EVALUATION OF EMERGING TECHNOLOGIES FOR REMOTE INSPECTIONS OF BUILDING WORK

FINAL REPORT

CONTENTS

CONFIDENTIAL:	☐Yes X No
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Disclaimer

EXECUTIVE SUMMARY

Inspections of building work during construction play a crucial role in ensuring compliance, safety, and quality within the building industry. The advancement in technology offers an exciting opportunity to revolutionise inspection processes by introducing remote inspection options. Integrated with conventional inspections, these innovative approaches have the potential to enhance efficiency, safety, and record-keeping while addressing industry challenges such as the shortage of qualified practitioners and transparency issues. Despite the high expectations, there are a range of critical questions that need to be answered before the industry starts adopting and integrating such practices.

To provide evidence-based recommendations for maximising the benefits and mitigating the risks associated with remote inspections, the research team undertook multiple research tasks, including a review of guidelines and technologies employed in current remote inspection practice and research, mapping of stakeholder perspectives on the use of Remote Video Inspection (RVI), and the field trial case study to evaluate the feasibility of a selection of remote inspection technologies. The key findings from these research tasks are summarised as follows:

- The utilisation of remote inspections, assistant-based technologies, and other inspection-enhancing tools should be supported by a robust policy, regulatory, and governance framework. This ensures that the benefits are realised while effectively mitigating associated risks.
- Several international guidelines exist for conducting remote inspections in both the building industry as well as other (related) industries. These guidelines embolden implementation efforts; they serve as reference points for Victoria's (and Australia's) own burgeoning guidelines.
- Stakeholders generally hold a positive and receptive attitude toward remote inspections. However, concerns do exist regarding conflicts of interest, costs, and operator competency.
- The current technology landscape supports the use of remote inspection for a wide range of inspection tasks, particularly those reliant on visual and geometric data. Yet, limitations exist for certain types of inspection tasks that involve precise measurements or testing with specialised devices.
- Various reality capture technologies were tested and proven technologically feasible for conducting a number of mandatory inspection tasks remotely on Class 1 building sites at multiple mandatory notification stages. Feedback from participating building surveyors suggested a preference for visual data (e.g. panorama images) over 3D models (e.g. point cloud or mesh visualisations).
- Informed by stakeholder engagement, regulatory analysis, technology assessment, and field trials, a set of recommendations has been formulated to address the critical decision-making points when considering remote inspections.

Based on the findings above, we summarise the benefits and risks of using remote inspection of building work (see Section 7.2) and recommend that the use of remote, assistant-based, and other inspection-enhancing technologies should be supported within an appropriate policy, regulatory and governance framework that ensures benefits are realised and risks mitigated. In order to establish this framework, four key questions must be answered:

- When can remote inspections be conducted?
    - Inspections of building work during construction should be conducted by the RBS (or other authorised person) in-person and onsite unless the use of remote or assistance-based inspection technologies can be shown to be more effective, efficient and/or safe.
    - Develop a multi-factorial tool to guide decision-making on the use of remote and assistant-based inspections, and the selection of suitable technologies matched to site and inspection stage and elements.

- Who decides to conduct a remote inspection?
  - The decision to conduct a remote or assistant-based inspection should be made by the person who is responsible at law for the conduct of the inspection, which:
    - in the case of mandatory inspections, is the RBS.
    - in the case of compliance and assurance inspections, is the person authorised by the legislation to conduct the inspection.
    - in the case of non-statutory inspections, the person with the contractual right to initiate and determine the scope and nature of the inspection.
- What technology should be used?
  - Government should prescribe technologically neutral outcome-orientated standards and requirements that remote and assistant-based inception technologies must satisfy in order to be used as part of statutory inspections (mandatory or compliance and assurance).
  - Government should work with industry and professional associations to develop systems to assess and rate technologies for remote and assistant-based inspections.
- Who can operate the technology?
  - The person deciding to conduct a remote or assistant-based inspection must satisfy themselves that the person who will operate the technology on site:
    - has building and technical knowledge commensurate with the nature of the inspection being conducted;
    - has the technical skills, knowledge, and competence (and in some cases (e.g. drones) licence) to use the technology for the purpose of the inspection; and
    - is sufficiently independent of the persons whose work is being inspected.
  - Government should work with professional associations and educational institutions to develop appropriate courses for persons operating remote, assistant-based and inspection-enhancing technologies.
  - Governments should work with professional associations to establish pathways to becoming a registered building surveyor or inspector for persons credentialed as an inspection technology operator.

GLOSSARY OF TERMS AND DEFINITIONS

Assistant-based inspections	Inspections that do not require the authorised inspector to be on the site but necessitate an onsite assistant to operate the data acquisition technology and/or to extract inspection information for use by the authorised inspector. RVI is an example of this type of inspection.
Conventional inspections	Inspections that require the authorised inspector to be physically present on the building site to collect inspection information.
Mandatory inspection	Mandatory inspections are conducted of core components and stages of building work to ensure key structural, safety and amenity matters are achieved. They occur at certain stages of building work, as set out in the Regulations, or as defined by the RBS.
Mandatory notification stages	Core components and stages of building works that the legislation requires be inspected for compliance with the Act, Regulations, and the building permit.
Relevant Building Surveyor (RBS)	The relevant building surveyor is the person appointed to assess, grant, and ensure compliance with the building permit. The relevant building surveyor provides independent oversight of buildings and building work throughout the construction process and upon completion of construction to ensure that buildings are safe for use, accessible, energy efficient and comply with relevant legislative and regulatory requirements (i.e. Act, Regulations, and building permit). The relevant building surveyor can either be a municipal building surveyor (employed by a local council) or a private building surveyor.
Remote inspections	Inspections that require neither the authorised inspector nor the assistant to be onsite to collect inspection information. Inspection data is collected using various sensors and the inspector is able to extract the relevant information and determine the compliance status of building components remotely. In some jurisdictions and contexts these inspections are referred to as virtual inspections. The terms are used interchangeably in this report.
Remote video inspection (RVI)	RVI is defined in this report as an inspection of building work during construction that is conducted by a registered building surveyor or building inspector from a remote location (without attending the site physically) using real-time/live video call applications (e.g. Zoom, Teams) or specialised applications that are capable of providing additional functions such as geolocation and on-screen annotation (e.g. Zyte, Artisan).

LIST OF ACRONYMS AND ABBREVIATIONS

ABCB – Australian Building Codes Board

ABS – American Bureau of Shipping

AR – augmented reality

BCR – building confidence report

BIM – building information modelling

BMF – Building Ministers' Forum

CCTV – closed-circuit television

DT – Digital Twin

DTF – Victorian Department of Treasury and Finance

GIS – geographic information system

GPR – ground penetrating radar

GPU – graphic processing unit

IoT – Internet of Things

LiDAR – light detection and ranging

MBS – municipal building surveyor

MLS – mobile laser scanning

MR – mixed reality

NCC – National Construction Code

PAP – Plumbing Audit Program

QMS – quality management systems

RBS – relevant building surveyor

RIT – remote inspection technologies

ROV – remotely operated underwater vehicles

RVI – remote video inspection

SLAM – simultaneous localisation and mapping

SMS – safety management systems

TLS – terrestrial laser scanning

VBA – Victoria Building Authority

VR – virtual reality

VMIA – Victorian Managed Insurance Authority

UAV – unmanned aerial vehicles

XR – extended reality

1. PROJECT OVERVIEW

Inspections of building work are a vital aspect of the building industry. They ensure compliance with building codes, regulations, and approved plans. These inspections are particularly important in Australia due to the high risk of natural disasters, such as bushfires and floods, along with the growing public concern about the quality of buildings, which has especially increased over the past few years. Technology has rapidly advanced – both in affordability and capability. This advancement has brought new opportunities for the building industry. These opportunities may result in an industry-wide paradigm shift, where remote inspections of building work become common alternatives to in-person ones. By removing the need for a building surveyor or inspector to be onsite to conduct an inspection, remote inspections have the potential to improve the efficiency and safety of inspections, as well as enhance record keeping (both pre- and post-inspection). These opportunities may address several challenges which the industry currently faces, including a shortage of building surveyors, lack of transparency, as well as health and safety risks.

While in Victoria mandatory inspections of building work during construction must be conducted in person and onsite, non-mandatory inspections have the potential to be carried out remotely and virtually, utilising emerging technologies. However, the effectiveness and suitability of remote inspection technologies are not yet fully comprehended and demand thorough evaluation. The objective of this project is to offer evidence-based recommendations for maximising the benefits and mitigating the risks associated with remote inspections. It meets this objective in three ways. First, it engages in a comprehensive assessment of the technology. Second, it maps the stakeholder perspective. And finally, it conducts a regulatory analysis. Figure 1.1 illustrates the research framework.

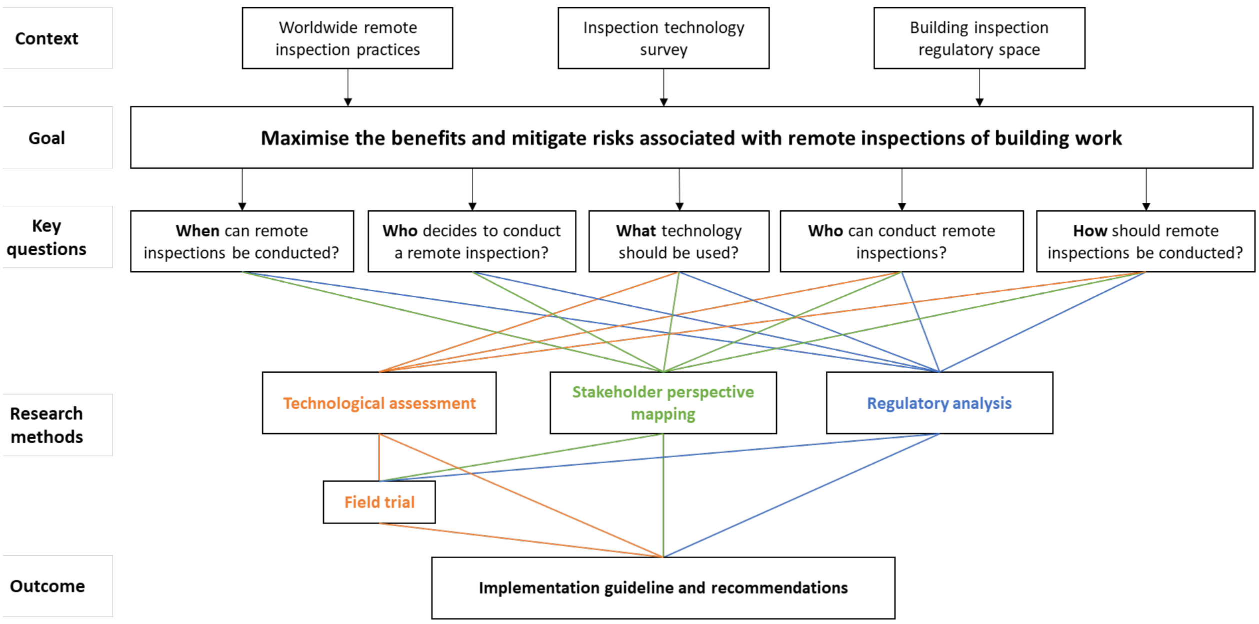

Figure 1.1: Research framework

This report brings together the regulatory contexts, best practices, emerging technologies, and case studies that concern remote inspections. It analyses and blends these elements into a holistic discussion regarding the viability and feasibility of remote inspections. The rest of this report is organised as follows. Section 2 reviews and describes the regulatory context, with a special focus on Victoria. Section 3 looks into guidelines and best practices of remote inspection from across the world and in multiple industries. Section 4 analyses stakeholder perspectives on remote inspection, with a focus on regulators and industry practitioners.

Section 5 reviews the technological landscape, discussing emerging inspection technologies. Section 6 reports and discusses the outcome of field trials and case studies of using certain inspection technologies on real building sites. Based on the findings presented in previous sections, Section 7 analyses the benefits and risks associated with remote inspections and provides recommendations to guide the implementation. Finally, Section 8 provides a conclusion and a set of further recommendations for guidelines development, regulatory reform, and the advancement of remote inspection technologies.

2. REGULATORY CONTEXT

2.1. Overview

This section provides an overview of the regulatory context within which building inspections take place. This is important because building inspections do not occur in a vacuum; they are part of a *complex* building regulatory framework. Understanding this framework, and the *crowded, contested, and changeable* regulatory space within which it sits, is important to fully consider the legal, regulatory, and policy issues associated with a move to remote inspections.

2.2. Building regulatory framework

Most building regulation occurs at the state and territory levels. Each state and territory (and in some cases, local government area) has its own unique regulatory and institutional environment. While conceptually aligned, significant differences exist in their legal, regulatory, and operational detail, creating the first source of complexity. In this report we focus on Victoria.

Victoria's building system is primarily regulated through the *Building Act 1993* (Vic) (Building Act), which has as its objectives protecting the safety and health of people who use buildings and places of public entertainment, and enhancing the amenity of buildings (Section 4). The principal means by which the Building Act seeks to achieve these objectives is by requiring owners and developers of land to obtain a building permit to be able to carry out building work on their land, and then to conduct that building work in accordance with the Building Act and Building Regulations 2018 (Vic) (and the codes and standards they incorporate, such as the National Construction Code (NCC)), other legislation that provides building standards (e.g. Disability (Access to Premises – Building) Standards 2010 made under the *Disability Discrimination Act 1992* (Cth)), and any conditions specified in the building permit.

Central to this system is the building surveyor. The building surveyor performs the core regulatory functions involved in all steps of the building process. They assess the building permit application and decide whether to grant a building permit; they conduct the inspections mandated by the Building Act to ensure the building complies with the Act, Regulations, and building permit; they grant the occupancy certificate or certificate of final inspection which certifies compliance; they prescribe regulatory requirements that continue through occupancy; and they assess and administer building permits that may be required for proposed renovations, refurbishments and eventually demolition.

However, the building surveyor is not the sole actor involved in the approval and inspection process. The building surveyor must also involve a range of reporting authorities. Reporting authorities include the council responsible for the land where the proposed building work will occur, any other affected council, and any relevant service authorities such as for drainage, sewerage, electricity, gas, or water supply. The purpose of the referral is to ensure that the proposed building work does not adversely affect the assets and infrastructure of the reporting authorities, the operational requirements of emergency services, or the amenity of the community. Reporting authorities are required to provide reports on (and in some cases, consent to) the proposed construction.

And during the building process, a range of compliance and safety certificates from persons other than the building surveyor may be required. Some of these may relate to structural, civil, hydraulic, and mechanical issues and are issued by certified engineers; whereas others may relate to water, gas, and electrical works, fire safety and energy efficiency matters. They are variably are given by licensed plumbers and electricians, energy safety regulators, fire authorities, and accredited energy efficiency assessors. Local government permits and consents also may be required if the building works affects council assets or community amenity.

2.3. Building regulatory space

The above description reveals that the building regulatory framework is complex. There are a variety of formal legal instruments giving effect to diverse legal, economic, and social objectives, and a variety of different decisions, permits, approvals, certificates, and consents made under those legal instruments.

It also is crowded with a number of state (public) and non-state (private) actors directly involved with approving aspects of the building process. But those actors with an interest in the building process extend beyond those actors with direct approval roles. These include:

- government departments and agencies (e.g. in Victoria, they include the Victorian Building Authority, Department of Transport and Planning, local councils, Consumer Affairs Victoria, Domestic Building Dispute Resolution Victoria, Victorian Managed Insurance Authority, Fire Rescue Victoria, WorkSafe Victoria, Building Regulations Advisory Committee, and Energy Safe Victoria)
- statutory oversight roles (e.g. building surveyors, inspectors and compliance roles within state and local government agencies)
- construction personnel (builders, plumbers, tradespersons etc.)
- designers (architects; draftspersons)
- developers
- professional associations, industry associations and unions
- specialist consultants (e.g. engineers; fire safety practitioners)
- product and material suppliers
- financiers and insurers
- education providers (e.g. of building surveyors, building inspectors and other building practitioners)
- consumer and community organisations.

Moreover, the interests of these actors are not always aligned. Many of the actors occupying the regulatory space have different interests and values, and different objectives that they would like to see a building and planning system deliver. These interests, values, and objectives can differ economically, socially, and environmentally. Even within government there are agencies with different missions, priorities, and regulatory roles. As a result, formulation of building policy can be a complex and at times contested process.

Finally, this space is not static. The building sector operates in a dynamic and changeable environment. Some of this change is brought about by changes in industry practice; some by technological change; some by events and crises; and some by changes in government policy. The speed with which the issue of remote inspections has appeared on the building regulatory reform agenda is evidence of this dynamic and changeable environment. In 2017, Victoria amended the Building Act to require that key mandatory inspections be conducted in person and onsite. And the February 2018 *Building Confidence Report* (BCR) commissioned by the Building Ministers' Forum (BMF) recommended that each jurisdiction require onsite inspections of building work at identified notification stages.[1] Relevantly, the BCR did not discuss remote inspections as an option. Yet less than three years later, the Australian Building Codes Board (ABCB), charged by the BMF with establishing national best-practice models in response to the BCR, issued guidance that "*mandatory inspections can be conducted virtually [i.e. remotely] as an alternative to onsite inspections*".[2] For a more detailed discussion of these developments, see Section 2.5.

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[1] Shergold, P. and B. Weir, Building Confidence: Improving the effectiveness of compliance and enforcement systems for the building and construction industry across Australia. 2018.
[2] Australian Building Codes Board, Mandatory inspections: Model guidance on BCR recommendation 18. 2021.

All of this combines to render the environment within which decisions about remote inspections are to be made – *complex, crowded, contested, and changeable*.

2.4. Victoria's building inspection regime

The relevant legislative instruments governing inspections in Victoria are the Building Act and the Building Regulations. Also instructive are the following guidance and practice note issued by the Victorian Building Authority (VBA) – the state government regulator of Victoria's building and plumbing industry:

- Building Practice Note MI-01: Mandatory notification stages and inspection of building work
- Guideline for the Conduct of Non-mandatory Remote Video Inspections (RVIs).

The Building Act provides for two broad types of inspections:

1. Mandatory inspections
2. Compliance and assurance inspections.

Each is explained below.

2.4.1. Mandatory inspections

2.4.1.1. What must be inspected?

Mandatory inspections are conducted of core components and stages of building work to ensure key structural, safety, and amenity matters are achieved. There are three types of mandatory inspections:

- **Inspections at mandatory notification stages –** Section 34 of the Building Act provides for inspections at the completion of a mandatory notification stage. The mandatory notification stages are set out in Part 12 of the Building Regulations by building work type: construction of a new building or alterations to an existing building; demolition or removal of a building; and construction of a swimming pool or spa. For the construction of a new building or alterations to an existing building, the prescribed stages are:
  (a) before placing a footing
  (b) before pouring an in-situ reinforced concrete member that is specified in the relevant building permit by the relevant building surveyor (RBS)
  (c) completion of framework
  (d) inspection of fire and smoke resisting building elements as required under regulation 172
  (e) final, on completion of all building work.[3]
- **Inspections at other stages –** These are determined by the RBS pursuant to the building surveyor's general powers under Section 35 of the Act, and prescribed as a condition of the building permit.
- **Inspections at other times –** The RBS's general powers (Section 35) also empower them to cause building work "*to be inspected at any time*".

While the obligation to inspect may be triggered by the completion of a mandatory notification stage (or other stage or time prescribed by the RBS), the inspection is not limited to the subject of the inspection stage (e.g. footings; framework). Rather, the obligation to inspect applies to all building work completed or in progress at that time.

2.4.1.2. Must mandatory inspections be conducted in person, onsite?

Inspections at mandatory notification stages must be conducted "*in person*" (Section 34). This is the only reference to "*in person*" in the Building Act or Building Regulations. The

[3] Regulation 170 provides that in the case of the construction of a new building or alterations to an existing building, the RBS may omit a mandatory notification stage if they are not relevant to the building work.

express reference to "*in person*" in Section 34 – and its absence in all other provisions – means other inspections do not have to be conducted "*in person*". Moreover, "*in person*" requires the person to be onsite. While there is no judicial consideration of the term "*in person*" in the context of its use in the Building Act, there has been in other contexts, most notably with respect to court appearances during COVID-19 where courts drew a distinction between remote hearings conducted electronically via some audio-visual format and in-person hearings where the persons are physically present in the court.[4] This interpretation also is consistent with the statutory intention of the 2017 amendments that introduced the requirement.[5] These amendments were designed to significantly strengthen the Building Act's regulatory oversight and enforcement mechanisms. Central to this was increased rigour and inspection around building work, and reinforcing the primacy and non-delegable role and responsibilities of the RBS.

2.4.1.3. Who may inspect?

Section 35B of the Building Act provides that the building work must be inspected by the RBS or their delegate. Their delegate can be:

> (a) a person registered as a building surveyor or building inspector under Part 11 of the Building Act and whose registration authorises the carrying out of that inspection, or
>
> (b) in the case of a prescribed class of inspection, a person who is prescribed to carry out that type of inspection (which could be a civil engineer; mechanical engineer; electrical engineer; or fire safety engineer).

The RBS is the person appointed by the owner to assess, grant (or refuse), and ensure compliance with, the building permit, and can be either a municipal building surveyor (employed by a local council) or a private building surveyor. Building surveyors must be registered with the VBA and, to be eligible for registration, must satisfy skill, competency and probity requirements, and hold professional indemnity insurance.

Building Practice Note MI-01 states that where the RBS causes a person specified in Section 35B to inspect the work on their behalf, the RBS remains responsible for the proper inspection of the work, and that the RBS should:

- satisfy themselves that the person holds relevant and adequate experience to undertake the inspection
- satisfy themselves that the person will undertake a thorough inspection to check that the building work complies with the Building Act, Building Regulations and building permit
- put in place procedures to oversee the work of the person to ensure that inspections are being carried out appropriately
- put in place procedures to ensure that the required record of the inspection is made and given to them promptly
- put in place procedures to ensure that the person notifies them promptly about any building work that does not comply with the Building Act, Building Regulations or building permit.

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[4] See e.g. *Southernwood v Brambles (No. 2)* [2022] FCA 973 at [40] per Murphy J*ASIC v Wilson (No 2)* [2021] FCA 808 at [35] per Jackson J; *Palmer v McGowan (No 2)* [2022] FCA 32 at [43], [45] – [47] per Lee J; *Auken Animal Husbandry Pty Ltd v 3rd Solution Investment Pty Ltd* [2020] FCA 1153 at [41] per Stewart J; *Long Forest Estate Pty Ltd v Singh* [2020] VSC 604 at [23] per Dixon J.

[5] *Building Amendment (Enforcement and Other Measures) Act 2017* (Vic).

This is consistent with the case law that makes clear that notwithstanding any delegation, "*the primary responsibility for inspection remains with the surveyor*" and "*it is not the duty to inspect, merely the act of inspection, which the surveyor is permitted to delegate*".[6] And while Section 128 of the Building Act provides that the RBS "*is not liable for anything done or omitted to be done in good faith in reliance on a certificate given by a registered building practitioner*", the courts have made clear the Section 128 statutory immunity is not available in circumstances where the RBS adopts "*an entirely 'hands off' approach to his (sic) … statutory and contractual obligations*"; "*blind disinterest is not good faith.*"[7]

2.4.1.4. How must mandatory inspections be carried out?

As noted above, Section 34 of the Building Act provides that mandatory notification stages must be inspected "*in person*". This is the only inspection the legislation requires to be conducted "*in person*". The legislation also arms the RBS and their delegates with entry and other powers to conduct inspections. Section 228D deals specifically with power of entry for inspections required or authorised by the Building Act or Building Regulations. Relevantly, Section 228D(6) provides:

> An authorised person[8] who exercises a power of entry of a building or land under this section may—
>
> (a) inspect the building or land and any thing on the building or land
>
> (ab) for the purposes of an inspection under paragraph (a), cause any building work (including any building product or material) to be demolished, opened or cut into or tested if reasonably required to facilitate the inspection
>
> (b) take photographs (including video recordings) or make sketches of the building or land or the building work or plumbing work concerned, and
>
> (c) to the extent that it is reasonably necessary to determine compliance with this Act or the regulations, require a person to produce documents to the authorised person relating to building work or plumbing work or the work of a building practitioner or a plumber.

Building Practice Note MI-01 states the RBS cannot conduct the mandatory inspection relying only on photographs, drone, video, declarations, or reports provided by a person who is not a registered building surveyor, inspector, or a prescribed person under Section 35B of the Act.[9]

2.4.1.5. Records and reporting

Record of inspection of building work

Section 35A of the Building Act provides that on completion of an inspection under Section 34 or 35, the RBS must ensure that a record of the inspection containing the prescribed information is made, and that it is made available on request to the VBA (among other prescribed persons).

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[6] Toomey v Scolaro's Concrete Constructions Pty Ltd (2001) 2 VSC 279 [236], [296].
[7] Toomey v Scolaro's Concrete Constructions Pty Ltd (2001) 2 VSC 279 [283] – [284].
[8] Section 228(1) defines an "authorised person" for the purposes of s 228D to mean any of the following persons: (a) a relevant building surveyor (or a person validly authorised by a relevant building surveyor); and (b) the chief officer (or a person validly authorised by the chief officer).

[9] Victorian Building Authority, Building Practice Note MI-01: Mandatory notification stages and inspection of building work. 2021.

Regulation 173 prescribes the information to be contained in the report, namely:

(a) the date and time of the inspection

(b) the purpose of the inspection

(c) the building permit number of the permit relating to the building work

(d) the address of the building or land on which the building work is being carried out

(e) the name and registration number of the registered building practitioner who carried out the inspection

(f) the stage of the building work inspected (if applicable), and

(g) the outcome of the inspection.

Relevantly, the report does not have to include the notes taken by the person conducting the inspection, or any photographs, sketches, or video, audio or audio-visual recording employed in the course of the inspection.

Reporting to the VBA

The Building Regulations impose reporting requirements on building surveyors. Amongst these requirements include an obligation to give to the VBA within 7 days after the end of each month, details of any mandatory notification stage inspections of building work relating to a building permit issued by the building surveyor.[10]

2.4.2. Compliance and assurance inspections

Compliance and assurance inspections are inspections expressly required or authorised by the Act to monitor, determine and, if necessary, enforce compliance with statutory requirements and to assure the safety of buildings and construction work. See for example:

- Sections 221ZP that provides for a person authorised by the VBA to inspect sanitary drains, associated gullies, and related work, and
- Section 221ZZZD that requires the VBA to arrange the inspection of any plumbing work, sanitary drain, or appliance or fixture that uses gas or water, brought to its attention by a gas company or water authority that believes the work, drain, appliance or fixture does not comply with the plumbing laws, is a real threat to health and safety, or is suffering from the infiltration of ground or storm water.

These inspections variably can be carried out by a VBA inspector, a municipal building surveyor (MBS) (or a person validly authorised by a municipal building surveyor), a compliance auditor or plumbing inspector appointed under Part 12A of the Building Act, and persons authorised by Energy Safe Victoria, the Fire Rescue Commissioner and the Chief Officer of the Country Fire Authority.

The manner of these inspections is governed by Part 13, Division 2 – Information gathering and entry powers. Section 228D (discussed above) applies to inspections authorised by the Act or regulations which includes some inspections undertaken for compliance and assurance purposes by, for example, the Chief Officer of Fire Rescue. It provides that the authorised person may take photographs (including video recordings) of the building or land or the building work.

The more relevant provision, however, is Section 228E. It contains an entry power for the purposes of monitoring for and determining whether the Building Act and Building Regulations are being complied with or for assisting in the enforcement of the safety of

[10] Building Regulations, Reg 47(2)(b) and 47(4)(b).

buildings and of building and plumbing standards under the Building Act.[11] Relevantly, Section 228E(3) states that an authorised person may enter and search a building or land under section 228E with the assistance of any person necessary to provide technical assistance to the authorised person; and Section 228E(4)(f) specifies that an authorised person who enters and searches any building or land under section 228E may "*make any still or moving image, audio recording or audiovisual recording*".

As noted above, there is no requirement for these inspections to be carried out "*in person*". Importantly, the VBA has issued a *Guideline for the Conduct of Non-mandatory Remote Video Inspections (RVIs)*[12] that applies to non-mandatory inspections, which it defines as inspections of building and plumbing work for the purposes of carrying out functions that support any or all of the following:

- monitoring programs carried out by relevant authorities
- National Construction Code and referenced standards
- Domestic Building Contracts Act 1995 (Vic)
- contractual requirements
- consulting services
- general project management and monitoring functions.

2.5. Regulatory reform context

2.5.1. Victoria's 2017 amendment to the Building Act and Building Regulations

As noted in Section 2.1.2 above, the Building Act was amended in 2017 to significantly strengthen its regulatory oversight and enforcement mechanisms. In response to concerns that some building surveyors may be sending unqualified people to check building work[13], the amendments:

- introduced the "*in person*" requirement for mandatory notification stage inspections
- specified the people to whom the RBS might delegate the inspection of building works (being: (a) a person registered as a building surveyor or building inspector under the Act and whose registration authorises the carrying out of that inspection; or (b) in the case of a prescribed class of inspection, a person who is prescribed to carry out that type of inspection (being a civil engineer; mechanical engineer; electrical engineer; or fire safety engineer))
- facilitated the proactive monitoring of compliance, and equipped regulators with appropriate entry and information gathering powers.

2.5.2. The Building Confidence Report (February 2018)

In the same year the Building Act was amended (2017), the BMF commissioned Professor Peter Shergold and Ms Bronwyn Weir to undertake an external assessment of the compliance and enforcement systems for the building industry across Australia. The BCR identified numerous shortcomings in the implementation of the NCC, and made 24 recommendations designed to enhance public trust in, and establish a national best practice

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[11] Section 228(2) defines an "authorised person" for the purposes of s 228E to mean any of the following persons: (a) a VBA inspector; (b) a municipal building surveyor (or a person validly authorised by a municipal building surveyor); (c) a person authorised by Energy Safe Victoria to exercise in relation to Part 12A or the regulations made under that Part; (d) a compliance auditor appointed under Part 12A; and (e) a plumbing inspector appointed under Part 12A.

[12] Victorian Building Authority, Guideline for the Conduct of Non-mandatory Remote Video Inspections (RVIs). 2020.

[13] Victoria, Parliamentary Debates, Second Reading Speech – Building Amendment (Enforcement and Other Measures) Bill 2016, Legislative Assembly, 7 December 2016, 4825 (Mr Richard Wynne, Minister for Planning).

model for, the effective implementation of building and construction standards, thereby strengthening the effective implementation of the NCC.[1]

Of direct relevance to our project are their observations and recommendations with respect to the mandatory building inspection process. They observed there are significant jurisdictional differences in the inspection process (e.g. with respect to the number of inspections; the notification stages; who should carry out the inspections; and how). In response, the BCR recommended:

> "*Recommendation 18: That each jurisdiction requires onsite inspections of building work at identified notification stages.*" (emphasis added).

They also recommended that onsite inspections should be carried out by, or be under the supervision of, registered building surveyors, inspectors and engineers for prescribed types of work. Relevantly for our purposes, the recommendation contains no reference to remote inspections.

2.5.3. The Australian Building Codes Board Model Guidance for Mandatory Inspections

In response to the BCR recommendations, the BMF established the Building Confidence Report Implementation Team within the Office of the Australian Building Codes Board (ABCB) to work with governments and industry to establish national best-practice models. With respect to Recommendation 18, model guidance for mandatory inspections was prepared.[2] This guidance represents a nationally agreed response to the recommendation. The guidance establishes a framework of eight principles that address matters raised in the BCR and, importantly, were identified through public consultation. Of relevance is Principle 6. It provides that:

> "*That mandatory inspections can be conducted virtually as an alternative to onsite inspections.*"[14]

On face value, this is inconsistent with the recommendation of the BCR that the guidelines purport to give effect. As will be recalled, the BCR expressly required *onsite* inspections of building work and did not mention virtual or remote inspections. Virtual or remote inspections also were not discussed in the ABCB's December 2020 discussion paper that preceded the model guidance.[15] However, a review of submissions made in response to the discussion paper reveals that several submissions called on the ABCB to provide flexibility for mandatory inspections to be conducted virtually or remotely.

The model guidance states that while mandatory inspections should generally be conducted in person and onsite, there are circumstances where alternative approaches for mandatory inspections should be supported. It gives as examples when access to a building site may be difficult (e.g. in remote locations) or when the statutory building surveyor may not be able to get onsite in a timely manner. Examples of alternatives to onsite inspections given in the guidance include video inspections, photographic evidence, and drone inspection technology.

Importantly, the model guidance recommends that the legislative framework provide for the following:

1. Mandatory inspections must be carried out by the statutory building surveyor or a practitioner carrying out the inspection on behalf of the statutory building surveyor, in person and onsite unless the statutory building surveyor agrees to the inspection being conducted virtually (remotely) and *where permitted by the regulator* (emphasis added).

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[14] The use by the ABCB of the terms 'virtual' and 'virtually' are synonymous with the use in this report of the terms 'remote' and remotely'.

[15] Australian Building Codes Board, Mandatory Inspections – A response to the Building Confidence Report: Discussion paper. 2020.

2. Where inspections are conducted virtually (remotely) on behalf of the statutory building surveyor, the statutory building surveyor must nominate a registered and competent practitioner to conduct the inspection (onsite) and the extent of the inspection must be overseen and controlled by the statutory building surveyor.
3. All data recorded during a virtual (remote) inspection must be stored and form part of the documentation lodged with the building regulator and provided to the building approval applicant (in accordance with Principle 7).

The guidance also goes on to state that where virtual (remote) inspections are permitted by the regulator, sufficient controls must be in place to ensure practitioners conducting inspections on behalf of the statutory building surveyor uphold their duty and ethical obligations; that virtual (remote) inspections do not compromise the quality of building outcomes; and that regular auditing needs to be in place to ensure that virtual (remote) inspections are of similar or better quality to in-person onsite inspections and to inform future use of technology for other inspections.

As noted above, the model guidance states that virtual (remote) inspections should only occur "*where permitted by the regulator*". This begs the question – when should the regulator permit a virtual (remote] inspection? We address this question in Section 6 below. Providing important context to the answers to this question (especially in Victoria) are the next developments.

2.5.4. Victoria's Building System Review

In November 2020, the Victorian Government established the Building Reform Expert Panel to review the building legislative and regulatory system and advise on changes necessary to ensure that Victoria's building regulatory system delivers safe, compliant, durable, affordable, and sustainable housing and buildings efficiently and effectively.[16] The review was a key recommendation of the Victorian Cladding Taskforce in its 2019 report to the Government.[17]

The Expert Panel has adopted a three-stage approach to its review:

- Stage One prioritises 'game changing' improvements to priority areas for reform, namely: practitioner registration; building approvals; regulatory oversight; and consumer protection.
- Stage Two will focus on statutory duties of care, dispute prevention and resolution, compliance, enforcement and discipline, insurance, new building technology and information, building maintenance, and complex and prefabricated plumbing.
- Stage Three will provide advice on the development of a new Building Act, including national harmonisation as appropriate, and changes to regulations and other legislation that impacts the building system.

In addition, the Expert Panel was requested in its Terms of Reference to advise the Minister for Planning on some early initiatives to improve the building system. One such recommendation was for the VBA to publish guidelines and inspection checklists for mandatory inspections.

The Expert Panel's Stage One Report was released in early 2023.[18] The Report contains 16 recommendations. Legislation to give effect to its first tranche of recommendations was

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[16] Victorian Government, Building system review https://www.vic.gov.au/building-system-review
[17] Victorian Government Department of Environment, Land, Water and Planning, Victorian Cladding Taskforce Report from the Co-Chairs. 2019.
[18] Expert Panel on Building Reform, Stage One: Final report to Government (2023) - https://www.vic.gov.au/sites/default/files/2023-03/Expert-Panel%E2%80%99s-Comprehensive-Review-of-Victoria%E2%80%99s-Building-System-Stage-One-Report-to-Government.pdf

introduced into the Victorian Parliament in March 2023, and has passed and received Royal assent in June 2023.[19] Neither the Stage One Report nor the legislation refers to or addresses the use of remote, virtual, or assistant-based inspections. However, the Report's discussion and recommendations provide important context for the potential authorisation and deployment of such inspections. The Report advocates for strengthening regulatory oversight, enabling a risk-based approach to compliance and enforcement, increasing accountability and competency of practitioners, and placing safety and consumers at the heart of the system. In particular, and relevantly, it calls for:

- a modern, responsive regulatory regime tailored to the underlying complexity of different types of buildings that will enable continuous improvement in practice and keep pace with technological change
- improvements in data collection, information sharing and the quality of documentation across the building lifecycle
- reforms to boost the number of building surveyors in the system including by creating new pathways into the profession
- aligning its recommendations with the ABCB's model guidance to support a regulatory approach that is nationally consistent.

The Expert Panel has not released a discussion paper with respect to Stage Two. It is expected to be released later this year (2023) and will address new building technology and information (among other things).

2.5.5. Victorian Government Frameworks for Remote Inspections

The onset of COVID and the restrictions on movement imposed to control its spread led regulators to investigate COVID safe mechanisms by which they could discharge their regulatory functions. In August 2020, the VBA issued its *Guideline for the Conduct of Non-mandatory Remote Video Inspections (RVIs)* that, as its title makes clear, applies to non-mandatory inspections only.[12] It outlines principles and considerations for establishing an RVI procedure, and provides that RVIs may be conducted where suitable technology to conduct the RVI is readily available and suitable conditions prevail, such that compliance with relevant legislation is assured, public safety risks are mitigated and quality, safe and compliant outcomes continue to be achieved. The Guideline has been used within the VBA to support its Plumbing Audit Program.

Also relevant is the Victorian Department of Treasury and Finance (DTF) June 2022 draft practice note on virtual and remote inspections.[20] It sets out key principles to help determine the appropriateness of pivoting to virtual and remote inspections, a framework for considering virtual and remote inspections, and key questions to consider when considering their use. Importantly, it makes clear that expanding the use of virtual and remote inspection tools aligns with Better Regulation Victoria's *Towards Better Practice* principles, most notably Principle 3.3 that encourages using innovative new approaches and tools to achieve regulatory outcomes.[21]

2.5.6. Agile Regulation and RegTech

Another contextual element to consider is the goal of government services (including regulation) being delivered more efficiently and effectively. The legislative change process can be relatively slow and cumbersome. Regulatory systems can struggle to keep pace with industry and technological innovation and changing consumer preferences and industry practices. There are numerous examples of regulation not adapting and adjusting to new technologies in an effective and timely manner (something the Expert Panel's Stage One

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[19] *Building Legislation Amendment Act 2023* (Vic.)
[20] Victorian Government, Department of Treasury and Finance, Draft Practice Note. 2022.
[21] Better Regulation Victoria, Towards Better Practice (Victorian Government, 2022).

Report identified to be the case with Victoria's building regulatory system).[22] For this reason, regulatory designers are increasingly looking to draft regulations in a manner that allows implementing agencies more flexibility to respond to a rapidly changing regulatory environment. The terms that are applied to such regulatory techniques are 'agile' or 'future-proofing' regulation.[23]

These techniques involve giving regulatory authorities the power to modulate their responses or even the regulatory regime itself by, for example:

- providing for the making of subordinate legislation in response to a changing landscape[24]
- use of technology neutral outcome orientated standards that define the outcome to be achieved and not how it is to be achieved, thereby allowing for advances in technology to be embraced[25]
- broad inclusive definitions capable of applying to future scenarios.

One area where the need for agility is increasingly apparent is in RegTech (regulatory technology). The term RegTech has its origins in the use by the private sector (originally banking and finance) of information technology and digital tools to reduce the compliance costs of complying with government regulations. Over time, however, the term's use has expanded to include the use by the government of technology to improve regulatory enforcement. RegTech today promises improved regulatory enforcement and compliance at less cost for both duty-holders and regulators.[26] The technology that enables remote inspections – and can assist and enhance building inspections more generally – is a form of RegTech.

Deployed well, agile or future-proofing regulation allows for regulation to be implemented and enforced with flexibility in response to changes in the environment while remaining true to its original objective. However, care also must be taken not to adopt an all or nothing approach. Agile regulation does not have to be to the exclusion of traditional regulatory techniques. Often a balance is needed; traditional regulatory techniques may still be required. That is, in-person manual inspections may be needed to complement the use of technology enhanced and remote inspections.

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[22] Expert Panel on Building Reform, Stage One: Final report to Government (2023) - https://www.vic.gov.au/sites/default/files/2023-03/Expert-Panel%E2%80%99s-Comprehensive-Review-of-Victoria%E2%80%99s-Building-System-Stage-One-Report-to-Government.pdf pp. 6-7.
[23] Re Agile regulation, see: World Economic Forum, Agile Regulation for the Fourth Industrial Revolution A Toolkit for Regulators (December 2020); Organisation for Economic Development and Cooperation, Recommendation of the Council for Agile Regulatory Governance to Harness Innovation (OECD/LEGAL/0464; adopted on: 06/10/2021); National Academy of Public Administration and Project Management Institute, Agile Regulation: Gateway to the Future June 2022). Re Future-proofing regulation, see: Sofia Ranchordás and Mattis van't Schip, 'Future-Proofing Legislation for the Digital Age' in Sofia Ranchordás and Yaniv Roznai (eds), Time, Law, and Change: An Interdisciplinary Study (Hart Publishing 2020); European Economic and Social Committee, Future Proof Legislation (SC/045, 2016); Pablo Ibáñez Colomo, Future-Proof Regulation against the Test of Time: The Evolution of European Telecommunications Regulation, Oxford Journal of Legal Studies, Volume 42, Issue 4, Winter 2022, pages 1170–1194, https://doi.org/10.1093/ojls/gqac016.
[24] Pablo Ibáñez Colomo, Future-Proof Regulation against the Test of Time: The Evolution of European Telecommunications Regulation, Oxford Journal of Legal Studies, Volume 42, Issue 4, Winter 2022, pages 1170–1194, https://doi.org/10.1093/ojls/gqac016.
[25] Eric L Windholz, Governing through Regulation: Public Policy, Regulation and the Law (Routledge, 2018) 157-159.
[26] Mitzi Bolton & Michael Mintrom (2023) RegTech and creating public value: opportunities and challenges, Policy Design and Practice, DOI: 10.1080/25741292.2023.2213059.

3. EXISTING REMOTE INSPECTION PRACTICES

3.1. Overview

Recent years have witnessed an increasing popularity and rapid adoption of remote inspections of building work. This is driven not only by advanced tools but also by the growing need for efficient and more adaptable ways to oversee construction work. As this practice continues to gather momentum, governmental bodies and professional associations have recognised the need to establish comprehensive guidelines that can streamline and standardise the integration of remote inspection methodologies. This section of the report embarks on a comprehensive exploration of the current landscape of remote inspection practices within the building industry and draws insightful parallels from analogous sectors.

3.2. Remote video inspection (RVI) for building work

A remote video inspection (RVI) is defined as an inspection of building work during construction that is conducted by a registered building surveyor or building inspector from a remote location (without attending the site physically) using real-time/live video call applications (e.g. Zoom, Teams) or specialised applications that are capable of providing additional functions such as geolocation and on-screen annotation (e.g. Zyte, Artisan). Several countries have begun incorporating such video-based technology into the inspection of building work. Their initiatives have demonstrated the potential for such technology to increase the overall effectiveness of inspections. These countries have each drafted their own RVI guidelines. These guidelines provide insight into the local conditions; they can shed light on the future benefits, limitations, and risks of using this technology for remote inspections of building work.

The following sections provide an overview of the guidelines that are currently in place within the United States, United Kingdom, Japan, and Korea, with respect to four key considerations: verification of inspection site, timing and processes of conducting RVIs, and personnel requirements. Table 3.1 lists the name and issued date for each guideline.

Table 3.1: Overview of international RVI guidelines

Country/Region	Reference Guideline	Date of Issue
United States (US)	Conducting Remote Video Inspections[27]	August 2018
	Guidance for Remote Video Inspection (RVI)[28]	Unknown
United Kingdom (UK)	Coronavirus (COVID-19) letter from the planning minister about guidance on the verification of building work[29]	May 2020
Korea (KR)	Remote inspection standard - KFS 1120 - Standard for remote inspections[30]	November 2021
Japan (JP)	Completion inspection based on the Building Standards Act: Related to the remote implementation of witnessing using the pointer[31]	May 2022

Verification of inspection site

RVIs are commonly conducted at job sites similar to those for traditional onsite inspections, with a focus on small-scale residential subdivisions or residences. To ensure a successful RVI, the guidelines emphasise the importance of verifying the correct building and proper worksite for inspection. The US guidelines outline three methods for building verification: (1) beginning the RVI on the exterior of the building and walking to the location of the required inspection, (2) showing the address marking if the inspection required building has an identifiable address, or (3) using a mapping tool, as long as it can be conducted on a live video stream. Further confirmation of the adequate worksite can be achieved by starting the inspection from a recognisable spot inside the structure and moving on to the proper position. The US guideline also highlights that verifying the inspection location is the responsibility of both the permit holder and the remote inspector.

Timing of conducting RVIs

The guidelines vary in their recommended timing for the use of RVIs. For instance, the JP guideline generally regards RVI as a completion inspection. The US and UK guidelines, however, each recommend that most remote inspections occur during the building process. The K.R. guideline outlines two levels of RVI (levels 1 and 2) for different purposes and stages. Level 1 RVI is a general remote inspection, conducted soon after building completion; level 2 RVI is an optional re-inspection. Level 2 only takes place if the building fails to pass level 1. Table 3.2 provides further information about the two RVI levels. The guidelines do not specify a fixed time for RVI, instead suggesting that building owners, inspectors, and other relevant parties should discuss and agree on the RVI schedule beforehand. The lack of fixed requirements may raise administrative issues, leading to a potential release of a formal policy to clarify RVI schedules and corresponding types.

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[27] NFPA, Conducting remote video inspections. 2018. Available at: https://www.nfpa.org/assets/files/AboutTheCodes/915/WhitePaperRVI.pdf
[28] NFPA, Guidance for Remote Video Inspection (RVI). 2020. Available at: https://www.nfpa.org/-/media/Files/Code-or-topic-fact-sheets/RVIFactSheet.pdf.
[29] Ministry of Land, Infrastructure, Transport and Tourism, Operational Guidelines for the Remote Inspection of Completion Inspections Based on the Building Standard Law Using Digital Technology. 2022.
[30] Korea Fire Safety Standards (2021) KFS 1120 - Standard for Remote Inspections. Available at: https://kfs.kfpa.or.kr/bbs/board.php?bo_table=kfs&wr_id=99.
[31] Japanese Ministry of Land and Infrastructure, Operational Guidelines for Remote Inspection of Building Works, 2022. https://www.mlit.go.jp/jutakukentiku/build/content/001482718.pdf

The items to be inspected through RVI are dependent on the worksite and the local standards for in-person inspections; this may involve dimensions, spacing, the number of specific items, and more. The US guidelines emphasise the importance of careful planning and obtaining agreement from all relevant authorities before conducting RVI. The plan should specify the inspection tasks and corresponding regulations as references to ensure consistency throughout the RVI process and final results.

Processes of conducting RVIs

The general process for conducting RVI typically involves the following steps:

1. Obtain approval from the relevant authority to conduct RVI in the target building.
2. Ensure that the remote inspector(s) and other onsite staff hold valid permits.
3. Specify the inspection building and RVI worksite(s).
4. Schedule a specific date and time for the RVI.
5. Specify the inspection tasks, methods, and standards in advance to ensure consistency throughout the process and final results.
6. Pay the inspection fees based on the cost of services provided.
7. Verify the inspection location before starting the RVI.
8. Check the internet connection and other necessary technology requirements.
9. Ensure the corresponding environment meets specific requirements for the RVI.
10. Process the RVI in accordance with local regulatory/guidelines.
11. Record the RVI results and issue relevant documents to related persons/authorities as needed.
12. Maintain the records according to specific requirements.

Personnel requirements

As with in-person inspections, all personnel in charge of remote video inspections should be qualified. Based on the general inspection process outlined in these guidelines, the key personnel in charge of the corresponding task(s) are summarised in Table 3.2. It is important to note that these recommendations involve at least two types of individuals for the inspection process: the onsite inspecting staff and the remote inspecting officer (also known as verifier or inspector). Depending on the specific circumstance, the onsite staff could be the general contractor for the overall structure, the subcontractor who installed the particular system, the building owner, or an approved third party. In addition, the remote inspector should have a valid professional license to verify whether each inspected item meets the requirements. Interestingly, the JP guideline highlights the need for an experienced assistant onsite who can help to hold the phone/tablet/camera when the remote inspector is viewing, evaluating, or moving around for inspection, as shown in Figure 3.1.

Table 3.2: RVI personnel in the guidelines

<table>
<tr><th rowspan="2" colspan="2">Country</th><th colspan="3">Personnel</th></tr>
<tr><th>Inspection guide and material preparation</th><th>Inspection</th><th>Inspection instruction and approval</th></tr>
<tr><td colspan="2">US</td><td rowspan="5">The building owner(s)
Or the person authorised by the building owner(s)</td><td>The onsite inspecting staff.
The remote inspecting officer(s).
The permit holder/jurisdictional staff, if needed to operate camera/ Unmanned Aerial Vehicles (UAVs).</td><td>Authority having jurisdiction (AHJ)</td></tr>
<tr><td colspan="2">UK</td><td>The onsite inspecting staff.
The remote inspecting officer(s)/verifier.</td><td>The remote inspecting officer(s)/verifier</td></tr>
<tr><td rowspan="2">KR</td><td>Level 1</td><td>The RVI inspector</td><td>The remote inspection approver</td></tr>
<tr><td>Level 2</td><td>The building owner(s)</td><td>The remote inspection approver</td></tr>
<tr><td colspan="2">JP</td><td>The onsite inspector.
The onsite assistant.
The supervisor on the Contractor/Project Manager side (remaining remote in the office), if needed to participate.</td><td>The person in charge of the inspection site's result</td></tr>
</table>

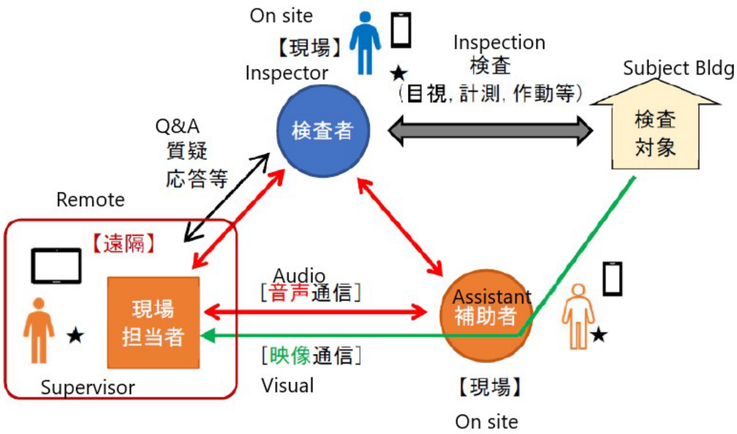

Figure 3.1: Relationship and communication between the onsite inspector, onsite assistant, and remote supervisor as per the JP guideline[31]

3.3. Remote inspection practices in other industries

3.3.1. Shipping industry – ABS issued guidance notes on "The Use of Remote Inspection Technologies (RITs)"

The shipping industry and the building industry share striking similarities in their structures, materials, functionalities, and production methods. Similar to building architects and engineers, naval professionals also focus on the arrangement of spaces, mechanical properties of structures, and the design of piping and plumbing fixtures.[32] Additionally, shipbuilding and construction are primarily local and highly volatile[33], with similar requirements for material logistics, information exchanges, and production workflows.[34] These similarities suggest shared inspection focuses (e.g. structural defects, material specifications, and compliance with design models), and common inspection processes, including stages for initiating inspections. This section will review the latest guidance notes for remote inspection in the shipping industry to explore the digital technologies used to inspect marine vessels/offshore units and their regulation.

In May of 2022, the American Bureau of Shipping (ABS) issued guidance notes on "*The Use of Remote Inspection Technologies (RITs)*". The guidance notes direct toward what is best practice for surveys using RITs to collect digital data (e.g. photos, videos, and LiDAR). Specifically, the use of RITs to collect from marine and offshore structures with remote inspection vehicles (RIVs). RIVs include such technologies as Unmanned Aerial Vehicles (UAVs), Remotely Operated Underwater Vehicles (ROVs), and robotic crawlers/arms.[35] The notes define the term RITs as "*techniques performed in the presence of the surveyors onsite and directed by the attending surveyor during surveys and when approved by flag State, statutory activities*". This distinguishes it from Remote Survey (RS), which is for non-attended verification of selected surveys. In this case, RITs are considered as an alternative way of accessing the marine and offshore structures, to conventional physical assessing methods. Physical assessing methods may involve, but are not limited to permanent accesses, staging, scaffoldings, ladders, and ropes. In contrast to these conventional methods, RITs have several potential benefits. They may reduce safety risks to surveyors, facilitate a more effective and efficient survey, and minimise operational intrusiveness.

The notes provide recommendations and guidance from three perspectives: (1) the scope, roles and responsibilities for RIT applications, (2) RIT service supplier selection, and (3) the survey/inspection process.

The scope, roles, and responsibilities for RIT applications

The notes provide seven examples where RITs can be utilised to aid in inspection-related activities. These include work at heights, underwater inspections, confined space entry, preliminary condition assessments prior to inspectors entering structures, monitoring known conditions assessments (such as periodically monitoring temporary repairs in hard-to-reach areas or reporting damages with photographic evidence), damage assessment for rapid responses in case of collisions, grounding of vessels or structural failures, and data collection for 3D modelling purposes.

ABS-certified service suppliers can offer RIT services for these scenarios, and the owner/operator can choose a supplier to help develop an inspection and operation plan, assess risks, and program RIT operations. Once approved by ABS, the supplier acquires digital data supervised by an ABS surveyor or per the Survey Planning Documents. Inspection results are evaluated by ABS, and data acquisition limitations are noted. Owners/operators may also perform self-inspection for periodic surveys, drydock activities, maintenance, and emergencies, with qualified personnel conducting inspections.

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[32] Ferraris S., L.M. Volpone, Aluminum alloys in third millennium shipbuilding: materials, technologies, perspectives, 5th Int. Forum Alum. Ships. 2005.
[33] Pero M., M. Stößlein, R. Cigolini, Linking product modularity to supply chain integration in the construction and shipbuilding industries, Int. J. Prod. Econ. 170. 2015. https://doi.org/10.1016/j.ijpe.2015.05.011.
[34] Boton C., L. Rivest, D. Forgues, J.R. Jupp, Comparison of shipbuilding and construction industries from the product structure standpoint, Int. J. Prod. Lifecycle Manag. 11. 2018. https://doi.org/10.1504/IJPLM.2018.094714.
[35] American Bureau of Shipping, Guidance Notes on the Use of Remote Inspection Technologies, 2022.

Additional scenarios enabled by developing RITs are not excluded. Pilot initiative proposals, including equipment, procedures, and survey scope, should be submitted to ABS before the survey to agree on arrangements. Blind tests should be conducted between RITs and traditional surveys to validate results, and ABS Surveyors should review and evaluate the outcomes for satisfaction. If RIT results are equivalent to traditional survey results, any limitations or conditions supporting the RIT process must be clearly stated in the results.

Regulations and Guidance for RIT Service Suppliers and Selection

ABS Recognised Service Suppliers are certified entities that provide services for equipment manufacturers, shipyards, asset owners, or other clients during classification/statutory surveys. The inspection results provide supporting information for classification and statutory survey decisions. ABS regulates these service suppliers to manage the safety and quality of RIT services. Specifically, the suppliers' certifications are renewed every three years to assess their Quality Management Systems (QMS) and Safety Management Systems (SMS).

Furthermore, the guidance notes suggest to the owner/operator a series of factors for service supplier selection. These suggestions aim to ensure the rigour of surveys. They help ensure the rigour of surveys that relate to equipment factors (equipment safety, operability, acquisition/review/security of RIT data, battery/tether handling, maintenance), personnel factors (safety awareness, supervisor proficiency, operator proficiency, inspection knowledge, fatigue management), and documentation factors (statutory and regulatory certificates, equipment registry, training/retraining record, operation logbook, operation manual, safety assessment plan).

Guidance on the survey/inspection process

The ABS offers guidance on the inspection process when employing RITs. It noted, first, that there are several circumstances in which using RITs as the only means of inspection is inappropriate; additional inspections with other techniques are necessary in such cases. These include cases where damages or deterioration requiring immediate attention are revealed; where data from RITs cannot generate meaningful information for examinations (e.g. condition of tanks); and where the inspection area is not clean. When RITs can be used as the only means of inspection, several operational limitations may degrade the quality of inspection, requiring a meticulous plan for operations or even the adaptation of technology. Table 3.3 lists the operational limitations of UAVs, ROVs, Robotic Crawlers, and Remote Cameras and Robotic Arms.

Table 3.3: Operational limitations of RITs

RITs	UAVs	ROVs	Robotic Crawlers	Remote Cameras and Robotic Arms
Operational environment	In air	Under water	In air and underwater	In air and underwater
Operational limitations	1. Thickness measurement on an inclined structure usually requires additional development of UAV. 2. High wind speed, insufficient ambient light, rain/snow, and shadows should be considered for external inspections. 3. The temperature should be noted for internal inspections to avoid overheating. 4. Acquire certification and permits for safety.	1. Ensure the in-water visibility. 2. Monitor the sea environment (e.g. waves) to avoid the loss of ROVs in external inspections. 3. Plan the return route of ROVs to avoid the entanglement of tethers.	1. Ensure the in-water visibility. 2. The height limit should consider the weight of tethers. 3. Crawlers have difficulty overcoming obstacles (typically 5cm). 4. Acquire certification and permits for safety.	1. Pendulum movement of a long robotic arm due to ship motions influences arm stability. 2. Ensure the visibility of shadowed/dirty areas and long-range areas. 3. Acquire certification and permits for safety.

To ensure a safe and effective inspection, it is crucial to develop a detailed operation plan that outlines specific scopes and addresses potential safety concerns – concerns such as dropped objects, collision risks, and lost link risks. Additionally, service suppliers must provide the ability to view data in real-time and through video replay or photo reviewing methods, enabling the attending surveyor to visually review the collected data and identify factors that may impact data quality.

Service suppliers are allowed to perform post-processing of the documented data, which may include advanced image processing for measuring anomalies (such as crack dimensions, coating breakdown areas, or space volumetric measurements), machine learning (ML) for identifying patterns related to cracks, fractures, or coating breakdown, data analytics for detecting anomaly trends and making predictions, and 3D model generation.

The generation of 3D models can be performed by both Light Detection and Ranging (LiDAR) and 360° photogrammetry. LiDAR needs to be logistically planned. This is so that the data size of the output files can be controlled by the equipment and software. The level of control will depend on the level of accuracy and detail sought. Photogrammetry with 360° imagery may yield greater visual quality compared with point cloud data, but it requires sufficient lighting. What becomes clear is that, with multiple factors influencing data quality, the attending ABS Surveyor becomes responsible for reviewing the data. The ABS Surveyor also becomes responsible for ensuring satisfactory dimensional accuracy and image resolution; at satisfactory levels, being able to extract meaningful information.

3.3.2. Oil and gas industry – "IOGP guidance for remote quality surveillance"

Oil and gas is another sector that shares some similarities with construction; it is leading the way in remote inspections. The oil and gas industry has rigorous quality assurance processes in place to ensure safe and reliable operations. These processes span the globe.

#33 – Evaluation of emerging technologies for remote inspections of building work

While quality inspections still take place onsite, technology solutions such as remote quality surveillance (RQS) are now available as a substitute for in-person quality surveillance. This provides the inspector with the option to remotely inspect critical elements and procedures in a safe, cost-effective, and sustainable manner, without the need to be physically present at the activity site. According to the Guidance for remote quality surveillance issued by the International Association of Oil and Gas Producers (IOGP)[36], remote quality surveillance might be considered for use when:

- companies wish to reduce their carbon footprint by minimising travel
- inspection activities are well understood, and straightforward in terms of observing
- the activities to be assessed are covered within the scope of the document
- travel to a supplier location is not practical (i.e. for safety reasons or travel restrictions)
- timing does not allow for in-person, onsite attendance
- the supplier has demonstrated its capabilities to facilitate remote quality surveillance
- to perform an RQS, a complete information and communication technology (ICT) process needs to be put in place. this consists of hardware, software, and connectivity.

This allows for clear and uninterrupted remote quality surveillance, for both the purchaser and supplier. The complete ICT process should meet the following functional requirements:

- the supplier personnel's freedom of movement should not be limited by the hardware; it should allow them, if necessary, to climb into/onto the equipment within the activity area
- the process should have the capacity to offer the remote observer a range of perspectives, from an overview of the activity area to small details in the view of the supplier's process operator, depending on the nature of the activities
- hardware and software should have a connection quality that allows the remote observer to have a real-time view of the activity area with minimal latency
- video quality should be such that the remote observer can make out small features, such as printed details on nameplate or welding quality details, and can see rapid changes, such as those occurring in bubble-testing or opening and closing of valves
- audio quality should be such that the supplier and remote observer can have a clear, uninterrupted two-way conversation over any noise that may be present in the activity area.

The remote quality inspection procedure begins with inspection planning. During this phase, all parties must review and agree upon RQS inspection points, video recording, sharing, and retention according to local regulations. The preparation phase follows, during which the supplier is expected to test the remote surveillance equipment to confirm the proper functionality of all components. In the execution phase, the supplier and purchaser's representative should ensure alignment of inspection scope, compliance with Job Safety Analysis (JSA) findings, usage of Personal Protective Equipment (PPE), and IP/confidentiality clauses and considerations. Prior to concluding the remote quality surveillance, the supplier leading the inspection should confirm that all activities have been completed to the satisfaction of all parties and agree on any follow-up actions. After the inspection, the supplier should provide access to or transmit all relevant documentation and, if required and agreed to, any additional material, to stakeholders within the mutually agreed timeframe. Additional material may include, as an example, photos or videos from the RQS session.

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[36] International Association of Oil & Gas Producers, Guidance for remote quality surveillance, 2022.

4. STAKEHOLDER PERSPECTIVES MAPPING

4.1. Overview

The practice of remote inspection involves a wide range of stakeholders, including policymakers, regulators, industry practitioners, and building owners. To understand the benefits and risks perceived by the stakeholders towards adopting remote video inspection (RVI)[37] in the inspection of building work, the research team conducted a series of stakeholder engagement activities, including semi-structured interviews with the government regulators, such as VBA and other relevant government agencies, as well as an online questionnaire survey and follow-up interviews directed towards industry practitioners (i.e. building surveyors, builders, and licensed plumbers). The results of the interviews and survey provide valuable insights into the motivating factors and obstacles associated with adopting RVI in the building industry. The following sections first explain the methods used for data collection and analysis and then present the findings from the interviews and questionnaire survey.

4.2. Data collection and analysis methods

The first phase of stakeholder perspective mapping sought to obtain insights from regulators who are well-versed in Victoria's building inspection context through semi-structured online interviews. Thirteen participants (eight from the VBA and five from four state government agencies) were recruited. The participants had diverse professional backgrounds, including responsibility for compliance and enforcement, data management, and complaint resolution, as well as policy and regulatory reform advisory. The interviews took place during November and December 2022, with each session lasting around 60 minutes. Prompted by the VBA's PAP[38], a compliance auditing program where RVI has been used for selected inspection tasks, interviewees shared their opinions on this approach with respect to the perceived benefits and risks this new practice brings. With participants' consent, interviews were either recorded and transcribed or documented through notes. The resulting transcriptions and notes formed a significant dataset totalling 60,532 words, establishing a strong basis for qualitative analysis. Using an inductive approach, the research team identified 85 themes (i.e. keywords) using NVivo, a qualitative analysis software. As patterns and connections emerged from the data, these sub-themes were grouped into 11 theme groups. These groups were further organised into two main clusters: "Benefits of RVI" and "Operational Challenges and Risks of RVI".

The second phase of stakeholder perspective mapping aimed to engage the practitioners and seek their perspective on using RVI for the inspection of building work. Based on the general themes identified from the regulator interview results, the research team created an online questionnaire survey that targeted active industry practitioners, including building surveyors, builders, and licensed plumbers. On 24 March 2023, invitations to participate in

[37] RVI is defined in this report as an inspection of building work during construction that is conducted by a registered building surveyor or building inspector from a remote location (without attending the site physically) using real-time/live video call applications (e.g. Zoom, Teams) or specialised applications that are capable of providing additional functions such as geolocation and on-screen annotation (e.g. Zyte, Artisan).

[38] PAP (Plumbing Auditing Programme): The VBA conducts risk-based compliance audits and below ground drainage inspections of plumbing work throughout Victoria. Compliance Auditors conduct onsite audits to sample performed plumbing work based on the lodgement of compliance certificates. The Auditor's role is to ensure that the plumbing work complies with all relevant plumbing laws and standards. The compliance certificates to be audited each month are selected using risk-based criteria. For more information: https://www.vba.vic.gov.au/plumbing/plumbing-audit-program

the survey were distributed to 2,200 practitioners who hold a current registration according to the VBA database. Upon the closure of the survey on 14 April 2023, the research team received 81 responses with a response rate of 3.7%. Practitioners who participated in the survey were given the opportunity to opt-in to a follow-up interview. Eight practitioners, including six building surveyors, one builder and one licensed plumber, participated in the follow-up interviews in July 2023. For the questionnaire survey, a representative statistical analysis was carried out to evaluate data distribution and identify prevailing trends. The practitioner interview results were analysed using NVivo to delve deeper into the two previously identified clusters (i.e. "Benefits of RVI" and "Operational Challenges and Risks of RVI").

4.3. Regulators interview result

This section presents the findings from the regulator interviews with respect to the perceived benefits, operational challenges, and risks of incorporating RVI as a part of the inspection practice.

4.3.1. Perceived benefits of RVI - regulator perspective

Increasing efficiency

The majority of interviewees acknowledged the efficiency gain presented by RVI. One VBA interviewee who has been actively involved in RVIs in PAP highlighted how RVI allowed for substantial time savings and as a result, enabled increased capacity for compliance monitoring, given that "*the conventional inspection method had created months of lags.*" These time savings are particularly significant for inspections on remote rural sites: "*We're dealing with as many as we can…, but if you're doing a bunch of visits, which are across the whole of Victoria, … it can take up an entire day just to go to one site.*" Broadly speaking, the time saved led to an expansion of the PAP's spatial coverage: "*It has enabled us to both maintain our spread of oversight from just beyond a metropolitan area to regional space, particularly in a lockdown environment where we couldn't travel … In regional areas of Victoria, where we don't have officers live in, our data, essentially, a heat map shows that it [RVI] is quite effective.*" Another key aspect highlighted in the conversations was cost reduction. These cost reductions were not only financial but also impacted the carbon footprint, potentially leading to efficient and sustainable utilisation of resources to better protect the community.

Mitigating shortage of building surveyors

With a boom of new construction on the horizon, interviewees expressed concerns over a potential shortage of building surveyors and building inspectors. This issue becomes even more critical given the predicted population growth and the consequent demand for housing. During the COVID-19 pandemic, RVI has been perceived as an effective return-to-work tool for inspectors whose capacities have been limited due to illness, as highlighted by a VBA interviewee. Moreover, RVI is anticipated to expand the pool of accessible building surveyors by enabling those with disabilities to conduct inspections remotely. In addition, RVI could provide a skill and experience development opportunity for those who are on the pathway to become building surveyors, by involving them as the onsite assistants in RVIs.

Improving inspector safety

Just under half of the interviewees recognised the safety advantages of RVI by protecting inspectors from onsite hazards, disputes, threats, and potential disease spread such as COVID-19. As a VBA interviewee stated: "*It potentially has safety benefits… So…it would be the builder, supervisor, contractor, etc… familiar with the site and then understand the site and the particular risks on that site versus a new person to the site coming in as an inspector and not necessarily being aware of the site conditions on that particular day.*" Moreover, RVI minimises unnecessary interactions between inspectors and onsite assistants, thus reducing the potential for physical confrontations and disease transmission. However, a VBA interviewee concedes that "*practitioners posing threats might be less likely to cooperate with remote technology*", and "*inspectors could still face verbal abuse*".

Improving record keeping

Nine out of thirteen interviewees suggested that RVI has elevated the quality of plumbing audits through comprehensive and efficient data management. For example, RVI allows for a complete and objective recording of inspection processes: "*If people are mindful that video evidence exists quite often they have much better recollection of events.*" Furthermore, RVI records could be easily shared among experts, fostering a multidisciplinary approach that can significantly improve inspection quality. It also provides access to an asset's historical data, helping pinpoint issues, thereby reducing repair costs and avoiding potential damage and loss. As such, some interviewees believe this could lead to lower insurance premiums.

4.3.2. Operational challenges and risks of RVI - regulator perspective

RVI competency and need for training

Six VBA interviewees revealed that, in PAP, considerable effort went into instructing the onsite assistant (i.e. plumbers) how to gather the necessary information to support remote inspectors' decision-making, particularly when adjusting camera angles and focus points during RVI. It is compounded by low video quality, the absence of measuring tools, and difficulties in referencing permit or certificate information. Eight out of all thirteen interviewees stressed the importance of training the onsite assistant on choosing photo angles, adjusting lighting, and familiarising with video conferencing functionalities. Meanwhile, remote inspectors also require training to provide clear and safe instructions to the onsite assistant, and make decisions based on the available information, particularly in potentially risky scenarios and challenging environments (e.g. low illumination).

Conflicts of interest and process governance

Eight interviewees raised concerns about the potential compromise of inspection rigour due to the physical absence of auditors during RVI-based PAP audits. Having the people whose work is being audited assist with the audit presents a potential conflict of interest. Having total control of the auditor's visual access to the site and the building/plumbing work, the onsite assistant could, intentionally or unintentionally, guide the auditor's vision selectively to their advantage. In response to these concerns, restricting RVI's scope to certain building elements or classes is a possible solution. For example, as a VBA interviewee pointed out: "*When we're looking at a hot water unit... that's a really good one... you can't hide from it.*" Another VBA interviewee added: "*We've limited ourselves to only particular classes of work because there wasn't confidence that we could draw the necessary compliant conclusions for some [complicated] classes.*" Beyond carefully delineating the scope of RVI, establishing protocols to confirm the inspection location at the start also serves as an important governance measure at the very beginning. This step provides an extra layer of verification to ensure the integrity of the inspection process: "*Well, it can also be the fact that they tried to show us a hot water unit, and we can't confirm the address. So, what we asked for the first part is to see the letterbox and the meter assembly.*"

Extra effort for site personnel

Four VBA interviewees believed that using RVI requires extra effort from site personnel, as they need to hold the camera and communicate with remote inspectors during the entire inspection compared to in-person inspections where they simply open the door/gate for the inspector. As such, one VBA interviewee suggested that RVI actually "*relies on the person on the other end being available.*"

Standardised and privacy-aware management of inspection data

Standardisation of inspection data was a key theme raised by six interviewees. The lack of a standardised data format could potentially lead to interoperability issues when sharing data between parties, and may create challenges in maintaining the long-term relevance of data. Other regulators suggested that necessary regulatory changes should facilitate more standardised, interlinking inspection processes. They argued that technology shouldn't exist in isolation but rather be harmoniously integrated with other systems and workflows.

In addition, privacy issues and the risk of information leakage were regarded as significant concerns. Both homeowners and practitioners were noted to have potential reservations about their personal spaces or images being captured, stored, and potentially exposed if managed improperly. Sensitivity towards privacy could vary depending on individual attitudes and the specific contexts of inspections. Closely linked to privacy is the issue of data security. The safety of captured and stored data is of paramount importance, which makes the selection of appropriate video conferencing tools and rigorous security protocols essential. This concern becomes especially pronounced when third-party technology providers are engaged in service management, resulting in intricate situations concerning data jurisdiction and the responsibility for ensuring data security.

Accountability of technology providers

As technology becomes an increasingly integral part of the inspection process, new challenges concerning data auditability and accountability surface. The potential involvement of technology providers in the inspection process was described by a VBA interviewee as "*adding another player*", which may complicate the matter of accountability. Due to the legal implications of compliance assurance inspections, the data acquired remotely in RVIs must be not only reliable but also capable of withstanding scrutiny and serving as a valid piece of evidence in case of disputes. As such, the veracity of the evidence, the means to validate it, and the platform used to store and manage it all come under scrutiny. Thus, the technology provider has to be tested, permitted, and certified to some extent and the liability of the technology provider needs to be defined.

Poor internet connectivity

Another concern raised by the interviewees is the impact of internet connectivity on the effectiveness of RVI. Notably, this issue becomes increasingly problematic in regional areas where poor internet connection is common. The fluidity of video conferencing can be hampered by weak internet connections, affecting the clarity of audio and visual communication between remote inspectors and the onsite assistant. As a result, the quality of inspection outcomes can be significantly degraded. One VBA interviewee illustrated this by explaining the increased difficulty experienced when conducting inspections of more than 15 items through a "*choppy video feed*". This suggests that beyond a certain threshold, the complications introduced by poor connectivity can seriously impede the inspection process.

Additional safety risks for onsite assistants

Four regulators expressed concerns about the additional safety risks posed to the onsite assistant during the execution of RVI. The primary concern centres around the risk of falls, especially if assistants were required to climb heights while holding a camera. A government interviewee surmised that the potential danger to the plumber might outweigh the safety benefits to the inspector: "*Asking the plumber to get on the roof with a phone was even more dangerous than the inspector going out, getting up the ladder and looking.*" Technology solutions such as hands-free devices could alleviate these safety hazards.

Furthermore, another risk pertains to conducting certain types of tests, which if performed incorrectly, could have grave consequences. A VBA interviewee stated: "*For example, with a heater. We can't guarantee that the plumbing practitioner is getting the carbon dioxide testing right. And it is death for someone if they get it wrong.*" However, the interviewee also reassured that preventive measures are in place, as the authority maintains an internal guideline detailing "*what we [VBA] can audit and what we can't audit*".

4.4. Practitioners survey and interview result

The results from the second phase of stakeholder engagement are presented in the following sections, starting with the demographic data of practitioners who participated in the survey and interview, followed by the analysis result of practitioners' perspectives on RVI.

4.4.1. Demographics of participating practitioners

The online questionnaire survey received a total of 81 responses, which consisted of 39 building surveyors, 26 builders and 16 licensed plumbers. Figure 4.1 presents the demographics of the survey respondents with respect to age, the role in the business they work in, the number of years they have been registered, company size, caseload in 2021-22, main operating area, and the building classes involved in their practices. As the sample size was relatively small, the insights summarised may not be representative of the entire practitioner population, and care should be taken when interpreting the results.

#33 – Evaluation of emerging technologies for remote inspections of building work

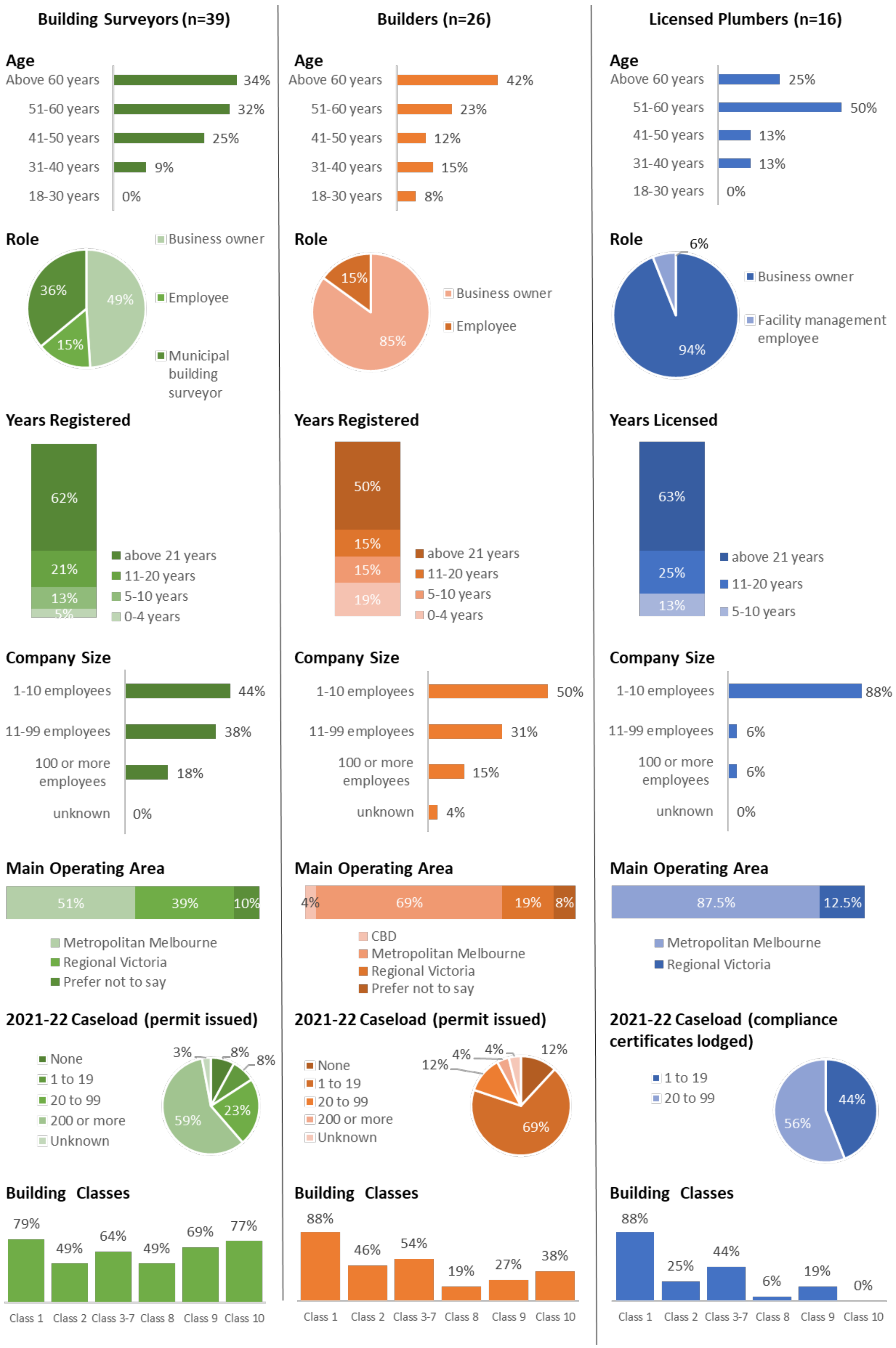

Figure 4.1: Demographics of survey respondents

4.4.2. General attitude towards adopting RVI in inspections

The survey results reveal that the respondents held a primarily favourable outlook towards using RVI. However, it is worth noting that the viewpoints expressed by various practitioner groups exhibit some degree of variation. This section shows the participants' agreement to the following five statements using a 5-point Likert scale.

- RVI of building work/plumbing work during construction will improve inspection efficiency;
- RVI of building/plumbing work during construction will improve the safety of inspection participants;
- RVI of building work/plumbing work during construction will positively impact the rigour of the inspection;
- The advantages of RVI of building work during construction outweigh the disadvantages; and
- RVI can replace in-person and onsite inspections of building work during construction.

48% of all respondents concurred that conducting RVI of building/plumbing work during construction holds promise to improve inspection efficiency (Figure 4.2). Among all respondents, builders were notably more optimistic with 61% in agreement, compared to 46% in building surveyors and 31% in licensed plumbers. Plumbers who had experienced a VBA virtual audit exhibited a higher agreement (40%) compared to those without such experience (27%).

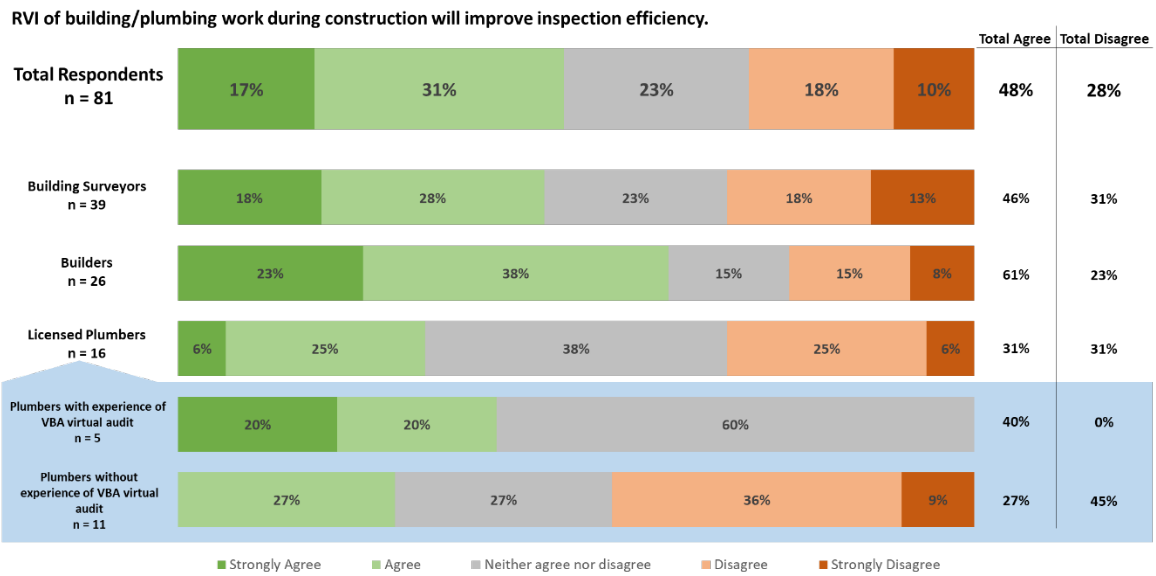

Figure 4.2: Practitioners' attitude towards RVI: Inspection efficiency

When it comes to safety, approximately one third of respondents agreed, and one third disagreed, that building/plumbing work during construction will improve the safety of inspection participants (Figure 4.3). Builders were more likely to disagree (47%), followed by licensed plumbers (31%). Only 13% of licensed plumbers agreed with the statement, compared to 34% of building surveyors and 35% of builders. The follow-up interviews revealed that the risks unique to plumbing work may contribute to heightened safety concerns, such as working at height and being exposed to sewer gas. Compared to those without RVI experience, plumbers who had experienced a VBA virtual audit presented a higher agreement (20% vs. 9%) and lower disagreement (0% vs. 45%).

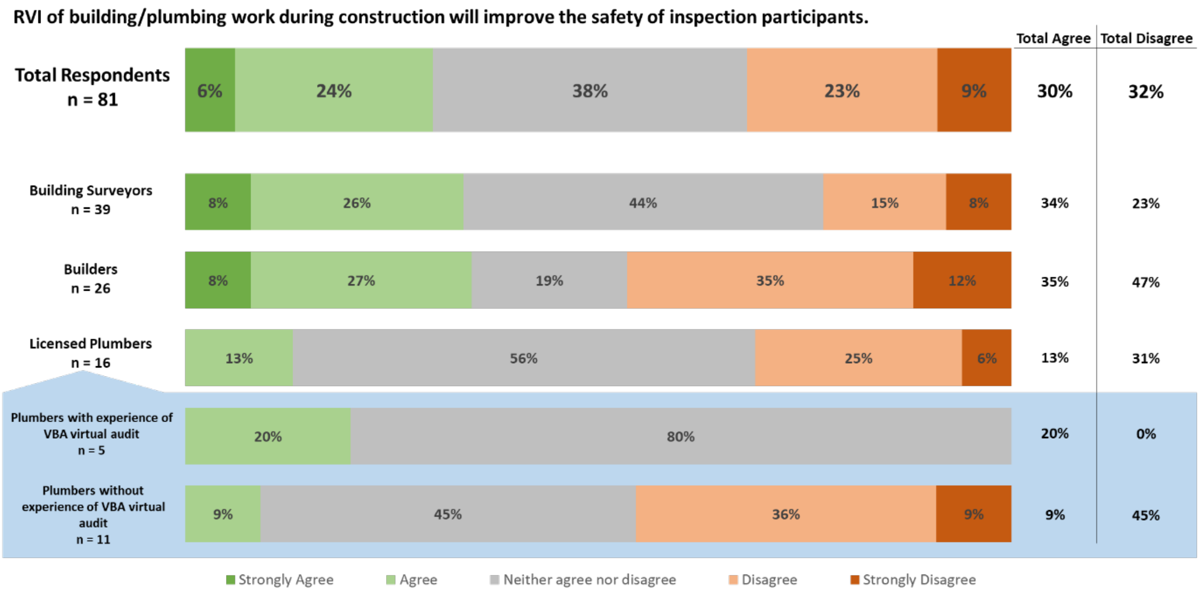

Figure 4.3: Practitioners' attitude towards RVI: Improved safety of inspection participants

One third (32%) of respondents agreed that RVI of building/plumbing work during construction would positively impact the rigour of the inspection, while 40% of respondents disagreed (Figure 4.4). 50% of builders agreed, among which 19% strongly agreed, that RVI will improve inspection rigour. However, the percentages of total agreement were much lower for building surveyors (24%) and licensed plumbers (19%).

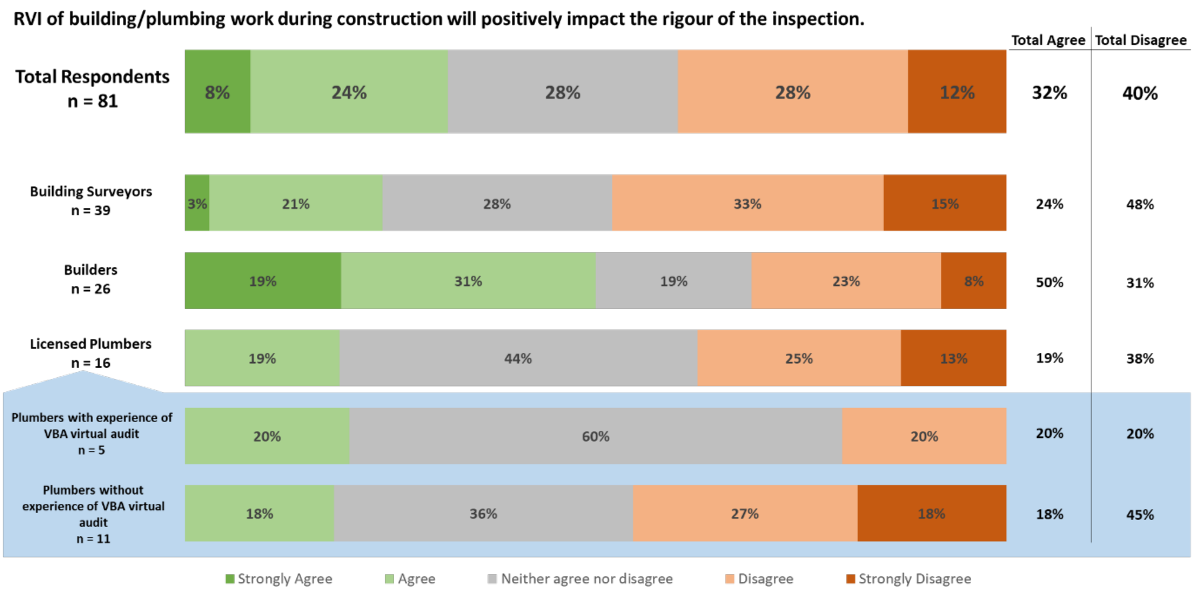

Figure 4.4: Practitioners' attitude towards RVI: Impact on inspection rigour

When asked to what extent they agree that the advantages of RVI outweigh its disadvantages, 38% of total respondents agreed and 29% disagreed (Figure 4.5). In general, builders (46%) were more positive than building surveyors (38%) and licensed plumbers (25%). It's worth noting that plumbers who had experienced RVI tend to agree more with the statement than those who had never experienced RVI.

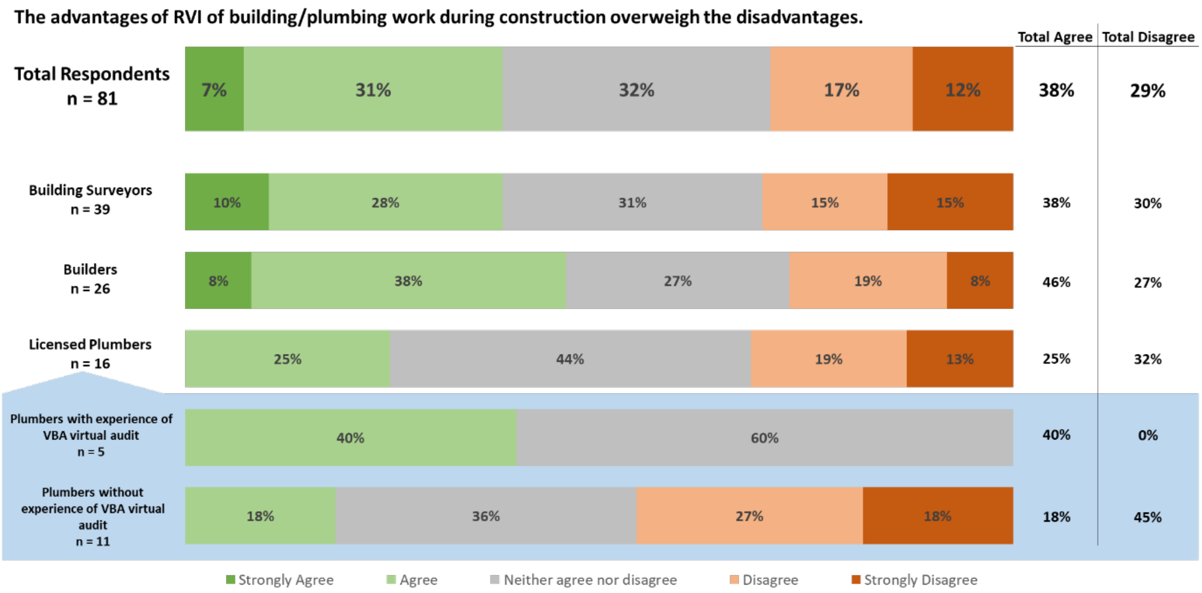

Figure 4.5: Practitioners' attitude towards RVI: Advantages outweigh disadvantages

Two in five respondents (38%) agreed that RVI can replace in-person inspections conducted onsite (Figure 4.6). Builders were most in agreement (50%), followed by building surveyors (34%) and plumbers (31%). Subsequent interviews suggested that some building surveyors preferred to consider RVI as a viable replacement for specific lower-risk inspection tasks, rather than as a replacement for all types of in-person inspections. A closer look at the plumber responses suggested that those who experienced RVI in a VBA virtual audit tend to agree more than those without such experience.

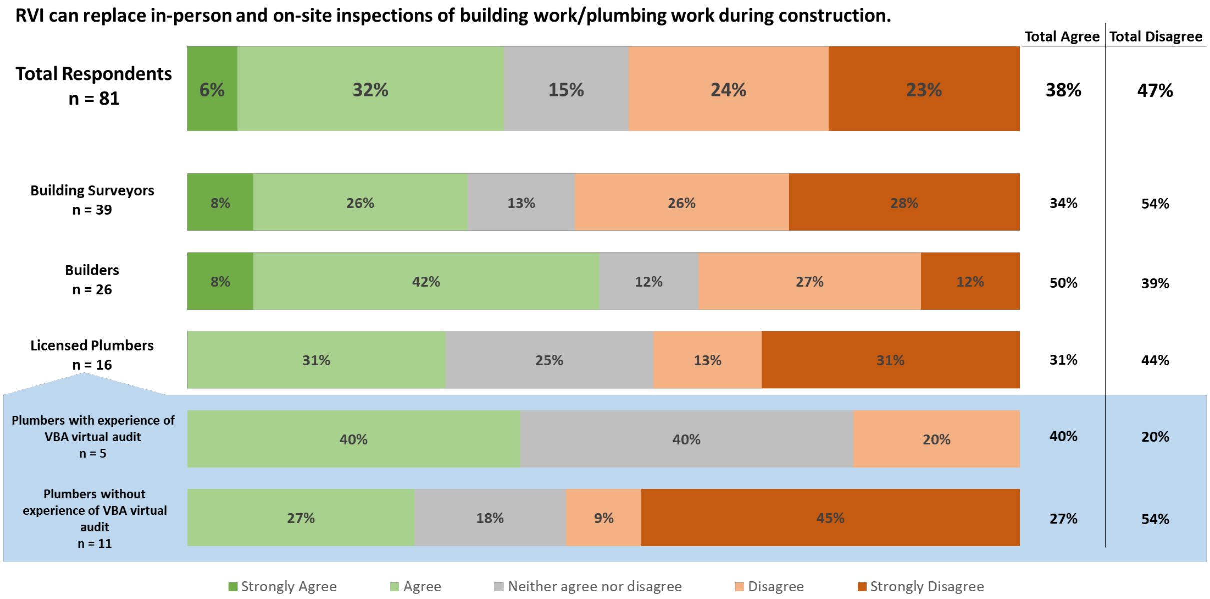

Figure 4.6: Practitioners' attitude towards RVI: Can replace in-person onsite inspection

4.4.3. Perceived benefits of RVI - practitioner perspective

Reducing travel time

When asked about the average travel time per inspection, only 31% of building surveyors spent less than one hour, while just under one third (28%) spent more than two hours (Figure 4.7). This is a significant amount of time, considering the inspection itself usually takes half to one hour, depending on the type of inspection. This means building surveyors can spend more time travelling to sites than inspecting the building work. As RVI removes the need for travelling, it's expected to significantly increase inspection efficiency, particularly for sites in remote rural areas.

Figure 4.7: Building surveyors' average travel time for each inspection

Facilitating training of building surveyors

During the follow-up interviews, three building surveyors shared the idea of deploying trainee building surveyors and inspectors to construction sites for data collection. They believe that this direct experience is substantially more beneficial than only traditional classroom learning. The recorded inspections can also serve as valuable training materials, allowing trainees who don't have the opportunity to participate in actual inspections to learn from reviewing and discussing the recordings.

Improving inspector safety

Almost three in four building surveyors (74%) reported encountering an unsafe scenario during an inspection of building work - 64% reported 'sometimes' (4-6 out of time times), and 10% reported 'very often' (>7 out of 10 times) (Figure 4.8). Only 5% suggested they had never encountered an unsafe scenario. The high frequency of unsafe circumstances underscores the safety benefits of RVI by allowing building surveyors to conduct inspections remotely.

Figure 4.8: Frequency of building surveyors' encounter with unsafe scenarios

Improving record keeping

More than two in three respondents (67%) agreed that RVI will improve record-keeping for inspections (Figure 4.9). Builders were most in agreement (81%), followed by building surveyors (67%) and plumbers (44%). Plumbers who had experienced a VBA virtual audit were in stronger agreement than those who had not (60% vs. 36%).

One building surveyor suggested in a follow-up interview that the current regulatory framework places substantial liability on building surveyors, given that it may be unrealistic to expect building surveyors to possess all expertise. As a result, they often depend on structural engineer and fire safety engineer expert reports to finalise an inspection and approve construction continuing. Recorded inspections enable the possibility of directly requesting engineers to approve structural or fire safety aspects. Moreover, recording inspections could offer some level of protection for building surveyors. For instance, if an original structure or frame was damaged post-inspection due to heating, ventilation, and air conditioning (HVAC) penetrations and holes, the recording could provide crucial evidence.

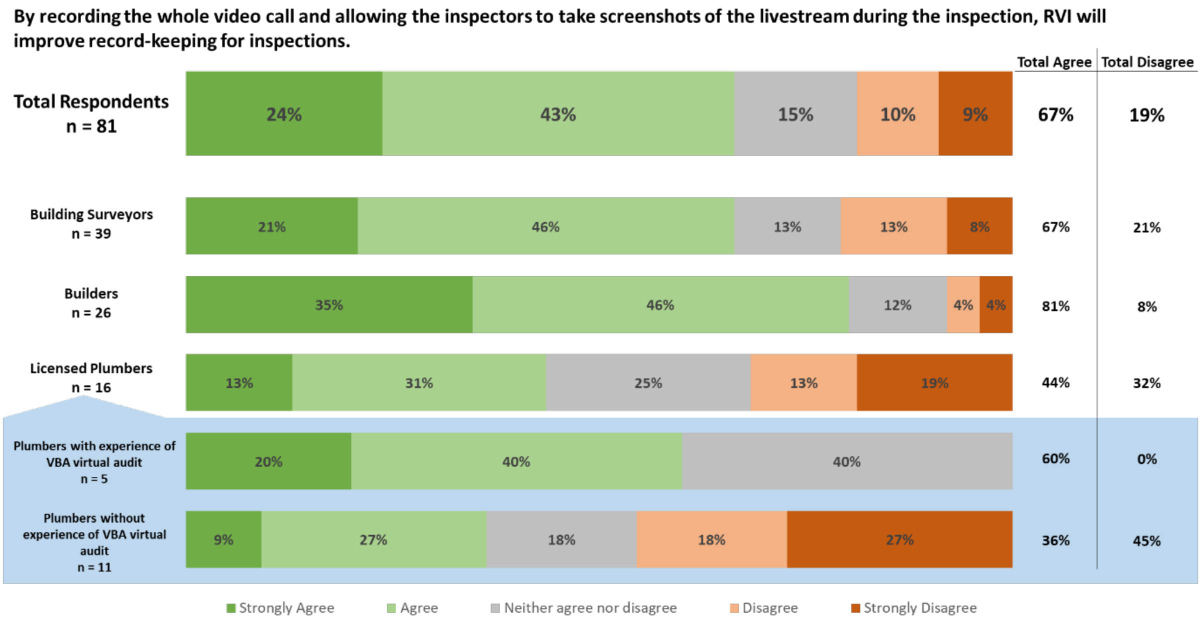

Figure 4.9: Practitioners' perception of RVI: record keeping

Reducing contingency for building/plumbing work

Reduced contingency for building/plumbing work is another benefit identified by practitioners in follow-up interviews. The adoption of RVI introduces an added degree of certainty and predictability to the workflows of building and plumbing practitioners. Traditional inspection methods are often associated with unsure wait times which can disrupt the flow of construction tasks. By offering a more predictable and timely inspection, RVI can reduce delays caused by waiting for an inspection, thereby decreasing uncertainties within project schedules. This process change has the potential to bring about considerable benefits at a project management level. By reducing uncertainties, project managers can better allocate resources, leading to faster project completion times.

4.4.4. Operational challenges and risks of RVI - practitioner perspective

RVI competency and need for training

Regulators previously pointed out that remote inspectors might find it challenging to instruct onsite assistants (e.g. builders, plumbers) how to gather the necessary information to support remote inspectors' decision-making. This challenge could be addressed by providing training to the practitioners. According to the survey, just under two third of all respondents (63%) agree that they will need training for RVI. Building surveyors were most likely to agree they require training for RVI (74%). Plumbers were least likely to agree that they needed training (32%), and none of those who had experienced a VBA virtual audit believed that they needed training for RVI (Figure 4.10).

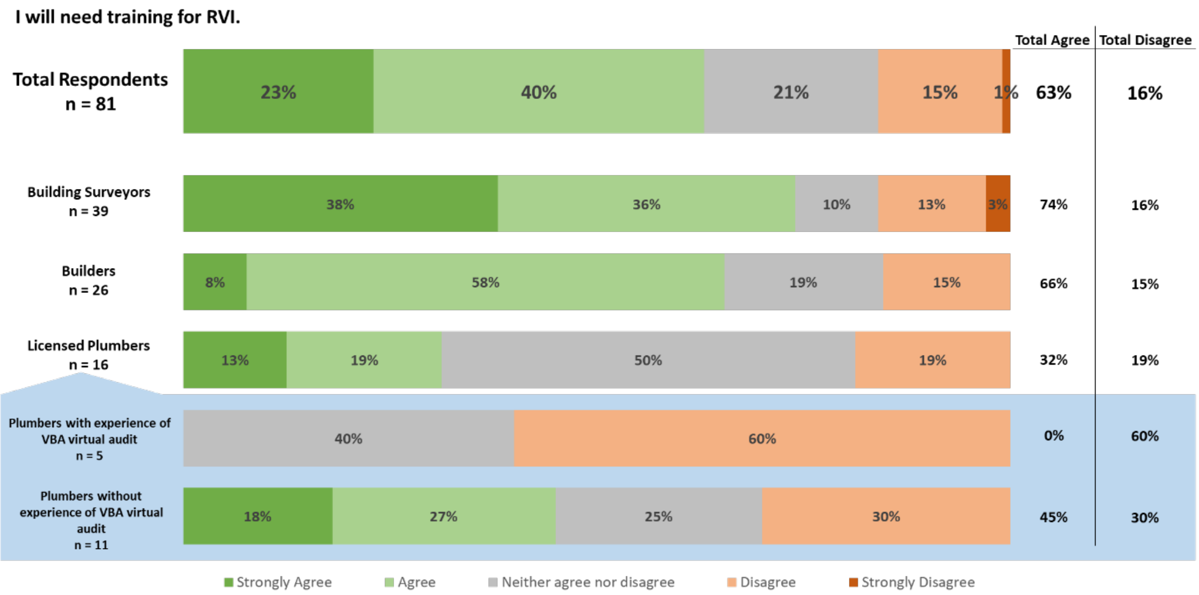

Figure 4.10: Practitioners' perceptions of RVI: Training needs

Conflicts of interests and process governance

One of the greatest concerns raised by the regulators on using RVI is conflict of interest and process governance. This concern is echoed by the survey respondents, 59% of whom agreed that RVI will compromise the ability to conduct a rigorous inspection (Figure 4.11). Plumbers who had experienced a VBA virtual audit were more positive than plumbers who had not experienced a virtual audit.

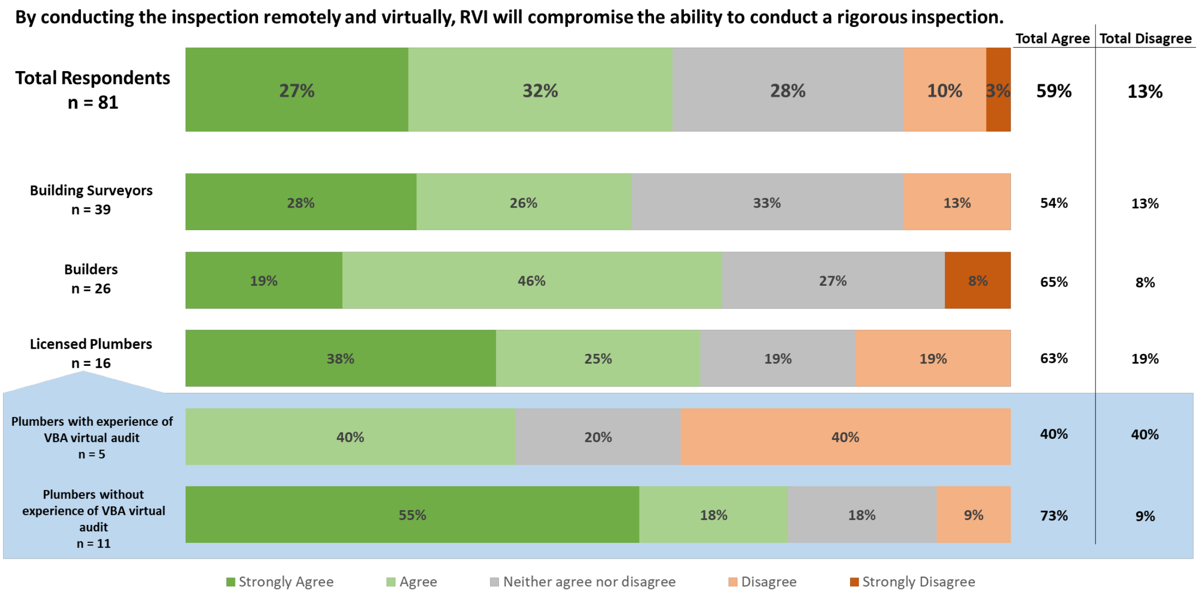

Figure 4.11: Practitioners' perceptions of RVI: Compromised rigour

From phase one interviews, regulators believed that potential conflicts of interest could be managed by carefully determining who should be the onsite assistant to operate the camera and facilitate the transmission of the RVI. We asked the survey respondents which individual they felt would be the best person to assist a remote inspector. Two thirds of respondents thought that a person skilled and competent in the use of technology and nominated by the

Relevant Building Surveyor (RBS) (33%) or the builder/site manager (31%) should be this person (Figure 4.12). Builders most often thought the builder or site manager should hold the camera during RVI (58%), followed by a person selected by the RBS. This result is confirmed in the follow-up interviews which indicated that the RBS should have the autonomy to decide how to implement RVI and to select the assistant to be onsite could enhance their acceptance of this technology.

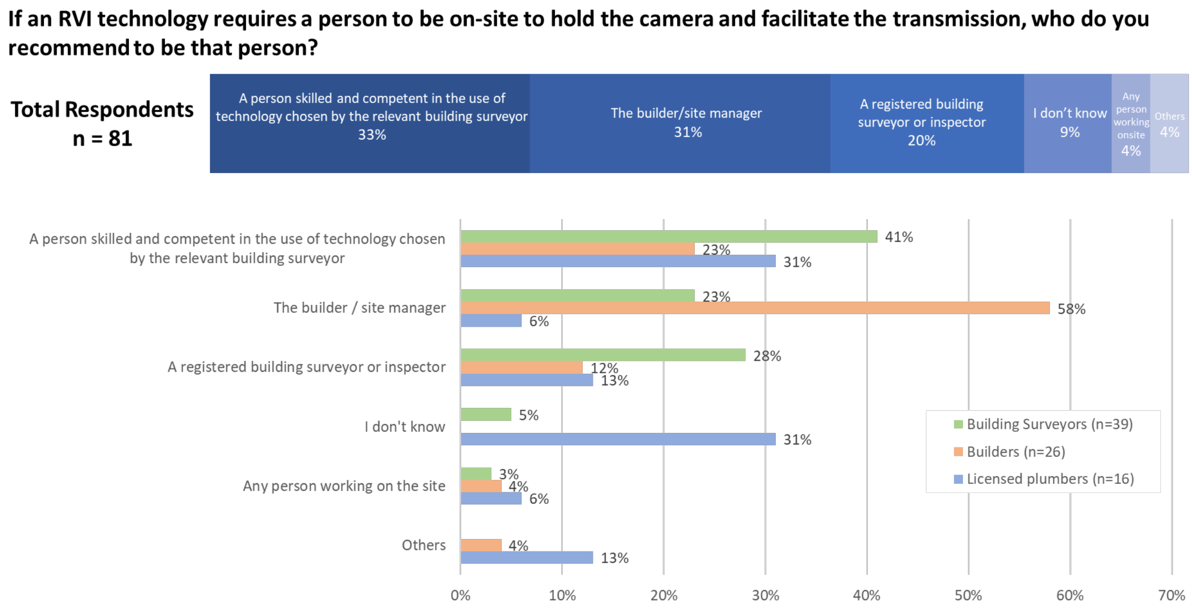

Figure 4.12: Practitioners' perceptions of RVI: Camera operator

Extra effort for site personnel

Regulators anticipated that the extra effort for the site personnel to be available onsite for an RVI may be a hurdle for RVI adoption. However, feedback from follow-up interviews paints a slightly different picture, suggesting that builders often choose to be present during inspections to establish a favourable impression with building surveyors and provide immediate answers to questions that may arise. Though not obligatory, their presence may be beneficial for instant clarification and efficient communication.

Standardised and privacy-aware management of inspection data

In the follow-up interviews, some practitioners suggested that while leaking footage of a building could be damaging, the impact is not significantly different from the unauthorised release of architectural drawings or 3D models. One of the builders stressed the potential fallout if inspection videos were to become accessible to non-professionals, especially clients. The reality of the building industry is that not all work can be 100% compliant with the highest standards. Consequently, leaking inspection videos could result in complaints that potentially deter builders from adopting RVI. However, the same builder acknowledged that video recordings of inspections do serve as a protective layer for builders. He is willing to share these recordings with professionals such as trainee building inspectors and regulatory bodies such as the VBA for mandatory inspection audits. This suggests that builders' privacy concerns could be addressed by implementing controlled access to the inspection recordings, thus ensuring that only authorised personnel can review them.

Accountability of technology providers

Some practitioner interviewees articulated concerns about the reliability of the technology involved in RVI, such as the live video conferencing software, as well as the need for clearly defined accountability for technology providers. Their concern stems from a potential lack of safeguards in case of technology failures, which could impact the inspection process. In sectors that allow technology-enabled inspections such as shipbuilding, the approach towards technology providers typically involves granting permissions and accepting the associated risks, rather than holding them accountable for every technological failure. It may not be practical or reasonable to assign full accountability to technology providers in case of every malfunction or mishap. Therefore, defining accountability for technology providers might involve developing permitting criteria that ensure a minimum uptime for the RVI technology. Moreover, creating contingency plans for any technological glitches that might occur during the inspection could also help address some of the practitioners' concerns.

Poor internet connectivity

Reliable internet connectivity is crucial for conducting high-quality RVI. When asked about the general level of internet or cellular connection on construction sites, 29% of all respondents reported very good and 54% reported good (Figure 4.13). Yet, 14% of all respondents suggested they experienced bad or unstable connection, among which plumber respondents reported the poorest onsite internet or cellular reception.

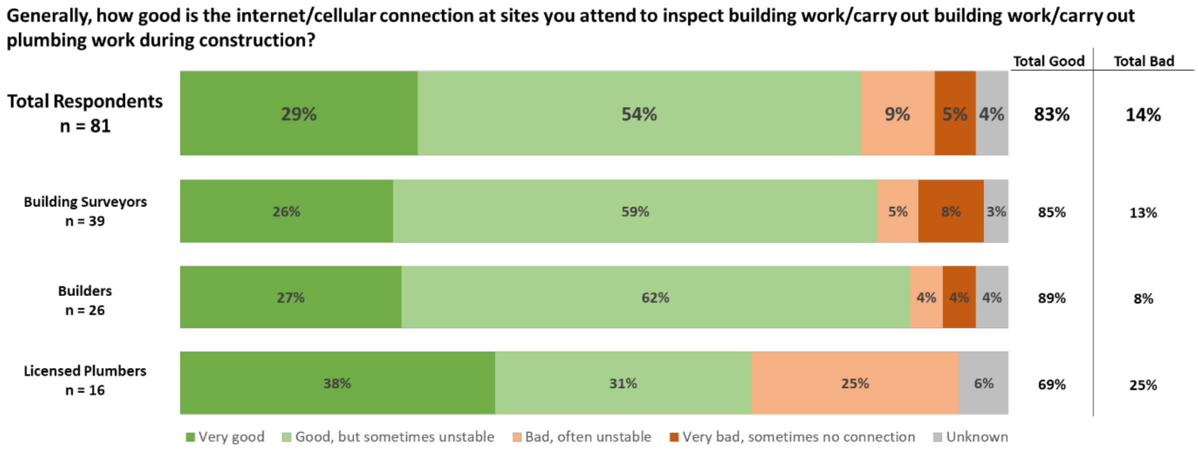

Figure 4.13: Onsite cellular/internet connection

Additional safety risks for onsite assistant

RVIs rely on the onsite assistant holding a camera (on a smartphone) to capture visuals of the site and the building/plumbing work. Two in five respondents (38%) agreed that holding a camera during an RVI presented safety risks to the camera operator and/or others (Figure 4.14). More specifically, approximately one third of building surveyors (36%) and builders (31%) agreed that camera holding presented safety risks. Plumbers who had not experienced a VBA virtual audit were most likely to agree (73%).

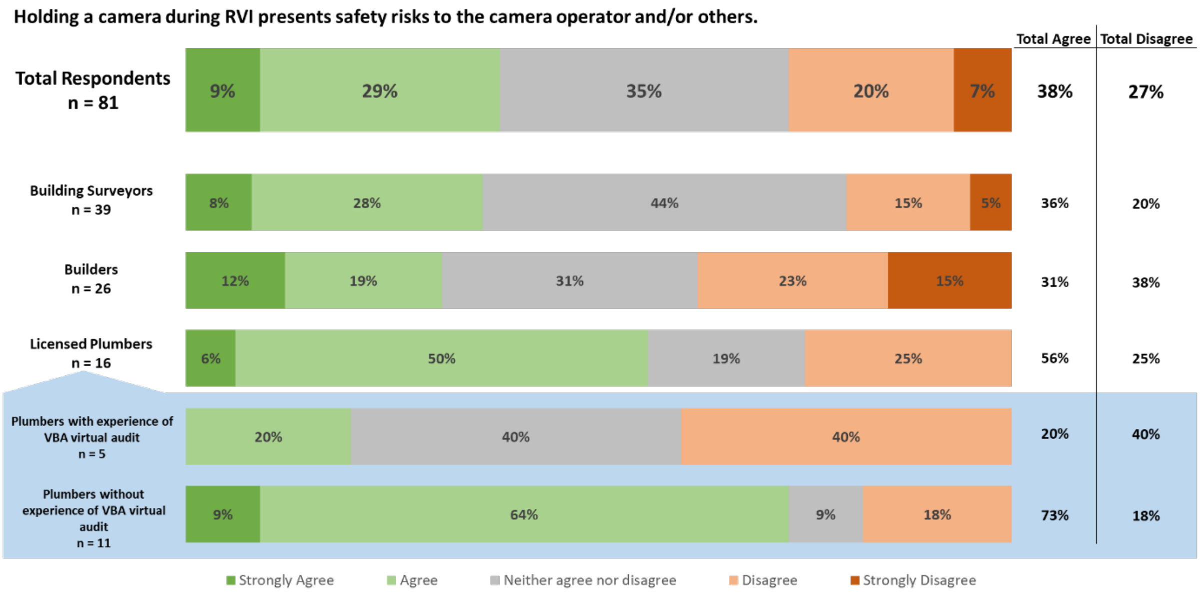

Figure 4.14: Practitioners' perceptions of RVI: Safety risks of holding a camera

4.5. Summary

While the sample size of interview and survey participants is relatively small compared with the entire industry, they have offered significant insights into the benefits and risks from the perspectives of regulators and industry practitioners (i.e. building surveyors, builders, licensed plumbers). These insights are vital in improving our understanding of the driving factors and concerns related to the adoption of RVI in inspection practices.

Most regulators and practitioners who participated in this research recognised the benefits of RVI in increasing the efficiency of inspection by removing the need for travelling to sites, particularly in remote areas. They also believed RVI could help address the shortage of building surveyors by allowing physically impaired individuals to conduct inspections remotely and offering training opportunities and materials for those on the pathway to becoming building surveyors. When it comes to safety, many participants acknowledged the benefit of eliminating the inspector's exposure to safety hazards in an unfamiliar site environment; however, participants noted RVI could introduce new safety risks for the onsite assistant who holds the camera during an RVI. Similar to the safety implications, the capability to store and share RVI recordings and data was considered to both positively and negatively impact RVI adoption. On the one hand, inspection records provide thorough and unbiased data for review. On the other hand, the absence of a standardised and privacy-conscious data management approach introduces notable risks in terms of data interoperability and possible data leakage. Regarding the technologies employed in RVIs, the reliability of their performance and the reliance on good internet/cellular connection were considered indispensable factors. Further, training for RVI was regarded as necessary so that both the remote inspector and onsite assistant handling the camera could apply best practices, thereby ensuring the safety, efficiency, and overall high quality of RVI procedures.

Generally, industry practitioners who participated in the research exhibited a strong willingness to explore RVI and other digital technologies that have potential to improve inspection practices. Across the majority of subjects in the survey, building surveyors and builders exhibited a more favourable outlook compared with licensed plumbers. Among the plumber respondents, those who had experienced a VBA virtual audit demonstrated a more optimistic perspective than those who had not. This finding implies increasing acceptance of RVI might be attainable by involving practitioners in RVI trials. This would allow them to comprehensively evaluate the benefits and risks of RVI from an informed standpoint.

5. EMERGING TECHNOLOGIES FOR REMOTE INSPECTION OF BUILDING WORK

5.1. Overview

Technology plays a vital role in remote inspections of building work. A variety of technologies have been used for different tasks in the inspection of building work. These include various sensors, platforms such as unmanned aerial vehicles (UAV), information models such as building information modelling (BIM), and visualisation tools such as mixed reality (MR), augmented reality (AR), and virtual reality (VR).[39,40,41,42,43,44,45] For the *remote* inspection of building work, raw data collected by sensors must be processed to extract the information relevant for inspection. The appropriate processing method will depend on the technology being utilised. The processing of the data will achieve three goals. First, it will allow for the extraction of necessary information from the data. Second, it will facilitate the comparison of the information with the design models and applicable regulations. Finally, it will make the subsequent determination of compliance status possible.[46] To process the data, different methodologies such as computer vision and machine learning have been used. [47,48,49,50,51,52] When processing the data, it is important to understand the capabilities and limitations of the

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[41] Guo, J., Q. Wang, and J.-H. Park, Geometric quality inspection of prefabricated MEP modules with 3D laser scanning. Automation in Construction, 2020. 111: p. 103053.

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[48] Shira, A., E. Zeneli, and F. Bidaj, Thermal imaging as an essential inspection procedure for identification of energy efficiency problematics in Albanian existing public buildings. Industry 4.0, 2021. 6(3): p. 93-95.

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relevant methodologies, as an unsuitable choice or incorrect application of the method may result in incorrect decisions by the inspectors and in further errors. This would lead to delays and additional costs.[53] Based on a literature review, this section discusses the emerging technologies and methodologies that have been employed for inspecting building elements. This section also discusses the process of inspection in terms of remote and assistant-based inspections, the potential for automation, and the capacity for remote inspection in real time.

5.2. A classification of building elements for inspection

In order to identify the technologies that can be used for the inspection of building work, this study classifies the building elements into six main categories: C1) boundary and excavation, C2) reinforcement, C3) framing, C4) insulation, C5) mechanical, electrical and plumbing (MEP), and C6) façade. This classification is done in such a way as to include all building components. Different building elements of each of these categories can be found in Figure 5.1.

5.3. Inspection technologies and methodologies mapped to building elements

A comprehensive review was conducted on the state-of-the-art technologies to identify available sensors, platforms, and data processing methods that can be used in remote inspection scenarios for different elements of building work. Figure 5.1 provides an overview of the academic literature where different technologies have been used for the remote inspection of building elements. In practice, the inspection process involves a large number of building elements that need to be inspected (inspection elements), and the reviewed studies cover only a subset of them. We divide these inspection elements where the inspection could be performed by using technology into two categories: geometric and non-geometric. Geometric tasks are the measurable features of building elements. For these tasks, it is necessary to capture the spatial information of the elements. Examples of geometric inspection tasks that have been performed with the help of technology include the measurement of dimension, position, orientation, spacing, displacement, and deformation. Non-geometric tasks are those attributes that can be interpreted without the spatial information of the inspection elements. These include environmental parameters such as temperature, pressure, and gas concentration, as well as corrosion, damage level over components, thermal bridge, and other abnormalities of the building elements.

Based on the literature review, the following are the types of emerging remote inspection technologies considered against the building elements. Figure 5.1 provides an overview of inspection tasks and the relevant technologies mapped to different building elements.

Reality Capture. Reality capture refers to the process of spatial data acquisition of an asset or site that provides a digital representation of the geometry and appearance of the object and can be converted into valuable inspection information. Reality capture sensors include conventional cameras (RGB), depth cameras (RGBD), infrared sensors (IR), laser scanning, and ground penetrating radar (GPR), on various stationary (fixed location) and mobile platforms. Collected data through these technologies can be processed by appropriate data processing methods to obtain spatial and non-spatial information of the building elements. Currently, reality capture technologies are the most extensively studied for technology-assisted inspection of various building elements.

GIS/BIM. A Geographic Information System (GIS) is an information system for storing, analysing, and visualizing spatial data, including geometric and non-geometric information of the building elements. A Building Information Model (BIM) is a digital representation of the physical and functional characteristics of the building components. In addition to having the

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same information storage function as GIS systems in inspection scenarios, a BIM can also be used as a virtual reality environment where inspectors can view the inspection information virtually. Moreover, BIM has been extensively used as a reference model for comparing the as-built state of the building with the as-designed models.

Internet of Things. Internet of Things (IoT) refers to the sensor networks that are connected to the internet, all collecting and sharing data. In inspection scenarios, the sensors are embedded inside or next to the building elements to collect real-time inspection data. For detecting environmental parameters (e.g. foundation pit, insulation, and MEP systems), IoT is the most commonly used technology.

Digital Twin. A Digital Twin (DT) can be considered a live BIM where data and information collected typically by IoT sensors are live-streamed and visualised in the BIM environment. A DT is also recognised as the as-built 3D model of the inspection elements, which accurately represents the spatial characteristics of the physical objects being inspected. Moreover, DT has been used as a virtual environment for virtual reality-based inspections and acts as a digital platform to record the inspection information. Due to the widespread use of reality capture technologies for data collection, as-built 3D models can be created for building elements, which has resulted in DT becoming more and more popular for inspecting building works.

Extended Reality. Extended reality (XR) is an umbrella term for virtual reality, augmented reality, and mixed reality, which is an immersive technology that merges the physical and virtual worlds. In most inspection scenarios, XR has been used for visualisation, data collection, and discrepancy identification between the as-designed and as-built models. Through these technologies, inspection information can be extracted, recorded, and visualised in the real environment. In virtual reality-based inspections, DT and BIM models are used to create a virtual environment of the building for the inspector, and in augmented/mixed reality-based inspections, they act as a reference model of the building elements for comparison with the as-built components.

Computer Vision. Computer vision is a field of machine learning that uses visual inputs such as RGB, RGBD, and thermal images, videos, radar and sonar signals, and point clouds to automatically perceive the scene and derive meaningful information. For inspection purposes, computer vision has been used for as-built 3D model reconstruction, tracking and positioning, spatial mapping, object detection and recognition, scene classification and segmentation, and thermography. Typically, computer vision has been used to extract inspection information from sensor data in technology-assisted inspection scenarios. In order to automate the remote inspection of building work, computer vision can play a significant role, since it facilitates the automated extraction of inspection information and the verification of compliance status.

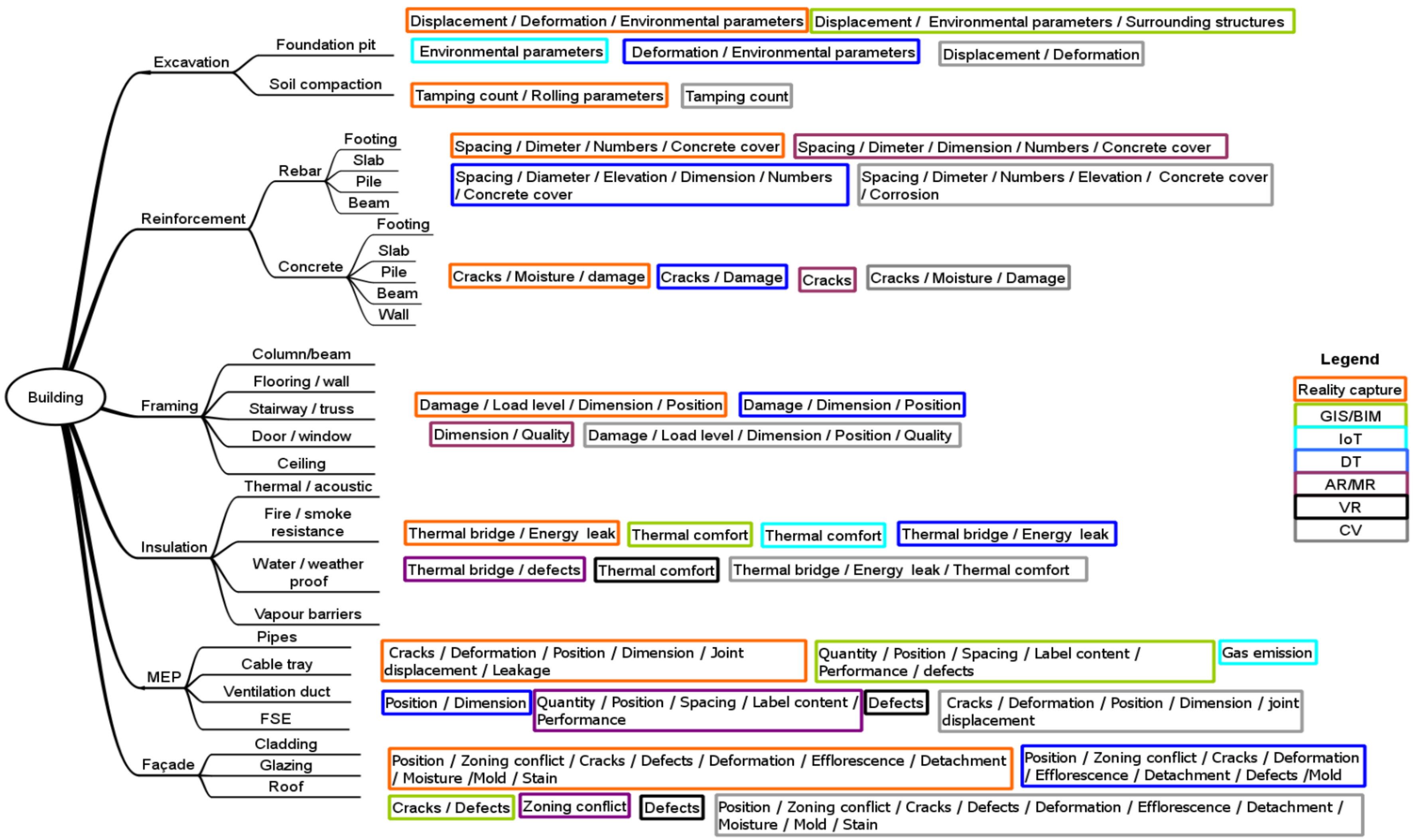

Figure 5.1: Distribution of different emerging technologies used for inspecting various elements of building work. The colour of the boxes differentiates the technologies, and the content of the boxes indicates the inspection task that was performed using the technology.

5.4. Assistant-based vs. remote inspection of building work

Remote inspection of building work is an emerging practice that encompasses a range of new concepts, technologies, and application scenarios. Therefore, it is crucial to establish clear definitions from the outset. Depending on where the inspector is located and whether an onsite assistant is required, inspections of building work can be categorised into conventional inspections, assistant-based remote inspections, and remote inspections.

- **Conventional inspections** require the authorised inspector to be present on the building site to collect inspection information.
- **Assistant-based inspections** do not require the authorised inspector to be on the site but necessitate an onsite assistant to operate the data acquisition technology and/or to extract inspection information for use by the authorised inspector. RVI is an example of this type of inspection.
- **Remote inspections** require neither the authorised inspector nor the assistant to be onsite to collect inspection information. Inspection data is collected using various sensors and the inspector is able to extract the relevant information and determine the compliance status of building components remotely.

In both remote and assistant-based inspection, the process of acquiring inspection information is performed using technology and relevant techniques. Whether an inspection scenario is completed as remote or assistant-based depends on several factors. The main factors include the technology platform and sensor and the inspection element. Open-space building elements –such as rooftops and façades – may be monitored remotely using drones. Moreover, inspection elements that are most relevant to the environmental parameters, which can be sensed via embedded or IoT sensors, can also be controlled without the need for the presence of an assistant onsite. However, inspection elements placed within the indoor environments – framing components being one example – require an onsite assistant to capture the information.

Stationary reality capture systems must be installed on the inspection site. They must be installed to gather data related to the inspection elements. As a result, when using these types of devices, the presence of an assistant will be required to execute the technology-assisted inspection. This will be the case unless a stationary sensor, such as Closed-Circuit Television (CCTV), is fixed in a specific location and can capture data from objects and send it to a data processing facility. Consequently, if the inspection element could be detected via received data, the inspection process could be conducted (fully) remotely. By contrast, in drone-based inspections where the data gathering process can be controlled remotely – that is, without the inspector being present onsite – the inspection can be considered fully remote. It is important to note that drone data collection requires an assessment of the surrounding environment and path planning before the flight. Although the user might have to be present at the site to perform these processes, since the entire process can be performed from outside of the inspection site, an assistant-based remote inspection can be considered in these cases. On the other hand, inspection of building elements that utilise stationary embedded or IoT sensors can be fully remotely operated. This is because there is no need for an assistant to be onsite to gather the data.

In remote inspection scenarios, where digital platforms such as GIS/BIM and virtual reality are used, the mode of inspection, i.e. remote or assistant-based, is completely determined by the sensors used for data collection. For example, in IoT based sensors, the inspection information is remotely captured and imported to the digital platforms. In inspection scenarios involving augmented/mixed reality technology, the as-planned model of the building being inspected (how the building is expected to be built) could be overlayed onto the real, physical building (how the building is actually built) to identify geometry-based non-compliance. If this identification can be done automatically, the identified compliant status could be overlayed onto actual building elements for real-time visualisation and confirmation. In either case, the inspection is performed by the wearer or user holding the augmented/mixed reality device, and thus, an assistant is always necessary at the inspection site. Further, any necessary measurements over the inspection elements must be performed by the onsite user, unless the measuring process can be automated. When DT is used as an inspection platform, there are two scenarios to consider. If the DT is employed as a live BIM that presents inspection data gathered through IoT sensors, then the entire process is conducted remotely. However, when DT is used as an as-built 3D model generated through image processing techniques applied to RGB and RGBD images or laser scanning, the method of DT generation can be performed either remotely or in-person, depending on the sensor platform used. Among the image processing techniques used for DT model generation, drones are the most popular platform that can be controlled remotely. In the case of laser scanning systems, however, the most popular platform is stationary or handheld. The latter requires an assistant to operate unless the sensor being used is itself mounted to a drone.

5.5. Interactive vs. automated remote inspection of building work

Existing approaches emphasise the automation of two processes: inspection information extraction (“**extraction/extracting**") and compliance status checks (“**checks/checking**”). Both of these greatly influence the tailoring of the remote inspection process. They would play an important role in building inspections, irrespective of the type of inspection being carried out. That is, whether the inspection is conventional, assistant-based, or remote. Therefore, in addition to the inspection information these technologies would already provide (and remotely), their automation of the two processes mentioned will make the remote inspection that much easier to perform. Traditionally, these processes are performed manually; the inspector would physically measure the quantitative items, and visually monitor the qualitative ones. It is worth noting that, in cases where technology assists in the collection of data for inspection, digital data for building elements can be used to perform the two automated processes mentioned (extraction and checking).

In a remote or assistant-based inspection of building work, the inspection process, as well as extraction and checking, can be carried out in one of three ways: manually, semi-automatically, or fully automatically. Manual means the inspector conducts the inspection processes themselves. Semi-automatic means the extraction or checks are conducted semi automatically with the need for human input or intervention to some extent. Fully automatic means the extraction and checks are done entirely automatically. Amongst the range of technologies used for remote inspection, computer vision, regression, and learning based models are those which are most capable of facilitating automatic extraction and checking. Automation offers benefits not only in terms of reliability, cost saving, operational efficiency, and agility, but also, in some cases, an appropriate assessment of the required level of expertise and/or effort required on the assistant’s part. For example, the automated or manual extraction of inspection information in augmented/mixed reality-based inspection scenarios results in the determination of the level of expertise of the onsite assistant regarding the use of the augmented/mixed reality system. The ideal case is that even an untrained assistant such as the builder of the building may be able to assist the main inspector.

Reality capturing sensors offer three modes of inspection: manual, semi-automatic, and automatic. Using computer vision and its diverse data processing techniques, the inspection process for most building elements can be automated. However, certain scenarios involving reality capturing sensors require a semi-automatic inspection mode. This occurs when data collection needs to be conducted at different time phases, which makes it difficult to fully automate the extraction of inspection information and compliance checks. Conversely, in the case of visual inspections using drones equipped with reality capturing sensors, although certain outputs like ortho-mosaic images are collected automatically, the actual process of extracting inspection information and checking compliance is performed manually by the user, resulting in a manual remote inspection.

Similarly, when GIS/BIM is used as a database for collecting inspection information, the process of inspection can be done manually, semi-automatically, or automatically. As an example, the inspection information is collected manually by the construction site engineering team and entered into the database, where the compliance check is also conducted only by checking the information in the database. All processes are carried out manually, but GIS/BIM acts as a technology tool in order to facilitate the inspection information gathering, storing, and visualisation. In contrast, if inspection information is gathered and compliance checks are performed automatically through the use of other technologies that have automation capabilities, a semiautomatic or automatic inspection mode is created.

Concerning the other technologies surveyed in this research, IoT based inspection processes which, when conducted for certain inspection tasks, can collect relevant inspection information, and determine compliance status, without the need for manual intervention; it automates all the inspection processes. In DT based inspection scenarios, given as-built 3D models of the building elements, both extraction and compliance checks can be performed automatically through spatial modelling of the objects. In some cases, however, DT models are used in conjunction with other technologies such as augmented/mixed reality, or they are created at different times and require manual compliance status check-ups. Due to the current capabilities of the augmented/mixed reality inspection system, most studies performed semi-automatic inspections. By using this technology, an as-built 3D model of the building element is created; the as-designed model is then superimposed over the as-built model. By comparing the as-designed model, which acts as a reference for constructing the building, with the as-built model representing the actual constructed elements, any discrepancies between the two models can be identified. This allows for the detection of any non-compliance or deviations that may have occurred during the construction process. Though this is what the technology does, all the measurements and conformity checks are still left to be performed by the device holder at the inspection site (i.e. manually). If the second process is automatically performed, then the "*automated inspection mode*" is considered. When this mode is considered, the inspection elements are then detected and measured automatically. In virtual reality systems, through the as-built 3D model of the building or as-designed BIM model, the inspector can monitor the building elements in a 3D virtual environment. Currently, inspection information is either manually or automatically connected to virtual reality systems. Since the compliance check is performed manually, the process is also known as manual or semi-automatic inspection.

5.6. Remote inspection of building work in real time

Some of the current technologies are able to perform remote building inspections in real time. Real-time technology-assisted inspection refers to the capacity to extract inspection information, check compliance status, and execute the data collection process all at the same time. For example, in the current video-based remote inspection system, the remote inspector is connected to the assistant on the inspection site. Through the assistant, the remote inspector can monitor the inspection in real time. Technology-assisted inspections can be categorised into online and offline modes based on their real-time capacities. In the former case, inspection information is extracted, and compliance is checked simultaneously with data collection, and in the latter case, inspection information is extracted, and compliance is checked separately from data collection phase. Several factors contribute to the decision to conduct a remote inspection either online or offline. The primary determinants include the type of technology sensor utilised, the data processing method and the resulting output, as well as the specific items being inspected. The following part discusses the real-time capabilities of the current emerging technologies.

Regarding the reality capturing sensors, if the inspection process is based on stitched images or the generated 3D model of the object, then the two main phases of the inspection must be conducted separately. This includes data collection as well as inspection information extraction and compliance checks. This is because, in such cases, there will be an extremely large number of captured images, data communication issues with the processing unit, and high data processing time. However, where the cases are, or involve, anomaly and defect detection scenarios or visual monitoring of building elements, it may be possible to simultaneously gather data, extract information, and do compliance checks. It is worth noting that the problems mentioned can also be considered when discussing the LiDAR point cloud. The major challenges presented by laser scanning systems, when considering them for online remote inspection scenarios, are threefold. First, these systems generate massive amounts of data. Second, they have large storage requirements. Finally, massive data processing issues may arise.

Concerning the remaining technologies, DT based inspection scenarios, which generate a 3D model of the building components through RGB and RGBD images or LiDAR data, cannot be performed in real-time, due to the challenges mentioned above. However, DT systems such as those incorporating IoT based sensors to collect real-time data and reflect the live situation of the building elements can carry out an online mode inspection. Whenever a GIS/BIM is used to record inspection information, or virtual reality systems are used to perform remote inspection, the time at which the information is collected determines whether the inspection is conducted online or offline. In this case, if the inspection data is collected and monitored at a separate time, the inspection is considered offline. Finally, augmented/mixed reality systems enable online inspection processes, as they provide the capability to visualise discrepancies between the planned and actual models. These systems also facilitate real-time detection of any abnormalities present in the inspection elements; this allows inspectors to report them immediately.

6. FIELD TRIAL CASE STUDY OF REMOTE INSPECTION TECHNOLOGIES

6.1. Overview

This section presents a case study that exemplifies the use of various technologies in remote inspections of building work to evaluate their feasibility. First, the technologies presented in Section 5 are narrowed down and suitable sensors are selected for the case study. Then, data collection and processing are discussed. This includes data acquisition with different sensors, data processing and finally a remote inspection based on these data by two building surveyors. For this case study, three different construction stages were examined: slab, framing and roof. Due to scheduling constraints, data capture for the three construction stages was carried out on three different construction sites. All three construction sites were located in Clyde North, approximately 50 km from Melbourne CBD.

6.2. Technology selection

Considering that reality capture was identified as the most promising technology for remote inspection of building work, we selected the following three sensing principles for reality capture of a construction site: Terrestrial laser scanning (TLS) with Panorama images, mobile laser scanning (MLS) and depth (RGB-D) mapping. Additionally, a drone was used with a mounted MLS and a colour (RGB) camera.

During the data collection exercise, the team utilised four reality capture scanners, namely, the Faro Focus S TLS, Geoslam Zeb Revo MLS, Emesent Hovermap ST MLS, and the Matterport Pro 2 RGB-D sensor, as shown in Figure 6.1.

(a) (b) (c) (d)

Figure 6.1: The four reality capture sensors used in the case study: (a) Faro Focus TLS, (b) Emesent Hovermap ST, (c) Geoslam Zeb Revo, (d) Matterport Pro 2

The Faro Focus S uses laser beams to capture the three-dimensional (3D) spatial data of any given scene. They are typically used in applications such as construction, land surveying, and civil engineering. Faro Focus S works by emitting a laser beam that sweeps across the environment and reflects off objects within its field of view. The laser beam is then detected by a sensor in the scanner, which measures the time it takes for the beam to return to the scanner. This information is used to calculate the distance between the scanner and the object and the object's position in 3D space. Repeating this process at different locations and angles can generate a dense point cloud of the environment. Faro Focus S data output consists of a point cloud, which is a large dataset of points representing the positions of objects in 3D space, and panoramic images. The point cloud can then be processed to generate various outputs such as digital surface, elevation, and 3D models. These outputs are useful for various applications such as visualisation, planning, and analysis of the scanned environment.

MLS systems such as the Geoslam Zeb Revo and Emesent Hovermap ST are active instruments that use laser beams to capture three-dimensional (3D) spatial data of a scene. One of the key advantages of MLS for building inspection is its ability to capture data from multiple angles and perspectives, making it particularly useful for capturing complex building geometries that can be difficult to capture with traditional land surveying methods. MLS systems use Simultaneous Localisation and Mapping (SLAM) technology to overcome the challenges of accurately capturing data while in motion. This technology allows the MLS device to track its position and orientation in real-time while simultaneously mapping the environment, enabling it to create a precise and accurate 3D model of a building. To achieve optimal results, it is important to traverse in loops, close each loop, and end at the same point where the scanning started. This ensures that the SLAM system is working properly, and that the MLS system is capturing data accurately.

Matterport Pro 2 is an RGB-D scanner designed to create three-dimensional digital models of physical spaces. It operates by using a combination of structured light and infrared sensors to capture accurate depth information, which is then integrated with high-resolution RGB imagery to create immersive, photorealistic models. The scanner captures 360-degree panoramic imagery and depth data in a single scan, and it also features built-in orientation sensors that allow it to track its position and orientation in space as it moves through the environment. The resulting data is processed using Matterport's proprietary software to create a fully-navigable 3D model of the scanned area. Matterport is widely used in various industries, including real estate, architecture, construction, and interior design, to create virtual tours, floor plans, and other digital assets. Its ease-of-use and accuracy make it a valuable tool for capturing detailed, high-quality data quickly and efficiently.

In this case study, two drones were deployed to conduct a roof inspection as well. One drone was carrying the Emesent Hovermap, as shown in Figure 6.1 (b). The other carried a high resolution camera, the Zenmuse P1, which is shown in Figure 6.2.

Figure 6.2: DJI Matrice 300 with mounted Zenmuse P1 camera

6.3. Data collection and processing

6.3.1. Framing

The field trial construction site for frame inspection pertains to a Class 1 single-dwelling residential building of approximately 250 square metres of floor plan area. The structural type of the building is a timber frame with a wall height of around 2.5 metres. The building comprises 23 enclosed spaces to be constructed on the site. The concrete floor had some residual water due to earlier rainfall. The surface of the wooden framework of the building was still wet. Apart from these conditions, no other unusual observations were made.

Overall, the data collection site was adequately maintained and suitable for the scanning technologies employed.

To assist the point cloud registration process of the Faro Focus S, checkerboard markers were set up around the building. The successful implementation of the Faro Focus S required a thorough understanding of the different settings available in the user interface of the scanner. For the data collection, a medium resolution was chosen, resulting in each scan taking 8 minutes and 15 seconds. While manual optimisation is necessary for specific data collections, the scanner also provides pre-defined profiles for different environments, such as indoor or outdoor settings. Compared to the Matterport Pro 2 scanner, the Faro Focus S proved less sensitive to moving objects and could filter out noises to a greater degree. Moreover, the TLS allowed for both interior and exterior scanning of the building. However, the point clouds obtained from Faro Focus S could not be registered and processed in real-time during the scanning process, and data processing was required after the completion of the data collection. For onsite registration, a laptop with the Faro software is required.

MLS sensors are typically controlled via a smartphone, which connects to the sensor via Wi-Fi. In this way, the Geoslam Zeb Revo provides a real-time preview map with the trajectory of the scanner, while the Emesent Hovermap ST does not have this feature. In addition to the LiDAR sensor, MLS systems use a camera mounted on the sensor, which records the scene during the measurement. This allows for later colourisation of the point cloud data, making distinguishing different objects and features in the captured environment easier. The scan with the Geoslam Zeb Revo, as well as the Emesent Hovermap ST, took about 25 minutes. Table 6.1 provides an overview of the data collection process using the different sensors.

Table 6.1: The overview of data collection using reality capture technologies

Scanner	Start time	End time	No. of scans	Individual scan time preparation (Minutes)	Overall scan time (Minutes)	Platform
Matterport Pro 2	10:30	13:00	33	1	150	Tripod
Faro Focus S	13:55	16:00	13	9	120	Tripod
Geoslam Zeb Revo	-	-	1	25	25	Handheld
Emesent Hovermap ST	14:25	14:50	1	25	25	Handheld

The Matterport Pro 2 scanner was found to be easy to set up and use, with a user-friendly interface requiring minimal training. Each scan took approximately 30 seconds to complete, after which the operator needed to move the scanner to a new location within a radius of 2-3 metres of the previous location. The scanner's automatic real-time registration allowed for the seamless integration of each scan into a complete 3D model. However, it was noted that the scanner encountered registration problems due to the strong ambient light, the lack of distinct features in the wooden framework of the building under construction, and the reflections in water puddles. Additionally, the scanner was unable to capture the exterior and outer edges of the building due to registration problems.

Once data is captured using reality capture technologies, it must undergo processing to enable its use for remote inspection. In most cases, the processing of different scan technologies is automated and dependent mainly on the processing power of the available computer system.

The point clouds obtained from Faro Focus S are processed and registered using the Faro Scene software, which can automatically align multiple scans to create a single point cloud. Due to the dynamic nature of construction projects, the point clouds obtained from construction projects are prone to high levels of noise and outliers. Thus, noise filtering is applied to remove noises created by moving objects or edges. Registration delivers a mean point error of 5.5 mm and a maximum point error of 21.3 mm. The individual scans were captured with sufficient overlap to ensure the completeness of the registered point cloud. The processing time depends on the amount of data and the computer's processing power. The full processing of the 13 scans of TLS point clouds was performed on an i7-Notebook and took approximately three to four hours. Figure 6.3. presents a side view of the scanned framing stage.

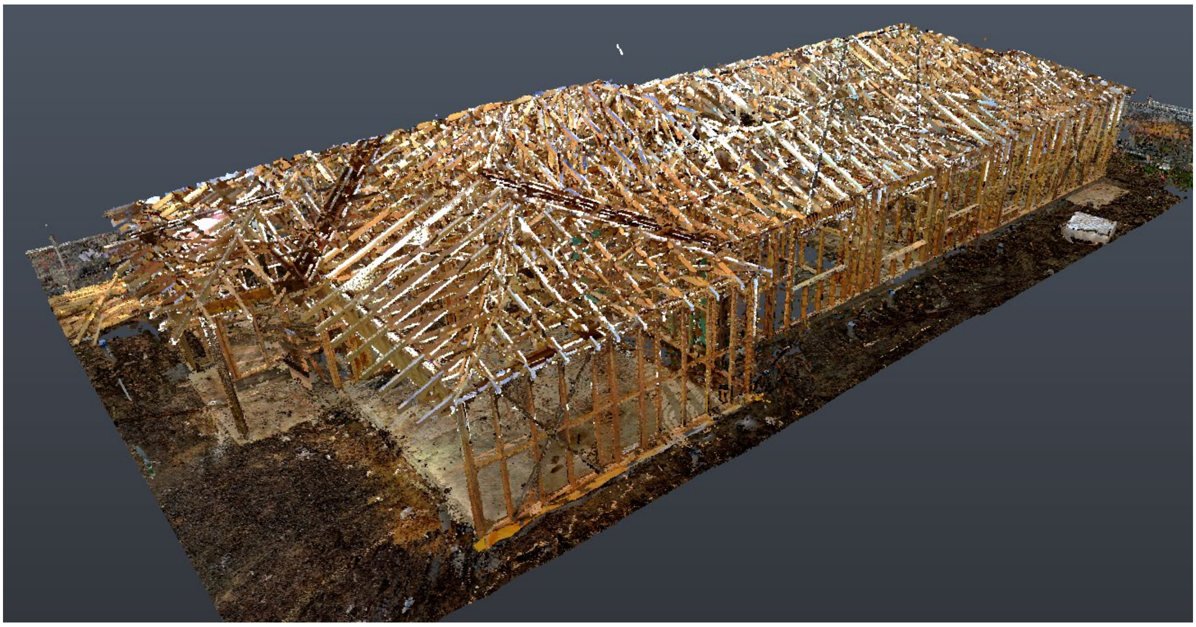

Figure 6.3: Point cloud captured by Faro Focus S, visualised in Autodesk Recap software

MLS scans, such as GeoSlam and Emesent Hovermap, provide unique software for data processing. The processing of the data obtained from MLS devices does not need registration. During the scanning of the building, the SLAM of Zeb Revo was unable to create a correct map due to repeating patterns in the wooden frame, rendering the resulting point cloud highly inaccurate and unusable as a model for the building. In contrast, Hovermap produced a point cloud with much higher quality. After the initial processing, which took about three hours, the point cloud was colourised based on the recorded video. This step took up to 8 hours on a laptop with a dedicated graphic processing unit (GPU).

In contrast, following completion of the Matterport Pro 2 scans, data is directly uploaded to the Matterport cloud, and processing occurs automatically without the need for manual interventions from the user.

6.3.2. Roof

The inspected construction site again corresponds to a Class 1 single-dwelling residential building, encompassing an approximate floor plan area of 250 square metres. The building's structural composition is characterised by a timber frame, accompanied by a wall height of approximately 2.5 metres. In terms of the roof configuration, the building features a "Hip roof" design. To ensure the safety of all individuals involved, it was imperative to suspend the construction activities temporarily before commencing the drone flights. It is important to note that drone operations necessitate the avoidance of direct flights over people, hence the need to halt the ongoing construction tasks during the inspection for safety reasons.

During the data collection, the team employed two distinct drones, each equipped with a different reality capture technology. To fly the drone, a professional drone pilot was hired.

The prevailing weather conditions during the inspection session at the site were marked by cloud cover, intermittently interspersed with episodes of sunlight. Throughout the majority of the day, the cloud cover remained persistent, thereby offering favourable lighting conditions for the functioning of the 2D cameras. Despite a slightly cold temperature, the weather conditions did not exert a substantial influence on the performance of the data collection team nor cause any significant discomfort. Moreover, the team encountered discernible winds during the exercise; however, these winds did not have a detrimental effect on the flight stability of the drones.

The data collection phase began at 10:00, subsequent to the formulation of a comprehensive plan for data acquisition. To be able to set the model into scale later, a distinct measuring tape was positioned next to the house. Initially, the team utilised a drone of type DJI Matrice 300 equipped with a 2D camera to gather data from three distinct altitudes of 30m, 20m, and 10m. This initial data collection phase concluded at 10:10. Subsequently, a different drone, a DJI Matrice 200, along with an Emesent Hovermap scanner, was employed for the second round of data collection, which entailed the inspection of the roofs. The preparations for this second drone were initiated at 10:12 and successfully completed by 10:19. Subsequently, the data collection using the second drone commenced at 10:21 and was concluded at 10:29. Following the data collection phase, the team engaged in the processing of the acquired data obtained from the first drone. This processing involved generating an overview of the captured 3D model, enabling the team to evaluate the captured data holistically and identify any blind spots or issues. The data processing stage concluded at 10:40, thus concluding the roof inspection session.

Drone 1 was utilised in conjunction with a 2D camera, while Drone 2 incorporated an Emesent Hovermap ST scanner. Table 6.2 provides an overview of the data collection process using these technologies.

Table 6.2: The overview of data collection using remote inspection technologies

Drone	Preparation time (Minutes)	Flight time (Minutes)	Sensor
DJI Matrice 300	10	At 30m: 2 At 20m: 2 At 10m: 3	2D camera
DJI Matrice 200	7	8	Emesent Hovermap

All 246 images were used to create a 3D model inside of the software Agisoft Metashape. After aligning the images, a point cloud was created and then triangulated to get a mesh model. The texture was generated and placed on the mesh model, which is visualised in Figure 6.4. By marking the positioned measuring tape, the whole model was set into scale. This whole process took about five hours on a laptop with a dedicated GPU. Additionally, the information of the mesh was used to create an orthomosaic, presented in Figure 6.5. An orthomosaic is an aerial image that has been geometrically corrected to remove distortions caused by terrain and sensor characteristics. It is created by stitching together multiple overlapping images to create a high-resolution map or mosaic of the area of interest. The resulting orthomosaic provides an accurate representation of the Earth's surface, where each pixel in the image corresponds to a specific geographic location. This allows for precise measurements, analysis, and interpretation of features on the ground. The processing of the Emesent Hovermap data of the roof was similar to the frame data. It took about five hours for processing and colourisation.

Figure 6.4: 3D mesh model

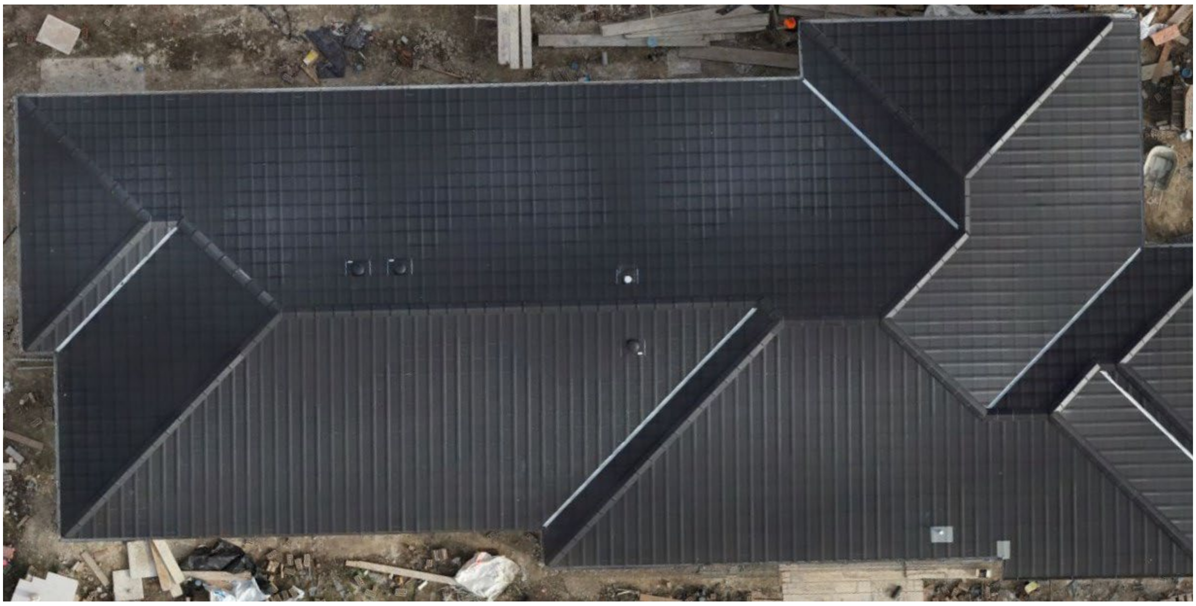

Figure 6.5: Orthomosaic

6.3.3. Slab

The scanning of the foundation slabs was conducted with the Faro TLS and the Matterport Pro 2. The construction site under inspection is characterised as two adjacent Class 1 single-dwelling residential buildings, each with a floor plan area of approximately 250 square metres. The foundation slab system employed in these buildings is an above-ground waffle slab foundation, utilizing Polystyrene waffle pods. The construction sites did not exhibit ongoing construction activities during the inspection.

The inspection session commenced with the team's arrival at 14:40, followed by the necessary preparations and planning of the scanning procedures at 14:48. The first reality capture technology employed was the Faro Focus S laser scanner. Each scan utilizing this technology required approximately 5 minutes, encompassing the scanning time and the relocation of the scanner to subsequent scanning points. The scanning process for the first building commenced at 14:58 and was completed by 15:44. For the second building, the scanning procedure commenced at 16:20 and concluded at 17:02. Subsequently, the team utilised the Matterport Pro 2 as the second reality capture technology. However, due to the absence of distinctive textures in the outdoor environment, the scan initiated at 15:50 proved unsuccessful and was subsequently discarded.

During the inspection session at the site, the prevailing weather conditions were characterised by cloud cover, which persisted throughout the majority of the day. This cloud cover provided advantageous lighting conditions for the optimal functioning of the scanners employed during the data collection exercise. In terms of temperature, there was a fluctuation observed, with the range varying between 16 and 14 degrees Celsius. These slightly cooler temperatures did not significantly impact the operation of the scanners or impede the progress of the inspection activities.

During the data collection exercise for the inspection of the foundation slab, the team utilised two reality capture technologies: the Faro Focus S laser scanner and the Matterport Pro 2 device. The Faro Focus S laser scanner proved to be successful in capturing the virtual model of the foundation slab. However, the Matterport Pro 2 device encountered difficulties in fulfilling its intended task. The scan conducted using the Matterport Pro 2 in the outdoor environment failed due to the absence of distinctive features necessary for accurate scan registration. As a result, the Matterport Pro 2 was unable to capture the desired virtual model of the foundation slab during the inspection. Table 6.3 provides an overview of the data collection process using these technologies.

Table 6.3: The overview of data collection using reality capture technologies

Scanner	Start time	End time	No. of scans	Individual scan time + preparation (Minutes)	Overall scan time (Minutes)
Matterport Pro 2	NA	NA	NA	NA	NA
Faro Focus S (Lot 810)	14:58	15:44	10	5	46
Faro Focus S (Lot 811)	16:20	17:02	10	5	42

The scanning procedure was the same as for the frame inspection with the exception that round targets were also included here, because there were no walls for checkerboards. The data processing followed the same procedure as for the framing described in Section 6.3.1. Figure 6.6 shows the top view of the point cloud data of the slab for the two residential building construction sites.

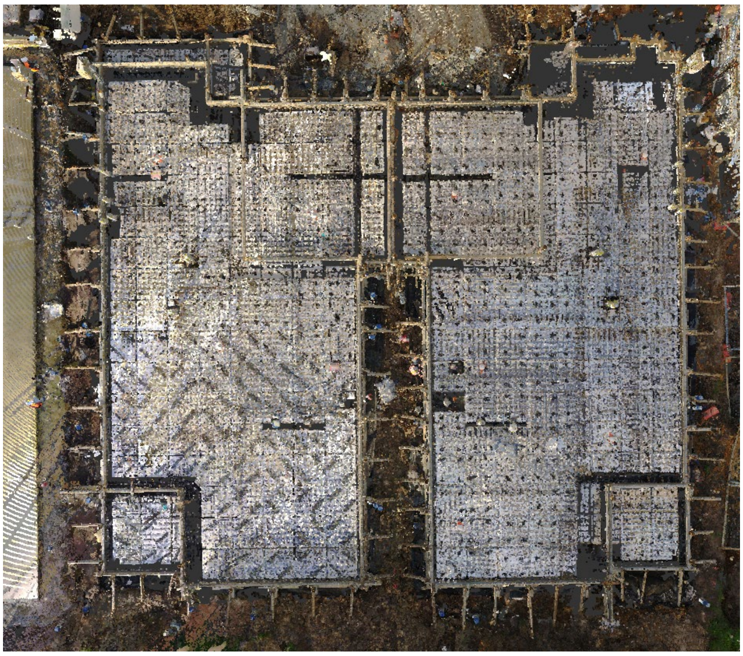

Figure 6.6: Point cloud of the slab, captured by Faro Focus S, visualised in Autodesk Recap

6.4. Remote inspection outcome

To evaluate the feasibility of the created models for inspection purposes, two experienced building surveyors, one of which was the building surveyor who issued the building permit for the site (i.e. the RBS), were introduced to all three remote inspection technologies and asked to perform inspections as they do it onsite. Each of the three technologies offered unique features and capabilities that could aid in a remote inspection. The feasibility of the different models for inspection purposes is compared below.

For the visualisation of the data obtained by the Emesent Hovermap ST and Faro Focus S, the software Autodesk ReCap is used. As desktop software, it relies on the computing power of the local machine and the processing can be computationally expensive. In this case study, the loading time between different panorama views amounts to four to five seconds. ReCap provides different measurement options like freehand, orthogonal, surface or pipe radius measurements. Furthermore, single points or groups of points can be marked and attached with a note, which can be useful for marking inspection issues.

6.4.1. Faro Focus S

During the remote inspection process, the obtained point cloud using Faro Focus S was evaluated, and several benefits and challenges were observed. One significant benefit of Faro Focus S is its ability to provide a clear view of the site in the scanning locations. This feature can be particularly useful in identifying defects accurately. Additionally, Faro Focus S offers a birds-eye view and an exterior view of the building, which can help gain an overall perspective of the building and its surroundings. Moreover, Faro Focus S was found to be reasonable for navigating and provided multiple angles to inspect an element. It also offered accurate measurement capabilities, making it a valuable tool for virtual inspections.

However, the obtained point cloud using Faro Focus S also posed certain challenges during the inspection. The computationally heavy software can impact the efficiency and speed of the inspection process. Another issue observed was the incomplete point cloud due to occlusions and water puddles. Faro Focus S also has systematic blind spots below the position of the scanner. Additionally, the complex navigation inside the model can also pose challenges for the building surveyor during the inspection process.

6.4.2. Emesent Hovermap ST

During the remote inspection of the framing, the obtained point cloud using Emesent Hovermap ST was evaluated, and several benefits and challenges were observed. One significant benefit of the Emesent Hovermap ST is its ability to provide an exterior view of the building. This feature can be particularly useful in assessing the condition of the building's exterior components. Additionally, the technology provides a birds-eye view, which can help gain an overall perspective of the building and its surroundings.

However, the obtained point cloud using Emesent Hovermap ST posed certain challenges during the inspection. One of the significant challenges noted was the complex navigation inside the model. This challenge can impact the building surveyor's ability to move inside the model and inspect individual components. Another challenge observed was the inability to measure all of the components within the model, which can limit the accuracy of the inspection. Moreover, the obtained point cloud using Emesent Hovermap ST was ineffective in providing a clear view of the site during the inspection process, which could hinder the building surveyors' ability to identify defects accurately.

6.4.3. Matterport Pro 2

Based on the observations made during the remote inspection process, Matterport Pro 2 offers several benefits and poses certain challenges. The benefits of Matterport Pro 2 include its easy-to-use user interface, which was found to be reasonable for navigating during the inspection process. The navigation is similar to Google Street View and enables a fluid motion between panorama views. The technology provided a clear view of the site and enabled the identification of visual defects in the building. Matterport Pro 2 offered multiple angles to inspect individual elements, providing a comprehensive view of the building's interior. Also, Matterport Pro 2 did not require any additional software to be installed, as its technology leverages a web-based application, and the building surveyor can effortlessly access it through a web link. This could potentially improve the efficiency of the inspection. Inside the model, it is possible to conduct freehand measurements to get the distance between two points. The accuracy of this distance is based on the accuracy of the triangulated mesh model.

However, several challenges were also identified during the inspection. One major challenge was the lack of an exterior view of the building due to the incapability of Matterport Pro 2 to capture outdoor environments. This limitation could impact the building surveyors' ability to assess the exterior of the building. Additionally, the Matterport Pro 2 was found to be unable to measure all of the components within the model, which could limit the accuracy of the inspection. Distorted images were also observed at specific locations, potentially hindering the building surveyors' ability to identify defects accurately. Systematic blind spots above and below the position of Matterport Pro 2 in each scan were also noted, which could adversely impact the ability of the building surveyor for the roof inspection.

6.4.4. Summary

Both building surveyors preferred the visual data of panorama images over point cloud or mesh visualisations. That felt the closest to their onsite perception and the most reliable compared to the point cloud and the mesh which exhibit data gaps. Several points of the inspection checklist are related to small objects like braces and screws, which have sizes smaller than 1 cm. While the MLS point cloud has the highest completeness, it does not achieve this level of accuracy, which is why it was not of use to the building surveyors. Even though the TLS point cloud has millimetre accuracy, the detection of fine structures in photos was preferred by the building surveyors. With a point density of 2 mm, one 5 mm screw might be represented with only 4-5 points, which is not enough for measurements. Also, points fall on random places on objects, rather than on their edges, which is another issue and a reason why a very high point density is required to capture objects and enable accurate measurements.

Many TLS scanners such as the Faro Focus S provide panorama images. But the number of stations and thus also the number of panorama views in this field study was lower than with the RGB-D. This was a crucial point for the building surveyors to lean more towards RGB-D data. In future studies the number of TLS scans could be raised which means that the point density of individual scans could be reduced.

Both building surveyors made Matterport the inspection technology of their choice. This was also based on the interactability, or more precisely the user-friendly interface and navigation which enabled them to do the most fluent and confident inspection. This proves that the way of visualisation and the smoothness of the workflow of an inspection is of great importance. In contrast, navigation and orientation in 3D point clouds in Recap were intimidating for the building surveyors. Another plus is the ability to share the Matterport scan online with other people who don't require a local program with local computing power or an account. However, it must be considered that this data is not the property of the user, but of the company providing the server. This could conflict with privacy concerns.

The building surveyors also noted that an experienced building surveyor or building inspector can do a very fast onsite inspection. The navigation with zooming and panning on the computer screen cannot reach the same speed. As the Matterport exhibits blind spots right above and below it, especially the inspection of the ceiling is challenging and requires finding the right position with the right viewing angle.

Table 6.4 summarises the feedback of the building surveyors on the remote frame inspection. They assessed the suitability of each visualisation in terms of accessibility of the information required for inspection, interactability for navigation and measurement, and overall ease of use.

Table 6.4: RBS rating of reality capture technologies for the inspection of framing work on a scale of 1-10, where 1 means unsuitable, 5 means moderately suitable, and 10 means most suitable

Visualisation	Accessibility	Interactability	Overall ease of use
TLS 3D panorama and point cloud	7.5	7	7
MLS Point cloud	5	7	5
Matterport 3D panorama and Mesh model	8	9	8.5

The visualisations of the roof were viewed by a VBA auditor/inspector. They were unable to access the 3D model generated by images and the 3D model generated by LiDAR data, as both require specialised software and high-performance computers for viewing. They examined the orthophoto which they found to be overall useful. The selected construction site has tile roofing with eaves gutter. For future case studies, they recommended a multi-storey building with a metal roof and internal box gutters would be an ideal candidate.

Table 6.5: VBA auditor/inspector rating of reality capture technologies for the inspection of the roof

Visualisation	Accessibility	Interactability	Overall ease of use
3D mesh model from Images (fbx file opened in Paint3D)	Unable to access the data using Paint3D	Unable to interact with the files	Unable to access
Orthophoto (tiff file opened in Windows Photoviewer)	Able to open file	Able to zoom in, spin, pan, and rotate	Good
Drone LiDAR point cloud (e57 file opened in CloudCompare)	File not found	n/a	n/a

7. DISCUSSION AND RECOMMENDATIONS

7.1. Overview

Section 3 of this Report established that there exists (and will continue to be developed) technologies that not only enable remote and assistant-based inspections of building work during construction, but technologies that have the potential to enable all inspections (including conventional inspections) to be conducted more efficiently and effectively. Many of these technologies are already being deployed in building and other industries. The field trial in Section 6 then demonstrated that the use of these technologies to conduct inspections of building work in the Victorian context is technically feasible, but that work is required to optimise their use and benefit.

Industry can be expected to continue to employ technology to support it to construct buildings more efficiently, effectively and safely. This includes the use of technologies to monitor compliance with building and plumbing standards, and to facilitate the early identification and rectification of non-compliant work and defects. Inspection supporting technologies may be used by the industry even in the absence of approval by building regulators.

However, the use of inspection technologies for regulatory purposes is subject to a number of legislative limitations (see Section 2.4). Most relevantly, in Victoria, inspections of building work at mandatory notification stages must be conducted by the RBS or their authorised delegate "*in person*". And while the legislation provides for use of a range of supporting technologies for some types of inspections, the manner in which those technologies are described has not kept pace with actual advancements in the technologies themselves.

The key question (and the question considered in this section) then is whether Australian governments should permit and facilitate the use of remote and like technologies in mandatory and compliance and assurance inspections.

7.2. Should governments permit and facilitate remote inspections?

Based on the practice and technology review (Sections 3 and 5), the mapping of stakeholder perspectives (Section 4), and the field trial case study (Section 6), Table 7.1 summarises the benefits and risks of using remote inspection of building work.

Table 7.1: Arguments for (benefits of) and against (risks of) remote inspections

For (Benefits)	Against (Risks)
• **Improve effectiveness of the inspection process** – identify non-compliances that potentially currently go undetected (e.g. at height; in cavities; use of sensors; etc.). • **Facilitate more persons being involved in the inspection.** • **Produce a more reliable record; improved data for decision making.** • **Potential to improve efficiency** – manage workflow bottlenecks (surveyor shortages); especially in regional areas. • **Potential to reduce cost** – less time of more expensive surveyor. • **More adaptive and flexible regulatory environment** – allows for new technologies and opportunities; adjust to shifting consumer / societal expectations. • **Produces a more consistent legislative approach across all inspections.** • **Technology can be used to enhance all inspections** (inspect cavities; at height). • **Facilitate compliance and enforcement** • **Enhance public confidence** (if implemented well).	• **Incorrect or faulty technology or incorrect use of technology** – non-compliance not detected (including by losing suite context). • **Cost of new technology** (and of upskilling people and systems to use it). • **Certain things cannot be inspected remotely** (tactile, acoustic, olfactory and dynamic/ kinetic aspects). • **Cultural issues around adoption** (resistance; low digital literacy). • **Potential conflict of interest / collusion opportunities** (depending on who operates the technology). • **Competitive issues from change landscape** (early adopters vs laggards). • **Lack of confidence in reliability of new technology.** • **Lack of confidence in industry's ability to use new technology well.** • **Risks to data provenance** (security, auditability, admissibility, etc). • **Can confuse accountability / liability.** • **Undermine public confidence** (if implemented poorly).

The above makes clear that there is great potential in remote and other like technologies; they can make the inspection of building work more efficient, more effective, and safer. For this reason, governments should support the use of remote and like technologies to assist inspection processes. This was the conclusion reached by the ABCB whose model guidance for mandatory inspections recommends a legislative change to permit mandatory inspections being conducted virtually (remotely) as an alternative to conventional onsite inspections.[54] Critically, however, the model guidance leaves definition of the circumstances in which mandatory inspections should be permitted to be conducted remotely to the regulator. Thus, the model guidance leaves many questions unanswered: when should the regulator permit a remote inspection? What conditions, processes and procedures should attach to them? These are important questions because the use of remote and like technologies to assist building inspections is not without risks, and experience with its use in a regulatory setting is not extensive. This leads to the conclusion that the use of remote inspection technology should only be permitted within a policy, regulatory and governance framework that ensures benefits are realised and risks mitigated.

[54] Australian Building Codes Board, *Mandatory inspections: Model guidance on BCR recommendation 18*. 2021, pp. 1718 (Principle 6)

Recommendation:

The use of remote, assistant-based, and other inspection enhancing technologies should be supported within an appropriate policy, regulatory and governance framework that ensures benefits are realised and risks mitigated.

7.3. Framework for maximising benefits and mitigating risks of remote inspections

As noted above, remote and assistant-based inspections should occur within an appropriate policy, regulatory and governance framework that ensures benefits are realised and risks mitigated. The key elements of this framework are set out below by reference to the following four (4) questions:

1. When can remote inspections be conducted?
2. Who decides to conduct a remote inspection?
3. What technology should be used?
4. Who can use the technology?

While aspects of the framework are drafted primarily from the perspective of government, the framework and the principles it espouses are also relevant to building practitioners and other entities involved in supporting Australia's building and construction industries who already are or might in the future employ such technology. Just as government policy and practice is informed by practices of the private sector, so too are private sector policies and practices informed by the policy settings and regulatory requirements of the government. The policy and operational frameworks government and private sector entities put in place to govern their own inspections can operate as benchmarks by which the adequacy and appropriateness of each other's frameworks are assessed.

7.3.1. When can remote inspections be conducted?

This question asks at which sites and for which stages and inspection elements remote and assistant-based inspections can be conducted. At a high-level the answer is relatively simple: when assured the use of the technology will enable the inspection to be conducted more effectively, efficiently and/or safely. Behind the simplicity of this statement lies significant complexity, however. First, remote visual inspections have, by definition, limited visual spans. Familiarity with the site may be necessary to properly contextualise and understand what is being shown (and what is not being shown). For example, the VBA Guideline for the Conduct of Non-mandatory Remote Video Inspections (RVIs) states that it *"is important for the responsible person to gain an appreciation of the site … to provide context and assess the process for inspection to observe the relevant elements*." Second, current remote technologies cannot adequately assess all aspects of a building's construction, for example tactile, acoustic, olfactory, and dynamic/kinetic aspects which provide cues to potential ventilation issues, drainage issues, and inadequately fixed building elements. Remote visual inspections also might not detect sub-optimal ergonomic performance for end-users, such as a door that requires too much effort to close. All of this suggests some onsite presence by the RBS (or other authorised person) will be required and that conventional in-person onsite inspection by those persons should remain the preferred mode of inspection unless use of remote or assistance-based inspections can be shown to be more effective, efficient and/or safe.

The question then turns to whether conventional or remote inspection would be more effective, and how that would be determined. Specifically, it involves asking – "*how do you determine if remote or assistance-based inspections would be more effective, efficient and/or safe than a conventional in-person, onsite inspection conducted by the RBS (or other authorised person)?*" A number of recent reform initiatives have recommended and/or are exploring introducing a graduated approach to determining the stages at which building works must be inspected. For example, the ABCB has developed a multi-factor Building Risk and Complexity Definition to categorise building complexity and risk. The Victorian Expert Panel has recommended that the ABCB Building Risk and Complexity Definition (and accompanying supporting tools) be introduced in Victoria, noting it will support nationally consistent building regulation.[55] They also have recommended additional inspections and an expanded role for local councils and municipal building surveyors for buildings categorised as high and very-high complexity, to increase oversight and scrutiny, recognising the ongoing (and in some cases heightened) need for conventional in-person inspections.[56]

A similar multi-factorial tool should be developed to guide decision-making around the use of remote and assistant-based inspections. The tool could build upon the ABCB Building Risk and Complexity Definition, and incorporate additional decision-making criteria that:

- Assess and match technologies to sites, inspection stages and elements (see Section 7.3.3 below); and
- Ensure the competency of the persons operating the technology (see Section 7.3.4 below).

In effect, the tool would reflect and guide the decision-maker through the key matters about which they must be satisfied before deciding that an inspection can be conducted remotely, namely:

- The suitability of the task (site, inspection stage and inspection element) for remote inspection;
- The suitability of the technology to conduct the remote inspection; and
- The skills, knowledge and competency of the person operating the technology.

To incorporate all the above aspects, we tentatively name this tool the “Task-Technology-Technician Tool”. The development of this tool should involve technology experts, regulators, and professional associations to ensure the accuracy, comprehensiveness, relevance, and contemporaneity of the information included. While the development of such a tool exceeds the scope of this project, we will outline the necessary steps to undertake this endeavour:

- Classify inspection tasks based on their reliance on appearance data, geometry data, or physical contact. Consider the site context and inspection stages as additional factors for consideration;
- Establish and maintain a dynamic list of technologies, organised according to a “family-technology-product” taxonomy (e.g. reality capture-laser scanning-Faro Focus S laser scanner). The product information should include key specifications relevant to the inspection tasks’ requirements, such as accuracy and resolution, as well as operational details such as capital and operational expenses, battery life, and weather-proofing levels; and
- Develop a multi-level competency framework for technicians who will perform inspection tasks of varying complexity and operate different types of technologies.

Table 7.2 on the next page provides two illustrative examples of how such a tool could be used to determine the matching of task, technology and technician.

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[55] Expert Panel on Building Reform, Stage One: Final report to Government (2023) - https://www.vic.gov.au/sites/default/files/2023-03/Expert-Panel%E2%80%99s-Comprehensive-Review-of-Victoria%E2%80%99s-Building-System-Stage-One-Report-to-Government.pdf pp. 61-4 (Rec 15).

[56] Expert Panel on Building Reform, Stage One: Final report to Government (2023) - https://www.vic.gov.au/sites/default/files/2023-03/Expert-Panel%E2%80%99s-Comprehensive-Review-of-Victoria%E2%80%99s-Building-System-Stage-One-Report-to-Government.pdf pp.57-61 (Rec 14) and 64-7 (Rec 16).

#33 – Evaluation of emerging technologies for remote inspections of building work

Recommendations:

Inspections of building work during construction should be conducted by the RBS (or other authorised person) in-person and onsite unless the use of remote or assistance-based inspection technologies can be shown to be more effective, efficient and/or safe.

Develop a multi-factorial tool to guide decision-making on the use of remote and assistant-based inspections, and the selection of suitable technologies matched to site and inspection stage and elements.

Table 7.2: Illustrative examples of the use of the Task-Technology-Technician tool

	Task	Technology	Technician
Description	*The suitability of the task (site, inspection stage and inspection element) for remote inspection*	*The suitability of the technology to conduct the remote inspection*	*The skills, knowledge and competency of the person operating the technology.*
Example #1	**Site:** Class 1 and 10 buildings & low-rise buildings of other classes **Inspection stage:** Pre-pour & framework inspection **Inspection element:** appearance and geometry-based inspection tasks (e.g. foundation steel bar clearance, frame overhanging, framework bracing)	**Terrestrial laser scanner:** A stationary sensor device that emits and detects laser pulses to measure the distance between the sensor and objects, thereby gathering accurate 3D (X, Y, Z) data of the Earth's surface and various objects.	**Building surveying knowledge:** Have general knowledge about building design, engineering, material, services and construction methods that is commensurate with the nature of the inspection being conducted. **Technical knowledge**: Understand the fundamental concepts and principles of laser scanning, including the physics of light, optics, and lasers. **Operational knowledge**: Proficiency in setting up the laser scanner, including leveling, calibration, placing the registration targets, and running the necessary application and software. **Safety requirements**: Consider the safety protocols to protect the laser scanner and ensure the safety of the operator and others.
Example #2	**Site:** All building classes **Inspection stage:** Pre-pour & final inspections **Inspection element:** appearance and geometry-based inspection tasks (e.g. foundation steel bar clearance, roof plumbing)	**Drones (also known as unmanned aerial vehicles or UAV):** A drone refers to any aerial vehicle that receives remote commands from a pilot or relies on software for autonomous flight. Many drones display features like cameras for collecting visual data and propellers for stabilizing their flight patterns.	**Building surveying knowledge:** Have general knowledge about building design, engineering, material, services and construction methods that is commensurate with the nature of the inspection being conducted. **Pilot licensing:** An individual operating a drone weighted more than 2 kg must obtain a remote pilot licence. **Ability to operate drones in a responsible and compliant manner:** Adhere to the general safety requirements and restrictions on the use of drones. **Operational knowledge**: Proficiency in operating particular drone models in an efficient manner, including preparing take-off/landing, planning flight path, and manage battery life.

7.3.2. Who decides to conduct a remote inspection?

The next question is who should be responsible for deciding to conduct a remote or assistant-based inspection (employing the multi-factorial tool). The ABCB model guidance providing for mandatory inspections states that virtual inspections should only occur where the "*statutory building surveyor agrees to the inspection being conducted virtually*". The VBA Guideline for the Conduct of Non-mandatory Remote Video Inspections (RVIs) provides that an RVI may be initiated by the building permit holder, parties to a contract, an individual responsible for the building or plumbing work, or the responsible person (defined to include architects, engineers, building surveyors and inspectors and VBA and other government officials who oversight conformity with legislation, standards, benchmarks, and guidelines). The broader set of initiators makes sense given the VBA guidelines cover the broader circumstances encompassed by non-mandatory inspections. However, they appear to operate by agreement, and are unclear as to who has the ultimate decision-making power to initiate and/or veto an RVI.

Clarity should be brought to who decides to conduct a remote or assistant-based inspection. The principle that should govern this decision is that the person who is responsible at law for the conduct of the inspection should make that decision.

- In the case of mandatory inspections, that person is the RBS;
- In the case of compliance and assurance inspections, it is the person authorised by the legislation to conduct the inspection; and
- And in non-statutory inspections (such as might be carried out by a builder, owner, or insurance company), the person with the contractual right to initiate and determine the scope and nature of the inspection.

Recommendation:

The decision to conduct a remote or assistant-based inspection should be made by the person who is responsible at law for the conduct of the inspection, which:

- in the case of mandatory inspections, is the RBS.
- in the case of compliance and assurance inspections, is the person authorised by the legislation to conduct the inspection.
- in the case of non-statutory inspections, the person with the contractual right to initiate and determine the scope and nature of the inspection.

7.3.3. What technology should be used?

As can be seen from the sample "Task-Technology-Technician Tool" shown in Section 7.3.1 above, some factors require a technical understanding of remote and assistant-based technologies that many decision-makers are unlikely to have – for example, with respect to the accuracy, range, utility and their feasibility for particular sites and inspection elements. Decision-makers would, therefore, benefit from guidance on the suitability of particular technologies for specific sites, and inspection stages and elements.

The question then is: who should provide that guidance? The risks associated with poor or inappropriate technology suggest some form of government involvement is warranted. However, it should not be unnecessarily heavy-handed or interventionist. For example, full government regulation, where governments set the standards with which the technology must comply, and then vet and pre-approve products prior to their use, risks stifling innovation, increasing the time and cost of bringing new technologies to market, and limiting the range of technology and developers. Rather, a co-regulatory model is warranted, one where the government sets technologically neutral outcome-orientated standards and requirements, and the industry develops and puts in place systems to comply with those standards and requirements.

Government standards should cover its minimum regulatory (legal and operational) requirements in the following areas:

- Data precision standards;
- IP licensing to enable regulatory oversight and data exchange;
- Compatibility and interoperability requirements – in particular, the data recorded during a remote (virtual) inspection must be capable of being part of the documentation lodged with the building regulator;
- Data provenience, management, and retention (auditable etc., to ensure admissibility in enforcement proceedings); and
- Privacy protection, data security and cybersecurity.

These requirements should be included in the Task-Technology-Technician Tool discussed in Section 7.3.1 above.

The existence of these requirements should incentivise technology developers and manufacturers to market their products by reference to them, and creates the opportunity for third-party verification and ratings of products (in much the same way as Energy Star ratings). Industry and professional associations may be well suited to this role.

Recommendations:

Government should prescribe technologically neutral outcome-orientated standards and requirements that remote and assistant-based inception technologies must satisfy in order to be used as part of statutory inspections (mandatory or compliance and assurance).

Government should work with industry and professional associations to develop systems to assess and rate technologies for remote and assistant-based inspections.

7.3.4. Who can operate the technology?

The ABCB model guidance providing for mandatory inspections states that "*the statutory building surveyor must nominate a registered and competent practitioner to conduct the inspection (onsite)*". The VBA Guideline for the Conduct of Non-mandatory Remote Video Inspections (RVIs) states that the operator must be onsite and have "*building and technical knowledge commensurate with the nature of the inspection being conducted*." The VBA Guideline does not speak directly to the operator's knowledge and skills in using the technology itself. However, both seem to be important – that the person operating the technology onsite has the technical skills, knowledge, and competency to understand both the nature of the inspection (and their role) and to properly use the technology. The second element – that the person operating the technology has the technical skills, knowledge, and competence to use the technology – increases in importance as the sophistication and complexity of the technology increases.

A simple example to illustrate – the use of a video recording to facilitate a remote inspection. Recalling that the obligation to inspect applies to all building work completed or in progress at that time (and not just to the subject of the inspection stage (e.g. footings; framework), an operator may need to have the skills and competencies to know when to take a wide pan to facilitate a broader assessment of the site, and when to zoom into specific elements. They also may need an understanding of the correct settings for fixed image and video cameras such as exposure levels, focussing and depth of field and focal length, and techniques such as incorporating scale elements to calibrate perceived size and proportions.

Added to this is a third requirement: independence. The person operating the technology should be sufficiently independent of the persons whose work is being inspected. In the case of mandatory inspections, construction personnel, plumbers, and other persons whose work is the subject of inspection should not operate the technology, or otherwise participate in the remote inspection in a manner that could create perceptions of a conflict of interest. The same principle also should apply to statutory compliance and assurance inspections, and private contractual inspections, although there arguably is scope for some flexibility in the strictness of its application if circumstances mean the inspection cannot otherwise be done in a manner that is efficient, effective, safe.

Deciding whether a person:

- has the building and technical knowledge commensurate with the nature of the inspection being conducted
- has the technical skills, knowledge, and competence (and in some cases (e.g. drones) licence) to use the technology for the purpose of the inspection
- is sufficiently independent of the persons whose work is being inspected,

should be made by the person who decides to conduct the remote inspection (see Section 7.3.2 above; indeed, it is part of the one decision as reflected in the Task-Technology-Technician Tool).

But like the decision with respect to what technology should be used (Section 7.3.3), the decision-maker would benefit from guidance and/or third-party verification of the suitability of a potential technology operator – with respect to both their competency to use the technology and their understanding of the nature of the inspection being conducted. And again, like the decision with respect to what technology to be used, government prescription of skills and competency standards for onsite operators of remote (and other inspection enhancing) technologies is likely to lack the agility required for technologies that differ in sophistication and complexity of use, and are evolving rapidly. It is unlikely government could maintain a regulatory framework tailored and calibrated to the complexity and rapid evolution of different technologies. Rather (as was the case with what technology to be used), the solution lies with industry and in this case, the education sector. Government should work with professional associations and educational instructions to develop courses and qualifications in the use of different remote and inspection enhancing technologies, that would be evidence of possessing the necessary technical skills, knowledge, and competence.

Becoming a technology operator also could form the basis of a cadetship or internship arrangement within building surveyor businesses and local councils. These too could be developed in association with professional and industry associations. Doing so aligns with the Victorian Expert Panel's Stage One Report that encouraged the development of new pathways to becoming a registered building surveyor or inspector, thereby boosting their numbers – a priority identified by the Expert Panel.[57]

[57] Expert Panel on Building Reform, Stage One: Final report to Government (2023) - https://www.vic.gov.au/sites/default/files/2023-03/Expert-Panel%E2%80%99s-Comprehensive-Review-of-Victoria%E2%80%99s-Building-System-Stage-One-Report-to-Government.pdf pp. 29-30 (Recs 6 and 7).

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Recommendations:

The person deciding to conduct a remote or assistant-based inspection must satisfy themselves that the person who will operate the technology on site:

- has building and technical knowledge commensurate with the nature of the inspection being conducted;
- has the technical skills, knowledge, and competence (and in some cases (e.g. drones) licence) to use the technology for the purpose of the inspection; and
- is sufficiently independent of the persons whose work is being inspected.

Government should work with professional associations and educational institutions to develop appropriate courses for persons operating remote, assistant-based and inspection enhancing technologies.

Governments should work with professional associations to establish pathways to becoming a registered building surveyor or inspector for persons credentialed as an inspection technology operator.

8. CONCLUSIONS AND FURTHER RECOMMENDATIONS

This project aimed to establish a comprehensive understanding of the benefits and risks associated with implementing remote inspections in Victoria. The key findings of this project are summarised as follows:

- The utilisation of remote inspections, assistant-based technologies, and other inspection-enhancing tools should be supported by a robust policy, regulatory, and governance framework. This ensures that the benefits are realised while effectively mitigating associated risks.
- Several international guidelines exist for conducting remote inspections in both the building industry as well as other (related) industries. These guidelines embolden implementation efforts; they serve as reference points for Victoria's (and Australia's) own burgeoning guidelines.
- Stakeholders (i.e. regulators and practitioners) generally hold a positive and receptive attitude toward remote inspections. However, concerns do exist regarding conflicts of interest, costs, and operator competency.
- The current technology landscape supports the use of remote inspection for a wide range of inspection tasks, particularly those reliant on visual and geometric data. Yet, limitations exist for certain types of inspection tasks that involve precise measurements or testing with specialised devices.
- Various reality capture technologies were tested and proven technologically feasible for conducting a number of mandatory inspection tasks remotely on Class 1 building sites at multiple mandatory notification stages. Feedback from participating building surveyors suggested a preference for visual data (e.g. panorama images) over 3D models (e.g. point cloud or mesh visualisations).
- Informed by stakeholder engagement, regulatory analysis, technology assessment, and field trials, a set of recommendations has been formulated to address the critical decision-making points when considering remote inspections.

Building upon the findings and recommendations outlined in the previous sections, the following sections provide additional advice on important aspects related to the implementation of remote inspections: 1) guiding implementation of remote inspection, 2) regulatory reform recommendations, and 3) technology scenarios for future remote inspections.

8.1. Recommendations for a guideline for conducting remote inspections

A number of guidelines and policy principles to inform the conduct of remote inspections fall out of the above analysis. In addition, there are a number of relevant existing sources. For example, the VBA *Guideline for the Conduct of Non-mandatory Remote Video Inspections (RVIs)* provides an excellent starting point for the topics that should be covered in "how to" guidelines. It is recommended that future guidelines adhere to the structure and considerations outlined below.

- Scope – which inspections can be conducted remotely (see Section 7.3.1)
- Safety – work, health and safety requirements
    - See the section on OHS in the Appendix "*Recommended drone use guidelines and checklist*" – it applies equally to other technological assistants.
- Technology – minimum technical requirements (see Section 7.3.3).
- Personnel – who can operate the technology (see Section 7.3.4).
- Initiation
    - Who decides to conduct a remote inspection (see Section 7.3.2).
    - Obtaining necessary approvals and consents (e.g. if required by regulations governing the use of drones).

- Operation of remote inspections – principles, process, and procedure.
    - Inspections must be directed and overseen by the RBS (in the case of mandatory inspections) and other authorised persons (in the case of compliance and assurance inspections) who remain responsible for the proper inspection of the work, and that they should put in place procedures to:
        - oversee the work of the person to ensure the inspection is being conducted appropriately;
        - ensure that all data recorded by the use of the technology is made and given to them promptly; and
        - ensure that the person notifies them promptly about any matters that call into question compliance with the Act, Regulations or building permit.
- Inspection conclusion
    - The inspection should be conducted employing the same standards and requirements as for in-person inspections, save for the additional data and record requirements (below).
- Inspection data and records – retention and security; privacy, data, and cybersecurity
    - The guidelines should also require that all data recorded during a remote inspection (using enhanced inception technologies) must be stored and form part of the documentation lodged with the building regulator and provided to the building approval applicant.[58]

8.2. Regulatory reform recommendations

To give effect to the recommendations in Section 7, the regulatory framework should be amended to do the following:

- Permit the RBS (in the case of mandatory inspections) and other authorised persons (in the case of compliance and assurance inspections) to use remote, assistant-based and other inspection technologies if satisfied that the use of the technology will enhance the thoroughness and accuracy of the inspection.
- Incorporate a broad and inclusive definition of remote, assistant-based and other inspection technologies that extend beyond photographs, still and moving images, and audiovisual recordings. That is, one that would also include new and emerging technologies such as laser scanning, radar, extended, virtual reality capture technology, infra-red thermography, etc.
- Authorise the RBS (in the case of mandatory inspections) and other authorised persons (in the case of compliance and assurance inspections) to nominate a competent person to assist with the operation of remote, assistant-based and other inspection technologies.
- Make clear that the RBS (in the case of mandatory inspections) and other authorised persons (in the case of compliance and assurance inspections) remain responsible for the proper inspection of the building work, the operation of the technology, and the activities of the technical assistant.[59]

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[58] This is in accordance with ABCB model guidance Principle 6, and the Expert Panel Stage One Report that called for improvements in data collection across the building lifecycle and to expand the recently developed Building Activity Management System (BAMS) to support a consistent approach to lodging and tracking documentation across a building project, with BAMS (or another single system) providing a central online portal for all building information (Expert Panel on Building Reform, Stage One: Final report to Government (2023) - https://www.vic.gov.au/sites/default/files/2023-03/Expert-Panel%E2%80%99s-Comprehensive-Review-of-Victoria%E2%80%99s-Building-System-Stage-One-Report-to-Government.pdf p. 18).

[59] VBA Building Practice Note MI-01 lists actions the RBS should take when authorising a person to inspect the work on their behalf pursuant to Section 35B. They include: satisfying themselves that the person holds relevant and adequate experience to undertake the inspection; satisfying themselves that the person will undertake a thorough inspection to check that the building work complies with the Act, Regulations and building permit; putting in place procedures to oversee the work of the person to ensure that inspections are being carried out appropriately; putting in place procedures to ensure that the required record of the inspection is made and given to the them promptly; and putting put in place procedures to ensure that the person notifies them promptly about any matters that call into question

- Require data recorded using remote, assistant-based and other inspection technologies to be securely stored and form part of the documentation lodged with the building regulator.

It also is important that these regulatory amendments are drafted in a manner that allows implementing agencies flexibility to respond to a rapidly changing regulatory environment while remaining true to the regulatory regime’s objectives. As noted in Section 2.5.6, in areas impacted by rapid technological innovation and changing consumer preferences and industry practices, regulatory agility is important.

But amendments to the regulatory framework alone - while necessary – are unlikely to be sufficient to ensure the effective and appropriate adoption of remote inspection technologies. We have seen that building inspections occur as part of a complex building regulatory framework, and within a crowded and sometimes contested regulatory space. Knowledge, resource, attitudinal and operational barriers exist to the adoption of remote inspection technologies at scale. As a result, support and resistance can be expected in equal measure. Therefore, reforms to permit and facilitate remote inspections must be carefully planned and implemented. Governments need to work proactively with stakeholders to explain and demonstrate the benefits of remote inspection technologies, and how the risks and issues associated with its use (as identified by stakeholders) can be appropriately addressed and mitigated. Governments also need to work with stakeholders to develop guidance, tools and the broader infrastructure to assist the sector to utilise remote inspection technologies effectively and appropriately. A number of specific tools and initiatives are recommended in Section 7.

8.3. Technology scenarios for remote inspections

The success of remote inspections hinges upon the continuous advancement of research and technologies to enhance their effectiveness, efficiency, and safety. In Table 8.1, three application scenarios for remote inspection technologies are predicted and illustrated. These scenarios span a broad spectrum, ranging from immediate and incremental improvements to the existing remote inspection methods to paradigm shifts that necessitate revolutionary advancements in multiple fields.

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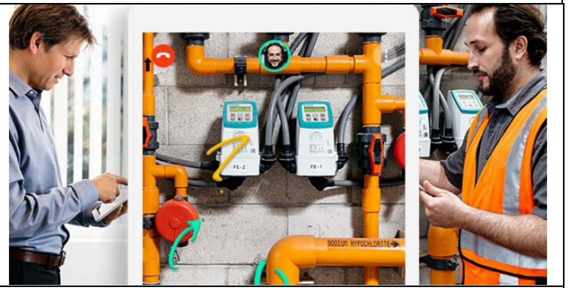
compliance with the Act, Regulations or building permit. The Practice Note could be amended (or an additional practice note issued) to address the actions the RBS should take when authorising the use of technology to assist with an inspection.

Table 8.1: Technology scenarios for remote inspections of building work

Scenario	Description	Example	Illustration
Assistant-based video inspection (0-3 years)	Inspection done remotely using video technology and specialised tools that facilitate communication between an off-site inspector and an onsite assistant while ensure privacy and authenticity.	Smartphone applications that allow real-time communication between the inspector and onsite personnel; enhanced by functions such as spatial annotation and location authentication.	
Technology-enhanced assistant-based inspection (1-5 years)	Data capture technology is operated by an onsite assistant to help the inspector see/sense things in places that they otherwise cannot access safely or at all. The technology collects the data; the inspector does the compliance assessment using advanced visualisation tools.	An onsite assistant operates a drone to see the building from elevated positions to inspect the roof. They control robots equipped with cameras and sensors to view confined spaces such as pipes, plumbing, cavities. Inspectors examine the data remotely using virtual or augmented reality tools for better spatial perception.	
Fully automated remote inspection (5-10 years)	Both data capture and compliance assessment are conducted automatically by robotic and artificial intelligence technologies. Inspectors confirm the inspection outcome remotely. No onsite personnel are necessary.	A self-piloted drone (“drone in a box”) takes photos periodically throughout the construction of a building; these images are analysed using a machine learning model trained to automatically identify non-compliance and notify relevant stakeholders.	

APPENDIX: RECOMMENDED DRONE USE GUIDELINES AND CHECKLIST

Recommended drone use guidelines and checklist

Overview

Drones can be used for building inspection purposes. However, care must be taken to ensure their use is consistent with:

1. the *Building Act 1983* (Vic)
2. the permissioning requirements of the Civil Aviation Safety Regulations 1998 (Cth)
3. conditions and restrictions on the use of drones found in the Civil Aviation Safety Regulations and other regulations governing the use of drones
4. the *Occupational Health and Safety Act 2004* (Vic).

This document summarises the requirements and limitations under each. It also briefly addresses issues of liability and insurance.

1. Building Act 1993 (Vic)

The *Building Act* differentiates between two broad types of inspections:

1. mandatory inspections conducted at statutory notification stages and at other stages and times determined by the relevant building surveyor
2. compliance and assurance inspections required or authorised by the Act.

The use of drones in each type of inspection is explained below.

Mandatory inspections

Mandatory inspections must be conducted by the relevant building surveyor or their delegate (and "in person" in the case of inspections at mandatory notification stages). Their delegate can be a person registered as a building surveyor or building inspector under Part 11 of the Act and whose registration authorises the carrying out of that inspection; or in the case of a prescribed class of inspection, an appropriately skilled engineer. The Act also provides for the building surveyor or their delegate taking photographs (including video recordings) of the building works. Combined, these requirements suggest that it must be the building surveyor or their delegate who takes the photographs or video recordings.

The Victorian Building Authority (VBA) Building Practice Note MI-01 states the building surveyor or their delegate cannot conduct the mandatory inspection relying *only* on photographs, *drone*, video, declarations, or reports provided by a person who is not a registered building surveyor, inspector, or prescribed engineer (emphasis added). Two points are worth noting:

- First, the Practice Note allows for the use of drones; drones are not mentioned in the Act.
- Second, it implicitly allows for persons other than the building surveyor or their delegate to use the drone, but provides it cannot be the only thing upon which they rely.

In summary, drones can be used by building surveyors and their delegates both to view the building works and to take photographs and video recordings of them. The legislative basis for them using technical assistants to operate drones could be clearer. If the drone is operated by a person other than the building surveyor or their delegate, it cannot be the only thing upon which that person relies.

Compliance and assurance inspections

Compliance and assurance inspections variably can be carried out by a VBA inspector, a municipal building surveyor (or a person validly authorised by a municipal building surveyor), a compliance auditor or plumbing inspector, and persons authorised by Energy Safe Victoria, the Fire Rescue Commissioner and the Chief Officer of the Country Fire Authority.

Authorised persons conducting compliance and assurance inspections (like persons conducting mandatory inspections) can take photographs (including video recordings) of the building works. However, in contrast to the situation with respect to mandatory inspections, the Act also provides that an authorised person conducting a compliance and assurance inspection may have the assistance of any person necessary to provide technical assistance to the authorised person.

In summary, drones can be used as part of a compliance and assurance inspection, the authorised person conducting the inspection can engage technical assistants to assist them with the drone's use, and the authorised person (presumably) can rely solely on photographs and video recordings taken by the drone.

2. Permissioning requirements

Drones (or remote piloted aircraft (RPA), as they are referred to in the regulations) are regulated under Division 101.F of the Civil Aviation Safety Regulations 1998 (Cth), which regulations are administered by the Civil Aviation Safety Authority (CASA). Drones are classified by weight (see Appendix 1), with some regulatory requirements specific to weight categories.

The Regulations impose three broad permissioning requirements on drones and those who use them:

A. a requirement that the drone be registered
B. a requirement that the pilot either be accredited or licensed
C. a requirement that businesses providing drone services be certified.

Each is explained below.

A. Drone Registration

Drones being used for commercial purposes (either as part of a business or person's job) must be registered. CASA lists as an example of such a purpose, "inspecting industrial equipment, construction sites or infrastructure". This applies regardless of the drone's weight.

Registering your drone is a relatively simple task. It involves two steps.

First, you must obtain an aviation reference number (ARN). An ARN is similar to a customer number. You need an ARN to hold obtain any permission (registration, accreditation, licence or certification) from CASA. ARNs can be issued to both organisations and individuals. The only pre-requisite is that the party must be a legal entity.

Click here (https://www.casa.gov.au/licences-and-certificates/aviation-reference-numbers) for the portals to apply for an organisation or individual ARNs.

Second, you must apply to register your drone. To apply, you will need to know the make, model, serial number, weight and type of drone. A registration fee also may apply.

Click here (https://www.casa.gov.au/drones/registration-and-flight-authorisations/register-your-drone) for the portal to register your drone.

B. Pilot accreditation / licensing

Persons piloting drones for commercial purposes (which includes inspecting construction sites) must either be accredited or licensed.

Accreditation: Accreditation is available for persons piloting drones that weigh less than 2 kg. Weight is calculated inclusive of all attachments such as cameras and sensors.

Click here (https://www.casa.gov.au/drones/get-your-operator-credentials/operator-accreditation) for the portal to apply for accreditation.

Most drones equipped to conduct construction site inspections are likely to weigh more than 2 kg. As a result, a remote pilot licence will be required.

Licensing: Persons operating a drone that weighs more than 2 kg for commercial purposes must obtain a remote pilot licence. Obtaining a remote pilot licence is more complicated than accreditation.

Step 1: Obtain an aviation reference number (ARN). See above.

Step 2: Pass the required theory and practical training. CASA has a list of approved training providers that provide the training and assess you at the end.

Step 3: Apply for a remote pilot licence. This is done by the training provider on the applicant's behalf, after they pass both the theory and practical training components.

A remote pilot licence is specific for particular drone types and weights, generally by reference to whether the drone weighs:

- less than 7 kg
- less than 25 kg
- less than 150 kg (with specific type ratings)
- more than 150 kg (with specific type ratings).

There also are mechanisms to have prior aviation experience recognised

Click here (https://www.casa.gov.au/drones/get-your-operator-credentials/remote-pilot-licence) for more information about obtaining a remote pilot licence.

C. Certification of businesses providing drone services

Businesses who operate as drone service providers must obtain a Remotely Piloted Aircraft Operator's Certificate (ReOC). "Drone services provider" is not defined in the Regulations; nor is there a definition on the CASA website. It would include businesses for which providing drone services is their sole or predominant activity. This is likely to include businesses that offer drone services to third parties (such as building surveyors and other persons authorised to conduct building inspections), but would not include building surveyors (and other authorised persons) who use drones in a supporting or ancillary manner to assist them to conduct inspections.

But remember: if a building surveyor (and other authorised person) uses drones in a supporting or ancillary manner to assist them to conduct inspections, the pilots of those drones would need to be accredited (if the drone weighs under 2 kg) or licensed (if the drone weighs more than 2 kg).

Click here (https://www.casa.gov.au/drones/get-your-operator-credentials/remotely-piloted-aircraft-operators-certificate) for more information about applying for a Remotely Piloted Aircraft Operator's Certificate

3. Conditions and restrictions on the use of drones

A. General safety

The Civil Aviation Safety Regulations also impose general safety requirements and restrictions on the use of drones. These apply even if the drone is registered, the pilot licensed or accredited, and the business certified. The main requirements relevant to the use of drones for building inspection purposes are:

- Drones must not be operated in a manner which creates hazards for persons, property, or other aircraft.
- Drones must be at least 30 metres away from other people, or with their consent 15 metres.
- Drones cannot take videos or photographs of other people without their consent.
- Drones must be kept within the user's naked eye line-of-sight.
- Drones cannot be flown at night, or through cloud or fog.
- A drone user may only operate one drone at a time.
- Drones cannot be flown higher than 120m above ground level.
- Drones cannot be flown over or near an area affecting public safety or where emergency operations are underway.
- Drones must not be flown over or above people or in a populous area (e.g., beaches and sports stadiums).
- Drones which weigh more than 250g must be flown at least 5.5km away from a controlled airport.

In addition, noise, privacy and other regulations govern the use of drones. These are summarised below.

B. Noise

All drones are required to abide by the *Air Navigation (Aircraft Noise) Regulations* 2018 (the Noise Regulations). This requires drones being used for commercial purposes (which includes inspecting construction sites) to obtain a noise approval to fly.

Click here (https://www.drones.gov.au/drone-noise-approval) for the portal to apply for a noise approval to fly.

Based on the answers provided in the self-assessment, the activity might be automatically exempt from requiring approval, granted an automatic approval or the applicant might be required to complete a full application. A full application is required if the activities undertaken by the drone operator are considered to pose a high risk of causing significant noise impacts to the community. Drones used for most construction inspections are unlikely to require a full application; a possible exception being inspections of complex or large construction sites located in densely populated or sensitive areas.

C. Privacy

Drone operators also must comply with relevant Federal, State and Territory privacy laws. Federally, the *Privacy Act 1988* (Cth) and the Australian Privacy Principles apply to businesses with an annual turnover in excess of $3,000,000. In Victoria, the *Privacy and Data Protection Act 2014 (Vic)* and the *Surveillance Devices Act 1999* (Vic) are relevant. The laws the collection, storage, access to, and dealing with, of personal information. The purposes of this advice does not warrant a detailed examination of the laws. The following principles should suffice:

- Consent is required of persons whose likenesses will be captured by and who will be identifiable from the use of the technology. It is therefore best that persons likenesses are not recorded or captured by the technology.

- The use of the technology should not knowingly record or observe a private activity of another person without that person's consent. Private activities mean those that the party can have reasonably taken to be observed only by the party themselves, but do not include activities carried on outside a building. Care should be taken to ensure people located inside in a neighbouring house or apartment are not captured in the inspection recordings. And while the law does not apply to recording people walking outside and doing general 'public' activities, care also should be taken to minimise the likelihood of their being recorded.

These laws are not drone specific laws. Currently, Federal, State and Territory governments, in consultation with industry and other key stakeholders, are developing drone specific privacy guidance. This is an emerging area of the law and should be monitored, by referring to https://www.drones.gov.au/commercial/privacy.

D. Other regulations and Requirements for the use of Drones

In addition to the requirements listed above, there are state and territory rules and local government regulations for drone use of which drone operators need to be aware. There are restrictions around flying drones in sensitive environmental areas, near marine parks, near major events, in some national parks, and around national monuments and correctional facilities. These restrictions increasingly are becoming more common. They also can change frequently. A detailed examination of them is outside the scope of this paper. However, they are catalogued at https://www.drones.gov.au/state-and-territory-rules.

There does not appear to be any laws relating to the operation of drones near, under or above electric transmission lines and towers (powerlines), although a framework is in development especially as it applies to drone delivery services. Some industry bodies such as the Queensland's state-owned Powerlink Queensland have issued guidance on how to safely fly drones around transmission lines. Central to these is a recommendation to keep drones at least six meters away from powerlines and towers. However, the recommendation seems to be premised not on safety, but because of the effect the electric and magnetic fields (EMF) emitted by these towers have on drones. Notwithstanding it is not legislated and not safe directed, the recommendation constitutes sound industry practice founded upon reasonable grounds.

E. Record keeping

Finally, there also are record keeping requirements. These are contained in CASA's Part 101 (Unmanned Aircraft and Rockets) Manual of Standards 2019 (as amended). The most onerous record keeping requirements apply to holders of a Remotely Piloted Aircraft Operator's Certificate (that is, businesses who operate as drone service providers). Fewer restrictions apply to drone pilots, although good practice suggests they should keep an operational log that records:

- the nature and purpose of the flying operation
- information identifying the drone, including the type, model and unique identification mark
- the dates and times of the operation
- the places from which and over which the drone flew
- any consents obtained
- the heights at which the drone was flown.

4. *Occupational Health and Safety Act 2004* (Vic)

The flying of drones at construction sites raises a number of potential work health and safety issues, including:

- the safety of the person operating the drone. Construction sites can be messy places with slip, trip and falls hazards. There often is hazardous machinery and tools being employed doing inherently dangerous activities.
- The safety of personnel on the site at risk from a drone falling or colliding with them, and from being distracted by their operation.
- The safety of person in the vicinity of the site, who too are at risk from a drone falling or colliding with them, and from being distracted by their operation.

The *Occupational Health and Safety Act 2004* (Vic) (OHS Act) imposes duties on numerous persons to take reasonably practicable measures to eliminate or mitigate these risks. These include:

- the pilot to ensure the operation of the drone is safe, and does not create risks to the safety or health of those at or in the vicinity of the site
- the employer of the pilot to ensure the pilot is appropriately trained and competent (and licensed or accredited) to fly the drone safely, and that there are appropriate policies and procedures in place (and being observed) governing its use
- the person in control of the construction site to ensure slip, trip, falls and other hazards that might pose a risk to the drone pilot are eliminated or mitigated to the extent reasonably practicable
- the building surveyor or other authorised person engaging the pilot to ensure the pilot has relevant and adequate experience to fly the drone safely, and is accredited or licensed
- workers on the site to take reasonable care not to engage in activities that might create a risk to their, the pilot's or other person's health and safety.

This would require the development of policies and protocols governing the assessment and selection of, and attendance at, construction sites for drone use. These protocols also should deal with the need for construction induction (white) cards.

Construction Induction (White) Card

The Occupational Health and Safety Regulations 2017 (Vic) state a person must not perform construction work at a workplace unless the person holds a current construction induction card – known in the industry as the "white card". The obligation to hold a white card does not apply to persons attending a construction site that do not perform construction work. "Construction work" is defined to mean "any work performed in connection with the construction, alteration, conversion, fitting out, commissioning, renovation, refurbishment, decommissioning, or demolition of any building or structure, or any similar activity." This would not include persons attending the construction site to inspect it, or to assist an inspection by operating a drone.

Notwithstanding the strict legal position, builders may require all persons entering their construction site to hold a white card. Such policies may create a barrier to the use of drones if the time and cost of training acts as a disincentive. On the other hand, it creates a potential competitive advantage for those drone service providers and building surveyors prepared to make the investment. In this regard, it is instructive that CASA maintains a registry of all certified drone service providers (holders of a Remotely Piloted Aircraft Operator's Certificate (ReOC)). Currently, 97 companies on the register are surveyors. Most are industrial or agricultural surveyors. There appears to be only one building surveyor - Brisbane Building Inspections. In their promotional material, they emphasise their CASA registration and ability to use drones more extensively than their competitors.

Finally, and regardless of whether a white card is or is not required (by law or company policy), the person in control of the construction site should ensure that all persons entering the site who do not have a white card are appropriately supervised to protect them from construction site risks and hazards, and to ensure they do not inadvertently create any risks to themselves or others. This would include the operators of drones.

5. Liability and Insurance

Liability for drone use is similar to liability for the use of motor vehicles. Except for cases where a manufacturing fault gives rise to a claim under consumer law, liability for drone use falls upon either:

- the individual operator, or
- in the case of a business who has employed an individual to operate a drone in the course of their employment, upon the business.

Persons and businesses operating drones therefore should consider insuring against the risk.

The Civil Aviation Safety Regulations do not require operators of drones in Australia to take out insurance. However, CASA strongly recommends all commercial and recreational drone operators to discuss with an insurer the potential liability for any damage to third parties resulting from the operation of the drone operation and consider taking out suitable insurance.

Broadly speaking there are two types of insurance available to commercial operators of drones:

1. third-party public liability insurance, and
2. UAV insurance, being a specialised insurance product for unmanned aerial vehicles.

Moreover, while there is no requirement for RPA operators to purchase insurance, CASA may impose a condition on a certified drone service provider to obtain insurance as part of that operator's risk management procedures. At the same time though, CASA will not consider an insurance policy as a risk control measure or risk mitigation strategy when assessing any application from a certified RPA operator.

Conclusion

Various Federal, state, territory and local government rules and regulations govern the use of drones in Australia. This report covers the main laws and regulations applicable for the use of drones by building surveyors in performing building inspections. The challenge for building surveyors, drone operators for inspection purposes and even for regulatory bodies like the VBA, is to ascertain the restrictions applying to them and to remain update on the rapidly evolving laws.

To assist there are a number of helpful government websites, most notably drones.gov.au (maintained by the Federal Department of Infrastructure, Transport, Regional Development, Communications and the Arts) and the drone section on the CASA website.

In addition, CASA maintains a list of CASA-verified drone safety apps that use location-based maps to assist in determining where drones can and cannot be flown according to aviation legislation. A list of these apps can be found by clicking here (https://www.casa.gov.au/knowyourdrone/drone-safety-apps).

Finally, Appendix 2 is a checklist developed for use by building surveyors and drone operators.

Appendix 1: Types of Drones (Remote Piloted Aircraft (RPAs))

Types of RPA

Item	The term …	means …
1	***micro RPA***	an RPA with a gross weight of not more than 250 g.
2	***very small RPA***	an RPA with a gross weight of more than 250 g, but not more than 2 kg.
3	***small RPA***	an RPA with a gross weight of more than 2 kg, but not more than 25 kg.
4	***medium RPA***	(a) an RPA with a gross weight of more than 25 kg, but not more than 150 kg; or (b) a remotely piloted airship with an envelope capacity of not more than 100 m^3.
5	***large RPA***	(a) a remotely piloted aeroplane with a gross weight of more than 150 kg; or (b) a remotely piloted powered parachute with a gross weight of more than 150 kg; or (c) a remotely piloted rotorcraft with a gross weight of more than 150 kg; or (d) a remotely piloted powered-lift aircraft with a gross weight of more than 150 kg; or (e) a remotely piloted airship with an envelope capacity of more than 100 m^3.

Appendix 2: Checklist for drone operation in building inspections

PRE-FLIGHT		
Has the building surveyor satisfied themselves the drone pilot has relevant and adequate experience to assist with a building inspection?		☐
Has the building surveyor briefed the pilot on conducting the drone inspection in accordance with relevant laws and applicable procedures?		☐
Is the pilot CASA accredited (drone weighs less than 2 kg) / licensed (drone weighs more than 2 kg)?	Click here to apply for accreditation. Click here to apply for a remote pilot licence.	☐
Is the drone registered with CASA?	Click here for the portal to register your drone	☐
Is the pilot flying for a business providing drone services? If yes, you the business must be certified.	Click here to apply for certification.	☐
ON-SITE; DURING FLIGHT		
Site-assessment	• Use CASA self-assessment to determine if drone requires noise approval? • Flying during daylight hours? • Flying in clear weather (no fog)? • Not flying over a populous area? (e.g., beaches and stadiums) • Not flying over an area affecting public safety, or emergency operation? • Not flying within 5.5km of a controlled airport? • Not flying within six meters under, near or next to transmission lines and towers? • Checked additional state/local council requirements? • Go to https://www.drones.gov.au/state-and-territory-rules • Checked whether you can fly in this space? • Use: CASA approved app (e.g., Ok2fly)	☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐
During operation	• 30m away from others (without consent); 15m away (with consent)? • Not taking photographs or videos of others without consent? • Drone within naked-eye line of site? • Operating one drone at a time? • Not flying through cloud or fog?	☐ ☐

	• Not flying higher than 120m (from the ground)?	☐ ☐ ☐ ☐
POST-FLIGHT		
Record keeping	Have you kept a record of: • Nature and purpose of drone operation; • drone identification info (type, model, serial no.); • date, time and location of drone operation; • consents obtained • height of flight. Note: If you are flying for a business providing drone service, additional record-keeping requirements.	☐ ☐ ☐ ☐ ☐

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