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DRIVERS AND BARRIERS TO DIGITALISATION: A CROSS-ANALYSIS OF THE VIEWS OF DESIGNERS AND BUILDERS IN THE CONSTRUCTION INDUSTRY

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Srinath Perera, Professor,
School of Engineering, Design and Built Environment, Western Sydney University, Australia;
Srinath.perera@westernsydney.edu.au

Xiaohua Jin, Dr,
School of Engineering, Design and Built Environment, Western Sydney University, Australia;
xiaohua.jin@westernsydney.edu.au

Marini Samaratunga, Dr,
School of Engineering, Design and Built Environment, Western Sydney University, Australia;
marini.sam@westernsydney.edu.au

Kasun Gunasekara, Mr,
School of Engineering, Design and Built Environment, Western Sydney University, Australia;
k.gunasekara@westernsydney.edu.au

SUMMARY: *The construction industry around the world has identified the significance of digitalisation, and a wide range of research has explored the drivers and barriers of digitalisation within the construction industry. However, none has compared the views of designers and builders separately. Hence, this research critically reviewed drivers and barriers that affect the digitalisation of construction for designers and builders with an in-depth cross analysis. A detailed survey was conducted to capture drivers and barriers to digitalisation impacting the building sector in NSW, Australia. The survey captured the views of 542 respondents (347 designers and 195 builders), enabling the interpretation of results at a 95% level of confidence. Descriptive statistics were interpreted and cross analysis between designers and builders, and within different organisation sizes were conducted using the Mann-Whitney U test and Kruskal-Wallis H test. The survey findings were further verified through a series of primary stakeholder interviews (designers, builders, and software service providers). The findings of the survey, the cross-analysis, and the interviews were triangulated and collectively discussed to derive an in-depth understanding of drivers and barriers. 'Greater level of accuracy and trustworthiness' was rated the most important driver by both designers and builders, despite having significantly different response profiles. On the other hand, 'high cost of software' was rated the greatest barrier to digitalisation by both parties, whereas their response profiles were similar according to the cross analysis. In contrast to the designers, all builders had rated the top barriers in a similar way, irrespective of the size of the organisations. The results provide a greater understanding on the diverse views of designers and builders on drivers and barriers to the digitalisation of construction in NSW. This will direct government programmes and policy decisions to avoid considering both designers and builders as a monolithic block, when aiming at improving the state of digitalisation and performance of the construction industry.*

KEYWORDS*: Designers, Builders, Software service providers, Questionnaire Survey, Interviews, Australia*

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1. INTRODUCTION

In the era of Industry 4.0, the adoption of digital technologies and ICT in industries has become essential to achieve smarter, safer, resilient and sustainable future practices with efficacy (Bachok et al., 2004). However, the construction sector is identified as the second least digitalised worldwide industry (Manyika et al., 2017). Previous studies have linked the lack of digitalisation to current significant issues in the construction sector, such as construction defects, work completion delays, exceeded project budgets, and increased safety risks (Turner et al., 2020, Asadi et al., 2015, Dallasega et al., 2018, Zhang et al., 2015, Aghimien et al., 2018). Therefore, the architecture, engineering and construction (AEC) sector are keen on the digitalisation of design and building practices (Gajendran and Perera, 2016, Perera et al., 2021). Digitalisation of construction refers to the adoption of information technology (processes, infrastructure, hardware, software and human resources) in design and construction phases of a project.

The AEC sector in many countries, including Australia, finds digitalisation challenging (Gajendran and Perera, 2016, Leviäkangas et al., 2017, Stewart et al., 2002, Eadie et al., 2012). E-procurement was the main component of digitalisation in construction a decade ago, and many studies have identified drivers and barriers to digitalisation since then (Eadie et al., 2010, Eadie et al., 2012). Today, the necessity for digitalisation has extended to practices beyond e-procurement and into all aspects of design and construction practices. Several researchers have explored drivers and barriers to digitalization of construction predominantly in terms of the adoption of a few prominent technologies. Ma et al. (2022) explored barriers to implementing Building Information Modelling (BIM) by consultants and contractors in New Zealand and China with a cross-analysis between the two countries. Further studies included identifying a refined set of drivers and barriers to BIM uptake in the UK, focusing on architectural practices (Jones, 2020) and the adoption of virtual reality by UK construction consultants (Badamasi et al., 2022). The drivers and barriers to utilising data mining in the construction sector, representing designers, builders, software service providers and academics, were explored by Ahmed et al. (2018).

Despite the wide range of research conducted exploring drivers and barriers of various digitalisation options within the construction industry, none of the papers has compared the views of designers and builders separately. Construction businesses require low capital to enter the market but can gain a high turnover (Ashworth and Perera, 2015). However, builders tend to achieve a lower profit margin compared to designers, who achieve a higher profit margin along with a low turnover (Baikie, 2021). In terms of organisational business setup, designers had ten times more sole trader setups, compared to builders in NSW, Australia (Perera et al., 2021). Furthermore, the main output of a contractor is a tangible and physical asset compared to an intangible concept or a design concerning a design organisation. As such, there are significant differences between these two sectors within the AEC industry. Therefore, it is worthwhile to critically compare and contrast builders and designers when assessing the factors associated with digitalisation in construction. To address this research gap, this paper sets out to critically review drivers and barriers that affect the digitalisation of construction for designers and builders with an in-depth cross-analysis. This will be achieved through two research objectives which are as follows: (1) In-depth and critical review of the drivers and barriers and (2) Cross-analyse the views of designers and builders for digitalisation of construction. Design practitioners such as architects and engineers who are responsible for making building design compliance declarations under the NSW Design and Building Practitioners Act 2021 are considered as Designers in this study (NSWGovernment, 2022). Building practitioners such as builders and developers responsible for executing principal construction work are considered Builders in this study.

The results contribute toward understanding actual factors that both positively and negatively impact achieving the best digitalisation practices. It provides the Australian construction sector with a rigorously analysed evidence-based perspective on eliminating barriers and enhancing drivers that would improve its digital maturity. This paper reviews the literature on drivers and barriers to the digitalisation of construction, followed by the analysis of survey findings and cross-analysis, which are supported by findings of interviews with designers and builders. The findings are discussed in detail, and conclusions are provided.

2. FACTORS AFFECTING THE DIGITALISATION OF CONSTRUCTION

Previous studies worldwide have discussed factors that drive and hinder digitalising the AEC sector. This section presents a brief literature review on drivers and barriers to the digitalisation of construction. It concludes with the state of digitalising the NSW building industry.

2.1 Drivers for digitalisation of construction

The global construction industry and its business models stand facing a transformation caused by megatrends such as digitalisation, urbanisation, globalisation, sustainability and even socio-demographic change (Pfnür and Wagner, 2020). With the advent of COVID-19, e-procurement in construction has become a greater necessity (Leung et al., 2021). Hence, digitalisation is identified as the overarching strategy to facilitate all current changes evolving in the construction sector (Sategna et al., 2019, Aghimien et al., 2018). The emergent digital technologies have led to new design and construction processes that have induced 'digital innovation' in global construction industry practices. These technologies assure increases in efficacy and competencies in the areas of design, construction, operation and maintenance (Weber and Frankfurt/Regensburg, 2017, Araszkiewicz, 2019). Implementation of such technologies has proven advantages in delivering complex projects that are lesser in cost within the time and prescribed quality (Leviäkangas et al., 2017, Shea and Luebkeman, 2005). Hence, such awareness and global acceptance of the advantages of digitalisation have driven its popularity in contemporary construction practice (McNamara and Sepasgozar, 2018).

Previous studies have identified the benefits of digitalisation as perceived by stakeholders in the AEC sector. These are considered to drive the digitalisation of construction. A study conducted by Aghimien et al. (2018) in the South African AEC sector identifies the following drivers for digitalisation: time-saving in construction projects delivery; increased productivity; increased speed of work; increased document quality; speeding up of response time; and more straightforward working methods. These findings agree with another similar study conducted by Eadie et al. (2010) in adopting e-procurement in the UK construction sector, which identifies cost savings, convenience of archiving completed work and increased quality through increased accuracy prominent drivers for digitalisation. Digitalising via adopting technologies like the Internet of Things (IoT) and BIM in the construction industry provides many benefits. As identified by Ghosh et al. (2020), key drivers include interoperability; data privacy and security; flexible governance structures; proper business planning and models.

2.2 Barriers to the digitalisation of construction

Even though the advancement of digital technology has the potential for intensely improving overall design and construction output, related literature shows that substantial barriers exist that hinder the effective adoption of these technologies, i.e. technological, financial, organisational, construction process, legislative, and psychological barriers (Ramilo and Embi, 2014, Johnson and Laepple, 2003, Intrachooto, 2003, Aghimien et al., 2021). Lack of equipment or computers, insufficient knowledge and skills, and lack of training are some of the anticipated technological barriers, while inadequate design fees to support digital innovation, high cost of digital tools and setting up equipment, lack of budget for team training/ higher salaries, cost of changing to a new system/ format are some identified financial barriers that may hinder construction digitalisation (Ramilo and Embi, 2014).

Identified organisational barriers in construction digitalisation are poor leadership and attitude toward digital innovation, inadequate personnel to implement digital innovation, and lack of collaboration (Aghimien et al., 2021). In terms of barriers in the construction process, lack of early contractor engagement, lack of performance of digital tools or software, slow speed of computers in processing and drawing extraction, mobility of software to handle complex geometry, the disintegration of 3D models to multiple sources can be anticipated to deter construction digitalisation (Lasarte et al., 2021).

Lack of legislative support to discourage drawing hardcopy submissions and lack of authority given to digital signature are considered as a governmental barrier that hampers digitalisation. Legal issues such as consent in sharing design information (Ownership, copyrights), unauthorised accessibility to drawings by multiple parties, liability in confirming the drawings (design/ as-built), and reliance on hardcopies in legal proceedings/ dispute resolution are identified to impede digitalisation potentials (Ramilo et al., 2016). Moreover, psychological barriers such as intimidation by the developer in the documentation process, fear of work changes, lack of psychological assurance, and lack of trust in digital technology are anticipated to obstruct the construction digitalisation (Obiso et al., 2019).

Similarly, many contemporary international studies have looked at various categories of drivers and barriers to the digitalisation of construction. However, in-depth exploration and understanding of these drivers and barriers from the perspective of designers and builders in NSW will further support the effective digitalisation of the construction sector.

2.3 Construct NSW - Keeping up with the pace of digitalisation:

Australia has also recognised the significance of digitalisation of construction documentation to establish effectiveness, compliance and trustworthiness in the construction industry across Australia (Shergold and Weir, 2018, Perera et al., 2021). In light of this context, NSW Government has executed the '6 Pillars' strategy for the future of building and construction under the Construct NSW programme (NSW-Government(a), 2020). The six pillars cover legislation and regulations changes, ratings systems, improving skills within the industry, ensuring contracts help meet standards and digitising the industry. Further, NSW government has forged the Design and Building Practitioners Act 2020 to reform the ongoing pursuit of improved regulation of the building industry. This Act was expected to affect a range of stakeholders in the residential building industry, particularly by calling for the registration of design and building practitioners and imposing a new statutory duty of care owed by designers and builders to building owners (Munro, 2020).

Digitalising the NSW building industry and moving away from analogue record keeping was deemed significant in connecting all new reforms because it intended to facilitate the implementation of shared industry-wide platforms to build public confidence (NSW Government, 2020b) . The newly introduced e-planning portal was the shared platform that stores all building information in digital format. Hence, digitalisation of the construction documentation was anticipated to align with the need for a "single source of truth to contain a building's certificates on a common platform, which will go with a building forever and be available to future owners and maintainers" (NSW Government, 2020a). Furthermore, the technology-driven e-planning platform is considered more relevant in the post-COVID era, where it would enable remote operation and management of building design and procurement.

3. RESEARCH DESIGN AND SCOPE

This paper focuses on the drivers and barriers to the digitalisation of construction. As illustrated in the research design map (See Fig.1), the study was carried out in four steps: literature review, questionnaire survey, interviews, and the discussion of findings via data triangulation. The adoption of both quantitative and qualitative methods provides in-depth investigation and a better understanding (Dunning et al., 2008, Ivankova and Creswell, 2009) into the construction stakeholders' perspective on eliminating barriers and enhancing drivers for the digitalisation of construction.

First, a literature review was conducted on factors affecting digitalisation in the local and international construction industries to identify the current drivers and barriers to the digitalisation of construction. It was also extended to understand the recent initiations of the NSW Government to keep up with the pace of digitalisation of construction. The literature review findings informed the designing of both survey and interview questions. In the second step, the questionnaire survey was conducted to capture quantitative data from a large group of designers and builders (Regmi et al., 2016). Sample questions of the questionnaire survey are provided in Appendix A. The population for the survey was estimated to be around 30,000 design and building practitioners based on data collected from the NSW registry of architects, Building Designers Association of Australia, Engineers Australia, and NSW registry of licensed builders (Fair Trading NSW). Qualtrics survey platform was used to create the online questionnaire survey, and the respondents were provided with a list of drivers and barriers that impact the digitalisation of construction, asking them to rate based on a five-point Likert scale of 'very low' to 'very high'. A recruitment survey was conducted where 619 designers and 523 builders indicated a willingness to participate. The primary survey was distributed to a total of 1142 designers and builders, where 542 responses were captured (347 designers and 195 builders) within five weeks period, leading to a response rate of 50%. The relative importance index (RII) was used to establish ranks based on the Likert scale answers provided by the survey respondents. According to Holt (2014), RII is often used to analyse survey data resulting from Likert scales in construction management research questionnaires. RII is typically calculated using the formula given below (Eq 1):

$$\text{Relative Importance Index (RII)} = \frac{\Sigma W}{AN} \qquad \text{(Eq 1)}$$

Where:
W = Sum of respondents selecting a response point multiplied by the point's integer value (1 – 5) for each option on the response scale
A = Largest integer on the response scale
N = Total number of respondents

Using Eq 1, the RII values were calculated for drivers and barriers, distinguishing between designers and builders and the ranks were assigned.

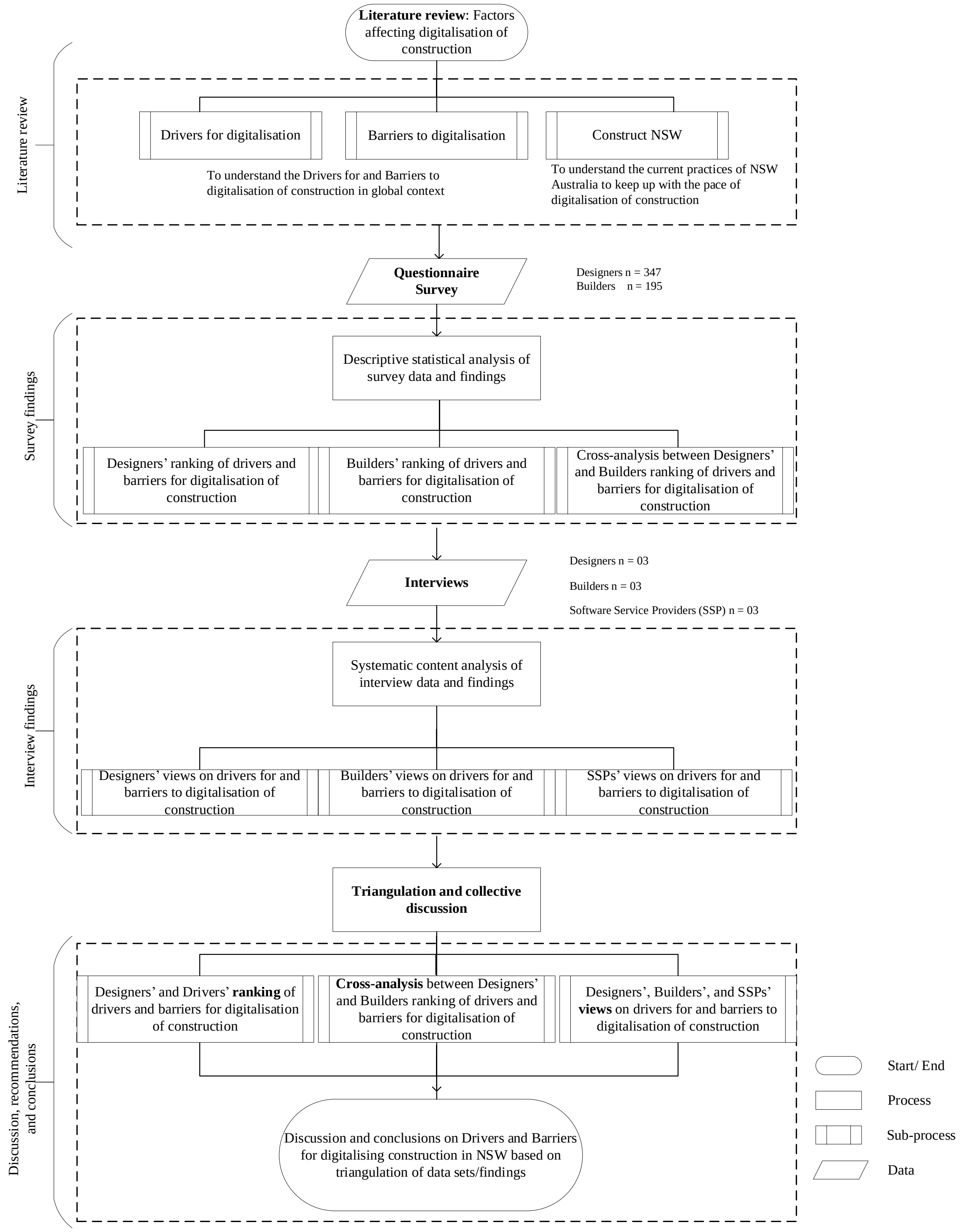

FIG. 1: Research design map

Mann-Whitney U (MWU) test is considered one of the most frequently used nonparametric tests when comparing two unpaired groups. As it can be carried out on small sample sizes and does not assume a normal data distribution (Demirkesen and Tezel, 2021, Smalheiser, 2017), the Mann-Whitney U test was used in this study to compare differences between the designers and the builders. It tested whether differences between the two groups were statistically significant at α = 0.05. On the other hand, the Kruskal-Wallis H test (KWH) was used to compare differences between organisation size categories (micro, small, medium and large) for drivers and barriers.

In the third step, nine semi-structured interviews were conducted with three types of construction stakeholders operating at the fringes of the construction industry. Three were designers, three were builders, and the other three were software service providers, representing large, medium, and small practices. Interviewees were selected to represent different organisational sizes and categories predominant in NSW construction sector. Interviewees were having a good level of experience, knowledge, qualifications and were highly reputed in the industry for their field of work. Hence, the views of these interviewees are considered adequate for this research. Interviews elicited narrative data that allowed for investigating stakeholders' views in greater depth Field (Alshenqeeti, 2014; Jain(Alshenqeeti, 2014, Jain, 2021). Sample questions of the semi-structured interviews are provided in Appendix B. All interviews were audio-recorded with the interviewees' consent and subsequently transcribed. Interview transcripts were then sent to interviewees for their approval before subjecting to a systematic content analysis (Mayring, 2004). A detailed coding system (Downe-Wamboldt, 1992) shown in Table 1 was developed for this analysis, depicting the interviewee category, scale of the practice, and steps in the statement building process. Therefore, they enable tracing back all steps of statements up to the original transcript. The systematic content analysis derived key statements for drivers and barriers, representing three categories of construction stakeholders, as presented in sections 4 and 5.

TABLE 1: Categories of the interviewee and relevant codes

Scale of the practice	**Interview Code**
Designers	
Large	DL
Medium	DM
Small	DS
Builders	
Large	BL
Medium	BM
Small	BS
Software service providers	
Large	SL
Medium	SM
Small	SS

Findings from the questionnaire survey, cross-analysis, and interviews were triangulated and collectively discussed to derive recommendations and conclusions in the fourth and final step. According to Bryman (2016), triangulation is an approach that uses multiple methods of investigation or various sources of data to not only derive an in-depth understanding of a selected area but also to establish trustworthiness and generate greater confidence in findings. It is also referred to as a cross-checking method for accuracy (Yin, 2003, Patton, 2002, Deacon et al., 1998). Findings of the questionnaire survey and interviews on drivers and barriers to digitalisation are presented in sections 4 and 5.

4. FINDINGS ON DRIVERS FOR DIGITALISATION OF CONSTRUCTION

The survey resulted in responses from 347 designers (architects, engineers etc.) and 195 builders (contractors, developers etc.), totalling 542 responses. The descriptive statistics of the respondent profile are presented in Table 2.

The results indicate that designers and builders share similar percentages for medium and large-scale organisation sizes. Micro and small scale organisations, based on the number of employees, also do not vary significantly. However, in terms of the business setup, there is a significant difference between designers and builders for the number of organisations being sole traders and companies. The next sections present key findings of the questionnaire survey and interviews on drivers of and barriers to digitalisation of construction, as perceived by designers and builders.

TABLE 2: Descriptive statistics of respondent profile-related questions

Ref No	Questionnaire Item	Answers	Frequency (F) & Percentage (P)			
			Designers		Builders	
			F	P	F	P
1	Number of people employed by the organisation	Micro (0 - 4)	205	59%	86	44%
		Small (5 - 19)	73	21%	70	36%
		Medium (20 - 199)	53	15%	30	15%
		Large (200 and over)	16	5%	9	5%
2	Business setup	Sole trader	69	20%	6	3%
		Partnership	18	5%	6	3%
		Company	255	73%	181	93%
		Other	5	1%	2	1%

4.1 Survey findings on drivers for digitalisation of construction

This section presents summarised ranks for drivers of digitalisation calculated using the relative importance index (RII) along with findings of the Mann-Whitney U Test (MWU) and Kruskal-Wallis H Test (KWH) carried out to compare differences between views of designers and builders. Table 3 presents the ranks for drivers of digitalisation calculated using RII. The detailed calculations are provided in Appendix C.

TABLE 3 - Ranked drivers of digitalisation by Designers and Builders

Ref	Drivers of digitalisation	Designers		Builders		Combined	
		RII	Rank	RII	Rank	RII	Rank
D1	Greater level of accuracy and trustworthiness	0.7937	1	0.7508	1	0.7782	1
D2	Improve quality and standards in construction	0.7533	2	0.7467	2	0.7509	2
D3	Better communication between stakeholders	0.7458	3	0.7159	4	0.7351	3
D4	Ability to deliver complex projects within budget, time and prescribed quality	0.7406	4	0.7231	3	0.7343	4
D5	Support building certification	0.6403	7	0.6944	5	0.6598	5
D6	Greater possibility of complex digital design composition, fabrication and visualisation	0.6784	5	0.6072	7	0.6528	6
D7	Gaining competitive advantage	0.6536	6	0.6185	6	0.6410	7
D8	Incentivising/ providing tax benefits to organisations moving towards digitalisation	0.5205	8	0.5815	8	0.5424	8

According to the combined responses of both designers and builders, the results of RII indicated that the top four drivers (D1 to D4) were similar for both groups, with only a swap between the third and fourth ranks. The topmost driver was *'Greater level of accuracy and trustworthiness'* (D1), while the least rated driver was *'Incentivising/ providing tax benefits to organisations moving towards digitalisation'* (D8).

4.1.1 Designers' ranking of drivers for digitalisation of construction

'Greater level of accuracy and trustworthiness' (D1) and *'Improve quality and standards in construction'* (D2) were designers' most highly rated drivers of digitalisation. The least rated driver was *'Incentivising/ providing tax benefits to organisations moving towards digitalisation'* (D8). It indicates that financial incentives are not considered an influential factor in driving digitalisation. Further, the ranking also indicates that designers do not believe digitalisation will significantly support building certification. This is probably born from the fact that there is less literacy about technologies such as blockchain and smart contracts.

‘Other’ drivers identified by designers were:

- Quality assurance and management
- Time management/time saving
- Standardisation between all parties in the industry
- Remote access
- Collaborative design with remote stationed team members

4.1.2 Builders’ ranking of drivers for digitalisation of construction

Similar to Designers, the top two and the least rated drivers were the same for builders (D1, D2 and D8). The ranking also indicates broad agreement (over 60%) that all the listed drivers are important.

‘Other’ drivers identified by builders were:

- Quality
- Avoiding change events and variations
- Better understanding of project at all levels
- Industry requirement

4.1.3 Cross-analysis between designers’ and builders ranking of drivers for digitalisation of construction

MWU test was conducted for the combined top three ranked drivers (D1, D2 and D3). The results are presented in Table 4. With p = 0.535, MWU test indicated that there is no statistically significant difference between designers and builders in their ratings for *‘Improve quality and standards in construction’* as a driver of digitalisation.

TABLE 4: MWU test results for top three drivers of digitalisation

Ref	Driver	Mean rank		Sum of ranks		Mann-Whitney U	Wilcoxon W	Z	Asymp. sig (2-tailed)
		D (N=347)	B (N=195)	Designer (N=347)	Builder (N=195)				
D1	Greater level of accuracy and trustworthiness	285.05	247.38	98914.00	48239.00	29129.000	48239.000	-2.824	0.005
D2	Improve quality and standards in construction	274.48	266.19	95245.50	51907.50	32797.500	51907.500	-0.621	0.535
D3	Better communication between stakeholders	281.43	253.84	97655.00	49498.00	30388.000	49498.000	-2.058	0.040

KWH test was also conducted for the combined top three ranked drivers for designers as well as builders to compare against different organisation sizes (Refer Table 5). While others had different response profiles, only *‘Improve quality and standards in construction’* (D2) did not have statistically significant difference among designers (p = 0.081).

4.2 Interview findings on drivers of digitalisation of construction

Further to the findings of the questionnaire survey presented in section 4.1, a systematic content analysis of interviews provided detailed information on the drivers of digitalisation. Key statements that were derived via this analysis process are presented under each interview category: designers’ views, builders’ views, and software service providers’ views.

TABLE 5: KWH test results for top three drivers of digitalisation

Ref	Drivers (Designers)	Mean Ranks – based on number of employees				Kruskal-Wallis H	Asymp. Sig (2-tailed)
		0 – 4 (n=205)	5 – 19 (n=73)	20 – 199 (n=53)	200 & over (n=16)		
D1	Greater level of accuracy and trustworthiness	157.56	197.33	201.92	185.78	15.407	0.002
D2	Improve quality and standards in construction	162.96	189.77	188.72	194.72	6.739	0.081
D3	Better communication between stakeholders	155.97	184.99	214.90	219.38	21.310	0.000
Ref	Drivers (Builders)	Mean Ranks – based on number of employees				Kruskal-Wallis H	Asymp. Sig (2-tailed)
		0 – 4 (n=86)	5 – 19 (n=70)	20 – 199 (n=30)	200 & over (n=9)		
D1	Greater level of accuracy and trustworthiness	85.24	106.07	114.53	102.06	9.215	0.027
D2	Improve quality and standards in construction	82.34	106.42	109.62	143.44	16.784	0.001
D3	Better communication between stakeholders	86.51	103.76	110.63	120.89	8.092	0.044

4.2.1 Designers' perspectives on drivers

Table 6 lists key drivers for digitalisation of construction that were identified by NSW designers, such as the fast-growing industry demand to use advance technologies such as BIM in order to keep up with the growing workload and size of projects, government legislation that would mandate digitalisation, and standardising council requirements with a clear checklist that would simplify the design declaration process.

TABLE 6: Designers' perspective: Drivers of digitalisation

Ref	Final statements	Trackable codes
1.	The fast-growing industry demands the use of advance technologies such as BIM to keep up with the growing workload and size of projects.	DL/A21/S48
2.	Designers perceive that to survive, they need to keep up with the current industry trends such as the use of advance technology.	DL/A21/S49, DL/A25/S59, DS/A10/S28
3.	Designers consider government legislation that would mandate digitalisation as a driver.	DL/A25/S58, DL/A26/S60

Moreover, designers stated that hard copy submissions are still required by many councils. However, they already produce 3D drawings that are converted to 2D to suit the local councils' submission requirements. Therefore, designers expressed willingness and confidence in their capabilities to adapt to any digital advancements suggested by government regulations.

4.2.2 Builders' perspectives on drivers

All builders that were interviewed provided both design and construction services. Table 7 lists key drivers of digitalisation of construction that were identified by NSW builders such as pre-existing digital capabilities, positive attitudes and understanding towards benefits of digitalisation, and legislations to mandate adoption of digital technologies. In terms of positive attitudes towards digitalisation of construction, builders widely perceived that digitalisation is associated with efficiency, productivity, and safety, which drives many builders to adopt new technologies in documentation and construction practices.

Moreover, interviews found that design services provided by builders were predominantly outsourced to external consultants. Similar to designers, builders also indicated that they can easily adapt to any transformations in terms of digitalisation if mandated by legislation.

TABLE 7: Builders Perspective: Drivers for digitalisation

Number	Final Statements	Trackable codes
1.	In this digital age, anyone entering the workforce is perceived to have pre-existing digital capabilities that supports the fast adaptation into industrial digitalisation.	BL/A80/S68, BL/A81/S69
2.	It is widely perceived that digitalisation is associated with efficiency, productivity, and safety, which drives many builders to adapt new technologies.	BM/A22/S37, BS/A57/S64
3.	Legislation is perceived to be a driver towards digitalisation across the construction industry.	BS/A18/S21, BS/A57/S63

4.2.3 Software Service Providers' (SSP) perspectives on drivers

SSP have observed that architectural practices in Sydney are digitally more advance than manufacturers, engineers, or builders. They have witnessed a sharp increase of digitalisation with lot of automation already taking place in designing of buildings. Table 8 lists key drivers of digitalisation of construction that were identified by SSP in NSW such the awareness through education on possibilities of smart technologies, fast growing advancement in technology, Government initiating digitalisation via legislation, and changing views of stakeholders to consider long term benefits of investing on technology.

TABLE 8: Software service providers' perspectives: Drivers of digitalisation

Number	Final Statements	Trackable codes
1.	Awareness through education on automated construction processes and methods, data driven, smart technologies that enable you to track materials better, and the possibilities of predictable outcomes will drive digitalisation.	SL/A5/S10, SL/A6/S13, SM/A26/S25
2.	Fast growing advancement in technology is a driver in finding solutions via digitalisation.	SL/A5/S11
3.	Government initiating digitalisation via legislation will be a driver for digitalisation.	SL/A5/S9, SM/A27/S26, SS/A19/S27
4.	Current interest in builders and subcontractors to have more control over their contract and documentation is considered as a driver for digitalisation.	SM/A10/S7, SL/A5/S10
5.	Changing views of stakeholders to consider long term benefits of investing on technology is considered as a driver for digitalisation.	SL/A19/S28, SM/A22/S21, SM/A26/S25

Views of designers, builders and software service providers on the drivers of digitalisation provide further understanding on the survey findings. It provided a narrative to why D1, D2 and D3 are considered as the three top ranked drivers by designers and builders. It was also evident that all interviewees operating at the industry's fringes indicated strong views towards the necessity of digitalisation and standardisation of construction practices in NSW. They all agree on the benefits of digitalising construction practices in terms of improving accuracy and trustworthiness. Further, they expressed positive views towards the impact of legislative initiatives on digitalising construction and firmly believed that the current digital capabilities of the industry are sufficient to adapt quickly.

5. FINDINGS ON BARRIERS TO THE DIGITALISATION OF CONSTRUCTION

This section presents key findings of the questionnaire survey and interviews on barriers to the digitalisation of construction.

5.1 Survey findings on barriers to digitalisation of construction

Similar to the drivers, this section presents summarised ranks for barriers to digitalisation calculated using RII along with findings of MWU and KWH carried out to compare differences between views of designers and builders. Table 9 presents the ranks for barriers to digitalisation calculated using RII. The detailed calculations are provided in Appendix D.

TABLE 9: Ranked barriers to digitalisation by Designers and Builders

Ref	Barriers to Digitalisation	Designers		Builders		Combined	
		RII	Rank	RII	Rank	RII	Rank
B1	High cost of software purchase/licensing	0.7890	1	0.7631	1	0.7797	1
B2	High cost of digital tools and setting up equipment	0.7233	3	0.7231	3	0.7232	2
B3	Inadequate design fee to support digital innovation	0.7481	2	0.6574	6	0.7155	3
B4	High cost of IT specialists	0.6813	4	0.7313	2	0.6993	4
B5	Issues related to legal ownership of a model and ambiguity of the liability of design	0.6761	5	0.6267	8	0.6583	5
B6	Lack of relevant knowledge, skills and training programmes	0.6403	7	0.6656	5	0.6494	6
B7	Unavailability of a single suite of software to deal with all aspects of design or interoperability issues	0.6265	8	0.6749	4	0.6439	7
B8	Issues in sharing design information by multiple parties and lack of collaboration between designers	0.6409	6	0.6349	7	0.6387	8
B9	Lack of support and leadership for digitalisation	0.5741	9	0.6072	9	0.5860	9
B10	Lack of authority given to digital signatures and reliance on hardcopies	0.5660	10	0.5928	10	0.5756	10
B11	Lack or inadequacy of hardware to support high computational requirements	0.5078	11	0.5313	11	0.5162	11

5.1.1 Designers' ranking of barriers to digitalisation of construction

The results of RII indicated that the top three barriers were *'High cost of software purchase/licensing'* (B1), *'Inadequate design fee to support digital innovation'* (B2) and *'High cost of digital tools and setting up equipment'* (B3) for designers.

'Other' barriers identified by designers were:

- Software being too complicated
- Hard to keep up with constant updates/ revisions of software
- Software compatibility issues
- Intellectual property, privacy & copyrights
- Breakdown of computers
- Issues in communications infrastructure
- Lack of national mandates and standards
- Model transfer issues
- Training the right people to participate

5.1.2 Builders' ranking of barriers for digitalisation of construction

While the first and third ranked barriers were shared by both parties, the second ranked barrier differed. Furthermore, the three least rated barriers (B9, B10 and B11) were the same for both designers and builders.

'Other' barriers identified by builders were:

- Education of trade-based users are very low
- Resistance to change by older generation
- Lack of infrastructure

5.1.3 Cross-analysis between designers' and builders' ranking of barriers to digitalisation of construction

MWU test was conducted for the combined top three ranked barriers. The results are presented in Table 10. With p = 0.058 and 0.865 respectively, MWU test indicated that there is no statistically significant difference between designers and builders in their ratings for *'High cost of software purchase/licensing'* and *'High cost of digital tools and setting up equipment'*, as barriers to digitalisation.

TABLE 10: MWU test results for top three barriers to digitalisation

Ref	Barrier	Mean rank		Sum of ranks		Mann-Whitney U	Wilcoxon W	Z	Asymp. sig (2-tailed)
		D (N=347)	B (N=195)	Designer (N=347)	Builder (N=195)				
B1	High cost of software purchase/licensing	280.64	255.23	97383.00	49770.00	30660.000	49770.000	-1.899	0.058
B2	High cost of digital tools and setting up equipment	272.32	270.04	94496.00	52657.00	33547.000	52657.00	-0.170	0.865
B3	Inadequate design fee to support digital innovation	295.44	228.91	102516.00	44637.00	25527.000	44637.000	-4.908	0.000

KWH test was also conducted for the combined top three ranked barriers to designers as well as builders, to compare against different organisation sizes (Refer Table 11). While others had different response profiles, only inadequate design fee to support digital innovation did not have statistically significant differences among designers based on organisation sizes. However, for builders, the KWH test revealed that all top three barriers had no statistically significant differences among the varying sizes, with p at 0.494, 0.246 and 0.546.

TABLE 11: KWH test results for top three barriers to digitalisation

Ref	Barriers (Designers)	Mean Ranks – based on number of employees				Kruskal-Wallis H	Asymp. Sig (2-tailed)
		0 – 4 (n=205)	5 – 19 (n=73)	20 – 199 (n=53)	200 & over (n=16)		
B1	High cost of software purchase/licensing	181.24	185.78	150.72	104.59	13.898	0.003
B2	High cost of digital tools and setting up equipment	181.81	183.07	152.99	102.13	13.392	0.004
B3	Inadequate design fee to support digital innovation	177.26	179.01	162.39	147.78	2.381	0.497
	Barriers (Builders)	Mean Ranks – based on number of employees				Kruskal-Wallis H	Asymp. Sig (2-tailed)
		0 – 4 (n=86)	5 – 19 (n=70)	20 – 199 (n=30)	200 & over (n=9)		
B1	High cost of software purchase/licensing	96.06	100.10	105.48	75.28	2.397	0.494
B2	High cost of digital tools and setting up equipment	98.76	102.68	95.05	64.17	4.146	0.246
B3	Inadequate design fee to support digital innovation	92.74	101.21	107.55	91.39	2.128	0.546

5.2 Interview findings on barriers to the digitalisation of construction

Further to the questionnaire survey findings presented in section 5.1, a systematic content analysis of interviews provided detailed information on the barriers to the digitalisation of construction. Key statements related to barriers to digitalisation that were derived via this analysis process are presented under each interview category: designers' views, builders' views, and software service providers' views.

5.2.1 Designers' perspectives on barriers

Table 12 lists key barriers to digitalisation identified by designers, such as the different levels of digital capabilities among staff members and stakeholders, disconnect between different age brackets in terms of technical competencies, lack of common data environment, interoperability of software, difficulties in migrating to alternative software, and high cost of software licensing. Among the barriers listed in the table below, designers expressed more concern about the challenge of having different levels of digital capabilities among staff members and stakeholders for digitalisation. Furthermore, they also perceived clients' inability to make use of offered advanced technology in documentation as a barrier to the digitalisation of construction.

TABLE 12: Designer perspectives: barriers to digitalisation

Number	Final Statements	Trackable codes
1.	Different levels of digital capabilities among staff members and stakeholders is considered a challenge for digitalisation.	DL/A5/S11, DL/A5/S12, DL/A5/S15, DL/A17/S42, DL/A20/S46
2.	There is a disconnection between different age brackets in terms of technology competencies.	DL/A21/S47
3.	Designers perceived that clients are not sophisticated to benefit from the technology that's being offered.	DL/A17/S42, DL/A25/S57, DM/A23/S45, DS/A10/S25
4.	Autodesk has a monopoly almost in Australia, compared to Europe or America.	DL/A7/S21
5.	Software licenses change from perpetual licenses to subscription-based situation, is inconvenient and expensive.	DL/A8/S23
6.	There is no single software suit to accommodate all design requirements such as complex geometry, environmental performance analysis, etc. Lack of interoperability of software is considered as an issue.	DM/A4/S17
7.	Complications in the design declaration process is a barrier in adjusting to changes with the Act.	DS/A11/S33
8.	It will be challenging to change the culture in the construction sites, where everything is hand drawn.	DS/A16/S46
9.	There are time and cost implications to digitalising sketches done on the construction site.	DS/A16/S47
10.	A barrier in digitalisation is the lack of an agreed universal drawing format, not only in terms of a file format but also visual representation of buildings elements. There is no common data environment.	DM/A27/S50

5.2.2 Builders' perspectives on barriers

Table 13 lists key barriers to the digitalisation of construction identified by NSW builders, such as the cost of software, misconceptions about the work distractions caused by technological devices on-site, gaps in existing software in data capacity and interoperability, and inconsistent digital capabilities among the workforce.

TABLE 13: Builders Perspective: Barriers to digitalisation

Number	Final Statements	Trackable codes
1.	Cost of software is considered as a barrier by all three builders.	BL/A75/S64, BM/A6/S15, BS/A8/S13
2.	There are misconceptions among builders that laptops or iPad on construction sites can lead to unnecessary usage and distract workers.	BM/A9/S19
3.	There are some gaps in existing software that make it too big of a data file or too slow to use.	BL/A53/S48, BL/A52/S47
4.	Lack of a software system that communicates with each other is considered a barrier.	BL/A39/S35
5.	Small builder perceives that lack of capacity of subcontractors especially at the finishing trades would be a major barrier towards digitalisation.	BS/A8/S14, BS/A22/S29, BS/A24/S36, BS/A57/S65, BS/A60/S67

Although the large and medium builders were content about the current level of digital capabilities of their ISO accredited subcontractors; the small builder indicated concerns over their current level of digital capabilities that may hinder the advancements in digitalisation of construction.

5.2.3 Software service providers (SSP) perspectives on barriers

Table 14 lists key barriers to the digitalisation of construction that were identified by SSP, such as the low-profit margin in the industry, lower level of digitalisation among international manufacturers, increasing software licencing costs, the government is less digitally advanced than the industry, liability concern in issuing digital models, and training issues in upskilling the industry. Among these barriers, the main barrier that SSP highlighted was the software cost which has drastically increased 60 to 70% over the last five years, forcing people out of their perpetual licenses into a subscription model.

Similar to the survey findings, the high cost of software licencing and equipment was identified by all stakeholders as a key barrier to digitalising construction.

TABLE 14: Software Service Providers Perspectives: Barriers to digitalisation

Number	Final Statements	Trackable codes
1.	Nature of this industry and profit margin being low is a barrier in digitalisation	SL/A7/S14, SL/A6/S12
2.	Lower level of digitalisation among international manufacturers is a barrier in digitalisation.	SM/A22/S19, SS/A13/S17
3.	Small practices have less scope and no budget for advance technology or automation and less likely to warrant an investment in advance digitalisation.	SS/A17/S23, SS/A17/S24
4.	Software cost have drastically increased 60 to 70% over the last five years forcing people out of their perpetual licenses into a subscription model.	SS/A24/S34
5.	Hardware that does not match with the software is a greater draw back than the costs.	SS/A24/S36
6.	It is perceived that government is far less digitally advance than the industry.	SS/A31/S48, SS/A31/S50
7.	There are liability concerns in issuing digital models.	SS/A31/S49
8.	Training issues around upskilling the industry may be a barrier in digitalisation.	SS/A42/S64, SS/A29/S45, SS/A30/S47

6. DISCUSSION

This discussion is based on the triangulation ensued from collectively reviewing findings generated via questionnaire survey, cross-analysis, and interviews. These insights were further reviewed against contemporary literature to compare and contrast. Hence, this rigorous approach provides the opportunity to critically review (Deacon et al., 1998) drivers and barriers that affect digitalisation of construction, as perceived by designers and builders in NSW, Australia. Sections 6.1 and 6.2 present the overall insights on drivers and barriers to digitalisation of construction respectively that were derived via triangulation.

6.1 Drivers of improving the status of digitalisation in design and construction

The survey and interviews explored the views of construction industry players in NSW on the perceptions of factors that drive the digitalisation of their organisations. While the survey captured a range of drivers and their level of impact, the interviews provided a detailed understanding of the same. This provided a holistic view of the drivers of digitalisation of construction.

Achieving a *'Greater level of accuracy and trustworthiness'* is the highest-rated driver selected by both designers and builders, which aligns with findings of previous studies of similar nature in other countries (Eadie and Perera, 2016, Bowmaster et al., 2016, Gajendran and Perera, 2017). This symbolises two of the most impactful factors that hinder the performance and function of the construction industry. Not only construction delays, and cost over-runs, but fatal building defects and failures are also caused by a lack of accuracy and trustworthiness (NSW Department of Finance, 2019, Braimah, 2013). Digitalisation is expected to improve these deficiencies in the construction sector significantly.

The second most highly rated driver is *'Improve quality and standards in construction'*. The digitalisation helps eliminate errors and improve quality and standards (Wong et al., 2018). Cross analysis indicated that there is no statistically significant difference between designers and builders in their ratings for improve quality and standards in construction as a driver of digitalisation. It is closely followed up by *'Ability to deliver complex projects within budget, time and prescribed quality'* and *'Better communication between stakeholders'*. Previous research that captured views of construction project managers also present similar findings that emphasise the influence of digitalisation on improving collaboration between stakeholders that results in successful delivery of large construction projects (Bryde et al., 2013). Therefore, positive perceptions of designers and builders on such benefits of digitalisation is considered as a prominent driver towards digitalisation of construction in NSW.

Although previous studies considered *'Incentivising/ providing tax benefits to organisations moving towards digitalisation'* as a driver for digitalisation (Andreoni et al., 2021, Woodhead et al., 2018), this research found it to be the least important driver for digitalisation in NSW, as perceived by both designers and builders. This could be interpreted as that digitalisation is considered by organisations for the purpose of advancement of their capabilities and incentivisation, though important, takes a lower preference than others.

6.2 Barriers to improving the status of digitalisation in design and construction

Understanding how the industry players feel about barriers to the digitalisation of their organisations provides a crucial insight in developing a strategy for the digitisation of construction. Similar to findings of Ramilo and Embi (2014), this research findings indicate the significant influence of financial barriers on digitalisation of construction.

Software provides a pivotal role in the process of digitalisation (Parviainen et al., 2017). *'High cost of software purchase/licensing'* is considered the most critical barrier by designers and builders. This finding substantiates findings of previous studies which have identified the costs of software to leverage the full benefits of digitalisation of construction (Love and Irani, 2001, Olatunji and Construction, 2011, Ma et al., 2022). This is followed by *'High cost of digital tools and setting up equipment'*. Both designers and builders perceive that soaring cost of software and hardware make digitalisation more difficult. Cross analysis indicated that there is no statistically significant difference between designers and builders in their ratings for *'High cost of software purchase/licensing'* and *'High cost of digital tools and setting up equipment'*, as barriers to digitalisation.

'Inadequate design fee to support digital innovation' is the third most rated barrier for digitalisation mainly because it was deemed as the second biggest barrier by designers, although it was only ranked sixth by builders. *'High cost of IT specialists'* was rated the fourth biggest barrier as it has been ranked as the fourth and the second biggest barrier by designers and builders, respectively.

7. CONCLUSIONS

The overall state of the digitalisation of construction right around the world has not changed in the past decade. It remains the second least digitalised sector in the global economy. Correspondingly, the drivers and barriers essentially remain the same. This study evaluated the drivers and barriers to digitalisation in the construction industry, cross-analysing its impact on two of the different key groups associated; designers and builders. The views were extracted via a survey and interviews and were analysed in detail.

According to the combined responses of both designers and builders, the three most prominent drivers were *'Greater level of accuracy and trustworthiness'*, *'Improve quality and standards in construction'* and *'Better communication between stakeholders'*, respectively. The top four drivers were shared by designers and builders, only with a slight deviation between the third and fourth ranks. The least rated driver was *'Incentivising/ providing tax benefits to organisations moving towards digitalisation'*, indicating that financial incentives are not considered an influential factor in driving digitalisation. The interview findings also generally agreed with the survey findings, providing further details and in-depth understanding. In addition, designers, builders and software service providers considered that government mandates would drive digitalisation further in the Australian construction industry.

Further, awareness programmes through education on the possibilities of smart technologies to support stakeholders' changing views would further benefit the construction sector's digitalisation. The cross-analysis of the driver *'improving quality and standards in construction'* indicated that both designers and builders had similar views. Designers, irrespective of the size of their business, had rated it to be a key driver. Notably, the builders' views had been influenced by the sizes of their businesses.

Financial barriers to digitalisation of construction such as *'high cost of software purchase/licensing'*, *'high cost of digital tools and setting up equipment'*, *'inadequate design fee to support digital innovation'*, and *'high cost of IT specialists'* were found to be the most prominent barriers of digitalisation of construction by both designers and builders. The prominence of financial-related barriers is explained by the fact that construction is predominantly a low-profit-making sector. Thus, it leads to less capacity for construction companies to spend on digital enhancements. Moreover, interviews which captured industry players' views emphasised the issue of software's lack of interoperability. This reduces construction companies' ability to quickly move between competing software, reducing the bargaining power of the consumer. Therefore, government initiatives are recommended to overcome barriers related to costs, and system interoperability are supported by a common data environment which would benefit the successful digitalisation of the construction industry. Regarding the two barriers about high software and hardware costs, both designers' and builders' views were very much aligned, indicating the impact on both parties. This is also explained by the fact that 95% of construction organisations fall in the category of micro SMEs. Such organisations cannot freely invest in digitalisation. However, designers of different sizes varied views on the high costs of digitalisation. This is based on the vision and capability of each design firm as there are organisations that frequently invest in latest CAD, BIM and other design applications and move towards more parametric designs, whereas other organisations rely on the existing platforms for more extended periods, mainly due to affordability. However, this is entirely different for builders who, irrespective of the organisational size, equally indicated the cost of software and hardware as a barrier to digitalisation. This difference in attitude between the two parties can be explained by the fact that builders work on relatively and significantly low profit margins compared to designers. Therefore, the cost is a major factor for builders then designers.

An important point to consider when comparing designers and builders is their output. A designer's product is virtual (a design/concept), while that of a builder is physical (a built asset). It is evident from the results regarding drivers and barriers designers and builders share some similarities along with some differences caused due to the uniqueness of the end products. Hence it is recommended that policy decisions regarding digitalisation be taken, giving proper consideration to both parties, without considering them as a monolithic block in the construction industry. Their requirements are diverse, and policies should consider those differences and implications where necessary.

This research is conducted in NSW Australia, thus the findings are geographically limited to the state of NSW. Although the findings may provide good indicators, it would be desirable to carry out similar studies in future for other jurisdictions so as to obtain contextualized findings. Further studies into comparing views of the major stakeholders in construction can provide better understanding of how to improve digitalisation in the construction sector. The evaluation of drivers and barriers to digitalisation of construction can form the basis of future development of a suitable maturity model for digitalisation of construction. These could help elevate the status of digitalisation of construction from being one of the lowest digitalised sectors globally.

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APPENDIX A- SAMPLE FROM QUESTIONNAIRE

Please answer the following questions representing the experience of your organisation.

Q1) Which of the following describes your organisation's business setup? Use your business registration classification to answer this question.

- Sole Trader
- Partnership
- Company
- Other (Please specify in the text box)

Q2) How many people are employed by your organisation?

- 0 – 4
- 5 – 19
- 20 – 199
- 200 and over

Q3) How do you rate the following drivers of digitalisation in your organisation in preparing your business planning strategy? (Indicate the relative importance of the following drivers)

	Very Low	Low	Moderate	High	Very High
• Gaining competitive advantage					
• Support building certification					
• Improve quality and standards in construction					
• Greater possibility of complex digital design composition, fabrication and visualisation					
• Ability to deliver complex projects within budget, time and prescribed quality					
• Incentivising/ providing tax benefits to organisations moving towards digitalisation					
• Better communication between stakeholders					
• Greater level of accuracy and trustworthiness					
• Other (Please specify in the text box)					

Q4) How do you rate the following barriers that will impact digitalisation in your organisation? (Indicate the relative impact of the following barriers)

	Very Low	Low	Moderate	High	Very High
• Lack or inadequacy of hardware to support high computational requirements					
• Inadequate design fee to support digital innovation					
• High cost of digital tools and setting up equipment					
• High cost of software purchase/licensing					
• High cost of IT specialists					
• Lack of relevant knowledge, skills and training programmes					
• Issues in sharing design information by multiple parties and lack of collaboration between designers					
• Unavailability of a single suite of software to deal with all aspects of design (complex geometries, rendering, environmental analysis etc) or interoperability issues					
• Lack of authority given to digital signatures and reliance on hardcopies					
• Lack of support and leadership for digitalisation					
• Issues related to legal ownership of a model and ambiguity of the liability of design					
• Other (Please specify in the text box)					

APPENDIX B- SAMPLE FROM SEMI-STRUCTURED INTERVIEW GUIDELINES

Interview Guidelines – Building Practitioners

Name:

Designation:

Professional affiliations:

Experience:

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1. How does your organisation handle as-built drawings?
    - Typical flow of activities and processes followed
    - In-house vs out-sourced components

2. In your organisation, what software do you use to prepare as-built drawings and in what formats are they shared to the project owner?
    - Software eco system: Proprietary or Open source
    - Types of license for the software/ Number of license

3. What are the biggest shifts in technology in terms of handling drawings and other documentation (eg: Use of iPad at sites instead of drawings) that your organisation has experienced over the years? How were those managed?
    - Turnover of the organisation
    - The amount spent on IT annually
    - The amount spent on R&D annually

4. How do you train your staff in obtaining new skill sets relating to new software and design processes?
    - Ad-hoc training processes
    - Structured training programme
    - Training policy and procedures

5. What are the drivers and barriers for digitalisation in your organisation?

Interview Guidelines – Design Practitioners

Name:

Designation:

Professional affiliations:

Experience:

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1. What are the building design services offered by your organisation?
    - Typical flow of activities and processes followed
    - In-house vs out-sourced components

2. In your organisation, what software do you use to develop the designs and in what formats are they shared with the rest of the project stakeholders?
    - Software eco system: Proprietary or Open source
    - Types of license for the software/ Number of licenses

3. What are the biggest shifts in technology (eg: hand drawn to CAD, CAD to BIM etc) that your organisation has experienced over the years? How were those managed?
    - Turnover of the organisation
    - The amount spent on IT annually
    - The amount spent on R&D annually

4. How do you train your staff in obtaining new skill sets relating to new software and design processes?
    - Ad-hoc training processes
    - Structured training programmes
    - Training policy and procedures

5. What are the drivers and barriers for digitalisation in your organisation?

APPENDIX C- CALCULATION OF RII FOR DRIVERS

Drivers	Very Low	Low	Moderate	High	Very High	Total for Designers	A * n1	RII for Designers	Ranking for Designers	Very Low	Low	Moderate	High	Very High	Total for Builders	A * n2	RII for Builders	Ranking for Builders	Total for Combined	A*N	RII for Combined	Ranking for Combined
Greater level of accuracy and trustworthiness	16	16	59	128	128	1377	1735	0.7937	1	4	19	50	70	52	732	975	0.7508	1	2109	2710	0.7782	1
Improve quality and standards in construction	20	20	75	138	94	1307	1735	0.7533	2	8	14	49	75	49	728	975	0.7467	2	2035	2710	0.7509	2
Better communication between stakeholders	18	23	89	122	95	1294	1735	0.7458	3	6	18	60	79	32	698	975	0.7159	4	1992	2710	0.7351	3
Ability to deliver complex projects within budget, time and prescribed quality	23	24	85	116	99	1285	1735	0.7406	4	7	21	53	73	41	705	975	0.7231	3	1990	2710	0.7343	4
Support building certification	27	56	124	100	40	1111	1735	0.6403	7	7	18	74	68	28	677	975	0.6944	5	1788	2710	0.6598	5
Greater possibility of complex digital design composition, fabrication and visualisation	25	55	90	113	64	1177	1735	0.6784	5	14	42	78	45	16	592	975	0.6072	7	1769	2710	0.6528	6
Gaining competitive advantage	32	55	103	102	55	1134	1735	0.6536	6	18	43	57	57	20	603	975	0.6185	6	1737	2710	0.6410	7
Incentivising/ providing tax benefits to organisations moving towards digitalisation	80	87	102	47	31	903	1735	0.5205	8	23	46	73	32	21	567	975	0.5815	8	1470	2710	0.5424	8

APPENDIX D- CALCULATION OF RII FOR BARRIER

Barriers	Very Low	Low	Moderate	High	Very High	Total for Designers	A * n1	RII for Designers	Ranking for Designers	Very Low	Low	Moderate	High	Very High	Total for Builders	A * n2	RII for Builders	Ranking for Builders	Total for Combined	A*N	RII for Combined	Ranking for Combined
High cost of software purchase/licensing	8	27	73	107	132	1369	1735	0.7890	1	2	14	57	67	55	744	975	0.7631	1	2113	2710	0.7797	1
High cost of digital tools and setting up equipment	12	42	92	122	79	1255	1735	0.7233	3	5	22	58	68	42	705	975	0.7231	3	1960	2710	0.7232	2
Inadequate design fee to support digital innovation	19	34	73	113	108	1298	1735	0.7481	2	10	32	76	46	31	641	975	0.6574	6	1939	2710	0.7155	3
High cost of IT specialists	16	67	99	90	75	1182	1735	0.6813	4	6	27	44	69	49	713	975	0.7313	2	1895	2710	0.6993	4
Issues related to legal ownership of a model and ambiguity of the liability of design	25	66	92	80	84	1173	1735	0.6761	5	9	45	74	45	22	611	975	0.6267	8	1784	2710	0.6583	5
Lack of relevant knowledge, skills & training programmes	17	72	128	84	46	1111	1735	0.6403	7	6	31	80	49	29	649	975	0.6656	5	1760	2710	0.6494	6
Unavailability of a single suite of software to deal with all aspects of design or interoperability issues	33	82	93	84	55	1087	1735	0.6265	8	8	37	62	50	38	658	975	0.6749	4	1745	2710	0.6439	7
Issues in sharing design information by multiple parties & lack of collaboration between designers	16	79	116	90	46	1112	1735	0.6409	6	10	39	72	55	19	619	975	0.6349	7	1731	2710	0.6387	8
Lack of support and leadership for digitalisation	41	90	120	65	31	996	1735	0.5741	9	14	43	75	48	15	592	975	0.6072	9	1588	2710	0.5860	9
Lack of authority given to digital signatures and reliance on hardcopies	36	113	107	56	35	982	1735	0.5660	10	14	46	83	37	15	578	975	0.5928	10	1560	2710	0.5756	10
Lack or inadequacy of hardware to support high computational requirements	62	110	114	48	13	881	1735	0.5078	11	28	56	72	33	6	518	975	0.5313	11	1399	2710	0.5162	11