Digital Info Screen - A Visual Management Tool for Construction Workers

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Abstract

The Info creen development is part of wider research project where automated data collection of site operations and processing the data for provision of role-specific and contextualized information to targeted professions to fulfil the predicted information needs are being studied. The specific objective of the research work reported in this article is to arrive at a suitable user interface design that is easy to use and provides contextualized useful information for the construction workers. A Digital Visual Management method is proposed to share dedicated information to workers at construction sites with digital Info screens. The concept development has focused on information needs in drywall installation and the coordination of needed work phases. The information needs and barriers have been studied earlier with interviews of drywall installers to select and define information contents for Info screens. The Visual Management methods have been applied for this purpose and digital tools aspects are investigated especially. In visualization on the screen, the 3D-view of Building Information Model (BIM) has been used as a basis to present the information. In the user interface most information types are presented in relation to the geometry of the building and visualized with BIM 3D-view. The preliminary results from the user testing with the help of structured interviews on usefulness & ease of use of the prototype are encouraging.

Keywords

Construction operations management; construction workers; digital tools; user interface; visual management.

1 Introduction

The methods for sharing the design and planning information to construction workers are quite traditional ones; document deliveries and verbal communication between the site managers and workers are most used. The site managers and trade contractors' foremen are responsible for detailed planning and controlling of activities at site, and to inform worker about schedules and correct work sequences. In practice, besides this management level input the workers must organize and plan their activities in the short term, and more formal decentralized planning approaches have been proposed [1]. In any case, better information exchange is expected to improve productivity with increasing the share of value-adding time of work and reducing waste [2].

Our earlier interviews among construction workers [3] have shown that the challenges and the demands that the workers have at the construction site partly originate from the issues outside the site and partly from the site itself. These interviews were conducted with 11 male Finnish drywall installers (average age & experience are 49 & 26 years respectively). Some of the demands, i.e., the ones originating from the site, would be relatively easily manageable. For instance, the need to consume time in searching for the tools or materials could be tackled by more efficient site management and better information flow to workers. Other demands, that is, the ones with roots in the work of the construction planning team, seem to require more profound changes in the construction "system"; extremely pressing timetable and problems with the floor plans and construction drawings are harder to meet or mitigate by simple orders or recommendations.

Many information needs could be met by providing workers with updated information about the situation at the site; in the following, the solutions found relevant, based in drywall installers' interviews, are briefly described in [3]. Pertaining to the demand to consider work proactively, an illustration of the finished space would support work, especially if presented at the location in question. To support flexible work sharing, one demand identified in the interview material, some digital means to inform other workers when personal share of work is done would support collaboration. Regarding lost tools and material, guiding the way to these items would diminish the time to find them. One

issue with construction plans and drawings is that they may be obsolete without the worker knowing it: thus, an efficient, updated document deliverer would mitigate this problem. Finally, there are many roles working with the same target. A shared illustration about the target, with information for all worker roles, would support collaboration at the construction site.

One possibility of directly delivering information to workers is through digital screens on site. Such screens are usually described as kiosks which typically consist of one or more large screens in fixed or movable positions at site with the protective casing needed in the physically demanding environment. Information contents varies from wide collection of design and management information [4] to more dedicated contents, like BIM-kiosks (BIM, Building Information Modelling) [5]. There are also research examples based on a screen at site for more specific BIM-based visual management use cases (see e.g., [6]).

The proposed Digital Visual Management (DVM) user interface is developed as part of a wider research project, ACTOR (Automatic Coordination of Construction Actors), involving the digital situational awareness of construction workers that empowers them in decision making. The prototype of the proposed system is demonstrated in the context of work phases needed for drywall installation. The drywall installation activity is divided in following work phases: a) installation of drywall frame and first gypsum board, b) electrical installations inside the wall, as well as HVAC installation if needed, c) installation of soundproof insulation, if needed, and installation of second sides board, and d) installation of joint tapes and plastering.

The anticipated information needs in drywall installation were derived from the interview result analysis and those are widely related in work preconditions of work defined in Lean Construction principles [3]. Workers need information on free workspace where previous activities are finished and correct external conditions exist, as well as information of availability of the design, materials, and equipment. Essential information is also the requirements and expectations for the work. Professional workers have skills to fulfill the core requirements, but project specific detailed requirements must be provided.

Accordingly, the following use cases are identified for the proposed design & development of the Digital Info screen - a Visual Management Tool for construction workers involved in drywall installation.

- Readiness assessment - checklist for a specific task to commence; availability of work front, resources such as materials, equipment, tools, etc.
- Suggestion for next work area to optimize the workflow at site.
- Design information - present the design information such as plans and specifications in 3D/4D.
- Incidence reporting - interface for reporting incidents and seeking assistance from managers.

Hence, the objective of this research work is to arrive at a suitable user interface design that is easy to use and provides contextualized useful information for the construction workers. Structured interviews with the construction workers were used to capture their demands & information needs as well as to test the ease of use & usefulness of the proposed user interface. It is targeted to provide workers with near real time information supporting their daily work. The collected information can also be utilized for site managers' views, like showing the work accomplished over a period against the plan or creating short term forecasts to identify potential issues.

An overview of Visual Management is presented in the following section and subsequently the details of the development of the tool. Later, the proposed interface for the tools is elaborated with the discussions along with the user testing.

2 Overview of Visual Management

There is inherent waste in the construction processes and [7] and the construction productivity is historically low compared to other non-farm sectors [8]. Lean production principles have been attempted in construction projects to improve productivity, reduce waste, and create value to stakeholders [9]. Visual Management (VM) is one of the fundamental elements of the lean production system [10]. A simple definition of VM as found in [11]:

> *VM is a managerial strategy that attempts to improve organizational performance through connecting and aligning organizational vision, core values, goals and culture with other management systems, work processes, work-place elements, and stakeholders, by means of sensory stimuli (information), which directly address one or more of the human sensory modalities (visual, auditory, tactile, olfactory, and gustatory).*

VM is also a management strategy that emphasizes using sensory information systems to increase process transparency or the communication ability of process elements [12-13] and an approach to manage and control information. VM can support the identification of issues, reduction of waste and detection of inconsistencies [14], contributing to cognitive, emotional, and social benefits [15]. VM can also serve a broad range of functions in an organization such as transparency, job facilitation, simplification, and unification [16]. VM and its tools are used to realize, communicate, and coordinate the lean

production system's targets in the workplace [17]. A range of tools, from the traditional analog to digital and hybrid tools are commonly used in VM [18]. VM using digital tools/platforms can be called Digital Visual Management. There are challenges reported in the adoption of DVM in construction sites [19-20]. It can be observed that there is greater emphasis on and the need for use of digital visual tools for automated provisioning of information to construction workers on situational awareness for their independent decision-making. Hence, it is proposed to design an effective user interface for DVM to promote situational awareness and independent decision making.

3 Application Development

3.1 DVM Info Screen System Requirements

The target of the proposed DVM system is to provide workers role-specific, context and location aware information in visual form. This would be achieved with automated data collection of site operations to provide up to date information for automatically coordinating actors and operations at site. The DVM Info screens are the information sharing component of ACTOR (Automatic Coordination of Construction Actors) research project. The shared information is processed in the backend systems and methodology for those are developed in other works packages of the ACTOR project.

This first version of the Info screen implementation is based on the idea of installation of touch sensitive info screens at ground floor in each staircase or beside of a door of an elevator in use during construction. Especially in high-rise buildings, the worker has some time to browse the screen when waiting for the elevator. In all cases the screens would be along centric movement routes at site. The information needs to be focused on the expected needs to provide instant value to the worker and be easily consumed. To reach these goals, the following requirements have been set for the DVM Info screen information sharing.

3.1.1 Role-specific Information

It is proposed that a worker's profession/trade can be identified automatically to provide dedicated information to a person near the info screen. Identification can be based on different methods but in this case, it would be based on indoor positioning and tracking system as this information is needed for other features in ACTOR project. It is noted that there are attitude barriers for tracking personnel at site and there is European regulation on how personal data can be used and managed.

3.1.2 Location-specific Information

As Info screens are installed along the central routes used by workers, the default content covers the areas inward from the screen location. However, this depends on the direction of the worker's movement as it affects the expected need for information.

3.1.3 Context-specific Information

The Info screen shall have the same kind of features for information selection as current public web services to predict what information user needs based on user's behavior. Some of this context sensitive information can be determined by the direction of the movement (inwards/outwards) and time in relation to work shift. Basic events are when the worker enters for the first time during the shift to the Info screen and then outward or inward around the breaks. In these basic use cases, and especially when user is entering/leaving the Info screen on any other time, there is a need to inspect the user's movement patterns recorded with indoor positioning, to make reasoning of the possible information needs. This reasoning will be executed in the ACTOR backend systems where the methods are based on results of ongoing and previous research, e.g. [21], [22], [23].

The shared information may contain uncertainties as the provided view is based on expected need and the information contents based on analysis of automatically collected datasets. The system needs to evaluate the reliability of shared information and notify users of uncertainties. This would improve the system's credibility by providing accurate information. The user can be asked if the detailed information is correct, which will also encourage the user to interact with the system but, in general, the user is not required to input data to the Info screen system. However, users will have the possibility with the touch screen to browse different views, change to another role (profession) or change language as some visual information is supported with text.

The limited number and the locations of Info screens at site affects the design of the shared information contents. Within this general information the system shows some QR-codes leading to more detailed information which could be picked up with mobile devices for usage at other locations. The suitability and acceptability of mobile devices for these use cases need to be evaluated in later user tests.

3.2 Choice of Technology

Main selection for Info screen implementation was using BIM 3D-view as a basis in user interface views. BIM provides geometrical visual representation of buildings, but also other model information can be shared with Info screen users. There are plenty of different tools

for showing and interacting with 3D IFC data, of which Trimble Connect [24] was chosen because it has good 3D visualization capabilities, as well as a programming API for interacting with the BIM data. The BIM data is uploaded in Trimble Connect in IFC-format and all IFC information content is available for retrieval by API. It is also possible to add new models in Trimble Connect and show those objects in addition to other models. This functionality is used for showing e.g., material storage in the UI.

In practice, the info screen would be implemented using a large touch screen. For development purposes, a Windows laptop with a 14-inch touch screen foldable in tablet mode was selected. Since Info screen is implemented as browser/server application, there are no specific requirements for the user terminal: any touch screen capable of running modern browser is enough. Same applies to the server used: since all the demanding BIM model handling is implemented by Trimble Connect, a basic Linux Ubuntu server, with 6GB memory and Intel Xeon 2.90GHz processor, was used for DVM Info screen backend.

3.3 System Architecture

Info screen was implemented as a web-based application (Figure 1) where user interface was implemented as JavaScript application using React programming framework. Server was implemented as Java Spring Boot application, with embedded Tomcat server. Server is used for serving user interface code, as well as offering REST and WebSocket application interfaces. Data used in the user interface is stored in a relational database (PostgreSQL).

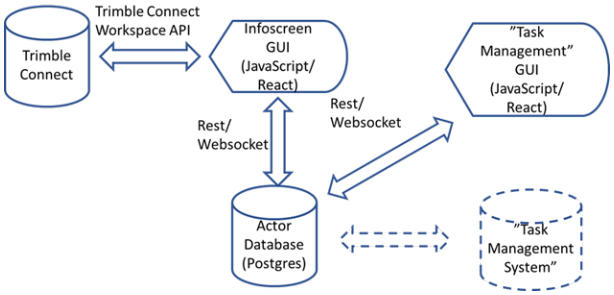

Figure 1. Info screen System Architecture

As described earlier, the Info screen is user interface for automated work management system investigated in ACTOR project. In Figure 1, the "Task Management System" describes this backend system, but integration has not yet been implemented due to parallel developments. Meanwhile, temporary UI is developed to input data in Info screen for testing purposes.

4 Proposed DVM User Interface

The basic features of the proposed DVM Info screen user interface is presented in Figure 2. On the header row are selections for language and profession/role of the user. These are set automatically to default values of user's profile if the user's profession can be identified automatically by indoor positioning system. If it is not possible or there are several professions nearby, the values can be selected manually with the touch screen.

Buttons on the left represent floors and those open 3D-view of the selected floor. The icons on the buttons summarize the work status of the selected profession in different floors. The blue check-box icon (☐) indicates where the work is going on currently. The green "checked" check-box icon (☑) visualize that all work is done in the floor. The thump (👍) and pointing finger (☞) icons express next possible work areas for the profession. The thump means the proposed next work location and the pointing finger indicates other possible free location.

For managing the activities at detail level, the DVM Info screen UI is following Location-Based Management System concepts (LBMS, [25]): the construction site is divided in work locations and there shall be just one activity going on in a work location at same time. Configuration of the DVM Info screen system requires definition of the activities / work phases as well as work locations in relation to IFC-objects in the BIM. In figure 2, the work locations are defined as sets of individual drywall objects. By default, in the UI the work locations where the work is going on are shown (blue) and the next proposed work location (light green) for this profession.

The work phases and locations shall be the same as are used in weekly planning of site operations, and DVM Info screen system is a channel to share the same information in visual format to the workers. The term "work phase" is used here to indicate that installation of a drywall requires a few work phases by different professions in correct order. The automated coordination of these is expected to improve productivity by increasing direct installation work time of workers total time at site.

Key objective in ACTOR approach is that the readiness of work phases can be recorded with sensing systems and no user input to update statuses is needed. Target is that on daily bases the work statuses will be checked with machine vision-based analysis [21] and at start of next work shift the statuses are expected to be known and will be showed to users at screen. During the work shift this baseline information will be compared to workers' indoor movement to detect whether the work has progressed to the next work location. In screen is shown question mark (?) to indicate that status of the work location may have been changed and user may update it manually.

Figure 2. DVM Info screen View for a Selected Floor with Visualization of Work Status of Drywall Installer

Other features in the UI are that user may highlight other information about work location occupancy, like other possible free work locations (yellow) and all finished locations (green) (Figure 2), and the locations that are restricted no-go areas (red) or reserved by some other activity (light yellow) (Figure 3). Users can also select to show the material storage locations (Figure 3). These materials and locations are targeted to identify with machine vision.

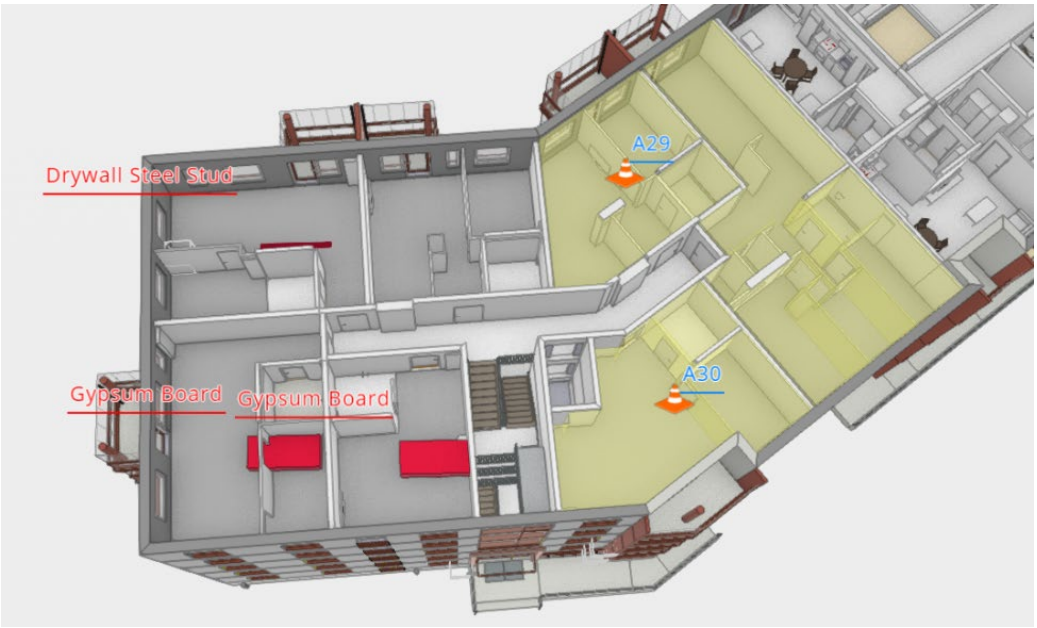

Figure 3. Examples of Visualisation of Restricted and Reserved Areas, and Material Storages

The information on design objects in BIM and drawings is one of the key information types for Info screen. Basic feature is providing links to drawings with QR-codes or open a drawing in info screen or showing detailed object data (Figure 4).

An important feature is to notify users of new versions of the drawing needed in user's work. The IFC data of individual wall can be shown e.g., wall types or the quantities in the work locations (Figure 4). Basic problem with drywalls is that structures are not modelled at detail level in BIM and specific requirements for wall installation e.g., additional braces in drywall frame, must be find out from related surrounding installations. However, this kind of detailed information is more needed at the work location and is not so important at the Info screen.

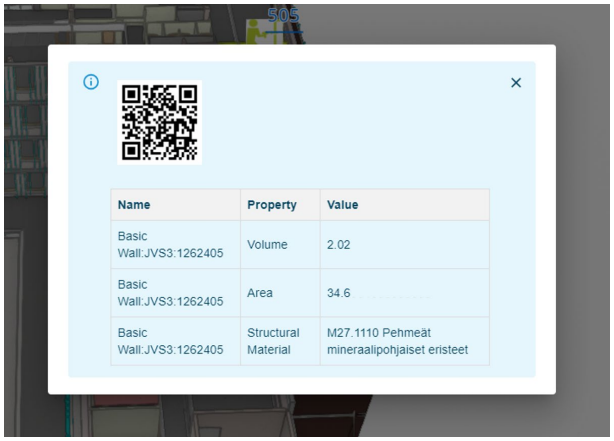

Figure 4. First example for showing drywall object data and QR-code to fetch data with mobile device.

The Info screen can also be used to push some notifications, even alarms, to give this information more visibility at site. Another idea is to add or read location specific notes ("virtual post-it notes") with Info screen UI.

5 User Testing

The potentiality of DVM Info Screen for future use was tested by workers at a construction site. Testing was performed at the office by the site. One researcher presented the user interface of Info Screen, conducted the interview, and wrote down the responses. The responses were then analyzed using narrative analysis to understand the perceptions of the users.

5.1 Method

Four carpenters performing drywall installation have been interviewed on the usefulness & ease of use of the Info Screen. Their average age was 48,5 years (min 39 years, max 63 years). Work experience was about 30 years on average (min 20 years, max 47 years).

Each interview lasted for one hour. During the interview, all main functionalities from the user perspective were presented and interviewees' opinions were asked about them.

5.2 Results

All testers except one found Info Screen easy to use. The only person expressing difficulties was the oldest one, not accustomed to digital technology. Despite this, all testers appeared to navigate through the 3D model effortlessly and had no difficulties in manipulating the device. As a grade, all testers found the usefulness of the information provided by Info Screen as good (4) and all, but one tester considered the usability of the device as good (4, average 3.25; the scale is 1-5 so that 1 is poor and 5 is excellent). One commented that it would be easy to learn to use the device, only brief instructions could be provided next to the device for the first use of it.

The information of the device can be located on a large screen at the site and/or in a mobile phone, as an application. Two testers would have the information in both ways, one considered the large screen as the best option, and one would only use the mobile phone application.

Testers were asked how much of the users' identity could be revealed to the device so that the device could provide tailored information when standing next to it. Options were the revealing of the person or the work role. Somewhat surprisingly, three testers found no obstacle in the ability of Info Screen to detect the personal identity of the worker when standing next to the device. One commented that the site is already full of cameras and there is such a hurry anyway that you cannot do anything but focus on the work. One tester would only allow the identification of a person's work role and the preferred language setting for the device.

No functionality provided by Info Screen was found unnecessary. The most useful information was found to be the statuses of the working locations (2 responses), easy access to design documents (1 response), or both statuses and documents (1 response).

The statuses of the working locations provoked discussions the most. Among the responses, only the symbols indicating a finished area and a forbidden area were found clear by all testers; the symbol indicating a possible work location was commented confusing the most often. Two testers stated that the status information about the work phase of the drywall installation is important to electrician, plumber, and painter; one noted that the information about the presence of other workers in the area would be useful so that when their work is about to be finished, the drywall installer can go there. This is in accordance with the fact that the construction

work is performed in harmony among various work roles and collaboration is important.

6 Discussion

This Info screen deviates from other information kiosks at construction sites, providing to workers role-specific, context and location aware information in visual form. However, the DVM Info screen development is a concept study. Practical implantation would require extensive automatic information collection from site and interaction with external planning and management systems. Sharing information with Digital Info screen would be one value-adding proposition for implementing this kind of emerging automated data collection and system interoperability. In addition to data collection, it is necessary to develop simulation and optimization methods to automate decisions about what are optimal next operations at site.

There were various information needs identified in the Finnish drywall installation interviews [3]. Some of these needs can be fulfilled with Info screen. Electricians, for instance, are involved in drywall installation as electricity related devices are installed in the walls so both drywall installers and electricians need the status information of the drywall. Regarding the need to conduct flexible work sharing, Info screen provides a means to inform all collaborating workers when some specific location is available for the work of the specific role(s). It can be concluded that Info screen would be beneficial also when work is done in solitude. The start of any work at a construction site usually requires that the previous work phase in some specific location is finished before the next phase can be started. Info screens can be used in these instances. Other information needs reported by [3] call for a different type of solution or solutions.

The results of the user testing revealed the challenges faced by some of the users, specifically, the older workers in using the proposed system. It is also reinforced during the tests that necessary training is required for effective use. There have been varied opinions on the fixed versus mobile and small versus large screens. It is also observed that there could be wider acceptance to such systems that can track the location (and personal work-related information) among the construction workers that is encouraging for the greater adoption of technology and collaborative work at construction sites. However, a large-scale validation is necessary to generalize these findings.

The Info screen system is the first attempt towards automatic coordination of construction actors at site environment. Beyond the first user tests further research is needed to improve the usability of the system and information contents, as well as adaptability to different approaches in workers' ways on organizing and planning their work recognized in [26].

Main visual element in the Info screen is the usage of BIM 3D-view as basis for visualizing work-related information. Current BIM models are produced for design purposes, even though those are also enriched for production use cases, like 4D-scheduling. The BIMs could also be enriched with information directed at workers e.g. including work requirements, detailing of structures or safety aspects. This information could be easily shared to workers in the Info screen UI. The detailed work planning tool used at site should also be linked to BIM in order exchange information between systems and making it easier to configure the Info screen system for a construction project. It can be noted that the management views are not in the scope of this paper.

7 Conclusions

It has been attempted to propose a suitable user interface for a digital visual management tool for construction workers. The design of the Info screen is based on the interviews conducted with the construction workers involving drywall installations on their demands & information requirements. Appropriate technical solutions have been chosen in the development of prototype with which it was possible to demonstrate the utility of the system under various use case scenarios. The initial testing of the prototype with the users revealed that the proposed system is easy to use and provides all the contextual information that is useful in their independent decision making. A wider study is required to generalize this proposed solution across other construction processes and locations.

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