Tackling Site-Based Challenges: The Mitigating Role of Construction 4.0 in Advancing Women's Participation

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Abstract

This paper examines how Construction 4.0 technologies tackle the challenges of site-based women in construction. The study also examines the role of Construction 4.0 in offering a competitive advantage to women in these site-based roles. The study adopts a qualitative method using semi-structured interviews with 9 women in site-based roles, purposefully selected from a broader study of 29 women across on-site, off-site, and fluid roles. This is followed by a mixed-gender focus group discussion to validate the findings of the interviews. The findings reveal construction technologies used by site-based women include hardware devices, enterprise systems, and design/CAD enabled design tools. Further, key challenges faced by women in these roles include gendered culture that undermines their credibility and voice, capability challenges and progression and career mobility. To address these challenges, study participants indicated that technologies enhance women's performance and credibility in meetings, reduce physical and safety burdens, and enable flexibility, thereby creating role-specific advantages around efficiency, safety, and confidence. However, both interviewees and focus group participants caution that Construction 4.0 offers a critical, but not self-sufficient, platform for change. Technologies can help dismantle some of the gendered challenges, yet their potential depends on being embedded within intentional strategies to challenge masculine industry norms and redesign job roles. This study forms part of a broader research seeking to empower women across on-site, off-site, and fluid roles through Construction 4.0 technologies.

Keywords –

Construction 4.0; women in construction; on-site roles; digital technologies, female participation.

1 Introduction

The construction industry remains one of the most gender-segregated sectors globally, with women significantly underrepresented in site-based and trade-oriented roles despite incremental gains in overall participation. Recent studies report that women are concentrated in office, administrative, and professional roles, while representation in on-site and physically intensive positions often remains below 5–10%, reinforcing a perception of site work as a male domain [1]. This imbalance persists even as labour shortages and ageing workforces intensify pressures on the industry to diversify its talent base and align with global agendas such as the Sustainable Development Goals (SDGs), particularly SDG 5 on gender equality and the empowerment of all women and girls [2].

A growing body of construction and built environment literature highlights that women in site-based roles face persistent challenges, including exclusionary masculine cultures, harassment, limited access to mentoring, inflexible working patterns, and inadequate amenities, which collectively undermine attraction, retention, and progression [3]. Empirical work on early-career women and tradeswomen shows that women on site must continually prove their legitimacy, navigate hostile or dismissive behaviours, and often experience constrained career pathways compared with their male counterparts, even where formal equality policies exist [2,3]. Despite policy interventions, many initiatives have focused on broad demographic targets rather than the role-specific constraints of women in site-based positions, limiting their effectiveness and sustainability.

In parallel, rapid digitalisation and the emergence of Construction 4.0 offer new possibilities to reshape site-based work and reduce reliance on traditional, physically intensive practices. Technologies such as building information modelling (BIM), virtual design and construction (VDC), digital collaboration platforms, automation and robotics, wearable safety devices, and remote monitoring tools are increasingly linked to improvements in productivity, safety, flexibility, and decision-making across project lifecycles [4]. Recent systematic reviews emphasise that these technologies are also associated with the emergence of new job roles notably "fluid" roles that integrate on-site and off-site responsibilities, potentially re-orienting focus from physical strength and continuous physical presence [2].

However, there is a lack of empirical evidence on whether and how digital tools mitigate challenges such as safety concerns, physical demands, and work–life conflict, for women on site, or whether these tools may inadvertently reproduce existing power imbalances in the industry [2].

Existing studies tend to either map women's roles and challenges in general, or examine Construction 4.0 adoption without a gender lens, resulting in limited understanding of how technologies are experienced by women on site [2, 3]. Again, there is the need to further the argument that construction 4.0 technologies generate competitive advantages for women in construction, e.g., in safety, productivity, visibility, and mobility across job roles. Moreover, relatively few studies have explored women's perspectives using in-depth qualitative methods that capture the socio-material and institutional lens of technology use.

Against this backdrop, this paper focuses specifically on women in site-based roles in the construction industry and examines how construction 4.0 technologies can mitigate challenges and create competitive advantages for these women. Some studies define competitive advantage as the presence of superior characteristics or capabilities that enable sustained outperformance, often operationalised through innovation, differentiation, and operational efficiency [5,6]. This study extends this concept to job roles of WIC, defining competitive advantage as role-specific capabilities and conditions that allow women in on-site construction roles to perform their work more efficiently, safely, and visibly. This is achieved by strategically leveraging Construction 4.0 technologies within male-dominated construction site environments. Aligning with this definition, reductions in physical and safety burdens, enhancements in performance and credibility, and increased flexibility and access are treated as key domains through which Construction 4.0 can generate competitive advantages for women on site.

The study aims to address the research question: *What competitive advantage can construction 4.0 offer to women in on-site job roles, and how might these capabilities address identified challenges?* To answer this question, the study adopts a qualitative research method comprising of 29 semi-structured interviews with women in site-based roles, followed by 3 focus group discussions to validate the emergent themes.

2 Method

Prior to the conduct of the study, ethical clearance was provided from the University of New South Wales Human Research Ethics Committee (approval no. iRECS6102). All participants provided informed consent, were assured of confidentiality and anonymity, and were advised of their right to withdraw at any time.

This study adopted a qualitative, two-stage design using semi-structured interviews and focus group discussions. Participants were recruited via purposive and snowball sampling methods. This approach was employed to identify female participants capable of providing in-depth insights into on-site roles and Construction 4.0 technologies. The inclusion criteria stipulated that participants must be female, aged 18 years or older, currently employed within Australia, possess a minimum of four years of experience in the construction sector, and be actively utilising one or more construction technologies in their present capacity. Recruitment commenced with the researcher's professional network on LinkedIn and engagement with women-centric industry organisations, such as the National Association of Women in Construction (NAWIC), the Architecture, Construction, Engineering, Development (ACED) Women Network, and Women in Building Information Modelling (BIM). Subsequently, recruitment was extended through participant referrals to ensure the inclusion of a diverse array of organisations and projects.

In Stage 1, individual semi-structured interviews were conducted with female construction professionals occupying a range of job roles. It is important to note that for this paper, we rely on a subset of data from the broader qualitative study. In the larger study, 29 female construction personnel were interviewed across on-site, off-site, and fluid roles. Specifically for site based roles, the sample (Table 1) included nine women and it is their interview data that form the basis of the analysis presented here. Example questions included: *What is your current job role and how long have you been in this position? What construction technologies are you currently using or have used in your job roles? How have these technologies impacted your work and responsibilities? In what ways do you believe women can gain a competitive advantage in the construction industry using technology?*

Table 1 Interview Participants information

Code	Profession	Years in Construction	Organisation Type
P1	Site Engineer	6 years	Builder
P5	Plumber	10 years	Sub-contractor
P6	Site Engineer	4 years	Builder
P8	WHSE Coordinator	4 years	Builder
P9	Carpenter	4 years	Builder
P11	WHSE Advisor	4 years	Builder

P12	Site Engineer	5 years	Builder
P24	Site Officer	7 years	Off-site Modular company
P27	Carpenter	8 years	Trade Sub-contractor

In Stage 2, an online focus group was conducted via Microsoft Teams for one hour, to validate the interview findings. The broader project conducted 3 focus groups with 18 participants. However, for this paper, only the 6 participants in on-site roles are included as their findings directly answer the research question raised. To minimise bias, participants were recruited from across different organisations and did not know each other prior to the session. The moderator presented a concise summary of the key interview findings on challenges, technologies, and perceived competitive advantages for women, then used open-ended questions to elicit agreement, disagreement, and additional examples. Structured turn-taking encouraged independent responses and ensured that all participants contributed equally. As seen in Table 2, the group comprised three male and three female participants with closely aligned site-related roles to allow for comparison. The focus group was run for a period of one hour and data was recorded and transcribed automatically on Microsoft Teams.

Table 2 Focus Group Participants

	Code	Profession	Years in Construction	Organisation Type
Males	MSR1	Electrician	4 years	Trade Sub-contractor
	MSR2	Senior site planner	12 years	Builder
	MSR3	Site Engineer	8 years	Builder
Females	FSR1	Site Engineer	6 years	Builder
	FSR2	Principal site engineer	7 years	Builder
	FSR3	Carpenter	5 years	Trade Sub-contractor

Both the interview and focus group transcripts were analysed using Atlas.ti version 2025, following an inductive thematic analysis approach. This software aided in coding, theme generation and analysis of data as well as the production of Sankey visualisation of the data. Analysis began with open coding of the interview transcripts, where segments of data were assigned descriptive codes reflecting participants' accounts of technology use, challenges, and perceived competitive advantages. Atlas.ti assisted the analytical process by searching the transcripts and suggesting inductive codes, as well as visualising how codes interrelated with each other across the dataset. Building on these code suggestions, the research team reviewed, refined, and grouped related codes into broader categories, which were further developed into overarching themes through iterative discussion. For the focus group data, the same coding framework was applied to assess the degree to which focus group participants confirmed, extended, or challenged the themes emerging from the individual interviews. Where focus group responses reinforced interview themes, these were retained as validated findings. Where new perspectives or contradictions arose, the themes were refined accordingly. This two-stage analytical process ensured that the final themes were grounded in both individual and group-level data. Thematic comparison between the interviews and focus group confirmed the main themes from the interview findings and led to minor refinements which are incorporated into the analysis presented in this paper.

3 Findings & Discussion

3.1 On Site Technologies

Figure 1 illustrates the range of Construction 4.0 technologies identified by the 9 site-based participants.

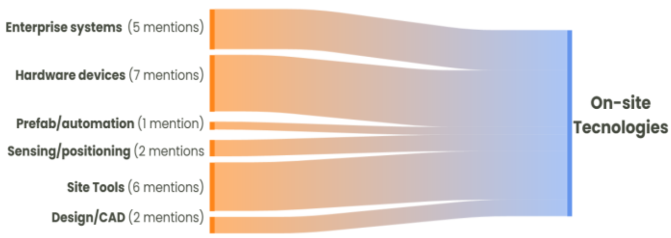

Figure 1- On site technologies identified

Interviewees highlighted hardware devices (e.g., laptops, iPads, smartphones, site cameras) as the most prominent technologies (7 mentions) followed closely by site tools such as hand tools, pliers, saws, hammers, etc. which are used on the sites (6 mentions). The technologies with the next highest mention were included enterprise systems such as (Microsoft suite, Aconex, etc.) which aid in collaboration and documentation and computer-aided design (CAD) tools (5 mentions).

Tradies emphasised that traditional hand tools and site tools remain fundamental, and that for some tasks there is still an expectation of physically handling materials. The carpenter (P27) described construction as "*very hands on*," saying "*you can feel the materials while you use it…*". For her, basic hand and power tools, lifting gear, and other site equipment are still core technologies, even as more advanced digital tools appear around them.

As seen from Figure 1, on-site professionals also relied heavily on enterprise systems to connect office and field work. A WHSE advisor (P11) described her role as "*software heavy*," explaining that while on site, she can "*bring my office with me to site on the iPad*," accessing project documentation while physically walking the project. Another engineer (P1) noted that several colleagues use OneNote or digital to-do lists, showing that email, corporate platforms, and digital note-taking tools are becoming routine parts of site-based work.

Finally, design and modelling software were consistently described as critical construction technologies for site-based roles. P1 stated that "*the modelling software is very useful*," and went on to say that having drawings and models "*consolidated in one*" environment "*definitely helps with the time factor*" when working under programme pressure. In another example she described a meeting where, instead of trying to explain a complex issue verbally, she "*brought up a model*" on the screen so that everyone could see the problem in 3D, which "*takes away a lot of tension and pressure*" and helps the group "*get straight to the solution.*" These technologies were corroborated by the focus group as well. This finding is consistent with research by Hasan et al., [7] who posits that mobile devices such as tablets and smartphones are now embedded in everyday site practice, which improves coordination, shortens information loops, and supports faster decision-making during site inspections and coordination meetings. Similarly, the continued importance of traditional hand tools and site equipment alongside these digital systems is also recognised in the literature. Construction studies note that, even under Construction 4.0, many trade tasks remain highly manual and rely on conventional tools, with digital technologies often augmenting rather than replacing hands-on work [8].

3.2 Challenges Site-Based Women Face

The interview findings revealed *gendered culture* was the most frequently mentioned theme and comprised *sub-codes such as gender bias, negative industry culture and relationships, and negative mindsets and attitudes*. Participants described having to continually prove their competence or manage sexist comments. As a site engineer stated: *"…when I was giving instructions on site about additional reinforcement or what I wanted to change it was questioned a little bit because I was younger and probably because I was a girl talking to 50-year-old men… sometimes [they] don't take you very seriously (P1)."* Capability challenges were the second major theme, with the skills and experience gap emerging as the largest sub-code. The third largest theme, progression and career mobility, centred on organisational culture as the largest sub-theme, with participants highlighting opaque promotion processes, a preference for "traditional" male career paths, and a lack of visible female role models in site leadership roles.

These findings are consistent with literature on women in construction, which identifies gendered industry culture as a primary challenge to women's participation and advancement in site-based roles. Galea et al. [8] demonstrate how informal "rules-in-use" and everyday practices normalise sexism and exclusion, reinforcing gendered bias and hostile or dismissive attitudes. Furthermore, recent work on gender diversity in construction notes that women are often denied substantive on-site tasks and mentoring, leading to fewer opportunities to build technical competence and site experience, which then reinforces perceptions that they "lack" capability [9].

3.3 Technology Impact on Site-based Roles

The highest impact of technology was seen in the efficiency and productivity of on-site tasks. Interviewees emphasised that digital tools and modelling software streamline core site tasks and decision-making. A site engineer noted that consolidating drawings and models "*definitely helps with the time factor*," allowing information to be "*all on the one thing*" instead of cross-referencing separate 2D drawings. Another interviewee reported that software tools "*helped me with my role and helped me be efficient… planning and doing sketches and getting things done," (P1)* and that learning advanced features *"really helps with our job and getting information that we need and processing information (P9)."* As echoed by P12, "*[Without the software] I'd be very slow... it would be a lot of paperwork".* Tools such as Bluebeam and similar platforms were described as *"really important… to be able to measure things at a glance"* and *"streamline things more efficiently (P11)"* when reviewing and checking information before issuing it to clients. A site-based carpenter (P27) explained that supervisors and engineers "*have iPads and they just show me what the building is going to look like,"* adding that seeing the model on the tablet "*puts all the pieces together*" and helps her plan ahead because she can visualise "*what's coming*" rather than relying only on what is half-built on site. The same participant referred to "*cameras*" and other site tools when discussing safety, indicating that digital hardware for monitoring and visual access is now embedded in everyday site practice, alongside tablets and phones as standard devices for drawings and coordination.

Interviewees also highlighted risks associated with over-reliance on construction technologies. One participant cautioned that *"a small thing that's done wrong or entered incorrectly… makes a big difference,"* noting *"a lot of room for human error… the more you digitalise things (P8)".* Others observed that younger staff can *"rely too much on the technology,"*. P1 vividly captured the dependence on digital tools by stating that *"if I left my laptop/iPad at home, I would die,"* illustrating that over-reliance on these devices can create vulnerabilities when systems fail or are unavailable.

Results from the focus group discussion indicated a general agreement that digital tools, especially 3D modelling and design technologies, support increased participation by opening more non-manual roles where traditional physical challenges are less salient. A male participant (MSR3) noted "*a higher proportion of women on the design side*" and suggested that 3D modelling *"is definitely increasing the female participation"* because those jobs are not *"a manual sort of job."*

Several participants also stressed equal opportunity, arguing that technology "*enhances everyone*" and creates *"a pretty even playing field,"* rather than uniquely privileging women. Relatedly, some were wary that framing technology as something *"to make it easier for women*" could backfire and *"actually do the opposite,"* risking perceptions of special treatment and gender imbalance (MSR2, MSR3). Focus group members also highlighted loss of foundational skills as a risk, echoing interview concerns about overreliance on tools: AI and digital aids were seen as helpful but also could make workers *"a little bit lazy because we're not learning the… foundations of how to actually do something," (FSR3)* especially in trades.

They reinforced that technology cannot by itself fix gendered culture, with MSR2 stating they *"just don't see how"* technology can reduce that challenge, while another argued technology is more likely to shift work structure, well-being, and capability (via online upskilling tools) than culture directly.

3.4 Technologies Addressing the Identified Challenges

Across the interviews and focus group validation, participants identified several advantages that construction technologies offer. The following subsections present the findings organised around three competitive advantage themes emerging from the data: (1) overcoming physical challenges, (2) performance and credibility, and (3) flexibility and access. As summarised in Table 3, each theme directly maps to a key challenge identified by the site-based women in this study, and demonstrate how specific Construction 4.0 technologies create competitive advantages for women in site-based roles.

Table 3 Analytical links between site-based challenges, construction 4.0 technologies, and competitive advantages for women

Challenge	Construction 4.0 technologies	Competitive Advantage (Theme)
Physical demands & high-risk tasks on site	Robotics, drones, assisted lifting aids, prefabrication	**Physical burden reduction;** participation without conforming to hyper-masculine physical norms
Being talked over, competence questioned, credibility undermined	BIM/3D modelling, design software, digital collaboration tools	**Performance & Credibility;** visible, undeniable technical authority in meetings and on site
Always-on site presence, rigid work structures	Mobile devices, iPads, cloud platforms, enterprise systems (MS Teams, Aconex)	**Flexibility & Access;** marginal softening of always-on-site expectations, enabling hybrid work

3.4.1 Overcoming physical challenges

Interviewees and focus group participants highlighted how technologies such as robotics, drones and assisted lifting aids can reduce the need for physically demanding or high-risk tasks on site. For example, P24 described how using robots or drones for external quality checks on high-rise façades means women do not need to *"physically go up and down …*" which was seen as especially helpful for those "*scared of heights*." Focus group comments on assisted aids for handling ceiling sheets similarly emphasised that such equipment allows tasks previously requiring two strong workers to be done more safely thereby reducing the physical strength requirement.

P27 emphasised that construction remains *"very hands on,"* involving heavy lifting, yet acknowledged the value of technologies such as plant and lifting equipment that because they ease some of the physical load. Within the focus group, participants pointed to prefabrication, remote inspection tools, and smart machinery as measures that reduce climbing, manual handling, and exposure to high-risk environments, allowing women to perform core site tasks without conforming to an idea of hyper-masculinity. This is consistent with Construction 4.0 literature which argues that automation, robotics, and digital tools progressively separate productivity from brute strength and shift value toward supervision, and coordination [4,10]. Evidence from other sectors indicates that such shifts can open up new technical roles and reduce gender gaps where physical demands had previously been used explicitly or implicitly to exclude women [4,10].

3.4.2 Performance and credibility

On-site engineers described digital tools as amplifying their technical performance and making their expertise more visible in high-pressure site environments.

P12 noted that Revit "*helps with understanding consultants' drawings and how they will work together in the physical space, as you can overlay the different layers and easily see where clashes occur",* enabling her to coordinate complex design information under programme pressure. Similarly, P6 explained that having a visual tool, such as a "*Bluebeam markup*", helped her "*communicate more clearly with subcontractors*." She noted that "*you are not only relying on your memory… you have an image… to assist you in communicating what you want"* (P6). This reduced the risk of being misunderstood or dismissed in a male-dominated site environment. Technologies that make expertise visible directly counter these assumptions. These accounts mitigate common challenges such as being talked over, having competence questioned, and struggling to have concerns taken seriously. These challenges are well documented in the women-in-construction literature [10]. Studies of BIM-enabled coordination similarly show that 3D and 4D models support shared understanding, reduce disputes, and shift authority toward those who can control and interpret digital information, thereby strengthening positions of women in project decision-making [11,12].

3.4.3 Flexibility and Access

Site-based women also framed technologies as offering an advantage in navigating rigid, site-centred work. A WHSE advisor (P11) described her role as "quite flexible", explaining that although she "*primarily need[s] to stay on site*," she can "*bring my office with me to site on the iPad*" by using the internal safety system in the field and occasionally working from home "*maybe one day a week*" when necessary (P11). An engineer noted that digital tools "*allow that flexibility… to still be engaged with your team through technology, but work from home,*" even though most responsibilities remain site-based (P6). These examples show how mobile devices, cloud-based documentation, and enterprise platforms marginally soften "*always on site*" expectations. This is corroborated by a plethora of literature that posits digitalisation can support hybrid work arrangements and more sustainable careers for women in construction. However, focus group participants were clear that "*technology alone does not change the nature of the work or the industry" (MSR3)* they emphasise that flexibility is highly dependent on the organisation's willingness to accommodate flexible work patterns.

Other advantages identified by interviewees include skill development, and communication and collaboration which were not validated by the focus group.

3.5 Gender Neutrality of Technologies in Construction

Both interviews and focus groups, however, revealed discomfort with presenting technology as something women uniquely "*need*." FSR1 from the focus group argued that while tools like BIM and project software are crucial, "*it's just a tool*" they "*don't help women any more than… a male"*. She also argues that competitive advantage comes from combining underlying skill with digital knowledge. A focus group participant (MSR1) similarly cautioned that suggesting technology is introduced "*to make it easier for women to do a job in construction"* could be "*misconstrued*" and "*actually do the opposite*" by implying women are less capable. These concerns align with Galea's critique that "*fixing women*" via special initiatives can inadvertently reinforce male advantage and leave underlying structures unchallenged [8].

The findings suggest that construction technologies are formally gender-neutral, but they operate within gendered institutions where men already benefit from norms around physicality, long hours, informal networks, and unexamined authority. In that context, women's strategic use of technologies creates specific, competitive advantages that help them navigate and partially resist those norms.

4 CONCLUSION

This study has revealed that Construction 4.0 technologies offer women in on-site roles concrete, advantages in navigating a workplace historically structured around male norms of physical strength, constant site presence, and informal authority. Across interviews and focus groups, women and men in the industry described how digital tools improved their performance, reduced physical limitations and opened up limited flexibility, in male-dominated site environments. These benefits did not arise from technology alone, but from how women strategically mobilised technologies to overcome challenges such as being talked over in meetings, having their competence questioned, and being constrained by constant site presence.

Literature has argued that digitalisation is reshaping job roles by shifting value toward information handling, coordination, and problem-solving, thereby creating conditions under which women can participate and progress on more equal terms. Wider evidence from research in Australia similarly suggests that digital tools, automation, and remote-capable platforms can reduce physical demands, enable new hybrid site–office roles, and support more flexible work models that are critical for women's retention [2,10]. At the same time, both this study and the literature caution against assuming that "gender-neutral" technologies will, by themselves, close gender gaps. Without deliberate attention to the deeply embedded rules-in-use that normalise male advantage, there is a risk that digital competencies and high-status technical roles will simply be captured by those already privileged in the system [8].

As part of broader research seeking to empower women across on-site, off-site, and fluid roles through Construction 4.0 technologies, this paper contributes role-specific, empirical insight into how women on-site women actually use technologies to carve out micro-advantages in performance, safety, flexibility, and credibility.

The findings of this study suggests that Construction 4.0 offers a critical, but not self-sufficient, platform for change. Technologies can help dismantle some of the gendered challenges, yet their potential depends on being embedded within intentional strategies to challenge masculine industry norms and redesign job roles. The findings point to a future where construction technologies are not merely tools for efficiency, but central components of an integrated framework to make on-site construction work a viable, attractive, and sustainable career path for women.

Future research should examine the barriers to Construction 4.0 adoption at the organisational and industry level, including cost, digital literacy, and resistance to change. Addressing these barriers is critical to ensuring that the competitive advantages identified in this study are accessible to all women in site-based roles, not only those in well-resourced organisations.

4.1 Practical Implications

Construction 4.0 has often been discussed in terms of broad industry change, but the women in this study mainly experienced it through everyday tools such as laptops, tablets, enterprise systems, and CAD/BIM software. These tools helped them do their work more efficiently, reduce some physical and safety risks, giving them clear advantages in on-site roles. However, the study also shows that technology on its own is not enough to improve gender equality. Simply put, the same tools are introduced into workplaces where long hours, strong site presence, and male-dominated decision-making are still the norm.

This has several practical implications. First, companies should not only provide access to digital tools but also offer targeted training so that women in site roles can move into higher-responsibilities or roles. Second, when organisations roll out new digital systems, they should consider how these changes affect women's workloads, flexibility, and progression, rather than assuming that "technology helps everyone in the same way." Third, clients and policymakers can link digitalisation and gender goals by encouraging or requiring projects to create visible Construction 4.0 pathways for women in on-site roles, for example through social procurement or gender targets.

As part of a broader study on empowering women in on-site, off-site, and fluid roles, these findings suggest that Construction 4.0 is a useful platform for change, but only when combined with deliberate efforts to redesign roles, support skills development, and challenge existing site cultures.

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