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PRODUCTION & MANUFACTURING | RESEARCH ARTICLE

Tool or hassle?- Production workers evaluation of the potential of digital assistance systems on the shopfloor in shipbuilding projects

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Abstract: Technology development opens up for new possibilities to facilitate the production processes through digital information systems. To optimize the systems' value, the form, content, and medium must fit the needs of the workers. This article aims to contribute to the discussion on value, use and design of digital assistance systems for production. It presents empirical data from a case study at a Norwegian shipyard, on production workers' perception of coordinative challenges, and the value (including content) of digital assistance systems in complex shipbuilding projects. A quantitative survey among supervisors and operators at the shop floor was conducted twice due to different circumstances at the yard. These variations in circumstances are valuable to enable an evaluation of the workers' perception of coordinative challenges and digital solutions in different situations. The findings indicate a pronounced positive attitude towards the potential of digital systems. Moreover, the role of supervisors and operators in coordinative challenges leads to different requirements to the solutions. The results from this study will have both

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Robert Rost is a senior researcher and doctoral candidate at the Institute of Production Management and Technology, which is part of the Hamburg University of Technology. He researches since more than five years on smart solutions for workers in ETO industries especially in the field of Augmented Reality. The solutions he and his team develop focus on supplying the shopfloor with automatic generated, interactive workplans supplemented with information from different subsystems to increase labour productivity on the shopfloor. The overriding goal is a development that is close to the process in order to enable rapid application and intensive testing in the field.

industrial and scientific implications, as they provide valuable insights to help develop user-friendly systems that aid both workers and the company in terms of efficiency and accurate communication.

Subjects: Shipbuilding Industry; Production; Digital Workflow

Keywords: Shipbuilding; digital assistance systems; production; engineer to order; coordination; cooperation

1. Introduction

Developments within digital assistance systems open for new ways of facilitating communication and cooperation in work processes. This article explores the potential of digital assistance systems for production through a case study from the shipbuilding industry. This case represents a cooperatively complex production process as it involves multiple disciplines (e.g., piping, electro, painting, etc.) working interchangeably within a small physical space over a short period of time. Since shipbuilding involves a significant number of different specialized suppliers, this also means that associated workers have different organizational affiliations. Illustratively, more than 80% of the product's value is added by contractors and subcontractors (Held, 2010). Thus, the need to effectively communicate and coordinate work between many workers performing different but interrelated tasks, and who often speak different languages, is challenging, but highly important for a successful delivery. Additionally, good coordination requires decisions to be aligned to reach the overall objective of the project. Yet, among common coordination problems are inadequate structures, poor communication, lack of external support, poor cooperation, unclear responsibilities, as well as an organizational structure that inhibits coordination, particularly in interorganizational collaborations (Mello, 2015).The Engineer-To-Order (ETO) approach that most European yards apply, further complicates coordination. ETO is a customer-centered production strategy of highly customized products that allows for changes in fit, form and function of the product far into the production process (Cannas & Gosling, 2021; Haartveit et al., 2012). This ETO context complicates accurate specifications in the drawings and creates issues with workforce management within and between projects. Thus, the challenges concern both the content and process of communication. Studies like Mello et al. (2017) and Kjersem (2020) argue that shipbuilding projects still have serious issues in the coordination of cross-business activities, especially the coordination of the interdependencies between engineering and production. These challenges trickle down into managing the workflow in production. One key challenge is getting the correct information at the right time (Gosling et al. 2015). Also Mello et al. (2017) argue that the industry should either find a better use of the existing communication tools and methods, or implement new ones better suited to its specific needs.

With the above backdrop, this article uses an explorative case study to evaluate the potential of digital communication in reducing the challenges of coordination and cooperation in the production phase of ETO projects. Thus, the article poses the following research question: How do production workers in shipbuilding projects evaluate the potential of digital tools to reduce coordination challenges and improve communication in the production process? To answer this question, the article presents data from a quantitative survey run twice, 2 years apart and in two different circumstances, targeting production workers at a Norwegian shipyard. The main contribution of the article is the empirical exploration of digital tools through the workers' perspective on their need for collaboration, as well as the potential of digital solutions. From this, the article will contribute to the examination of the potential for digitalization of the communication process in complex ETO projects. Particularly, in terms of what the design of such tools should focus on to successfully help improve coordination and cooperation issues in shipbuilding.

The next section introduces the theoretical backgrounds about digital assistance systems and crucial acceptance factors, followed by an introduction of the adopted methodological approach and the empirical data. The data include information concerning who these workers are, what do they find most challenging in terms of communication and coordination as well as their evaluation of possible digital assistance systems. A descriptive analysis of their experiences and opinions about collaboration in general, is necessary for a good understanding of the challenges the workers face in their daily activities. This is also a critical step in identifying important requirements when developing appropriate solutions.

2. Theoretical background

This article centres on an explorative understanding on how production workers in shipbuilding perceive whether and how digital tools can assist the execution of work. This requires an understanding of (1) the general conditions under which work takes place, (2) the current state of the art within digital tools and (3) the influencing factors of technology acceptance.

2.1. General conditions

The production of a ship requires the interaction of a large number of individual work processes in which different disciplines, such as outfitting or electrics, are involved and which are each represented by different roles such as foreman, team leaders and workers. Such multitude of processes bring individual challenges and problems. In a broader perspective, further challenges and problems arise in the coordination of the interacting processes. This is further complicated by the composition of the workforce on site that consists of multiple different suppliers (organizational complexity) and several different nationalities (cultural and linguistic complexity; Sánchez-Sotano et al., 2020). One consequence is the interferences between the yard and the subcontractors and a closer look at the processes on the shopfloor reveals that workers, especially in the ETO industry, have a very high demand for up-to-date and detailed engineering information. Additionally, a lot of experience is needed on the shop floor to master complex assembly tasks in a short period of time (Wei & Nienhuis, 2012). However, the available documents often do not cover this demand adequately (Halata et al., 2014).

2.2. Digital tools

As digitization grows in importance and capability to serve all kinds of processes, shipyards around the world have started to adopt and implement digitalized solutions for many of their work processes (Jahn et al., 2020; Sánchez-Sotano et al., 2020; Sullivan et al., 2020; Von Lukas Uwe, 2010). Due to their assistive functionalities for the dominant manual work processes, e.g., step-by-step guidance in a work task, these solutions are often referred to as digital assistance systems (Hinrichsen & Bendzioch, 2019). Those systems open for the possibility to combine textual or 2D descriptions of work, with 3D-model visualizations of the product. Halata et al. (2014) state the importance of geometrical information for manual work processes in ETO shipbuilding processes since they can answer questions like where a specific part has to be installed or how a complex construction needs to be assembled in a very efficient and intuitive way. Augmented reality (AR) as an addition to 3D modeling enables transmitting the digital information to the physical world. Virtual objects are connected with the physical environments, interactively and in real-time (Azuma et al., 2001). According to Porter and Heppelmann (2019), AR-based solutions are increasingly adopted in industrial settings and case studies. Paula et al. (2018) highlight assistance in production as one of seven different areas in shipbuilding that show a promising potential for AR-solutions. Romero et al. (2016) emphasize the potential such solutions can have in respect to facilitating work processes, particularly that they can help overcome language barriers. Additionally, AR-based assistance bears potential to empower production workers by improving knowledge management in terms of creation, distribution and consumption (Hannola et al., 2018). While there are several examples of studies where the technology has been applied in a small scale (Halata et al., 2014; Von Lukas Uwe, 2010), there are also a few examples of studies about a large-scale implementation in the shipbuilding industries (e.g., Paula et al., 2018). AR based solutions, showing the status of activities on the production floor, have demonstrated potential to improve efficiency and productivity (Wang et al., 2020). This is especially in processes where different subcontractors work closely together, and where communication is a key factor for the project performance (Tam et al., 2011). The study of Apt et al. (2018) show the necessity for cooperation and communication skills as well as the potential on how these abilities can be improved by digital assistance systems. However, the numerous digital solutions developed for, or adopted in shipbuilding, are suitable for selected process problems. Existing digital assistance systems, which make use of 3D visualization in either the form of a CAD viewer or via AR, like those created in research by Halata et al. (2014), or that are commercially available (e.g., WorkLink by ScopeAR, Vuforia Instruct by PTC or REFLEKT ONE by RE'FLEKT) have a strong focus on visualizing the tasks of a single person or department. Some of them are also capable of offering functionality like showing the result of tasks. But those tools lack a visualization of how "my task" integrates into or interacts with tasks and results of other workers or departments. With respect to large-scale implementation of AR-based solutions, there are several ethical, legal, and practical concerns related to the strain on the operator and these need to be further explored (Hjartholm, 2019).

Although many of the described approaches exist, only a few of them find their way into practice (Palmarini et al., 2018). According to Egger and Masood (2020) user acceptance is crucial when implementing new technologies. The following sections therefore discuss different acceptance factors according to the Technology Acceptance Model (TAM) as a basis.

2.3. Acceptance factors

The successful implementation of any digital tools in a production environment depends on several factors that relate to functionalities as well as the medium. Merhar et al. (2019) identified influencing factors in device acceptance and these relate to perceived usefulness, technology design, working environment, social influence, individual factors, organizational factors, and safety factors. Concerning the latter, both data safety and data protection are mentioned as examples. The concern about outside actors getting access to sensitive data or the fear of misuse of available data shows the increased complexity in respect to cyber security when using such tools. Schuir and Teuteberg (2021) have conducted a study of future workers (students) and concludes that for head-worn AR systems safety enhancement and productivity gain are two main drivers. The Technology Acceptance Model (TAM) provides further important clues in regard of the influencing factors independent of the device but rather for the technology as a whole (Davis & Davis, 1989). The first important factor is perceived usefulness, which implies that a technology must provide a benefit for each user with his or her individual problems. The second important factor is perceived ease of use, which must also be ensured for each individual user. Both factors shape the attitude of the user towards the technology and thereby establishes the intention to use it, which ultimately leads to the actual use behavior of the user (Kong et al., 2021).

The desires and wishes of the individuals according to the TAM are therefore crucial for a successful implementation of new digital technologies and their deployment in order to achieve the desired effect based on a high degree of overall acceptance (Jones & Kochtanek, 2004; Monica et al., 2020). The approach of this paper is therefore to explicitly examine the desires and requirements of a relatively large number of potential users and to consider different roles, disciplines and situations in shipbuilding independently of particular solutions.

3. Materials and method

To build a ship is a coordinatively complex endeavor that raises critical challenges in terms of communication and coordination. As such, a potential benefit of digital assistance systems is to reduce these challenges though information handling, distribution, and visualization. However, as discussed in the previous section, digital solutions must be in tune with the needs of the users. The aim of this article is to identify users' perception of key coordination and communication issues, as well as their evaluation of the value, including what would be the most valuable content, of digital assistance systems in shipbuilding. The following part of the article explains and argues for the methodological choices made to explore this.

The adoption of digital tools can be suitable at different levels of the shipbuilding process. As such, it is necessary to demarcate which part of the building process the investigations shall focus on. In this case, it is the production work done on the shopfloor in the outfitting phase of the build that takes place after the hull arrives at the yard. It is a particularly interesting phase to concentrate on for several reasons. First, it is characterized by a short-time window. Second, these tasks are done within a small physical space. Third, it represents an intra- and interorganizational complex workspace, as the workers belong to different disciplines as well as formal organizations. Fourth, these workers have different national, cultural, and linguistic backgrounds. These factors can both be seen as a key argument for the value of digital assistance systems, as well as dimensions presenting some of the key challenges.

The articulated research question in this article is as follows: How do production workers in shipbuilding projects evaluate the potential of digital tools to reduce coordination challenges and improve communication in the production process? The aim is to foster knowledge on their evaluation of communication, coordination and digital solutions that might guide future user-oriented design of such solutions. To be able to explore this question among production workers, several methodological strategies are possible. The coordinatively complex context of shipbuilding and the identified research question raise some requirements that the chosen research method needs to be able to meet. The method must be applicable at multiple points in time to cover different situations. Further, the method needs to address/incorporate all partners in the production process. This means the question must be relevant for suppliers as well as permanent staff, across disciplines and must be understood by a culturally and linguistically complex group of respondents. In this case, a quantitative survey among production workers was chosen. The survey targeted production workers within all disciplines, including subcontractors present at the yard. At the production level, there are three hierarchical positions—foremen, bas, and operators. The bas works as a middle-level supervisor between a group of operators and the foremen. In this article, “production worker” is used as a term to capture all three levels. While addressing any of the groups in this article, these three hierarchical levels are used to distinguish between them.

Quantitative methods are suitable when the aim is to get information on a few subjects from many people. It enables a systematic and structured approach to data collection that presents the respondents with the same questions and alternatives. In this respect, the method is valuable to get a general overview, but does not allow an understanding of more dynamic matters of work execution, topics that would require a more qualitative approach (Ringdal, 2018). Several dimensions speak in favor of choosing a survey to answer this research question. The first one is to be able to ask the opinion of many workers. The second is language, as a survey can be distributed in several different languages. A third is availability, as asking the respondents to fill out a survey is less invasive in terms of time, than asking many workers to participate in qualitative interviews. A fourth reason is that it allows the research team to test out several different pre-defined possible options for content and medium—to see what the respondents favor. A fifth reason is replicability, as it allows the researchers to repeat the survey. This is particularly valuable to avoid special situations, e.g., that the results were very affected by the timing of the survey. The potential to investigate the latter was optimal for this survey as it was conducted twice at a yard experiencing major changes over a period of a few years. The difference in situations between the two rounds of surveying is explained shortly.

A key issue with quantitative surveys is that the researcher defines both the questions and relevant alternatives for the respondents. Thus, it becomes essential that the researchers have enough context information to accurately define the central questions (Ringdal, 2018). In this respect, the validity of the survey is strengthened in that it is part of a larger research project. This project is a case study that followed a shipbuilding company and its suppliers through a significant transition phase where the yard started building a new type of ship. As Yin (2014) points, case study is a research methodology suitable when *how* or *why* questions are asked with regard to contemporary issues of practical relevance and where the researcher has no control over the studied phenomenon. This methodology approaches each problem in depth, offers high conceptual validity and a good understanding of the problem's contexts and processes as well as the causes of the studied phenomenon while fostering new hypotheses and research questions (Flyvbjerg, 2011). Moreover, the case study is an effective approach when conducting empirical research and demonstrates validity with respect to theory building, testing, and further development (Yin, 2014).

The research project focused on integrated planning, work processes, and the potential of implementing new digital assistance systems. The other processes of data collection were key input to strengthen the design of the survey. The design took form in different phases.

3.1. Design, distribution, processing, and analysis of the survey

Prior to designing the questionnaire, the research team performed 29 qualitative semi-structured interviews, focusing on the organization of two different shipbuilding projects. The selection of interviewees included technical and production coordinators from all disciplines, project planners, purchasers, and the production manager. These interviews included questions to grasp the processes of work and the guide was centered on issues concerning planning, coordination, and cooperation. The research team asked specifically about the contextual shift in the type of vessels being produced. The interviews also included a discussion of how digital assistance systems could affect work, and these questions were facilitated by an illustration of a tablet version of such a system. In addition to the interviews, the research team observed seven different project meetings divided between a weekly foreman meeting, a project meeting for technical and production coordinators and at a project management level.

The insights from these interviews and observations served as a base for the survey design. A first draft of the survey was outlined by the main author. This draft was distributed to the rest of the research team as well as the yard. The recipients at the yard included among others the production manager. The yard was invited to both evaluate the relevance of the identified questions and to propose new ones. This resulted in some rounds back and forth to refine the questionnaire. To further ensure the reliability of the results, the survey was distributed in five of the most used languages at the case yard (Norwegian, English, Polish, Lithuanian, and Romanian). All translations of the original Norwegian survey were quality proofed by native-speaking yard employees.

The survey was first distributed digitally, and later on paper to increase participation.

For the first survey, the total population was estimated to be 820 workers present at the yard that day. Out of those, 316 responded, where 16 were taken out due to incomplete answers. This leaves a response rate of 37%. Given an extremely high work pressure at that time, this is viewed as a decent response rate. The *second survey* had a population of 614 workers. Out of these, 327 replied, of which eight were taken out due to answering only a few of the questions. Thus, the analysis of the second survey is based on 319 respondents, which gives a response rate of 52%. Distribution took place in meetings, in the lunchbreaks, and through foremen to ensure a broad distribution. The surveys done on paper were registered digitally afterward. Each 10th digital registration was checked up against the paper version as a quality control of the plotting. The collected data were analysed using SPSS. Results were presented and discussed with the yard and the rest of the research team. This conversation stimulated further analysis of the data.

The timing of each survey is quite significant, and the difference in context will be explained under the case description below.

3.2. Case company

The case shipyard is located on the Northwest part of Norway, a region where an innovative maritime cluster gained worldwide recognition on the ability to deliver highly complex, technologically advanced vessels. Previously, this regional yard has been specialized mostly towards the offshore market but has reoriented itself to building specialized cruise vessels. The research team followed the yard and its suppliers during this transition as this circumstance challenged several aspects of communication and collaboration among the actors within the cluster. The second circumstance was connected to the Covid 19 pandemic that started in 2020, which also brought unforeseen challenges to the way project participants communicate and collaborate across organizations. Before we present these circumstances further, a short description of the context of the research and the tools used by the yard and its suppliers is in place.

3.3. Production as the research context

The article focuses on the outfitting part of the production phase that takes place at the local yard, which ranges from 6 to 18 months depending on the finished level of the pre-outfitting phase. During the outfitting phase, the hull is equipped with all necessary machinery, electrical cables, piping, isolation, ventilation, interior, etc., to transform it from a large empty hull into a finished ship to be delivered to the customer. All the involved disciplines are quite interdependent during this phase, working interchangeably onboard the ship. This causes high demands for sequence coordination, as well as good, and effective communication between the different project participants.

Each discipline splits its total work into work packages and specific tasks. Some of these work packages are outsourced to suppliers through a fixed price, while others are performed by yards' employees. Outsourcing relates to capacity and/or competence. The division of work is often solved by assigning the total work of the discipline on certain decks to the suppliers. The foremen or the bas assigns a task to an operator, who reports back to be given a new one after this work is done. The foremen keep track of the overall progress of completed tasks, including the cooperation with other disciplines. For the operator, the interdisciplinary nature of the work is mainly actualized in practical matters in terms of task execution. Most foremen and discipline coordinators spend a substantial part of their working day searching for information and communicating it to the operators. This information is usually to be found in computers located in offices around the yard premises, which in turn implies walking to the offices and back to workplaces within the vessel that might have several floors and quite intricated walking routes. However, since changes to the final product can happen until a late stage in the building process, many drawings might be updated after the foreman has communicated them to the operators. Furthermore, the existing points of information on the vessel, are place at fixed places and require some walking time from the working place to their locations on the vessel. Therefore, a closer point of access to the necessary information is a strategic improvement that the yard wishes to adapt.

The works done at the offices and at the production level are highly interrelated. In the current article, the focus is on the work taking place onboard the ship during the production phase, and it is reflected in that the survey targeted production workers. This means it leaves out the important activities that are prerequisite of this work, e.g., project planning, the work done at the administrative coordinative level (production and technical coordinators for each discipline) and delivering the production material like the drawings (engineering).

3.4. Circumstances of the two surveys

While the survey was run twice at the same yard, the situations at the yard at these points in time were quite different. The contrast between these two circumstances is empirically interesting. They posed quite different challenges for the yard, and potentially also for the production workers' requirements and preferences to the content of digital information systems that help information flow and coordination. The following presentation introduces these circumstances in more detail. This is an important contextual information to interpret the coming discussion of the workers' evaluation of cooperation and coordination, and their preferences with respect to digital solutions.

3.4.1. Situation 1: 2019

In 2019, the survey took place at a point in time where several local yards got footing in a new market, cruise. This caused a rapid upscaling of personnel as well as activity levels, after the downsizing caused by the collapse of the offshore market. Some key contextual factors emerged as a result. For one, relying on suppliers to help this situation meant that the share of workers employed by the supplier was very high as shown in Figure 1. Second, there was a high demand for workers in both the European and Norwegian shipbuilding industry, which meant that the yard encountered difficulties in setting demands for which workers they wanted from the suppliers (e.g., workers they had used before).

As Figure 1 illustrates, 18.4% of the workers have worked less than a year in the shipbuilding industry. These numbers suggest that many of them (even if they could have relevant disciplinary backgrounds) were dependent on quite detailed instructions to be able to execute work. The results also showed that 3.4% of the respondents[1] were new to the professional field they were representing. Furthermore, 40.7% of the respondents[2] were at the yard for the very first time. Even if many of these 40.7% have had experience from other yards, they would still need to familiarize with the case yard's specific way of working. This further strengthens the need for detailed instructions and control.

An additional factor significantly influencing the 2019 situation was that this was the yard's first large-scale outfitting of a cruise vessel. The yard had previous experience with building cruise vessels, but this new type of buildings introduced the employees to unfamiliar customers, suppliers, products, work priorities, and requirements. The qualitative interviews confirmed that these issues combined caused substantial challenges in terms of cooperation and coordination among project participants.

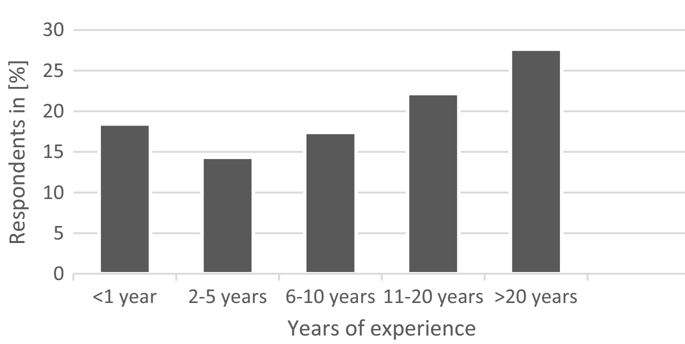
3.4.2. Situation 2: 2021

The situation was quite different in the 2021 survey, which was conducted during the corona pandemic. First, the yard had delivered two large cruise projects and had gained experience (including on which suppliers to invite back). Next, there was a significant decrease in the number of workers with less than 1 year of experience in the industry, from 18.4 to 1.6%. Moreover, the number of workers that were at the yard for the very first time had also been considerably reduced. In 2019, most of the workers were at the yard for the first (41%) or up to five times (33%), while in 2021 only 13.9% was there for the first time, and 36.6 had been there between two and five times. This reduction both reflects that the yard had taken serious measures to control who came to the yard and that the market in general was more stable. A more experienced workforce was thus combined with more experience in building such vessels at the case yard. Qualitative interviews and observations done as part of this project confirmed a calmer atmosphere and a more systematic approach to coordination and cooperation.

3.5. Distribution of participants

A key indicator of the validity of the results is whether the respondents reflect the population. The following graphs show the respondents divided between yards own staff and suppliers.

Figure 1. Respondents from 2019, split between years of experience in the industry (N = 293).



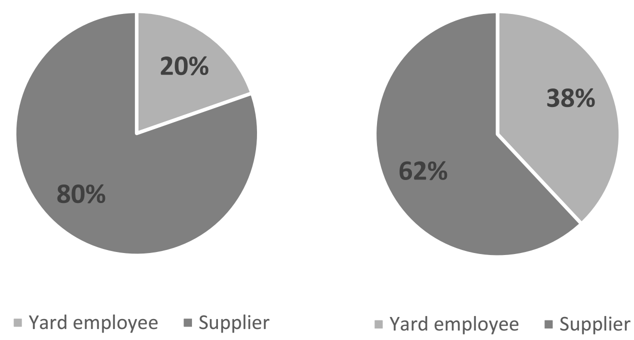


Figure 2. Respondents by employment affiliation in the two surveys 2019 (left N = 295) and 2021 (right N = 313).

As Figure 2 shows, the number of respondents affiliated with the suppliers is quite large in both surveys, respectively, 80% (2019) and 62% (2021). The ratio between suppliers and yard employees reflects well the information given by the yard. Results indicate a change in the composition of workers between the two periods, as only 29.2% of the respondents in 2021 answered they had participated in 2019.[3] In short, while this survey is at two different times, the change in respondents means that while there is continuity in respect to the yard, the change in respondents means a minimal overlap between the datasets in terms of respondents.

Next, it is relevant to look at how the respondents are spread in respect to discipline.

Figure 3 shows that respondents represent all the different disciplines, with a weaker participation in some of the categories. The involvement of workers from different disciplines depends on the lifecycle of the production process, so it might very well be the case that some divisions are less active than others at a given point in time. The spread between the different divisions is quite similar in the two graphs.

A third dimension that is relevant to examine is the ratio between operators and foremen.

Figure 4 shows the ratio between the different positions among the respondents. The yard confirms that this fits well with the general ratio between the groups. The differences between the 2 years are also small. As shown in Figure 4, most respondents to the survey are operators—respectively, 83% in 2019 and 82% in 2020. These are the largest number of production workers. The other two groups supervise the operators' job and coordinate between the different work teams. In this survey, the Bas, and foremen each make up around 9% of the respondents. The bas are 9% in 2019 and 8 in 2021, while the foremen are 8 in 2019 and 10 in 2021. The latter indicates a larger spread among foremen in the last round. The validity of the results is strengthened as it

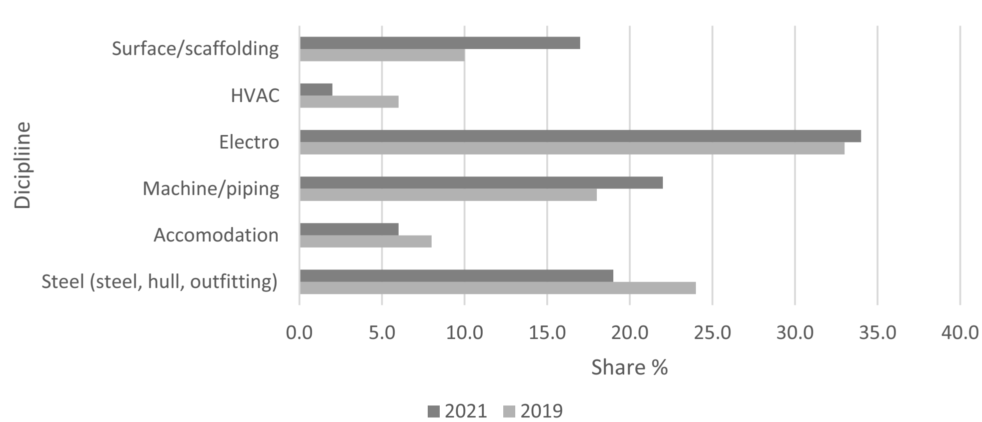
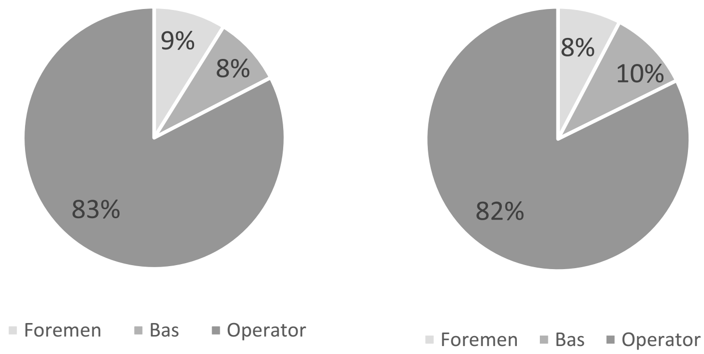


Figure 3. Respondents split by discipline affiliation 2019 (N = 298) and 2021 (N = 315).

Figure 4. Overview respondents split between position/role 2019 (left N = 293) and 2021 (right N = 313).



reflects the ratio between the groups, and the results also demonstrate the wide distribution of the survey beyond management level.

4. Results

The following section presents and analyzes the findings from the survey backed-up by the interviews, direct observations from the production, as well as participation in different planning meetings. The first step is to present the way production workers evaluate relevant aspects of their project work in two different circumstances. For the second step, we look at worker's evaluation on how a market in transition and a global pandemic challenged the collaboration among project participants. The third step is to present workers perception of digitized solutions as potential tools to improve cooperation and communication across disciplines and organizations.

4.1. Worker's evaluation of the dimensions complicating work

The circumstantial differences between 2019 and 2021 are interesting contextual factors when asking how production workers in shipbuilding evaluate the potential of digital tools to reduce coordination challenges and improve communication in the production process.

The situation in 2019, with rapid upscaling in an unfamiliar market, and in 2021, when the yard has gained more experience in the market and workers were there for longer periods of time posed two quite different challenges in terms of the information and level of instruction needed. Moreover, one can assume that the factors influencing coordination and control can possibly be different. One of the questions in the survey asked the workers to evaluate 11 different predefined factors said to complicate work. Each of the factors was graded from one (most challenging) to five (least challenging). Table 1 shows the production workers' evaluation of the factors on an aggregated level.

Table 1 depicts small variations between the 2 years, even if the situation was quite different at the yard. *Rework* was scored among the top three factors on both years. Rework means that someone must redo part of, or even their entire tasks. In some cases, rework concerns that execution is not according to the agreed standard, but the typical cases brought up in the interviews concerned rework due to poor cooperation. Quite often, this is caused by someone trying to compensate for lack of progress in one area by starting on another. Often, operators do not have a complete picture of the status of the work of the other disciplines and/or what needs to be completed before they can start their specific task. In this sense, rework also relates to *time pressure*, one of the other dimensions that scored in the top three both years. Delays and changes into the production process are quite common in ETO projects, and these are combined with set project dates that create tight deadlines. As a result, the interviewees described a proactive attitude among yard's workers and suppliers alike, to keep the progress by reprioritizing among the defined activities.

Lack of competence among workers is another issue that scored high among the top two complicating factors both years. One way to mend this is to increase the control of the formal

Table 1. Rating of factors complicating cooperation and coordination on a scale of 1 to 5 (1 = most challenging)

2019		Average (SD)	2021		Average (SD)
1	Re-work	3.0 (1.1)	1	That other workers lack necessary competence	3.2 (1.4)
2	Lack of competence in other workers	3.03 (1.2)	2	time pressure	3.22 (1.2)
3	Confusion about the work process	3.06 (1.0)	3	Re-work	3.23 (1.1)
4	Language—having to speak a foreign language	3.10 (1.2)	4	Language—to have to speak in a foreign language	3.28 (1.3)
5	Time pressure	3.17 (1.2)	5	Language—to understand what people say	3.39 (1.2)
6	Physical space to do the work task	3.23 (1.2)	6	Confusion concerning the work process	3.40 (1.1)
7	Language—to understand what is being said	3.25 (1,1)	7	Language—to understand the meaning of what is being said	3.41 (1.1)
8	Language—to understand the meaning of what is being said	3.30 (1.1)	8	The physical space to do the work	3.42 (1.1)
9	Disciplinary cultural differences	3.33 (1.1)	9	National cultural differences	3.76 (1.2)
10	Cultural differences between companies	3.37 (1.2)	10	Cultural differences between the different companies	3.80 (1.2)
11	National cultural differences	3.38 (1.3)	11	Disciplinary cultural differences	3.82 (1.1)

competence of hired workers. However, when the workers are at the yard, they speak about the need for more detailed and easy-to-understand instructions.

Confusion about the work process score higher in 2019 (#3) than 2021 (#6), which is likely due to the differences between the situation in 2019 and 2021. In 2019, both the workers and the yard were tackling unfamiliar processes. A final element that goes into the top five dimensions of both years is having to speak a foreign language.

Overall, complications, according to these workers, has more to do with coordinating workflow in an environment within a space characterized by limitation both in physical space and time, and where the production material is subject to changes due to the ETO context. Here competence and language further complicate cooperation, and it obscures a shared understanding of the situation. While there are slight differences in prioritization between the two surveys, the similarities between them (despite quite stark differences in circumstances) indicate that these prioritizations between various cooperative issues are consistent.

4.2. The workers evaluation of cooperation challenges

The coordinatively complex production processes in shipbuilding means that planning, coordination, and cooperation become essential to ease the workflow.

Table 2 shows the results of four different statements about cooperation and coordination. The respondents were asked to rate each of these statements using a Likert scale from 1 (totally disagree) to 7 (totally agree). The table displays the average score of each statement, as well as the standard deviation. The table also include the result of an independent-sample Kruskal–Wallis Test, comparing the statements to the role of the production workers. The null hypothesis is that the response is the same across categories of roles. This means that if the hypothesis is confirmed, there are no significant variations in the evaluation of this statement because of the role the production worker holds. If there are significant differences, the null hypothesis needs to be rejected. The significance level is 0.050. Table 2 shows the results for both years.

Comparing the results of these four statements it can be stated that all of them score an average between 4.19 and 5.52. The corresponding standard deviation is listed in parenthesis for each average score. On a seven-point score, one can argue that middle value of four represents a neutral position, while the score to either side can be seen as a, respectively, negative or positive evaluation. All these statements are given a higher score in 2021 than 2019. Yet within the years, the order of the statements (from the highest to the lowest score) are the same. The slightly more positive score in 2021 than in 2019 might relate to the situational differences. In 2019, the yard was in a situation where they aimed to get footing in a new market. This meant unfamiliar customers, products, requirements, and processes that concerned all. Moreover, the rapid upscaling in a pressed market meant a lot of new workers.

Evaluating the results of the Kruskal-Wallis test, all the statements are significant in 2019, while statement # 2 and 3 are not significant in 2021. As mentioned, a significant result means that the null hypothesis of the Kruskal-Wallis test (that the evaluation of these statements are the same regardless of the role the respondent holds) is rejected. This means that in 2019, the role of the respondents influenced how they evaluated the above statements. In 2021, however, role did not explain variations among the respondents in how the respondents evaluated statements no. 2 and 3. In the following section, the two statements significant both years, which means role influence the respondents' answer the statement are investigated further.

The above graph in Figure 5 shows the answers split by role. The graph shows the spread of the answers, where the blue box displays the interquartile spread of values, while the black line indicates the median value for each of these groups. In the below discussion, the spread refers to the interquartile spread. A first observation is that foremen and bas are noticeably more negative than operators to the statement in Figure 5. Moreover, all groups are more positive in 2021 than in 2019.

Table 2. Evaluation of statements on collaboration and coordination from 2019 (N = 264–269) and 2021 (N = 286–290). 1 = totally disagree 7 = totally agree. Order by most positive to negative evaluation (highest to lowest score)

Statement		2019		2021	
		Average (SD.)	Kruskal-Wallis Test	Average (SD.)	Kruskal-Wallis Test
1	It is easy to solve technical problems that occur	5.23 (1.51)	0.002	5.52 (1.50)	0.034
2	It is easy to solve problems that occur in regard to cooperation	5.14 (1.46)	0.001	5.40 (1.43)	0.297
3	The cooperation between the different disciplines is good during the building process	4.90 (1.66)	0.000	5.18 (1.55)	0.715
4	I rarely have to wait for others to be able to complete my own tasks	4.19 (1.92)	0.000	4.56 (1.87)	0.001

In 2019, this statement is significant in the difference between foremen and operators (.000) and for Bas and operators (.001). In 2021 foremen-operator is significant (.007), but not the others.

Compared to the latter, the difference between groups in Figure 6 is not as stark, but the spread among foremen is larger and the median score lower. Also, the range is larger in 2019 than in 2021 for all groups. In this statement, it is only the difference between foremen and operators that is significant in 2019 (.003) and 2021 (.040).

The respondents' evaluation of the above statement leaves the impression that the supervisors struggle more trying to sort out cooperation issues that occurs than the operators. To investigate this further, Table 3 displays the answers to the question concerning who the operators turn to when they experience problems. The alternatives to choose from in the survey were as follows: Their closest co-workers, other workers, their bas, their closest foremen, other foremen or others. This was a multiple-response set, where workers ticked off all relevant. In the below table, these categories are lumped together in fewer categories, to illustrate the extent to which the operators turn to hierarchy (summing up all options relating to asking foremen or bas vs. all categories related to workers) and to what extent they discuss issues with others outside their closest circle (summing up all options related to "their own" workers, bas, or foremen vs. "other" workers, bas, or foremen).

Table 3 depicts that, in both surveys, operators report that they turn to their supervisors more than their fellow workers, but when they do discuss with others than their supervisors, it is those they are closest to. The system for division of work makes it is fair to assume that "other workers" means workers from other disciplines working in the same zone. As such, the results show that despite the interdependent task execution between disciplines, the operators most frequently address problems by communicating with their supervisor and to some extent also discussing them within their team. They discuss cooperation issues outside their work group to a lesser extent.

The above figures and tables give an overall introduction to the challenges of cooperation and coordination as seen by those involved in production. The results indicate that there is real potential to make improvements within these areas in the production process. Before analysing this issue further, it is interesting to look closer at the questions asking the respondents to evaluate the potential of digital solutions as a communication tool, and their preferences in terms of type of content.

4.3. Respondents' perception of digital solutions- content, medium and potential

The respondents were asked to evaluate whether digital solutions could be of help in their work. The first question consisted of a battery of seven statements presenting the respondents with different alternatives of content and prioritization of information within such digital information systems. They were then asked to evaluate each statement on a Likert scale from one (to a very little extent) up to seven (to a very large extent).

The other column shows the result of an independent-sample Kruskal–Wallis Test where the statements are compared to the role and employment (yard vs. supplier) of the production workers. The two background variables are relevant to consider if developing digital assistance systems for yards dependent on extensive intra- and interorganizational cooperation and communication.

Table 4 shows that the respondents have a positive attitude towards digital solutions, as all alternatives have a high average score.[4] Scores range between a high four and high five for all options, both years. Also, the respondents scoring of the various alternatives are quite similar between the 2 years. Both in 2019 and 2021, they are most positive to the options prioritizing 3D visualization of the work—whether the task, the totality it fits into, or the results. The statements prioritizing background information, like resources needed to complete the task or information about the status of the necessary components, are given a slightly lower score. Several of the statements are significantly differentiated by role in 2019 (#3–6), while in 2021 this only applies to two (#1 and 3). Differentiated by employment, the null hypothesis remains for all statements, except 2 (the totality the task fits into) and 3 (presents the task in 3D) that is significant in 2021. Hence, the findings show that the organizational affiliation of the worker has little significance for their evaluation of digital tools.

The statement about digital solutions that presents the work tasks in 3D in respect to role, is significant in both years and is used as an example to illustrate how the response differs by role.

Figure 7 shows an overall high evaluation of the value of 3D presentation of tasks, the bas having the most positive median value score across the 2 years. The median score of the middle-

Figure 5. Production workers evaluation of the statement "I rarely have to wait for others to be able to complete my own tasks" split by role from 2019 (left N = 269) and 2021 (right N = 286).

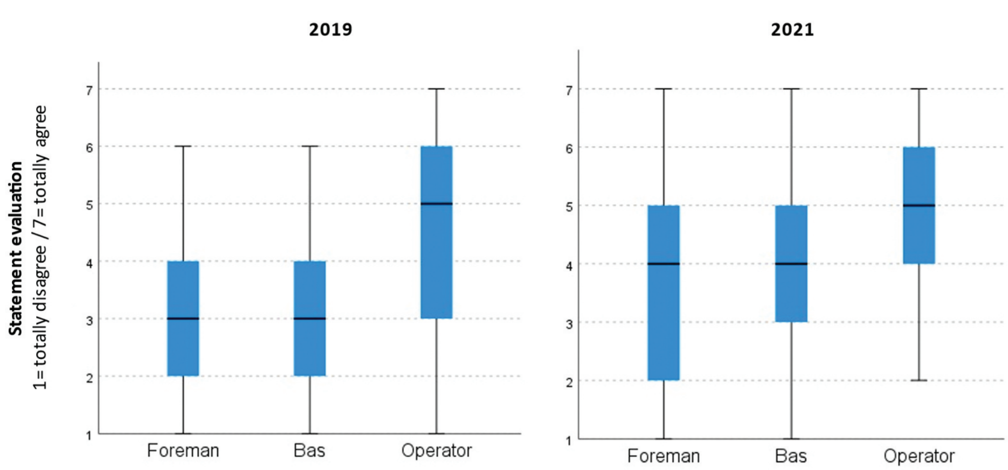


Figure 6. Production workers evaluation of the statement "It is easy to solve technical problems that occur" split by role in 2019 (left N = 255) and 2021 (right N = 278).

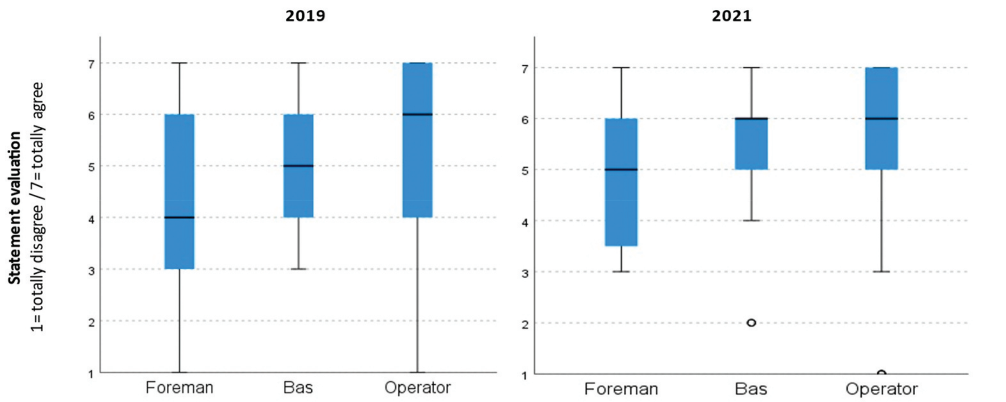


Table 3. With whom do operators communicate if they have a problem from 2019 to 2021 in absolute numbers (Multiple-response set)							
2019				**2021**			
Hierarchy	**252**	**My group**	**246**	**Hierarchy**	**168**	**My group**	**289**
Workers	126	Others	91	Workers	139	Others	89

level managers (bas) is 7 both years. Among the foremen, the median score in 2019 is also seven, but has been reduced to six in 2021. Regardless, this is a very positive score of the value of such visualization. The median score of the operators is consistent at six both years, while the spread is somewhat larger in 2019. This suggests a consistent high score between the 2 years among all groups. Concerning differences between the groups, a pairwise comparison shows that in 2019, it is the relation operator-foreman that is significant (0.035), while operator—bas scores just over the set significance level (0.053). In 2021, it is bas in respect to foremen (.050) and operator (0.009) that is significant.

After evaluating these different solutions, the respondents were asked whether they meant such solutions would be helpful in their work. The respondents could choose between five options ranging from "to a very little degree" up to "to a very large degree."

Figure 8 depicts that the respondents are overall positive to the potential of such solutions to assist their work. The median value for all respondents in 2019 in 4, while in 2021 the operators' median value went down to 3. Frequency analysis shows that in both years, around 50% of the respondents chose to a large or a very large extent (47.4 in 2021 and 56.5 in 2019). If "to some extent" is included, the results sum up to around 80% of the total respondents (85.6 in 2019 and 78.3 in 2021). The Kruskal-Wallis test shows that the null hypothesis must be rejected in both years, which means that the role is significant.

In terms of preferred medium, the respondents were given three concrete options to choose from, as well as a fourth rest category.

Figure 9 shows that, between the three identified mediums, the respondents' favoured option was the phone. In fact, 47.5% of the respondents in 2019 and 57.2% in 2021 answered they would prefer to get the information through their phone. While 17.3% preferred a tablet in 2019, this decreased to 5.7 in 2021. Both years around ±30% of the respondents stated they had no opinion on the matter. Thus, among the respondents, there is a strong preference for the telephone as the medium for such digital assistance systems. In expert talks with production workers during a later test done by the research group on a developed prototype, a risk assessment of tablets relates to

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Table 4. Evaluation of different forms digital solutions 2019 (N = 270–280) and 2021 (N = 205–228)

“It will be useful to have digital solutions that can … ”		2019			2021		
		Average (SD)	KWT role	KWT employment	Average (SD)	KWT role	KWT employment
1	allows me to see the final result will look like in 3D	5.59 (1.6)	0.393	0.096	5.67 (1.7)	0.016	0.075
2	allows me to see the totality my work tasks fit into	5.54 (1.6)	0.884	0.096	5.65 (1.9)	0.067	0.003
3	presents the work task in 3D	5.49 (1.7)	0.026	0.384	5.71 (1.7)	0.009	0.020
4	makes the production basis available	5.08 (1.8)	0.002	0.148	5.32 (1.8)	0.212	0.307
5	overview of what components/ material/tools I will need to complete the work task	5.07 (1.8)	0.035	0.365	5.25 (1.9)	0.644	0.189
6	show me purchase- or production status of the components/ material I need to complete my work task	4.69 (1.9)	0.004	0.204	4.96 (1.9)	0.104	0.050

the risk of breaking, and the workers reluctance to risk damaging employer supplied hardware. Also, smartphones are often preferred over tablets due to their compactness. Smartphones can be easily stowed away in work clothes in almost any work situation and environment while tablets need to be placed in the environment or a carrying bag if not used or both hands are needed for a work task.

A final statement included in this battery of questions presented the following statement to the respondents "I believe such digital solutions will help overcome current language barriers as it allows us to show each other what we are talking about." Figure 10 presents the respondents average score to this statement.

Figure 10 shows that the respondents are quite positive in terms of the potential such solutions can possibly have with respect to overcoming the linguistic barrier table one demonstrates the workers are quite concerned about. Correlation analysis of the included background variables shows that none of them provide significant results to explain variation among the respondents' evaluations.

The following section further analyzes the findings of the data presented in this article and discusses the implications for the requirements of digital assistance systems answering in this way the research question.

5. Discussion

The first reflection is the production workers' positive evaluation of the potential digital assistance systems can have upon work execution in production. The result shows a high percentage of workers giving a positive score for the potential of digital solutions to be of help in their daily work. As such, the respondents seem to share the view of the potential such digital assistance system can have in respect to improved coordination and communication on the shop floor (Apt et al., 2018; Tam et al., 2011; Wang et al., 2020). Thus, the results demonstrate the respondents' positive evaluation of the perceived usefulness, which Davis and Davis (1989) identify as a key acceptance factor. As mentioned, the desires and wishes of the individual according to the TAM are thought to be crucial for a successful implementation of new digital technologies and their deployment in order to achieve the desired effect based on a high degree of overall acceptance (Jones & Kochtanek, 2004; Monica et al., 2020).

The first factor is preferences in terms of medium. The results show that over 50% prefers solutions developed for a smartphone. Talks with respondents state several practical reasons as

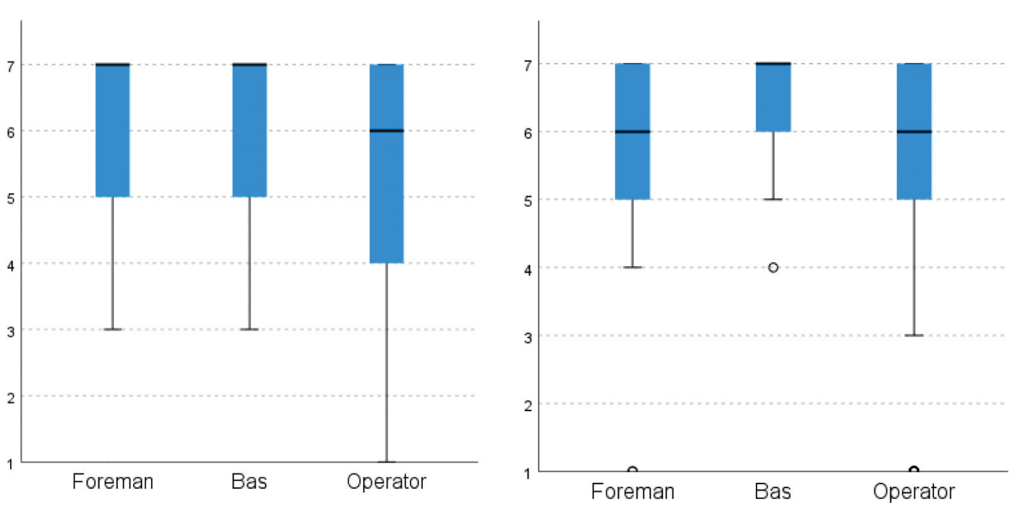


Figure 7. Respondents' evaluation of the usefulness of a digital system that presents the task in 3D 2019 (left N = 233) and 2021 (right N = 214).

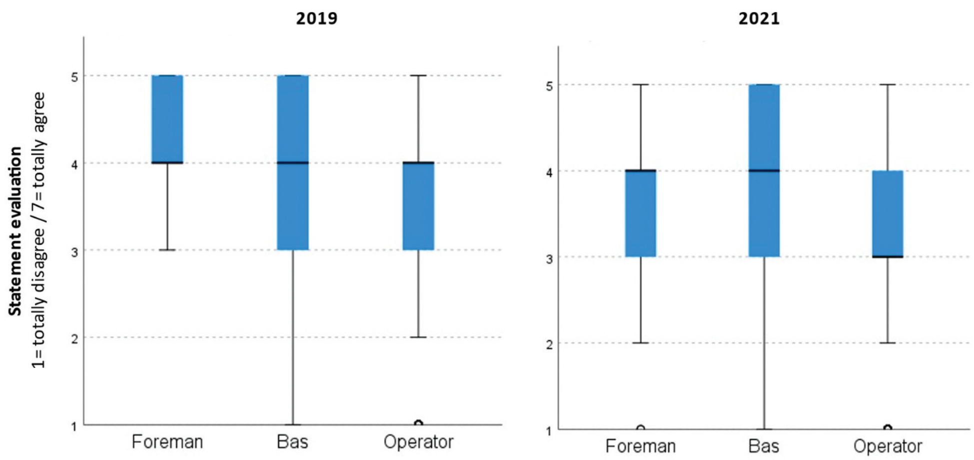


Figure 8. Respondents' evaluation of if they find digital tools to be of help in their work" 2021 (N = 295) and 2019 (N = 278).

the ability to stow them away and risk assessment (having to take responsibility of employer supplied hardware). Thus, the respondents' evaluation relates to Davis and Davis (189) second acceptance factor of perceived ease.

Given the fact that during the surveys no users were presented or asked to test samples of digital assistance systems on any device type, it is still to be evaluated on how the opinion changes when respondents are confronted with examples of such tools prior to assessing preferences. VR glasses are less established device type in both private and work environment compared to tablets and smartphones. Thus, familiarity can also be a factor in the respondents' evaluation of the different mediums. Jahn et al. (2020) proposed to study and compare smartphones with tablets in experiments and demonstrations on real-work tasks in order to focus on the real application in the work environment. They also argue for an evaluation of differences in using digital assistance systems on both the most preferred devices (smartphone and tablet) from a practical point of view with focus on benefits for work tasks and the impact on efficiency when performing them (Jahn et al., 2020).

The matter of visualizing the information speaks to two different dimensions: First, the collected data show a language barrier among the workers due to the extensive outsourcing strategy that results in a nationality diverse workforce. As Table 1 shows, in both surveys, the respondents list "having to speak in a foreign language" as the fourth most important factor (of the 11 identified) to complicate coordination and control. Also Romero et al. (2016) emphasized the potential of digitized tools to help overcome language barriers. The respondents to this survey share this positive assumption, as in both surveys the statement of "[...] such tools can be of help to

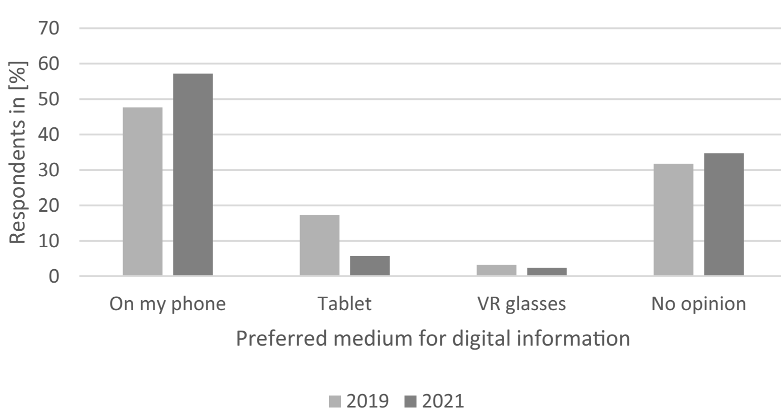
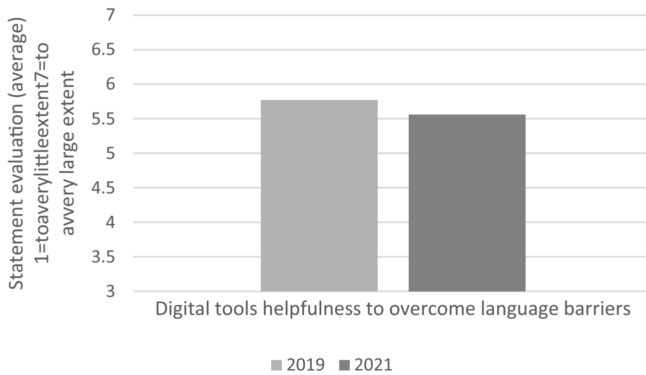


Figure 9. Respondents' evaluation of what medium they would prefer to receive digital information through split between 2019 (N = 277) and 2021 (N = 297).

Figure 10. workers assessment of digital tools helpfulness to overcome language barriers split between 2019 (N = 219, SD 1.6) and 2021 (N = 271, SD 1.7)).



overcome language barriers by visualizing what they are talking about" is given a high average score (5.8 in 2019 and 5.6 in 2021 out of seven). Second, the data show an increased need for detailed instructions with workers that are less familiar with the yard, the cruise market and so forth. The benefit of visualization is also evident from Table 4, showing that the workers prioritize the solutions that enable visualization of the task, the results, or the totality the tasks fit into.

The type of visualization mentioned in these answers, was especially a three-dimensional visualization. A positive rating of the visualization type, when used to visualize task-related information, has been further observed in previous studies on digital assistance systems as an evaluation scenario (Halata et al., 2014). However, this test was performed with only a small number of participants. Nevertheless, the current study shows that this can also be observed in a larger and more representative group of shipyard workers.

A major coordination issue, according to the production workers, is rework. Reducing rework implies doing the tasks right in the first place (instructions) and doing the tasks in the right order (coordination). The first part about instructions has multiple dimensions. One of them is accurate drawings, a highly relevant issue in shipbuilding, but outside the scope of this analysis. Another dimension is the competence of the workers performing the tasks. In Figure 4, as well as in the situational descriptions, it is evident that there are lot of workers with limited experience from the yard, but also the industry. This enhances the need for more detailed descriptions and instructions for work. Thus, there are clear benefits of adding visual aid to these instructions.

Investigations into the coordinative and cooperative issues the production workers face give important indications on the significance of designing such systems in close collaboration with the user. Table 2, as well as Figures 5 and 6, show that it is the foremen who are left with finding solutions to cooperative and coordinative challenges. The findings presented in Figure 6, where foremen and bas report having to wait for others much more often than operators, can be explained by their tasks requiring a higher degree of communication with other disciplines. Foremen' roles imply that they must be available for specialized consultation either on the ship or at his/her office located within the yard's premises. Therefore, it is of special importance to support these roles in terms of more efficient means of communication.

The implications for digital tools are several. The results show that when given solutions are in tune with the production workers' needs, they have a positive attitude towards the potential of such systems. To ensure that the systems are aligned with the workers' needs, the results show that considering the difference in cooperation and communication challenges depending on role is important. For the operators, digital assistance systems should provide them with the ability to perform their job well the first time. This relates to instructions, coordinative information, as well as visualization. These will reduce the problem of confusion concerning the work process that disturbs and inhibits cooperation. For the supervising roles (foremen, bas) the role of the digital assistance system is more related to assist them in coordinative/cooperative matters and problem solving while aiming for shorter waiting times. Returning to Table 1 on coordinative issues, it is evident that support on solving problems from cooperation and coordination assistance in assigning tasks to workers with suitable competence would reduce one of the most highly rated reasons for problems. Less waiting times can reduce the time pressure leading to coordination problems. Further support on dealing with rework should be aimed for. Further implications are that a closer interconnectivity between digital assistance systems, a possibility to easily report work results and feedback to others and the integration and suitable visualization of the necessary 3D information that does not belong to "my task" but tasks of others are required. To be suitable for ETO production, such a digital tool needs to avoid laborious content creation processes and to be suitable from an economic point of view.

There are multiple factors to be considered, which lead to a certain medium (device type) being preferred over others. Merhar et al. (2019) formulate influencing factors on acceptance, which are perceived usefulness, technology design and working environment, social influence, individual factors, organizational factors, and safety factors. The results presented in this research are in line with previous investigations, regarding the aspect that VR glasses are less accepted when comparing mobile and wearable devices being used as digital assistance systems in manufacturing environment yet (Merhar et al., 2019).

6. Conclusions

This article posed a research question that focused on production workers' evaluation of the digitized solutions that would be implemented as a mean to achieve a better coordination and collaboration across participants in complex shipbuilding projects.

The results show there is a real potential for improvement of coordination and communication issues in production. The issues relate to the changes produced by ETO context and having to do their work in a highly interdisciplinary space limited by both physical space and time. Rework and having to wait for others are key issues. Competence and language further complicate coordination and obscures a shared understanding of the situation. The respondents' evaluation leaves the impression that the supervisors struggle more than operators when trying to sort out occurring cooperative issues. This impression is strengthened as the findings show that operators most frequently address problems by communicating with their supervisors and to some extent also discussing them within their team.

The production workers are very positive to the potential of digital assistance systems to help solve such issues. The responses show preferences in terms of both content and medium, which have implications for future design of solutions based on digital information assistance. Moreover, the findings show that the requirements for content vary depending on the role of the respondents, which relates to the supervisors' role in solving communicative and coordinative issues.

Combined, the positive attitude towards digital assistance systems as well as the indications concerning content, will also have industrial implications as it is an indicator for the value of investing in such solutions for the production workers.

Further studies might focus on whether AR-based solutions are able to answer workers requirements in a complex, uncertain, and dynamic ETO environment. Another key matter is the issue of cyber security that the literature highlights as a key driver from implementations. Important questions regarding both privacy issues and data access needs to be explored further.

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Notes
1. N = 297.
2. N = 297.
3. N = 290.
4. To ensure that respondents did not place themselves in the middle if they found the topic irrelevant, they were also given the option “not relevant” (not included in this presentation)

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