

## IDENTIFYING USER REQUIREMENTS FOR DIGITALLY ENABLING OFF-SITE FABRICATION WITH MIXED REALITY AND GAMIFICATION

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### Abstract

There has been limited study into the user-requirements of steel-fixers in the off-site fabrication of reinforced concrete and steel reinforcement. This work seeks to understand and specify the context in which steel-fixers are working and identify the user-requirements. Steel-fixing video footage was analysed, enabling the production of targeted questions, which were then posed to industry experts at in-person site visits. The user-requirements are categorised into three groups: the users' safety & comfort, environmental, and task-specific requirements. These requirements are intended to be used in future work to develop a new system and approach to the off-site fabrication of steel reinforcement.

### Introduction

This research project is about identifying the user requirements for digitally enabling off-site fabrication with mixed reality and gamification. User requirements, as defined by Mo, Bil *et al.* (2015), are the requirements of the end-user and task, the answers to the question of 'What must the system do to deliver capability?'. The authors describe 'good requirements' as being complete, they contain all the information for implementation. 'Good requirements' are solution independent, stating *what* the requirements are but not *how* they should be met; they are clear and testable, so that the requirements can be measured to determine if the design goal was met. 'Good requirements' are also traceable, meaning that it is possible to trace a requirement back to the rationale it was derived from.

'Digitally Enabling' refers to the practice of making a process possible or easier through the use of digital systems and technology. 'Off-site fabrication' specifies the process of producing or fabricating a structure, or an element thereof, at a secondary site away from the primary construction site. The secondary site is often a more controllable environment, frequently a factory specifically designed for this process (Aydinlik 2016). 'Mixed Reality' refers to the blending of the physical and digital worlds (Microsoft 2020). 'Gamification' refers to the use and application of game-design elements and principles in non-game contexts (Merriam-Webster 2020).

Off-site construction can provide many benefits such as higher construction speeds, enhanced quality, and lower construction costs (Goulding, Rahimian *et al.* 2012). Razkenari, Fenner *et al.* (2020) found that reduction in construction time was the single most important driver for

off-site construction. Shamsai (2006) reported that the rate of production for automatically manufactured reinforcement is greater than that of manually tied or welded reinforcement. Despite the benefits of automatically tied rebar, a significant portion of steel reinforcement is still manually tied or welded. It is a commonly held view that of the entire process for the fabrication of reinforced concrete, steel-fixing and cage assembly is the most challenging part to automate.

Steel-fixing is the act of positioning and securing reinforcement bars, or rebar, and other steel reinforcement (e.g. steel fabric) during the manufacturing of reinforced concrete (National Careers Service 2021). There is no 'book' on how to do steel-fixing and reinforcement cage assembly. However, certain aspects of it are covered in the documentation outlining the standards for reinforced concrete and its reinforcement. For example, BS 7973-2:2001 details the regularity and where the reinforcement should be fixed for various structures. BS EN 10080:2005, in conjunction with BS 4449:2005+A3:2016 (bar, coil and decoiled product), BS 4482:2005 (steel wire) and BS 4483:2005 (steel fabric) describes the material requirements of the steel reinforcement for reinforced concrete, while BS 8666:2020 describes the standards for the scheduling, dimensioning, cutting and bending of the steel.

The current automated reinforcement cage manufacturing process is not suitable for more than 2 layers of reinforcement or circular reinforcement cages (Garg and Kamat 2014). Further, Relefors, Momeni *et al.* (2019) identified several issues with using industrial robots for the automated installation of reinforcement. In a systematic review of robotic technologies in concrete building construction Gharbia, Chang-Richards *et al.* (2019) found that only 6% of the proposed robotic technologies were implemented commercially. Only an additional 14% were deemed viable by the authors; so while there have been some attempts to address some of the problems of manual steel-fixing, including automatic rebar tying guns for muscular-skeletal issues and Building Information Modelling (BIM) for enabling understanding of project documentation, these either fail to address the full scope of issues faced by steel-fixers or have not been tested beyond prototypal stages.

The act of steel-fixing has been linked to a high risk of developing musculoskeletal issues. Solomonow, Baratta *et al.* (2003) and Punnett, Fine *et al.* (1991) found that working in a static extreme trunk flexion or nonneutral trunk posture for more than 10% of working time, respectively, increases the risk of developing lower back disorders. Lower back injuries being the most prevalent

musculoskeletal disorders experienced by rebar workers (Hunting, Welch *et al.* 1999). Studies have found that rebar workers currently spend 37 – 48% of the working time in a nonneutral trunk working posture (Burdorf, Govaert *et al.* 1991, Buchholz, Paquet *et al.* 2003, Forde and Buchholz 2004, Lingard, Raj *et al.* 2019). As such, it follows that the manual process of rebar tying leads to a high risk of musculoskeletal disorders (Umer, Li *et al.* 2017).

Another of the current challenges in the steel-fixing process is the impact of the learning curve and the time required to understand the project build. The need to frequently refer to the approved reinforcement drawings to ensure a correct assembly is a useful and supportive task, but not one that directly results in completed work. A study on time consumption during manual steel reinforcement fabrication for high-rise buildings found that 35% of labourer time was spent on ineffective tasks, 34% on supportive or contributory tasks and only 31% on effective tasks (Nguyen, Vo *et al.* 2020). A significant positive relationship was also found between the quantity of reinforcement fixed (the amount bars fixed into place or tied together) and the productivity rate (Jarkas 2012). Jarkas believed that this relationship could be partially attributed to the initial ‘contributory’ time during which the labourers review the drawings, reinforcement details, prepare the work areas and the reinforcing steel bars before undertaking the ‘direct’ work. For smaller-scale activities a major portion of the labour input will go towards the initial ‘contributory’ work, so reducing the time spent on the ‘contributory’ work would allow for a significant increase in average labour productivity rates for small-scale and/or unique projects.

## State of Research

Kwon, Park *et al.* (2014) proposed an augmented reality (AR) system to manage defects within reinforced concrete (W5). This involves transferring the BIM geometry information to an AR Toolkit and then registering the AR markers to the information. Workers would next attach markers to the assigned locations in the physical world, allowing them to view the augmented BIM geometry information superimposed onto the real site components via a mobile device (W5). The authors noted that the process of setting up markers was very time consuming and suggested the use of real-time fiducial marker and markerless tracking for AR would enable faster and more convenient target detection.

Similarly, Meža, Turk *et al.* (2015) reported that AR can significantly contribute to the understanding of project documentation. However, technological interventions can cause discomfort to users and place them at risk if the intervention is not properly tested in the final environment. Studies have reported that the use of mobile augmented reality (MAR) in complex environments can lead to an increase in cognitive burden, such that important cues from the actual environment could be missed (Doswell and Skinner 2014, Abbas, Seo *et al.* 2020). This is of particular concern in a construction site where spatial and situational awareness is critical for site

safety (S5). In an experiment, Abbas *et al.* (2020) found that rebar-drawing information provided by superimposed computer imagery helped to reduce their users’ cognitive load in a ‘clean’ environment, compared to a paper-based (control) group. The paper-based control group took longer but were able to identify more errors than those using MAR technology due to the perception issues associated with MAR systems. Head-mounted MAR was found to decrease the users understanding of the surrounding environment and increase the inspection task completion times, not only compared to the control group but also compared to a tablet-based MAR test group. Overall, the two main existing modalities of MAR-based inspection were found to negatively affect cognitive load, task performance and situational awareness (Abbas *et al.* 2020). The phenomenon of simulation sickness, a subset of motion sickness, must also be considered when proposing a MAR system for head-mounted MAR devices. The choice of hardware (central processing unit, graphics processing unit and display performance) and the visual set-up (refresh rate, field of view and flicker) can impact the likelihood and severity of simulation sickness (Rangelova and Andre 2019). Incorrectly chosen hardware can increase the difficulties for users to adapt to new technology.

Kerai, Kiroff *et al.* (2020) found that when adapting to new technologies the three greatest difficulties of construction workers were: adapting to computers; a lack of motivation to accept new technology; and the way technology affects the interaction of workers in the industry. Construction managers rated the top three challenges of adapting to new technology as: poor worker attitude towards technology; resistance from staff to changes; and issues with using all the properties of new software (*ibid.*). The potential test groups easily available in an academic research environment (students and early career researchers) are unlikely to have the same difficulties. As an industry, construction is slow on the uptake of new technology and will rarely invest in new technology if the value is not clearly demonstratable (Heinzel, Azhar *et al.* 2017). Frustration when technology does not do what is expected, or the user cannot figure out how to operate the system, can contribute towards barriers to uptake and communication.

Communication barriers are frequent on construction sites and pose risks to the workers’ safety. Approximately 10% of the UK construction workforce are non-UK nationals (ONS 2018). This is highlighted by Health and Safety data; data from Australia, the US and the UK has found that the injury rate of migrant workers is twice that of local workers (Oswald, Smith *et al.* 2015). Hare, Cameron *et al.* (2013) highlighted the issue of understanding following on from Halverson’s (2003) study that training did not reduce accident rates among non-English speaking workers. If simple safety messages cannot be communicated, it can only be expected that the more complex technical messages will also get lost in translation. There are technological solutions to the communication barriers surrounding technical issues, such as neural machine translation engines or machine

translation engines that use deep learning and feature extraction to provide low error and semantically correct language translations (Burlot and Yvon 2017, Du 2019). However, these solutions do not address the communication of visual cues and context that can be necessary. Miscommunication increases the likelihood of errors, increasing the number of change orders issued and impacting project success. The inclusion of technologies into construction sites and prefabrication facilities bring opportunities to increase the overall worker safety while also decreasing the unnecessary cost, time, and material wastage on projects.

One type of technology used with the aim of increasing worker safety is rebar-tying machines. Steel-fixers could use rebar-tying machines to reduce the risk of musculoskeletal issues. This leads to a decrease in static trunk bending and thereby decreasing the peak and cumulative compressive forces on the lower back (Vi 2003). Lingard *et al.* (2019) investigated the impact of tool selection on back and wrist injury risk during steel-fixing, and found that no single tool (nips, hand-held automatic rebar tying power tool, and/or long-handled stapler tool) was best in all situations and that work at different heights (in relation to the worker's body) involves different levels of risk to the back and wrist. However, Badgajar, Divekar *et al.* (2019) reported that knots tied using automatic rebar-tying tools were less rigid and stiff than those done manually with nips.

### Gaps In Knowledge

Through the literature review into current practice of steel-fixing and its associated difficulties, the following gaps in knowledge were identified:

- an understanding of the actual current state of practice for the off-site prefabrication of steel-fixing;
- the user requirements of off-site steel-fixing;
- the technology requirements and implications of the user requirements; and
- the best introduction methods for, response to and uptake rates of new technology in the UK off-site steel-fixing and prefabrication of reinforced concrete industry.

This work will address the first two gaps.

### Methodology

BS EN ISO 9241-210:2019, the British Standard for human-centred for interactive systems, highlights the importance of understanding the context of use and analysing existing or similar systems as a method of revealing the constraints, needs and problems that may otherwise be missed but which still need to be addressed. To achieve this under the constraints of a global pandemic and varying levels of travel restrictions, video footage taken during 2015/16 at an off-site reinforced concrete prefabrication facility (henceforth referred to as Site 1) as part of a previous research project was used as an initial

means of observation, and later supplemented with in-person site visits to two further prefabrication facilities (Sites 2 and 3). The three companies observed as part of this project include the UK's largest manufacturer and supplier of precast concrete solutions, one of the most recognised names in construction, and the fastest growing reinforcing steel fabricator in the UK and Ireland (according to their company websites and industry publications<sup>1</sup>). By sampling these three sites, a sufficiently detailed understanding of the industry and task of off-site steel fixing could be made for the purpose of identifying the requirements to digitally enable off-site fabrication.

I undertook a workflow analysis to both understand and specify the context of use (integrify 2021), the results of which are presented through process-mapping. The site visits were done to confirm the relevancy and usefulness of the video observations. The site visits also enabled the characteristics of the environment to be directly observed, including the way the wider environment interacts with the task. Six workers were observed assembling a total of three cages from start to finish at Site 1. A combined total of ten workers were observed at Sites 2 and 3 assembling a total of seven cages, and a further six industry experts from across the two latter sites were interviewed. The six industry experts comprised of a steel-fixing foreman, two desk-based managers at one of the sites, a steel-fixer primarily working on the cutting and bending of rebar, a steel-fixing research and development engineer for one of the sites, and a project director with extensive hands-on experience working in all the off-site steel-fixing and ancillary roles.

Multiple workers were observed showing the same behaviours, which were then corroborated through the interviews, and the combined data set (observations and interview data) was analysed with the inductive qualitative analysis methodology (Thomas 2003). Generalisability is possible on the basis of theory building (Falk and Guenther 2006) by observing and analysing data from three distinct sites, and therefore populations.

The interviews were semi-structured in nature and the questions were derived from the observations made of Site 1. The questions sought to understand motivations behind the observed practices, to answer the 'why' question posed for each observed step in a workflow analysis (integrify 2021), and to corroborate the findings from the state of practice and research literature reviews. The interviews took between 30 minutes to 2.5 hours depending on the range of steel-fixing experience and process oversight the interviewee had. The questions were originally written with a target group of interviewees who are practicing steel-fixers. Due to the difficulties in getting interviews with steel-fixers, the questions were

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<sup>1</sup> In the participant information sheet and consent form made available to companies prior to taking part in this research, company and individual

worker anonymity was assured. If required the exact citations can be made available upon request to the author, subject to company authorisation.

then adapted to the available industry experts from Sites 2 and 3. This included the removal of interviewee irrelevant questions, and the simplification of language where necessary because of language barriers.

The user- and other stakeholder-needs were then identified from the context of use, the characteristics of the environment and the standards and guidelines governing the steel reinforcement and reinforced concrete industry in the UK

### Site Observations

Though the three sites differed in some of their detailed procedures, a common method was observed across all three sites (see Figure 1).

Initially upon receiving a design file, typically an IFC or PDF file (W1.1), the company/site will look at the structure to determine whether it can be built as a single large entity or will need to be broken down into sub-units. In the context of off-site fabrication, the size of structure or reinforcement unit that can be transported to the end destination site via either road or rail, often determines whether a reinforcement cage needs to be broken down.

The design file is then used to generate the schedules and workshop drawings for the workers (W1.2). Even if sites do not cut and bend their own steel (though two of the three sites observed expressed a clear preference to do so), a bar schedule is useful as it details the reinforcement bars' types and dimensions given in the workshop drawing (W1.4).

At Site 2 it was observed when cutting and bending the steel, that the shapes on the system often had to be manually adjusted to take account of the real-world behaviour of steel (W4). Figure 2 shows a comparison of a real-world bar and the adjusted computer model of the bar needed to achieve that bar. The worker operating the machine would manufacture a few bars and adjust the model manually by altering the lengths and angles until the bars are manufactured to the original schedule.

The workers were observed manually lifting and arranging temporary scaffolding supports to prepare the work area (W2.5) at Sites 1 and 2; whereas at Site 3 large, specialised scaffolding rigs would be fabricated and lifted via crane. Workers were seen to create "kit boxes", boxes or bins with all the rebar needed to fabricate a specific reinforcement cage to enable the efficient assembly of reinforcement cages. The kit box was placed in an easy access position in the vicinity of the work area as a final step prior starting the fabrication of the cage. The use of a kit box reduces the amount of time workers were spending searching for and fetching bars (W1.5).

Workers were observed measuring the intersection points onto a reference bar and then using spray paint to transfer these measurements onto a few bars that were then placed intermittently along the length of the reinforcement cage (W1.3) in order to reduce the time spent making measurements while steel-fixing. The reinforcement cage is then "framed", which is the process of creating a stable structure with the minimum number of fixed points. Site 3 chose to use knips to fix the frame over automatic rebar

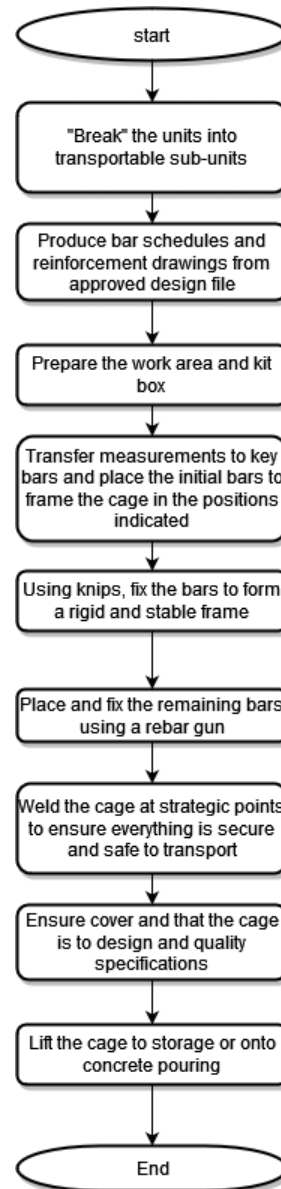


Figure 1: From the three sites combined, the process of off-site steel-fixing was observed

tying guns as the observed strength of ties done with a rebar gun were deemed insufficient to create a stable frame. Bars frequently were observed being pulled into position due to the real-world aspects of steel, such as deviations and misalignments (W4).

The remaining bars are then placed and fixed using either rebar guns or knips. The cage is then often welded at strategic points to ensure it is completely rigid and can safely travel to the site without any of the bars shifting or coming loose. This is important in the realm of off-site fabrication as the fabricated reinforcement cage may need to travel significant distances to get to the end destination site. Where welding is present the site should be a member of the CARES scheme for welded reinforcement and be certified to Appendix 6 and Appendix 10 of the scheme for the in-house welding of reinforcing bars (W3.2).



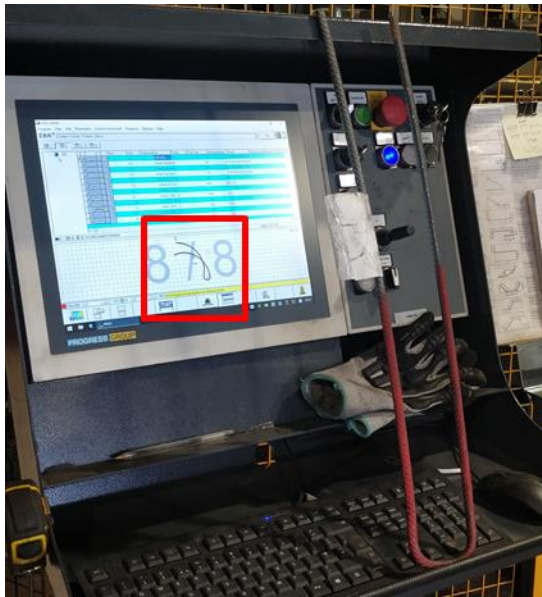


Figure 2: Comparison of real-world bar (on the right) and the adjusted computer model needed to achieve that shape at Site 2 (highlighted in red box).

After a reinforcement cage is fabricated and before it is transported to either the next stage of the off-site manufacturing process or to the end destination site, it is necessary for the cage to be checked to ensure there will be sufficient concrete cover (W3.4, the minimum distance between the exposed concrete face and the internal steel reinforcement surface or element). This may include the cutting of reinforcement bars and/or flattening of metal ties (W3.5). Additionally, the cage will be checked against the design and quality specifications to ensure that the fabricated cage is fit for purpose. All three sites had a quality checking process compliant with BS ISO 9001:2015 (BSI 2021) (W3.1). Using their existing processes and specially fabricated scaffolding, Site 3 are able to efficiently achieve accuracies of millimetre bar placement (W3.3).

The final stage of the off-site prefabrication of reinforcement cages is the transport of the cage to the next stage in the off-site production of pre-cast reinforced concrete or to the end destination site for the in-situ casting of reinforced concrete. Manual lifting of the reinforcement cages was observed at two of the three sites for smaller reinforcement cages, though mechanical lifting systems were preferred. Forklift trucks, overhead gantry systems, and cranes were all observed methods of lifting. To enable easier placement and tracking of the reinforcement cage through to its end destination, all cages would be tagged with their name and end destination (W1.7).

At each of the sites the process to clarify information from the workshop drawings was observed. This could include asking the foreman for clarification or inspecting the 3D digital model of the reinforcement cage (W1.6). It was noted that even when 3D models were available, steel-fixers preferred primarily using “traditional” 2D workshop drawings due to their inclusion of bar mark information (W1.4).

## Context of Use

It was observed at two of the three sites that workers were manually lifting and adjusting the temporary scaffolding to fit each specific rebar cage. Where possible, workers used the temporary scaffolding to bring the reinforcement cage up to waist-height (S4), reducing the amount of bending required. The more complex cages with curves or non-standard angles are currently assembled at floor-level allowing the workers to draw/ mark the design on the floor to improve quality.

From discussions with the site manager, other company sites have experienced issues with the accuracy of the projection system due to vibrations and deflections to the shed structure caused by movements and usage of the overhead gantry system. For a spatial measurement or projection system to be accurate it will need to be fixed in space and isolated from vibrations and deflections of the surrounding structures (E6).

It was observed that workers were relying on paper copies of reinforcement drawings which quickly became dirty and smudged due to the working environment (E5). Construction sites and facilities are rarely clean environments by nature and Site 2 was no exception: dirt, aerosol paint sprays, oil, steel cutting sparks and welding sparks (E1) were all observed within the steel shed.

The primary language of communication in the steel shed was Russian, and except for one British national, only the steel shed foreman had more than a very rudimentary grasp of English. All communication between management and the steel-fixers was translated via the foreman. Any solution or system would need to be accessible to workers with different preferred languages and English abilities (E7).

Some commonalities were observed across the three sites. The workers and steel-fixers were always observed to be wearing the appropriate level of PPE for that point across the site: including hardhats, safety boots, high visibility clothing and ear protection where appropriate (S1, S2, S3). Even in the regions where ear-protection was not mandated, the environment was noisy (E3) and the author struggled to hear spoken conversations. Workers were observed to build multiple cages consecutively (E4), and over a reported workday from 7am – 7pm (E2), any system would need to be functional for prolonged usage and across a whole day.

## User Requirements

Table 1 summarises the user requirements that were derived as part of this study, with the origin of the requirements is given throughout the above text for purposes of traceability. The user requirements can be broadly categorised into three groups. Those pertaining to the user’s safety and comfort (SX), the environmental conditions (EX) and those that arise specifically due to the task (WX). These user requirements can be used as the basis of a designed “system” to address the previously identified issues and problems with the off-site process. The word “system” is used here to describe a possible set of processes, methods and/or technological tools that

Table 1 – Derived User Requirements

Safety & Comfort (SX)		Task Specific (WX)	
S1	Head protection	W1	Part information
	<i>S1.1 PPE compatibility</i>		<i>W1.1 Retrieve information from files</i>
	<i>S1.2 Head-supported mass</i>		
S2	Eye and face protection		<i>W1.2 Produce rebar drawings and schedules</i>
S3	Hearing protection		
S4	Musculoskeletal safety	<i>W1.3 Bar location details</i>	
	<i>S4.1 Reduce repetitive movements or sustained postures</i>	<i>W1.4 Bar information</i>	
	<i>S4.2 Ergonomic equipment</i>	<i>W1.5 Progress state and location for part or project</i>	
S5	Awareness and comfort	<i>W1.6 Methods to seek clarification</i>	
	<i>S5.1 Situational awareness</i>	<i>W1.7 Cage information</i>	
	<i>S5.2 Vision preservation</i>	W2	Assembly process
	<i>S5.3 Hearing Preservation</i>	<i>W2.1 Item tracking</i>	
<b>Environmental Conditions (EX)</b>		<i>W2.2 Item recognition</i>	
<i>E1</i>	<i>Heat and sparks</i>	<i>W2.3 Recommend assembly sequences and fixing points</i>	
<i>E2</i>	<i>Different lighting conditions</i>		
<i>E3</i>	<i>Noise</i>	<i>W2.4 Generate assembly sequences and fixing points from the model</i>	
<i>E4</i>	<i>Multiple consecutive builds</i>	<i>W2.5</i>	
<i>E5</i>	<i>Airborne particles, dust, dirt</i>	W3	
<i>E6</i>	<i>Vibrations to the structure</i>	<i>W3.1 Quality management system</i>	
<i>E7</i>	<i>Language barriers</i>	<i>W3.2 CARES Appendices 6 and 10</i>	
		<i>W3.3 Accuracy</i>	
		<i>W3.4 Concrete cover</i>	
		<i>W3.5 Defect and improvement identification</i>	
		W4	Real-world behaviour and characteristics
		W5	Model to space registration

would work in tandem and encompass/ address the whole complex. Ignoring one of the “necessary” requirements will result in a non-functional system that either places the user in an unsafe situation, does not work for the end use environment or is simply not suited to the task. The derived requirements also include a number of “desirable” requirements; these are requirements that are not essential to the functioning system but will improve the overall user-experience if met.

## Conclusions

This work highlights the importance of understanding all the user requirements and the context of use prior to designing a system. The high degree of replicability in general observations and patterns of behaviour across the three sites, allows for generalisation of this research to the wider off-site steel-fixing industry in the UK (Falk and Guenther 2006). Table 1 lists the user requirements that need to be met to produce a system that efficiently addresses the off-site steel-fixing complex. The absence of any necessary requirements will create a system that is not safe to use, appropriate to the environment or suited to the task at hand. Augmented reality is a potential area of research that shows potential as a solution to many of

the challenges faced in the off-site steel-fixing complex; however, this research has identified the importance of considering the wider context and environment of use. This echoes the findings of Gharbia *et al.* (2019) and Wang, Wang *et al.* (2020) that more research and proposed solutions need to be taken beyond the theoretical and prototypal stages and tested in the actual end-use environments.

## Limitations

This research has limitations due to multiple barriers. These barriers include the challenges involved with getting site access to off-site prefabrication environments. Due to the global Coronavirus Pandemic, not many prefabrication facilities are open to visitors. Additionally, research into construction processes frequently face barriers to *in situ* observations due to issues of site safety. The owners and contractors on construction sites in the UK have a legal obligation to ensure that everyone on-site has undergone the appropriate safety briefings and/or have constant supervision. As a result, researcher visits to construction sites and facilities places additional burdens onto the companies and individuals responsible for the

sites and can result in researcher visits being declined on the grounds of time and cost.

Company secrets can often be what give one particular contractor an edge over their competitors in a very fierce industry with narrow profit margins. In order to prevent their company secrets becoming public knowledge, Site 3 restricted the data that could be collected.

Finally, there were barriers to interviewing the steel-fixers. As identified by Kerai *et al.* (2020), construction workers and steel-fixers are a technologically averse group. Technology that may seem second nature now to many during the last year of remote working, is still relatively alien to many steel-fixers and it was not possible for me to get any steel-fixers to agree to online interviews. Conducting interviews in-person faced the same issues as site visits, with the additional barrier that in order to interview a steel-fixer the company would effectively be a person down for the duration of the interviews. There was an additional language barrier issue that I was not explicitly informed of prior to the visit to Site 2 visit. For the above reasons, this study relied primarily on observations made of the workers supported by discussions with the 6 industry experts.

## Future work

This research provides a complete list of requirements that need to be met for the problem to be addressed. This work provides the basis for a PhD project on designing a new system of information transfer for the off-site fabrication of steel reinforcement. There has been a lot of theoretical work on proposed solutions, but very little has been taken beyond prototype, and the PhD project plans to produce prototypes and test them in actual off-site steel-fixing facilities with steel-fixers. This will help bring a new approach to off-site steel-fixing to the industry, addressing the current productivity bottleneck and assisting towards streamlining the whole off-site prefabrication of reinforced concrete process.

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