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Current benefits and future possibilities with digital field reporting

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ABSTRACT

Mobile phones and tablets enable contractors to digitally collect large amounts of production remarks and facilitate the acquisition. The increased data access and machine learning techniques allow the construction industry to take a significant step forward in shifting from implicit to explicit knowledge. However, this step requires both standardisation and data quality assurance combined with project incitements ensuring continuous data collection. Therefore, this study examines the current data quality and standardisation of inspection data generated using the production software Dalux Field, mining a dataset of more than 95000 production issues. Additionally, a survey of production software users assesses project and project member benefits and future possibilities with digital inspection reporting. The results show considerable benefits with digital inspection reporting, such as time savings, cost reductions and increased general quality control. However, the standardisation in reporting between projects and team members is low. Finally, this paper suggests methods for improving data quality and standardization for automation of the data analysis, allowing new projects in project-based organisations to benefit from previous project experiences.

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Inspections; digitalisation; field-reporting; quality

Introduction

Even though the construction industry is one of the largest in the world economy, it is one of the least digitized (Agarwal et al. 2016). However, one area where the construction industry is initiating a transition towards digital data is field problem reporting, such as inspection issues. The pursuit of digitalisation in production problem reporting emanates from the production personnel rather than being imposed as a central mandate from the organisational hierarchy, indicating project benefits with digital reporting (Bengtsson and Ekholm 2007).

In addition to project benefits, potential organisational knowledge advantages are associated with the availability of large volumes of digital inspection data. Since the construction industry struggles with delivering projects with sufficient quality, and many quality flaws are caused by poor performance (FIDIC 2004; Sigfrid and Persson 2007; Khadmin et al. 2023), understanding and analysing inspection data can be an important step towards a preventive quality increasing approach for the contractors.

Inspections are a common way of verifying a construction project's quality (Bengtsson and Ekholm 2007; Ma et al. 2018). The use and purpose of the inspections are different, but most of them are made ocularly by an independent inspector, and all inadequacies are noted (Bengtsson and Ekholm 2007). Traditionally, the remarks discovered during field inspections have been written on paper and later transferred into Word and PDF documents. The manual and time-consuming compilation has led to low usage of inspection data despite being considered a useful information source for improving quality performance (Navon 2005; Lundkvist et al. 2010). Other explanations for the low inspection data usage found in previous studies are a lack of time among construction managers and a lack of well-defined analysis methods and processes within construction companies (Lundkvist et al. 2010; Soibelman and Kim 2002).

Regarding technologies enabling digital reporting of production and inspection issues, the first attempts were explored in the 1990s since reduced paperwork was assumed to generate time savings (McCullouch and Gunn 1993; McCullouch 1997). Cox et al. (2002) studied the potential of digitalising inspection forms and predicted digitalisation would be the key to data quality improvement. Today, data acquisition from quality inspections has been facilitated by the introduction of specialised production software and the possibility of using mobile phones and tablets for the collection (Horak et al. 2014; Yousif et al. 2021). The facilitated acquisition is part of a general shift towards digital building information, which enables new possibilities by providing the construction industry with a large amount of data (Kopsida et al. 2015; Aibinu et al. 2019; Akyazi et al. 2020; Yan et al. 2020; Musarat et al. 2022). However, further using the collected inspection data requires availability, standardisation, data quality assurance, and dataset integrity, emphasising the need to focus on the data input (Kopsida et al. 2015; Solihin et al. 2015; EPRS 2021). Data quality and standardisation become particularly important if key enabling technologies such as artificial intelligence are applied to automate the analysis and support decision-making (Yan et al. 2020; EPRS 2021).

Since work safety has been a challenge for the construction industry, most research regarding the analysis of field data focuses on safety. For example, Lin et al. (2020) explored machine learning techniques, such as keyword extraction and topic modelling, applied to on-site safety inspection data.

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Shayboun et al. (2021) compared accidental causation models and machine learning for applied analysis within accidental reports. Baghwat and Dehli (2021) systematically reviewed construction safety research, and their results show a significant focus on safety in published journal papers from 2019 to 2021. However, the on-site inspection data regarding quality has not gotten the same attention. Therefore, this study focuses on quality inspection remarks generated in production software to investigate the current standardisation and data quality. Additionally, there must be project incitements with digital reporting to ensure continuous future data collection. Therefore, a survey of production software users assesses project and project member benefits with digital inspection reporting. The results in this study serve as a base for data quality improvements within project-based organisations aiming to benefit from knowledge transfer by analysing unstructured text data. The results also provide insights regarding the benefits of digital reporting.

Method

This research was done in four steps: inspection data analysis, interviews, a survey, and survey analysis. Since inspection data can be a possible source of quality performance knowledge, the first step in the research was data collection and analysis of a large production dataset. The analysis was made focusing on data availability, standardisation, and quality since those factors impact the possibilities of using the data for future quality monitoring on an organisation level. In the second step of the research, interviews were conducted to help interpret the data and provide insights into improving future data collection and usage. Furthermore, the interviews served as a survey preparation by discussing and elaborating survey questions. The third step was a survey, investigating the usefulness of digital issue reporting for project members and projects. The survey also explored future possibilities with digital reporting. Step four was a statistical data analysis of the survey results. Figure 1 presents an overview of the study outline.

Step 1: Inspection data collection and analysis

Data collection

A large dataset of production issues was analysed to investigate the current status of digital inspection reporting. The dataset contained 100928 production issues from 117 construction projects, generated with the software Dalux Field (Dalux.com, 2023) at a large Swedish contractor company between 2018-2021. The projects had an estimated budget of 50 to 1800 million SEK; the project typologies are presented in Figure 2. The issues were registered by 507 users employed by the main contractor, sub-contractors, clients, and inspection companies. Information like title, description, and to whom to assign the issue is added when reporting an issue. The data was collected using an application programming interface (API).

The software was selected since it is one of the most common production issue software in the Scandinavian construction market. The software has a field module where production issues can be reported to facilitate collaboration between the main contractor and sub-contractors. The software also provides access to 3D BIM models and traditional PDF drawings to give each production issue a specific coordinate, simplifying the localisation of the problems on the construction site.

Data analysis

The possibilities of using the data for quality monitoring purposes can be determined by data aspects such as availability,

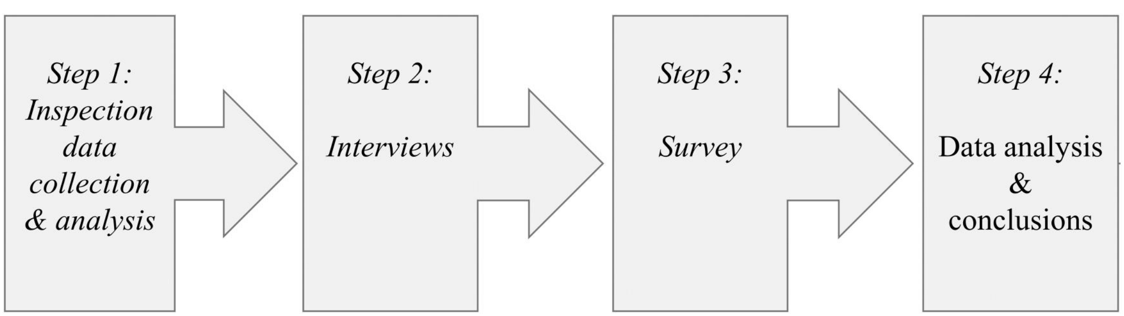

Figure 1. The four method steps: Inspection data collection and analysis, survey preparation interviews, survey, and survey data analysis.

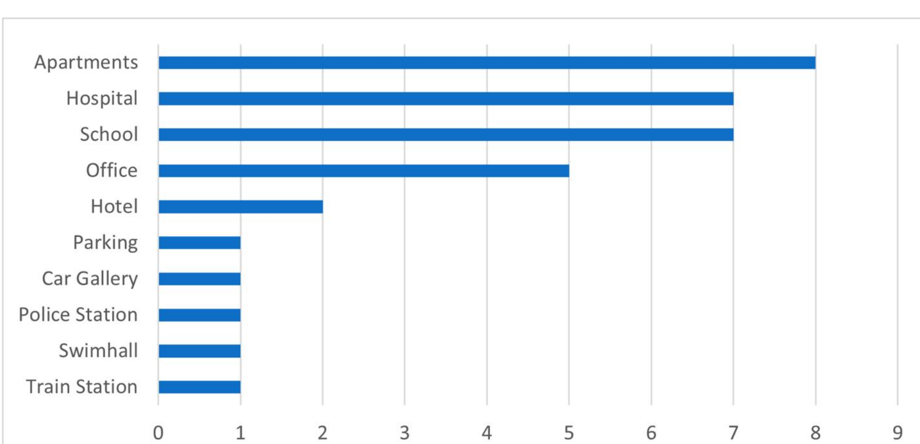

Figure 2. Number of projects of a specific type.

Table 1. Interviews, business roles of interviewees, and interview purposes.

Interview	Interviewees business role	Employer	Purpose
1	Production Supervisor	Contractor	Project objectives with digital reporting
2	Production Supervisor	Contractor	Project objectives with digital reporting
3	Sales manager	Production Software Developer	Differences in software uses
4	Project manager	Contractor	Project objectives with digital reporting

Table 2. List of field management software.

Software	Supplier	The main region of usage	Focus
Dalux Field	Dalux	Scandinavia	Issues, checklist, 3D-visualisations
BIM 360 Field	Autodesk	World wide	Issues, checklists and reports
PlanRadar	PlanRadar	World wide	Issues, communication and reports
SnagR	SnagR	World wide	Field data, reports and visualisations
Viewpoint Field View	Trimble	UK, USA and Australia	Snagging, forms & permits
Zepth	Zepth	Asia, USA	Snag lists, reports and monitoring
Ing			

quality, and standardisation (Cichy and Rass 2019). Therefore, a data mining was performed, aiming to answer the following questions:

- Which data is available?
- Which quality does the data have?
- How standardised is the data?
- What are the most frequent remarks?

The data availability was assessed by an inventory of the data possible to extract from the production software. Then, the quality was reviewed by grading each data feature as high, average, or low. The qualitative text fields were reviewed manually, judging the content and how often the field was left blank. The standardisation was evaluated depending on the diversity of the data registered and how the users interpreted what information to insert. Finally, the issue frequencies were statistically analysed.

Step 2: Interviews

Four semi-structured interviews were performed as a survey preparation and data interpretation enrichment. The interviewees were experts in various domains related to inspection performances. The interviewees' business roles, employer and interview purpose are presented in Table 1. All interviews were conducted digitally, recorded and transcribed for further analysis. The choice of interviews as a method was because it allowed displaying the dataset, visualising trends, and discussing possible explanations.

Step 3: Survey design

The survey was performed using SurveyMonkey and consisted of 22 questions. The survey invitation was sent by email to 282 Dalux Field users. The response time was three weeks, and a reminder was sent after one week, two weeks, and the day before closure. Since the survey explored technology new to the construction industry, the design took inspiration from the process of "Future Workshops" (Jungk and Müllert 1987), which has been proven successful by other researchers (Bosch-Sijtsema et al. 2021). The "Future Workshop" process is divided into identifying challenges, discussing opportunities, and understanding actions needed before implementation. Therefore, the survey questions were structured similarly, with questions Q10-Q12 targeting challenges and questions Q13-Q18 targeting opportunities. However, since the survey targets projects already performing digital inspection reporting, the implementation category was replaced by "desired future features" improving usability and data quality, and this category was the focus of questions Q19-Q22. The survey was also enriched with questions about the respondents' background and reporting habits.

The survey was designed with closed-answer questions, a five-point Likert scale, and several open-answer questions. All survey questions are further presented in Table 5 in the results section.

Step 4: Survey analysis

The open-answer questions were analysed by manually reading all comments and labelling them with main topics and subtopics. The identified main topics were increased control, facilitation of inspections, time-savings, all information in one place, models and drawings, digitalization, and no benefits. The subtopics identified are presented in the results section in Figure 6.

Limitations

The study investigates digital inspection reporting benefits from a main contractor perspective, even though there are probably possible benefits for consultants and sub-contractors.

The study uses data from only one software, Dalux Field. Even though the software provides access to drawings and pictures, the study only focuses on data in text format. Similar software is used for the same purpose; some are listed in Table 2. The software has a somewhat different focus, but typical for all is that it allows for digital issue reporting and makes the user select titles and descriptions. This makes the methods used in this research applicable to data from any of the software in Table 2.

Results

This section addresses the data analysis, interviews, and survey results. Concerning the data analysis and interviews, the results are presented from the perspective of available data and data quality. The survey results are presented based on the five categories of the 'Future Workshops' concept.

Inspection data analysis

After eliminating projects with inconsistent issue reporting, 34 projects remained. Figure 2 shows the projects' main building category.

Table 3. Features in the dataset.

Project Features	Issue Features	User Features	Company Features
Project name	Creation date & time	First name	Company Name
Project ID	Issue ID	Last name	CompanyID
Project number	Issue Number	UserID	Ass. to CompanyName
ContractID	**Title**	Email address	Assigned to CompanyID
	Description	Assigned to user	
	Discipline	ModyfiedByUser	
	Inspection Type		
	Safety/No safety		
	Due date		
	LocationID		
	Modification date		
	Revision number		
	Object name		
	ObjectID		
	Name		
	Coordinates		

Table 4. Issue types and frequencies.

Issue type	Number of issues	Percentage
Pre-inspection	43806	45.9
Inspection	17967	18.8
Deviations	9458	9.9
Control	8782	9.2
Observations	7034	7.3
Final inspection	2190	2.3
Safety issue	2188	2,3
Inventory	1204	1.3
As-built information	225	0.2
Warranty, reclamations & after-sales	184	0.2
Self-inspection	145	0.2
After inspection	97	1.5
Changes & additional work	70	1.5
Other issues	2003	2.1
Total:	95353	100

Available data

The available data found in the dataset is presented in Table 3. The features have been divided into four categories depending on whether they contain project, issue, user, or company information. This study focuses on text data; therefore, only text features are presented in Table 3. However, the dataset also contained pictures, drawings and model information.

Data quality and standardisation

The data quality for each feature is presented in Table 3. Bold letters indicate low quality, cursive letters average quality, and regular letters high quality. Autogenerated data, like issueID, creation date and user data, had a very high data quality. Other features, like "assigned to user" or "assigned to company", had a high quality in those cases the reporter had chosen to use that feature, but since those fields were not mandatory, in many cases, they were left blank.

If the reporter had assigned the issue to a BIM object, helpful information about the object type and name could be found. However, very few reporters had chosen to use this functionality. In the cases the BIM object was a standard element within the contractor's product portfolio, for example, a standardised inner wall, information about its structure could be found. If used, the information provided could help validate the product portfolio performance.

Free text features, like title and description, had a low data quality since there was no standardization regarding how to choose a title or how specific the description should be. However, there is a large dispersion between the issues. For example, some titles and descriptions are remarkably detailed, while others are very general. Today, the field 'description' can be left blank, leading to many issues missing an explanation. Developing guidelines for choosing a title and making the discipline field mandatory is suggested to enable better data usability. In the present dataset, if the title is poorly chosen and the description field is blank, it becomes almost impossible to understand what the issue concerns.

The field 'discipline' is predefined in terms of a drop list, but users can also add disciplines they find missing. The interpretation of what data shall be inserted varies between users and even more between projects. For example, some write about which technical field the issue concerns, like plumbing, structural systems, ventilation, etc. Other writes which part of the building the issue concerns, for example, building A, staircase C, etc. Other specifies which building part, like walls, ceiling, and facade. Another frequent use of discipline is to establish from who to whom the issue is sent, for example, 'Inspector to Ventilation' or 'Contractor to Painter.'

Type of issues reported

The most common issue type reported was remarks generated during pre-inspection, representing almost 46% of all registered issues, followed by inspections representing nearly 19%. All issue types and their frequencies are presented in Table 4.

More than 54% of all issues were assigned to the contractor company, followed by 10% assigned to the painting company and 6% to the electricity company. Most projects had a low frequency of issues reported at the beginning of the project, a smaller peak somewhere in the middle of the project, and the largest peak towards the end. However, there was no linear correlation when comparing the frequency of new reported issues per month, with the number of on-going project activities reported in the projects' Gantt charts. On the contrary, when many activities are performed at the beginning of the projects, the reporting frequency is low. In contrast, the reporting frequency is high towards the project's end when few activities are performed. Figure 3 shows a common issue frequency pattern in several projects, plotted against the number of ongoing project activities.

Interviews

All interviewees from the contractor company showed a large positivism towards digital inspection reporting, even though their

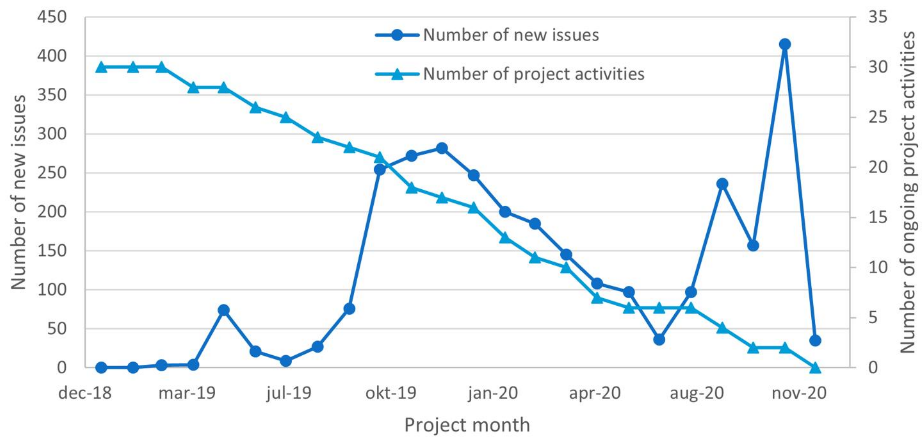

Figure 3. The variation of issue frequency plotted against the number of ongoing project activities per month for a typical project.

usage was very different. One of the interviewees wanted to keep it simple, used a minimum of functions, and did not use the possibility of importing 3D models to position the issues within the building. Another interviewee used many functions and spent several months planning how to structure the problems, handle the communication, and onboard project members. However, independent of how they performed the issue reporting, all were convinced it gave considerable benefits to both the project and them as supervisors and project managers.

When asked which issue types they found suitable to report, all interviewees answered that all production issues are relevant and that no issue is too large or small to report. When asked about the low issue reporting frequency at early project stages, the interviewees' answers were due to time restraints. Earlier in the projects, there were a lot of issues keeping the supervisors and project managers busy, and they had to prioritise problem-solving instead of reporting. Additionally, they fear ending up with an overwhelming number of issues if they start reporting earlier. Therefore, they prefer that the project has a higher completion rate before beginning the issue reporting. Even though the reasoning is understandable, some helpful information might get lost because of not starting to report earlier. Another consequence is limited insights from monitoring issue frequency for predicting project progress.

The number of safety issues being meagre in all projects was explained by a company demand to use different software for reporting work safety issues.

Some projects showed an innovative way of reporting information to be considered when producing the as-built drawings at the project end. None of the interviewees had used the software for this issue type but would consider doing it in future projects.

The large number of issues assigned to the contractor company was explained by some of the interviewees as a consequence of initially assigning all inspection issues to the contractor company and, after finishing the inspection, reassigning them to the proper receiver. However, all interviewees agreed that a large number of issues correctly were the direct responsibility of the contractor.

The data usage for purposes other than following up on the inspection reports and dividing issues between coworkers was low. However, one common way to use some of the collected data was in economic discussions with sub-contractors.

Except for the interviewee, who had developed an onboarding program for new project members, the need for a standardised way of reporting issues was considered low. As an explanation, the simplicity of using the software was given. However, considering the immense diversity found in the data analysis, the need and benefits of standardising on both organisational and project levels are probably more significant than the interviewees assumed.

Survey

A total of 131 responses were received, corresponding to a response rate of 46% and a margin of error of 6% with a confidence interval of 95%. Some persons receiving the survey invitation replied that even though they were registered users, they never reported any issues and were not qualified to answer the survey. Consequently, the response rate decreased, but the answers can still be considered representative of the population. Some questions with free answers had a lower answering rate. All questions and their response types, response rate and alternatives are presented in Table 5.

Background & role

The respondents had, on average, been using Dalux Field in four projects, and the most common project type where it was used was office buildings, followed by hospitals and apartments, see Figure 4. In addition, the respondents had an average experience within the construction industry of 17 years. Table 6 presents how many persons in each project role answered the survey and their average working experience within the construction industry. The two most common project roles among the respondents were supervisors, representing 26% of the respondents, and inspectors, representing 17%, see Table 6.

Reporting habits and project guidelines

The type of issues the respondents reported varied depending on their project role, but the three most common issue types were inspection remarks, deviations, and pre-inspection remarks. The supervisors reported all kinds of issues but most frequently deviations, pre-inspections, inspections, and self-inspections, while inspectors naturally reported mainly inspection issues. Clients, on the other hand, reported mostly deviations and pre-inspection problems.

More than 48% of the responders had received guidelines for using the issue-reporting software, and 74% answered that they

Table 5. Survey questions.

ID	Question	Response type	Resp. Rate [%]	Response alternatives
	Background & role			
Q1	How many years of working experience within the construction industry do you have?	Fixed	45	0-40 years
Q2	Which role did you have in the project where you performed digital reporting?	Fixed	46	Site manager, Project man., Supervisor, BIM coordinator, Consultant, Architect, Inspector, Sub-contractor, After-sales, Install. Manager, Other
Q3	In how many projects have you performed digital reporting?	Fixed	46	0-10 projects
Q4	In which types of projects have you performed digital reporting?	Fixed	46	Hospitals, Apartments, Hotels, Schools, Offices Parking houses Swim hall, Other
	Issue reporting			
Q5	How often do you usually report issues?	Likert scale	46	1- Every day 2-Every week 3-Every month 4- Less than once p. month 5- Never
Q6	Which kind of issues do you report?	Fixed	45	Pre-insp., inspections, Deviations, Controls Observations, Final inspections, Safety issues, Inventory, As built inform. Warranty, recl. & After-sales, Self-inspection After inspections, Changes & add. Work, Other issues.
Q7	In your most recent project where you performed digital reporting, did you get any introduction or demonstration of the software?	Fixed	46	Yes No Do not know
Q8	Did you have any common guidelines for reporting issues in your project?	Fixed	46	See Q7
Q9	Did you have any common guidelines for adding information to your project?	Fixed	46	See Q7
	Challenges			
Q10	Can you get support from either the contractor or the software supplier in case you need it?	Fixed	46	See Q7
Q11	How easy to use is the software, in your opinion?	Likert scale	46	1- Very difficult 2- Slightly difficult 3- Neither/nor 4- Rather easy 5- Very easy
Q12	Is there something in DF that should be improved?	Free	17	
	Opportunities			
Q13	Where did digital issue reporting give you the most significant benefits for you as an individual?	Free	35	
Q14	Where did digital issue reporting give you the most significant benefits for your project?	Free	33	
Q15	To what extent do you agree that digital issue reporting generated value for your project?	Likert scale	45	1- Completely disagree 2- Somewhat disagree 3- Neither/nor 4- Somewhat agree 5- Completely agree
Q16	To what extent do you agree that digital issue reporting reduced costs in your project?	Likert scale	45	See Q15
Q17	To what extent do you agree that digital issue reporting saved time in your project?	Likert scale	45	See Q15
Q18	One of the most common issues to report is pre-inspections. Do you think it would be possible to report and address those issues earlier in the project?	Fixed	45	See Q7
	Future Features			
Q19	If a function suggests a title and description for frequently used issues, to what extent would it be beneficial for your issue reporting?	Likert scale	44	See Q15
Q20	If there would be a function suggesting common problems when clicking on a BIM object or drawing part, to what extent would it be beneficial for your issue reporting?	Likert scale	44	See Q15
Q21	If it would be possible to report costs connected to a specific issue, to what extent would it be useful?	Likert scale	44	See Q15
Q22	If it would be possible to report delays connected to a specific issue, to what extent would it be useful?	Likert scale	44	See Q15

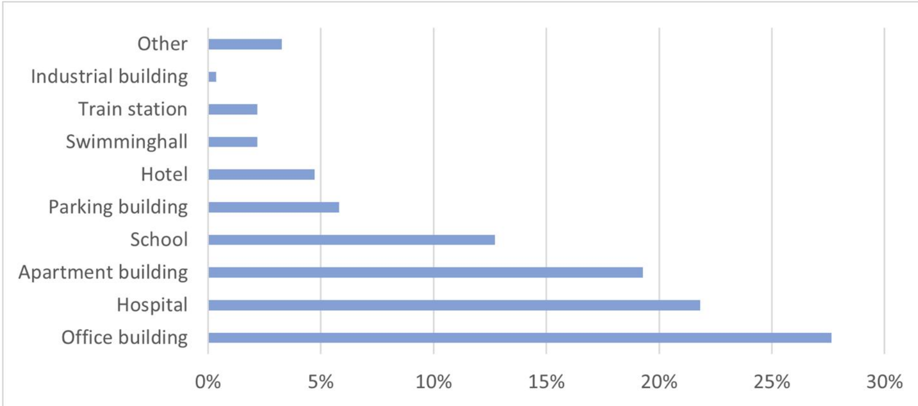

Figure 4. Project types where the respondents used digital issue reporting.

Table 6. Number of survey responders per role.

Role in Project	Number of persons	Percentage	Average years of experience
Supervisor	34	26.0	14
Inspector	22	16.8	28
Installation Fitter	14	10.7	15
Consultant	10	7.6	20
BIM-coordinator	10	7.6	8
Site Manager	9	6.9	16
Project Engineer	6	4,6	9
Installation Manager	5	3.8	17
Client	8	6.1	20
Blue collar	4	3.0	16
Subcontractor	3	2.3	20
Project Manager	2	1.5	15
QEHS responsible	2	1.5	15
Cost Estimator	1	0.8	30
After-sales Responsible	1	0.8	16

had also received instructions regarding which issues to report and who to address them. Regarding information input, for example, how to write a proper title, which field to always fill in, and an explanation of categories, more than 48% answered that they have also received these guidelines.

Challenges with performing digital issue reporting

To a considerable extent, the responders considered digital issue reporting easy to do, see Figure 5. Only 8% answered that it was difficult or very difficult, and 78% found it easy or very easy.

One identified challenge with digital issue reporting concerns how to address multidisciplinary problems. For example, how shall data be entered, and who shall be responsible for adjusting an inspection remark if it involves several disciplines? One specific example mentioned in one interview was the need to move an electric socket. The issue included detaching the socket, drilling a new hole, adjusting cables, remounting the socket, and lastly, repainting the wall upon which it was placed, and it involved three different sub-contractors. Some users solve these kinds of multidisciplinary issues by simply creating three separate issues. However, this survey shows that many users would like to find a way to handle it as one single issue.

Other challenges identified were carefully thinking through how to set up the communication structure in a project, clarifying responsibilities and administering changes within an ongoing issue.

Some respondents suggested new features when asked about challenges. The most common suggestions in this category were various drawing features, like creating links between drawings and product names. An example of such a suggestion for a new feature was if a specific product, like a fire damper, is mentioned in a document and you click on the product name, you will find it highlighted on all drawings where that fire damper shall be mounted. Other answers wanted a feature where you could draw on a pdf drawing to show needed changes in the as-built drawings. However, during the data-mining process, it could be seen that the hospital projects had solved this by creating a discipline called as-built drawings, where you could add issues later to be addressed while producing as-built drawings.

Opportunities and benefits with digital issue reporting

The respondents were asked about the main benefits for themselves and the project. The two questions were asked as open-answer questions, and the answers could be divided into seven categories presented in Figure 6.

Increased control. One large benefit category for individual project members and the project was the simplicity of digitally reporting inspection remarks and that the administration got much easier and faster when digitalised. Another positive consequence was that the team leader or supervisor could easily forward and assign remarks to team members, which decreased the risk of forgetting to address an issue. Many responders also mentioned a general sense of control and tidiness provided by digital issues reporting. Team members felt less stressed about forgetting things, they could get a better overview of the remaining work, and they considered it much easier to follow up on the progress of an issue.

Benefitting inspections. Performing digital issue reporting was considered particularly benefitting for inspections. The motivation to why was that it simplified the administration and distribution of tasks. Another often-mentioned benefit was to perform the self-inspections digitally, where the possibility to document the inspection by adding photographs was considered helpful since it improved the understanding of the content of the inspection.

Time saving. The time saving with digital issue reporting was considered high. Reporting issues digitally was considered faster than writing on paper and reduced the manual paperwork. Supervisors, site managers, and inspectors had also discovered that directly adding issues to the database made them immediately available for the other project members, making the project

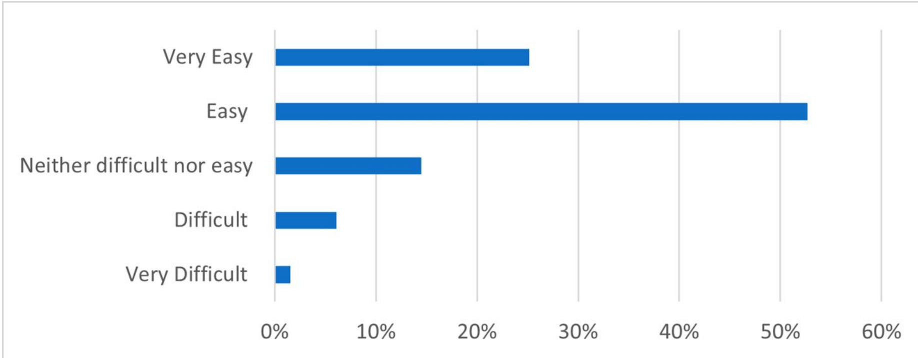

Figure 5. The responders' rating of easiness of performing digital issues reporting.

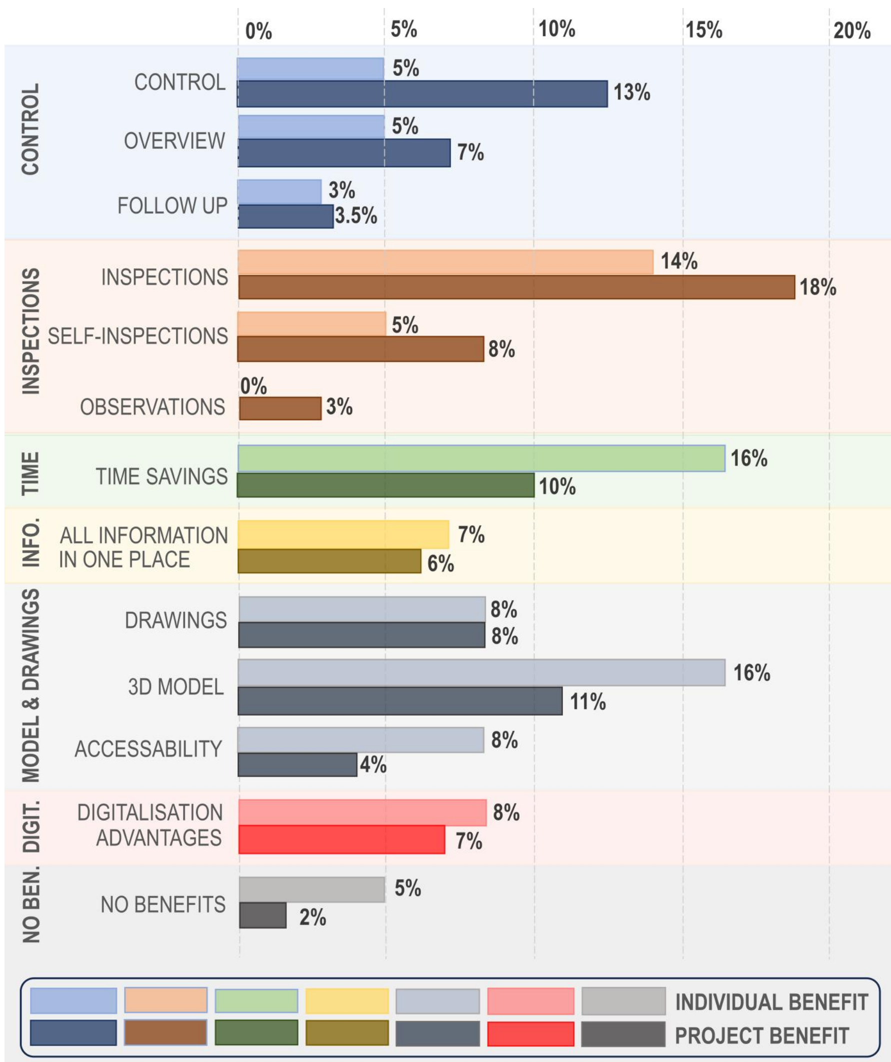

Figure 6. Main and subcategories for most significant individual and project benefit. The numbers in percentage represent the frequency of answers identifying a specific benefit topic for both individuals and projects.

save time by not having to wait for an inspection report. This was considered crucial in late project stages, where time is often limited. The supervisors also saved time by not needing to walk around physically with blue collars showing and explaining various remarks. They could instead assign the remarks to them, which the receiver could calmly read through and analyse before starting the adjustment works.

All information in one place. Finding all information, such as drawings, issues, documents, time plans etc., in one place was considered a benefit for both the individual and for the projects. Many responders mentioned being used to search for information in different document management systems and on different servers in traditional projects, whereas in the projects performing digital reporting everything was found in one place.

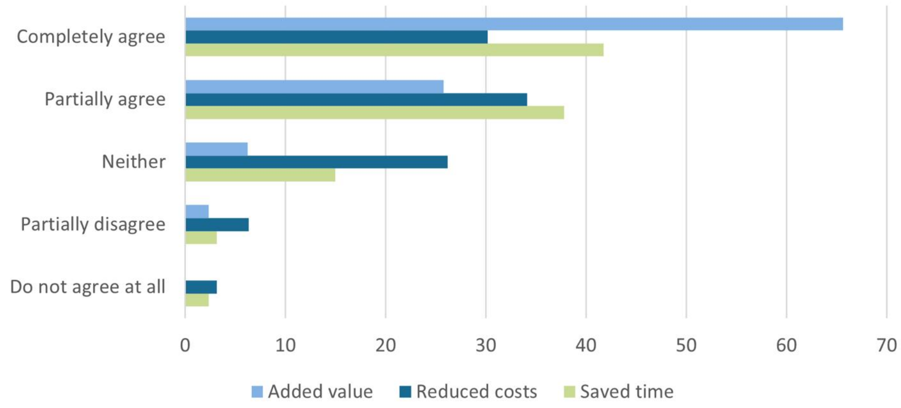

Figure 7. Answers to questions; to what extent do you agree that digital issue reporting A: Added value to the project? B: Reduced project costs? C: Saved project time?.

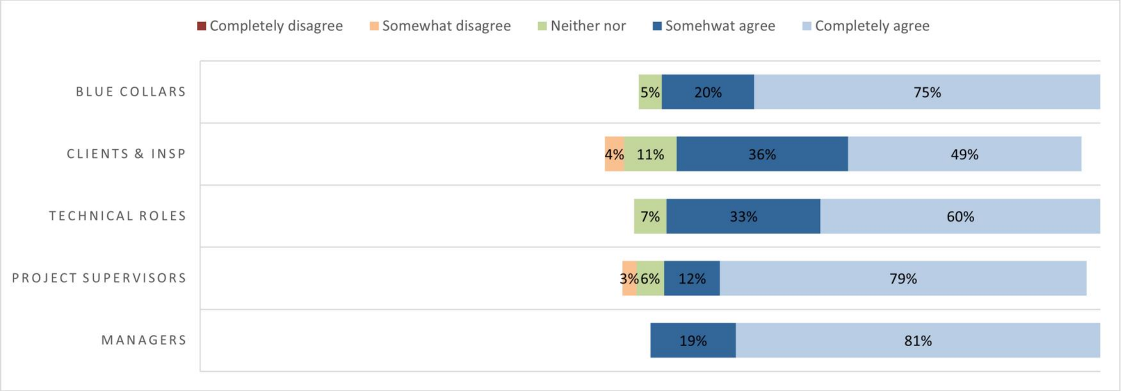

Figure 8. Trends in answers to the question: *to what extent do you agree that digital issue reporting added a general value to your project*?.

Drawings and 3D model. Another large benefit category, the largest for individuals and the second largest for the projects, was the possibility of locating an issue on a pdf drawing or in the 3D model. Not only did this remove uncertainties about where a remark was found, but a side effect was that many more blue collars used the 3D model as work support. Instead of only locating issues, they discovered advantages with BIM and started to use the 3D model also for preparing and planning their work.

In the same category, another benefit of digitalisation was the certainty of always working with the latest updated drawings, and if there was a drawing update, they got a real-time notification on their device.

The simple accessibility to both issues, drawings and 3D model through tablets and cell phones was considered a large individual benefit.

General digitalisation advantages. Some survey respondents mentioned that the fact of having the issue reporting data digital facilitated their work and also enable future possibilities of statistically analysing the data.

No clear benefits. Some respondents, as few as 5%, answered that they could see no personal benefits with digital inspection reporting, and all those respondents worked as inspectors. Some inspectors stated that digital work methods increased their workload, but they could identify some project benefits. The results show that digitalising the inspections benefits all professions except some inspectors. Regarding project benefits only 2% of the respondents stated that they did not see any project benefits.

General value and time- and cost-saving. After the free answer questions about benefits, the survey respondents were asked to rate to what extent they agreed that digital issue reporting added value in general, reduced costs, and saved time. As seen in Figure 7, 90% totally or partially agreed to digital issue reporting adding value to the project. More than 64% partially or completely agreed that digital issue reporting reduced costs, and 80% partially or completely agreed that it also saved project time.

To further understand the perceived benefits depending on the respondents' roles, the answers were grouped into five categories depending on their roles and responsibilities:

- Blue collars: production workers for the main contractor, subcontractors and installation fitters.
- Clients & inspectors
- Technical roles: BIM coordinators, consultants, after-sales representatives, project engineers, cost estimators and QEHS responsible.
- Production supervisors
- Managers: Site managers, project managers and installation managers

Figures 8–10 compare the answer trends between the role categories. Regarding general added value with digital reporting, the production supervisors, managers and blue collars considered digital reporting to add the highest value. The least optimistic group was clients and inspectors. The same group also considered time and cost savings less than the others. When comparing the answers regarding the main benefits of digital issue reporting, the

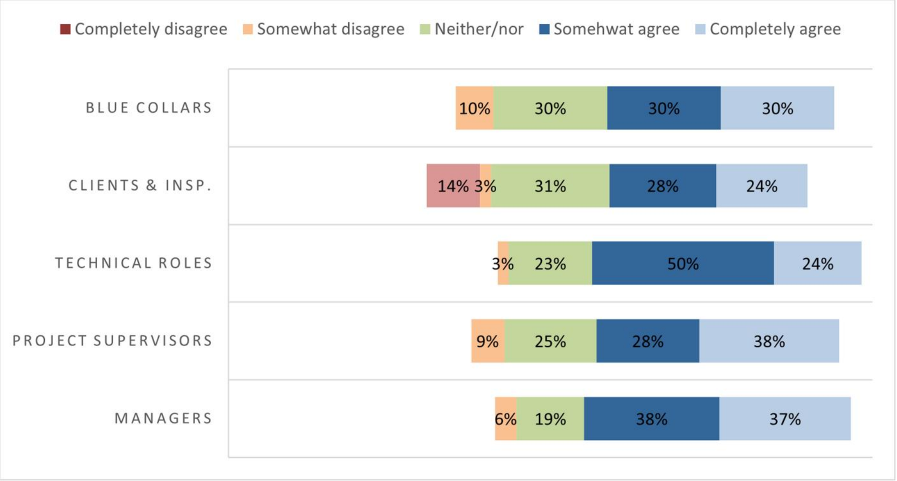

Figure 9. Trends in answers to the question: *to what extent do you agree that digital issue reporting reduced costs in your project?.*

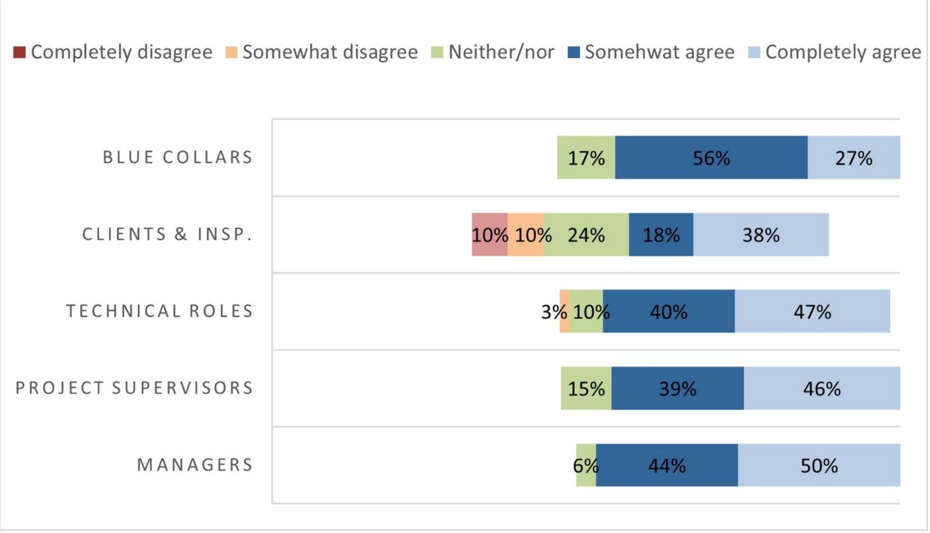

Figure 10. Trends in answers to the question: *to what extent do you agree that digital issue reporting saved time in your project?.*

client and inspector groups focus more on increased control than the other groups.

As discovered in the data analysis, the most common issue to report is pre-inspection remarks, which are usually reported very late in the project. In the survey, the responders were asked if, in their opinion, it is possible to start the issue-reporting earlier. More than 67% answered that they think so, and several responders also commented that they are already doing so.

Future features increasing data quality

To enable a simplified future data analysis, it is suggested to improve that data quality by both making the data input better and improving the pre-processing automatization. In the survey, the data input improvement was addressed by four questions. The first question addressed text analytic techniques, where one is sentence autocomplete. An example is when an issue reporter starts writing the title 'Painting', the software can automatically suggest autocompletion like 'Painting damage', 'Defective painting,' or 'Missing painting.' This can help the reporter be more specific in the choice of title and make the data analysis more accurate. When asked about such a feature would be helpful for them as issue reporters, 7% answered that they completely or partially disagreed that it would be useful, and 19% responded that it was neither useless nor useful. On the other hand, 74% said they partially or wholly agreed it would be useful. This indicates that introducing such a feature would help both the issue reporter and the later data analysis.

Another natural language processing technique for data improvement is topic identification. When a project member clicks on a BIM or drawing object, topic identification is used for presenting the most common issue types connected to the chosen object. When asked if such a feature would be helpful for the individual issue reporter, 11% answered that they partially or totally disagreed, 29% responded that they found such a feature neither/nor helpful, and 60% partially or completely agreed that it would be helpful.

A connection between issues and generated costs would enable issue data as a decision base on an organisational level. However, when asked if they found it useful to report issues cost, 56% of the responders answered that they completely or partially disagreed or found it neither useless nor useful.

The final question was about the usefulness of reporting estimated adjustment time for an issue. The survey respondents were slightly more positive toward time reporting than cost reporting. However, some interviewees stated that time estimations are not easily done and that there is a difference in reporting 'active' time and time until the issue is addressed in cases involving several disciplines.

Discussion

The findings in this research will be discussed referring to time-savings, standardised methods for data analysis, possibilities to use inspection data as input to new projects, and present and future use of technology.

Time-savings

Collecting and compiling inspection data has been identified as a time-consuming task (Navon 2005, Lundkvist et al. 2010). The study presented in this paper has shown that the introduction of digital inspection reporting software has solved the collection and compiling problems and improved the general usage of digital 2D drawings and 3D models in production. The survey results also show that digital inspection reporting saves time by reducing administration and minimising waiting times between the inspections and when problems can be addressed. The perceived time-savings stimulate the projects to continue to perform digital reporting, which is essential for providing continuous data to the contractors.

Standardised methods for data analysis

Regarding the lack of automated methods for analysing the collected data identified by Lundkvist et al. (2010) and Soibelman and Kim (2002), the interview answers show this is still a problem. The literature review by Yan et al. (2020) indicated knowledge generation possibilities, but no use of such methods has been recognised in this study. Even though the reporting software has some built-in functions for simple data visualisations, they are not used. Except for the intended purpose of monitoring production issues, the only further use of inspection data noted has been filtering issues on specific sub-contractors to use for economic discussions. However, the interviews found that if inspection issues from all projects were available to the whole organisation, the supervisors and project managers would also consider filtering issues on specific subcontractors or suppliers when evaluating them for future projects and estimating cost risks.

Possibilities to use inspection data as input in new projects

One of the most significant benefits of digital inspection reporting was controlling all the issues reported, who they were addressed to and the current issue statutes. The administration was simplified, and the final inspection was facilitated using digital inspection reporting for pre-inspections. However, since the data at present is not further used, digital data only generated reactive benefits. Considerable benefits may also be found in using the data for a proactive approach to new projects. Inspection data can be helpful when developing standardised technical solutions or planning and designing checklists. The quality of the inspection data must be improved to simplify its future use. Therefore, a first quality-improving step can be to inform project members that the data might be used on an organisational level, and an increased effort shall be spent on making titles and descriptions understandable for project-external readers. Data quality improvement can also be achieved using drop-down lists or predefining common issues. It would also be useful to add information about project size, project type, contract information, and the total building or gross area to allow comparisons like the number of painting issues per square meter, indicating project or subcontractor performances.

A link between issues and costs would be beneficial to increase the usefulness of analysing inspection data on an organisational level. Only looking at issue topic frequencies is insufficient for deciding on quality improvement actions since some persistent issues might not cost much to address. In contrast, other low-frequent issues might have severe economic consequences. However, the survey results show little interest in adding costs to the issues. Therefore, it is suggested that this be addressed by linking other data, e.g. invoice data, to issue clusters instead. However, the estimated severity of an issue can be considered during the issue reporting by allowing some classification.

Production issue data can potentially facilitate change management control, as Schönbeck et al. (2022) discussed. The dataset used in this study contained information about problems discovered in production, but most issues reported tend to be visual symptoms rather than actual causes. Thus, including the issue coordinates and combining the data with BIM model change logs can give valuable insights to the after-sales team (Ma et al. 2018).

Present and future use of technology

Even though the technology for performing digital inspections is available, the choice of using it depends on the project members and the inspectors. During the interviews, it was found that sometimes the inspectors prefer to use their traditional method, which is often walking through the building and recording remarks with a Dictaphone or writing on paper, to later transcribe and distribute in PDF format. Some of the free text answers in the survey also showed a tampering fear among the inspectors towards the inspection digitisation. Other researchers have discussed the tampering risk with technology (Zhong et al. 2020), claiming that the present technologies cannot secure data. However, the data analysis in this study shows good digital revision traceability. The answers in the interviews and survey indicate that the reporters find it too difficult to modify reported issues and consider the modification restrictions too rigid. In the case of inspectors not willing to perform the reporting digitally, some projects found it worth making a supervisor from the contractor add the issues digitally to understand better the volume and start addressing them while waiting for the official documentation. However, this generates double administration.

Artificial intelligence has been identified as a key enabling technology by the European Parliament (EPRS 2021), listing data availability, quality, and dataset integrity as challenges that must be overcome to use AI techniques for data analysis successfully. The results in this paper show that regarding the current status of production data, the availability is good, but data quality and dataset integrity must be improved. Solving the integrity problem is crucial for having a continuous, reliable data supply and minimising time spent on data pre-processing. Despite the low quality of titles and descriptions, the data availability enables the use of machine learning techniques, such as clustering and keyword extraction, to generate insights from unstructured data.

Conclusions

Reporting inspection remarks digitally gives project advantages such as time savings, a smoother inspection process, and increased control and use of the 3D model. For project individuals, time savings, increased use of 3D models, and ease of locating remarks have been the most significant benefits of digital reporting. In addition, digital inspection reporting has solved the industry's collection and compiling struggle. However, even if inspection data is considered a valuable information source, its usage on an organisation level is minimal.

This research shows that there are already project and project member incitements for digital inspection reporting, but it also enables knowledge generation at an organisational level. However, to succeed with knowledge generation, companies must standardise the data collection and improve data quality, allowing comparisons and insight generation between projects.

Inspectors seem least optimistic about digital inspection reporting. This leads to the conclusion that even if digital inspection reporting potentially should benefit the inspectors, the present way of reporting does not satisfy all inspection documentation requirements. Therefore, further investigating if there are ways of reporting that meet both the contractors' and inspectors' documentation needs is essential.

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Data availability statement

The data that support the survey findings of this study are available from the corresponding author, upon reasonable request.

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