy to view and compare directly on the app. Subcontractor Y also suggested adding the function of viewing the corresponding construction drawing in the app, which would make it even more useful.

This study examined the procedures that are used by private project subcontractors when they conduct inspections for quality management. It can serve as a reference for academics in extending construction quality management levels and improving the knowledge management of work by subcontractors to promote health and safety. The created checklist and app template can help small and medium-sized subcontractors in private projects effectively handle construction quality. The hope is that they can therefore manage construction quality conveniently and efficiently, digitize construction data for storage in clouds, and properly store their construction quality records. Quality management personnel can organize and analyze relevant inspection content and improve construction quality management by referring to historical information. The paperless design eliminates the risk of transferring viruses, such as COVID-19, among workers.

We suggest that the construction drawings of projects be linked to the app in the future so that workers can perform inspections without carrying image files with them. For practical purposes, we suggest the addition of an inspection frequency field so that inspectors can clearly specify when a task is to be inspected and of a GPS function to locate more accurately construction errors and make inspections more effective. The function of automatically notifying the site director once a subcontractor has performed inspection of a task and signed off on it can also be added. The site director will thus obtain a clear idea of what has been signed off and what has not been inspected. If construction personnel download documents associated with completed inspections, they can then analyze the error data; identify construction tasks that are commonly associated with errors, and indicate them to the subcontractor for future consideration.

The main limitation of this investigation was that all of the interviews were conducted by telephone, owing to the serious COVID-19 pandemic encountered during the research period. To obtain opinions and ideas about the management of subcontractors, a total of 12 individuals from ten subcontractors and two construction companies in private housing projects were interviewed. To increase the generalizability of the proposed simplified checklist and app platform, further studies that gather interview data from various subcontractors, construction firms, and countries are recommended.

Regarding the future development of the app, it is well suited to extend the functionality of building information modeling (BIM) technology. The integration of AppSheet and BIM will have the following advantages: all major inspection tasks and locations are determined before the site inspection trip; the inspector's tasks are straightforward and mainly involve BIM data collection. By doing so, the inspector's tasks at the construction site can be well-defined and free of possible interference from site engineers.

Replication of results

The datasets, codes, and replication of results that are generated and/or analyzed in this study are available from the corresponding author upon reasonable request.

Declaration of interest statement

We declare no known conflict of interest associated with this publication and that no significant financial support for this work could have influenced its outcome.

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User flow for app development tutorial

The video that shows the app being used is available in the YouTube website (https://www.youtube.com/watch?v=fq7zTf80tVI).

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