CONSTRUCTION INDUSTRY 4.0: ENTANGLING COLLIDING PRACTICES

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Industry 4.0 (i.40) transforms traditional manufacturing and industrial practises with new smarter technologies. Within construction it has a very challenging adoption curve. The aim of this paper is to understand why i4.0-technologies have problems being exploited in construction practices. The interaction of new technologies within the workspace and how it is organised is known as sociomateriality. Using the concept of performativity, we will examine the enactment of new technologies both in the supply chain and implementation on site. The data collection method includes 10 action-oriented interviews with i4.0-technology-vendors, specialised in technology for the construction industry. The research results show that there are colliding practices. One practice at the construction site and another practice is the designers of the automation solutions. However, the existing knowledge and experience from i4.0 is also an opening for experimentation with new approaches based on the interaction between the different practices and technology.

Keywords: Industry 4.0, automation, practice, design, sociomateriality

INTRODUCTION

In the construction industry, different indicators suggest that conventional construction methods have reached their technical performance limits. Worldwide, automation and robotic technology are considered a key element of the future of the construction industry (Pan *et al.,* 2018) and its ability to improve productivity, safety, and product quality (Chu *et al.,* 2013). Despite a focus on new technologies, the sector has so far not experienced large-scale real-world implementation (Pan *et al.,* 2018). The construction practise's difficulty to change is referred to as an inertia in construction (Buhl, Andersen and Kerosuo 2017). So, the construction industry is under pressure. Historically, there has been a focus on process improvements, e.g., Lean principles and methods have had a long-standing role as an embraced concept for developing construction processes. The critical studies reveal a piecemeal adoption of Lean and long-term adaption to practice and lack of needed reorganisation. That leads to an overrating of the impact on productivity. These kinds of commentaries are opening up assumptions previously taken for granted (for example, on the normativity of the research and technology determinism) or providing

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alternative ways of interpreting the field by expanding the methods and research approaches used for making research on construction practice (Koch, Paavola and Buhl 2019).

Worldwide, automation and robotic technology are considered a key element of the future of the construction industry to improve productivity, safety, and product quality. Construction practices are influenced by information technology (IT) and automation technologies, the latest trend is the German high-tech strategy i4.0. The i4.0 strategy originates from general manufacturing industries (Bock 2015), addressing an industrial revolution within large manufacturing companies and related industries, increasing the use of information and automation technologies (Oesterreich and Teuteberg 2016). The promises and premises of i4.0 should be understood in this context. It is a very different practice compared to current construction projects or even an industrialised construction process. Adding and connecting the i4.0 technologies (robotics, additive manufacturing, sensing, cloud computing, machine learning, big data analytics, Internet of Things (IoT), augmented and virtual reality, and so forth) seems not to have revolutionised the built environment yet.

Our research aims at creating understanding of design and implementation processes informed by practice theories that can improve automation in construction. The sociomateriality concept "performativity" nails our ambition fine. Performativity is not the same as performance. Where "performance" refers to the action of an activity (such as when a physician "performs" a medical examination or the musician "plays" in front of an audience), performativity refers to "enactment". For sociomaterial researchers, it draws attention to how relationships and boundaries between humans and technology are not predefined or fixed, but "enacted" in practice. It is often referred to as the "practice turn", which is based on an understanding of: "how boundaries and relations are enacted in recurrent activities…. In this view, an organisation is held to be a recurrently enacted and patterned set of relations, reproduced over time and space" (Orlikowski and Scott 2008: 462).

The purpose of this paper is to investigate how i4.0 vendors view the practice they are trying to automate. Phrased as three research questions: - How do sociomateriality approaches give us new perspectives and understandings of i4.0 design and implementation? - How do i4.0 vendors develop their solutions to the construction practice? - How do i4.0 vendors understand technology development (design processes) in construction?

METHODS

Exploring technology in a broader context can be seen as a need to experiment with technology in order to get experience with technology in use. During the past decade, we have made several research projects about automation in construction. The overall theme for our research is technology implementation (literacy) and understanding of construction practice. The research is embedded in an environment focusing on innovation and experimentation as part of an applied science research strategy. To develop our socio-technical approach we have studied practice theories, starting with Cultural-Historical Activity Theory (Engeström 2008; Buhl, Andersen and Kerosuo 2017), ANT/boundary objects (Fox 2011; Buhl, Andersen and Klitgaard 2019) and now sociomateriality (read next section). Our interaction study of practice is action research, we would like to produce/create knowledge together with actors in practice (stakeholders from practice). Construction practice is influenced by many. We aim to do away with technology determinism and "process improvement culture", and instead investigate openings towards new practices in construction collaboration and use of technologies. We combine a process lens (experimental action research) and practice lens (sociomaterial practice theory) to study how construction practices can be developed. Our normative stance is to transform the construction sector from a technology deterministic understanding of "improving processes" to a relational understanding of the complexity and dynamics of entangled practices creating "sociomaterial agency" (Buhl, Andersen and Kerosuo 2019).

For this paper, we have conducted "action research interviews". The interview in an action research optic is a planned dialogue that seeks to explain local actors' perspectives on perceived challenges in their own context. Directed by a known and accepted purpose, the action researcher, with interviews as a method, seeks to create an analytical basis for making choices targeted to this: to increase both individual and collective action in relation to the challenges experienced. In other words, the interview is orchestrated as a method for creating reflective space for a potentially transformative common learning experience for researchers and study participants (Nielsen and Lyhne 2016). An important difference from the classical qualitative interview (Kvale 1997), where the information achieved might be validated by the interviewee. The researcher will do the interpretation based upon their wisdom and training. In the action-oriented interview, the interpretation of the interview is done (as much as possible) together with the interviewee. Analytical concepts used in the interpretation with participants will be related to the used theory. As part of the interpretation of the interviews, the researcher returns to the interviewed (Nielsen and Lyhne 2016: 60).

We have conducted 10 interviews with vendors, specialised in technology for the construction industry. We became aware of these vendors through a regional robot development cluster. They are on the way to market with new solutions within the scope of i4.0; covering solutions like robots for assembly of brickwork, windows and drywall installation, drones, exoskeletons, field-scanning technologies, machine control and support for digital solutions like BIM.

In the first round of interviews, we have been concentrating on their understanding of construction practice and the build environment and the interplay concerning their technologies. In the second round of interviews (after COVID-19) the focus shall be on creating a reflective space for a potentially transformative common learning and performativity.

Approaching our participants for an interview, we framed the interview as a talk about i4.0 (Construction automation), its innovation potential through "re-configuration" or possibly a paradigm shift in the industry's way of organising building processes. For instance, the development of new industrial processes and products, organisational structures, management, business models etc. This shall require a change process and a new practice in order to fully realise the potential. We asked questions on: How does your solution/product create value in construction and contribute to automation (digitisation)? What experiences do you have in designing, implementing and disseminating your solution? How is the solution being received by the various parties in construction? How do you work on implementing your solution in construction? What do you see as the biggest challenge for your solution and for automation (i4.0) in construction?

The analysis strategy is to look at how participants view the practice they are trying to automate: What problems do they see, what will they achieve, what opportunities do they see, who are the actors/stakeholders and their relationships (entanglement and performativity)? Our aim is to be open for anything that the participants overlook that is or can reduce their understanding of the complexity of the practice they will automate.

Sociomateriality Perspectives

Orlikowski has discussed sociomateriality in many recent papers. She examines sociomateriality through a practice-lens as "Sociomaterial assemblages" that are "situated and recursive process of constitution" (Orlikowski 2000: 409). Social and material are deeply connected and "there is no social that is not material, and no material that is not also social" (Orlikowski 2007: 1437). Orlikowski (2009) recalls that materiality largely ignored in studies of organisations and technology is either being dealt with as "absent presence", "exogenous force", "emergent process" or "entanglement in practice". Absent presence means that that materiality is not acknowledged and accounted by researchers in their studies.

When technology is an exogenous force, it is investigated as "hardware", a discrete artefact constituted of machines and instruments, or a thing separated from humans and organisations. Technology can also be treated as an abstraction, i.e., characteristics of tasks in assessment of workgroup effectiveness. As an exogenous force, a device that transmits, manipulates, analyses and exploits digital information. The criticism of technology as an exogenous force concerns the lacking role of history, social context and human agency. Consequently, the dynamics and situations of the constitution of technology have not been considered in practice. "We have a tendency to talk of [technological] artefacts as if they were a piece—whole, uniform, and unified… as if they were single, seamless, stable, and the same, every time and everywhere… such technologies are rarely fully integrated, flawless, unfailing, and they can often do break down, wear down and shut down" (Orlikowski and Iocono 2001: 131).

Technology, as an emergent process, accounts for material artefacts as socially defined and produced in social and institutional contexts. A situated and a reciprocal process of interpretation and interaction with particular artefacts are required for the technology to emerge. Technology is discussed in its general meaning without any specific characterisation. It may mean devices, software programs etc. and can be equated with materiality. However, the approach of the technology as an emergent process has been criticised for a tendency to downplay the specific technological properties of an artefact. Orlikowski (2009) suggests entanglement in practice lens could better account for both technology and social in studies of technology. Although an ontological priority is given either on technology or on social there is an underlying assumption in both approaches related to the ontological separation of the technology and the social that she calls "ontology of separateness". According to Suchman (2007), the ontology of separateness is "an ontology of separate things that need to be joined together" (Suchman 2007: 257).

Whyte and Harty (2012) introduce alternative approaches to study sociomateriality of artefacts. Leonardi and Barley (2010) separate the social and the material analytically to examine the relations and connections between them. Gherardi investigates sociomateriality as embodied within and across social and material artefacts (Gherardi 2012). Sociomateriality is, in this context, about developing ways of thinking, reflecting and talking about the social and material world as entangled in concrete practices (Suchman 2007). Harty (2008) uses the term "relative boundedness" to study innovations during the shift from non-IT artefacts to 3D IT-tools in the construction industry. Relative boundedness “considers the ways that processes of innovation can bring in or exclude a wide range of actors and material artefacts as they play out” from the perspective of actor network theory (Harty 2008: 1029). This means that more or less effectively stabilised material and social relations can be studied in all techno-logical artefacts such as bridges or buildings during their design, construction and use.

Leonardi emphasises human enactment in the understanding of sociomateriality and how the social and the material become entangled. He writes: “(Whereas) materiality might be a property of a technology, sociomateriality represents that enactment of a particular set of activities that meld materiality and institutions, norms, discourses, and all other phenomena we typically define as ‘social’... Coordinated human agencies (social agency) and the things that the materiality of a technology allows people to do (material agency) and become interlocked in sequences that produce empirical phenomena we call ‘technologies’, on the one hand, and ‘organisations’, on the other” (Leonardi 2011: 34-35).

According to Leonardi, the sociomaterial entanglement is, therefore, enabled by the ability of a human agency in the realization of one’s goals and the capacity of material agency embedded in technologies social practices. The metaphor of “imbrication” initiated by Leonardi (2011) suggests how social and material agencies become entangled. The verb imbricate has a Roman origin referring to roof tiles “tegula” and “imbrex” tiles being interlocked in waterproof roofs. Leonardi (2012) assures: Social and material agencies, though both capabilities for action, differ phenomenologically with respect to intention. Thus, like the tegula and the imbrex, they have distinct contours and through their imbrication they come to form an integrated organizational structure” (Leonardi 2012: 37).

Sociomateriality approaches and vocabulary (e.g. performativity, enactment, entanglement and imbrication) provide an analytical understanding of the connection between technology and practice. Technologies are formed in practice and used in many ways, and there is not a one-to-one relationship between design, application, and function. Users are well-informed and creative on their own terms, far from the simple twist that the concept of the user assumes them to be (Krippendorff 2006; Buhl, Andersen and Kerosuo 2019). Sociomateriality approaches can help to explore the challenges of designing and implementing new technologies in construction and to create knowledge for an active intervention (action research). Because it can inform our understanding why i4.0-technologies have problems being embedded in construction practices.

FINDINGS

There seem to be some common features in the way development processes and automation of solutions take place. Automation and robotic companies are the drivers, typically by looking for potential opportunities in practice as the first step to develop ideas, which may lead to the development of new technology solutions or the further development of existing technology solutions. The development process often goes through tests by prototyping multiple laps, a method which positions the technology as an outside force trying to adapt to practice.

An example of this is a company, working on the development of transformative technologies for the construction industry, including the development of a cutting robot for heavy pavement tiles. The company strategy is to generate new technologies, developing a basic concept and subsequently developing it into a prototype that is sent out to the user for the purpose of testing the idea. If the idea is received favourably, the development process can continue. In this specific example, the prototype evolved by having the cutting robot tested seven times by a contractor on various sites before the company decided that they had a product that could be finalised.

The prototyping process results in several different actions. Among other things, the contractor had promised to supply a generator on-site so that the prototype could get power. It turned out that the generator and prototype power connectors did not fit together. That resulted in the prototype being equipped with its own generator to meet this problem going forward. Similarly, at one of the workplaces, water could not be obtained, and the prototype was then equipped with a 100-litre filtered water tank before the next site visit so that the water could be recycled. A third challenge through the prototyping process was to get the tile close enough to the cutting robot for machining. Therefore, both the trailer and the conveying robot, as well as the cutting robot, were equipped with a small 125-kg crane.

Another example is a company that worked on the development of a semi-automated lifting machine for the installation of interior glazed walls in office environments. The company developed the idea for the robot based on being able to get in contact with a large Danish construction company (specialising in mounting ceilings and wall systems). As a result, the company in the subsequent process ended up developing three prototypes, all of which were tested on a construction company's construction sites. Feedback from the craftsmen brought about various mechanical changes in the process. Along the way in the development of the prototypes, the robot vendors also realise that construction sites are complex.

> There are two ways to test; one was to drag it out on to the construction sites, and the other was that we had our own little laboratory where we set up simulations and mounted walls. The goal was that we could mount in under 3 minutes…. we could.

The interviewer then tells about the real-life issues they encountered at the construction sites, space conditions, and the challenge that several different trades work in the same areas at the same time. "The environment we experienced on the construction sites actually caught us out".

One company stands out compared to the others. The company is developing a voice-controlled plasterboard cutting machine. Atypical of the other participants interviewed, the idea developer and driver is a carpenter who, based on his own practise, seeks out a local robotic environment where he presents the idea. For the first meeting, everyone looks at the "chrome-plated solutions", which indicate that they (the robot designers) do not know their practice. As a result, the carpenter must explain that he needs hands-free solutions. Development status is that prototype 2 is ready to be tested in the market. The test involves a service technician (formerly a carpenter), responsible for setting up and introducing the cutting machine; an observer focused on how the people on site handle the robot; and a developer collects ideas for improvement. The company expects improvements in this process on an ongoing basis before an actual product is ready.

In this case, the development of the prototype is based on a practise understanding through the carpenter's knowledge of specific interpretations of and interaction with plasterboard assembly. Its places the technology as a product of the ongoing human interpretations, i.e., as an emergent process where the understanding of technology is neither fixed nor universal but emerge from situations and reciprocal processes of interpreting and interacting with artefacts over time (Orlikowski 2012: 8). The example also illustrates that robot Vendors' understanding to begin development of ideas is based on the technical process and - solution-based thinking. If the technology positioned as an outside force, we will argue that the development and implementation process will be vulnerable, technologies are often rarely fully integrated, flawless and unfailing, and they can break down, wear down, and shut down (Orlikowski 2012: 10).

Our data collection shows that the companies' approach to developing and innovating in construction with automation solutions is built around prototyping and tests. The focus is a design and process challenge, which is reflected through the process with a continuing interest in solving immediate problems while also developing the design, a method that is reflected in a socio-technological approach. (Bjørn and Østerlund 2014: 19). In general, "our" participants understand that there are some complexity and challenges in practice, which they deal with through their focus on specific design processes, which includes both specific technical content and social process content, i.e., the user who applies the technology. It means, that "our" participants were "zooming in" on the socio-technical configuration related to how the technology is used.

The companies share some common challenges. To the question of what they see as the biggest challenges for your solutions and automation (I4.0) in construction, the general answers were: Long development processes, expensive development costs, and getting the technology out into practice, as one of the participants put it.

> The biggest challenge is getting the mindset accepted. On-site they may well keep an excavator which costs DKK 600.000, which is not used all day, but it can be difficult to convince people to invest DKK 700.000 in a robot.

In this perspective, it seems to be interesting to focus on a change to work. We suggest a focal shift from the socio-technical approach on design processes, i.e., from design interest per-se to investigate the users work-practices as composed from a variety of different logistics and capabilities (actors, fields of knowledge, tools, products, activities, operations, complexities). Our first findings show examples on the missing understanding of the enacted practice. It cries out for sociomaterial design approaches and understandings of performativity (enactment) and entanglement (imbrication) that can provide connection between technology and practice. We have scoped a number of questions concerning the consequence of bringing new technology into practice. For instance: Roles and hierarchies in changing the construction; the new dynamics created, and the methods and work processes that are changed, not only are for the individual operator's work, but for other professional groups as well. Do they have to adapt to other technologies? Can architects and engineers in the design phase adapt their designs and construction solutions in relations to automation and robot technologies to the construction site?

CONCLUSION

This endeavour was started by a wondering - why do solutions for automation in the construction end up in a hidden corner at the construction site? As subscribers to a sociomaterial ontology we looked into practice to find answers.

In our interviews about how i4.0 vendors understand technology development (design processes) in construction, we came across colliding practices. One practice at the construction site and another practice for the designers of the automation solutions. How are they colliding, and what can we learn about automation in construction?

The vendors understand predetermined processes (technologies in use), they do not capture the complexity of the site practice. That may be intentional, but it is not an advantage. The vendors improve processes and technology through a prototyping process. Their prototyping approach must be elaborated to understand the entangled nature of the construction site. They have discovered the practice (or have they?) - they're still working in their own laboratory to mature the technologies. As Birgitte Munch (Former professor from University of Aalborg) quote:

> Technology is not a 'mist' that falls from the sky and blesses us with greater productivity and better design. Technologies are not born ready, and by the time they are 'finished' or 'mature' can be contested. Where can we go to buy an "IT system" that we just have to plug in - and then it "works?"

Technologies are enacted - performativity refers to how technology is enacted and performed in relationships and boundaries between humans, and are therefore not pregiven, but recurrently enacted in practice. How can sociomaterial thinking and vocabulary affect vendors? One cannot design affordance, but one can analyse the use of technology in the context in which it appears (in our second round of interviews, we shall bring up this theme about lacking understanding of the interaction between practices and technology - if the understanding of the social is very rational and instrumental the challenge is to find a way to talk about practice).

We think technology determinism plays a major role in understanding the problems of diffusion of i4.0 technologies. In our analysis of interviews, we have spotted traditional understandings of the social and the technical, that somehow affect the design and implementation process - prototyping is a common way to explain the development process (no one talks about themselves as "socio techniques"). The technology is present, but the understanding of the change processes in practice is absent.

Rethinking prototyping could be a way to work constructively with the collision between practices. A facilitated prototyping process could serve as an invitation to explore and test new practices by fostering interaction in a construction context. However, the existing knowledge and experience from i4.0 is also an opening for experimenting and implementing technologies. Prototyping serves as an invitation to engage and explore the i4.0 solution. The idea is to open up for an experimental approach based on the interaction between the practice (actors) and technology, an 'invitation' to inspire and challenge dominant perceptions of construction and futures. This involves navigating between existing realities and unknown futures to empower transitions of existing non-sustainable practices.

Furthermore, because i4.0 futures are not yet known, it is a specific challenge to create and qualify experiments with alternative future realities. The rehearsals of possible solutions become a key element in development. This directs attention to discussions about how uncertainties and alternatives are addressed to open up opportunities to explore sustainable futures.

In our ongoing action research project on i4.0 vendors' development of solutions to the construction practice, we work on how to entangle colliding practices by experimentation such as laboratories, prototyping and temporary interventions are applied to empower technology with the capacity to open opportunities to explore possible futures.

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