INTERNATIONAL DESIGN CONFERENCE – DESIGN 2024
https://doi.org/10.1017/pds.2024.21

The Karakuri IoT toolkit: a collaborative solution for ideating and prototyping IoT opportunities

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Abstract

This paper presents a collaborative solution developed to enable people without prior Internet of Things (IoT) knowledge to ideate, conceptualise, role-play and prototype potential improvements to their work processes and environments. The solution, called the Karakuri IoT toolkit and method, was tested in two workshops with eight production leaders at a Swedish manufacturing company. Outcomes were analysed from the perspectives of materials interaction and instruments of inquiry. Results indicate the solution can help people conceive and prototype improvement ideas at early design stages.

Keywords: collaborative design, internet of things (IoT), early design phase, participatory design

1. Introduction

The Internet of Things (IoT) is a technological paradigm that enables the Industry 5.0 transformation (Akundi et al., 2022) and draws upon the capability of physical elements to compute and communicate within networks (Wiberg, 2018). This capability demands new methods to address interactions between digital and physical materials, as well as methods that support people's needs (Wiberg, 2018). However, as a multifaceted technology, IoT is a challenging concept for people outside the IoT field to grasp (Gianni et al., 2018). To lower the entrance threshold, there has been an ongoing creation of IoT support tools, including analogue tools like card decks, with at least fifty-two toolkits documented (Roumelioti, 2022). However, there is still a gap in ideation tools with IoT (Peters et al., 2020); from a methods and theory perspective, a knowledge foundation is lacking when it comes to designing across the analogue and digital aspects of IoT systems (Wiberg, 2018) and there are few methods and materials for scaffolding the transition from idea generation to proof of concept (Roumelioti, 2022, chap. 2).

Among the variety of analogue tools, the card format is a frequent occurrence. One reason is that the "familiarity with the card approach leads to repetition of its use" (Peters et al., 2020). After reviewing seventy-six (76) analogue tools, Peters et al. (2020) argued that there is an opportunity to explore other formats to add value through affordances and embodiment. Based on our previous work with ideation cards with IoT (Aranda-Muñoz et al., 2020, 2021), we share this view. Our previous observations show that cards present advantages to support ideation with IoT (e.g., cards can be used to inspire opportunities), and the ideas generated often include the dimensions of people, technology and the environment. However, to conceptualise such ideas into potential improvements, these dimensions and the interactions between them are not directly supported by the card format. For future work, we have considered redesigning the card deck to emphasise these aspects (Aranda-Muñoz et al., 2020).

The concept of a toolkit or kit is often vaguely defined in the literature (Peters et al., 2020). In this paper, the IoT toolkit is inspired by the business origami method, a design activity facilitated in workshops to engage stakeholders in modelling services and systems (McMullin, 2011) through visual, verbal and

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audial information exchanges (Söderlund et al., 2020). Such modelling is accomplished through interactions with paper tokens representing people, technologies and parts of the environment, where a whiteboard surface acts as a stage. The participants can combine tokens to explore the relationships. Such interactions "play out to tell a story" in a scenario (Hanington and Martin, 2019, chap. 14). In this regard, we present the Karakuri IoT toolkit as a collection of materials that include instructions, activity templates, examples of expected outcomes, paper tokens, and commercially available sensors.

We included sensors in the IoT toolkit to familiarise participants with the properties of IoT and to help them materialise their ideas more tangibly so they can discover unknowns about how such prototypes could be integrated into their industrial contexts. To conduct this first study, we decided to test our IoT toolkit by including MESH sensors that we did not develop ourselves ("MESH", 2021). MESH is a commercially available product that masks the complexity of programming and is often used in educational contexts to introduce STEAM to students and help them create smart objects.

The research aims of this paper are exploratory and focus on 1) scaffolding the transition from idea generation towards prototyping IoT solutions, and 2) seeing whether participants, who do not necessarily need to be familiar with programming, electronics or communication technologies, can use the Karakuri IoT toolkit and method to express opportunities for factory improvements through prototypes. To guide the research, we ask the following research question: What materials and methods can support the transition from idea generation to IoT proofs of concept?

We conducted a study in Sweden with a manufacturing provider of various tooling systems, where we facilitated six workshops to test the Karakuri IoT toolkit and method. This paper focuses on observations and learnings from the first two workshops, where eight production leaders participated. This view on helping industrial workers ideate and conceptualise improvement opportunities is akin to seeing them as active creators who can engage in strategic problem-solving (Taylor et al., 2020; Wichmann et al., 2019) and drive more sustainable manufacturing environments (Romero et al., 2019).

2. Theoretical perspective and related work

In collaborative design approaches with technology, designers and participants engage in a mutual learning process where designers gain insights into the participants' contextual aspects and everyday activities, and participants aim to express their imaginations and needs based on what capabilities the technologies can offer (Simonsen and Robertson, 2012). To help participants ideate, explore the problem space, and discuss and materialise such imaginations, designers create tools that can act as instruments of inquiry (Dalsgaard, 2017). The nature of such instruments can support exploration and creativity and attend to five qualities: perception, conception, externalisation, knowing-through-action, and mediation (Dalsgaard, 2017). Such instruments are often called generative toolkits in collaborative design (Sanders and Stappers, 2014) and usually include cards, games, and various materials (Peters et al., 2020).

The role of "making" with these tools is vital, as the tangible facets of these generative toolkits allow participants to question and dialogue with the materials, exploring different combinations of elements that involve creating and transforming meaning (Sanders and Stappers, 2014). This role of making is akin to the concept of *transinstrumentality* (Dalsgaard, 2017), where designers work on the problem space without a clear goal in mind, trusting the use of their instruments to make new understandings during this process (Dalsgaard, 2017). In the context of IoT, this view on transintrumentality can be augmented with a material interactions perspective, which considers such material interactions to be a craft-based approach that combines "intellectually exploring and imaging computing in material form", where participants create new conceptualisations with the materials provided (Wiberg, 2018). In this regard, Wiberg (2018) defines material sensitivity as the skill "to carefully consider how different materials could be brought together in the design of an interactive system".

2.1. Overview of IoT support tools

Several IoT support tools have been designed to help people ideate IoT products and services in the early design stages of the double diamond, specifically in the discover and define stages; even if the methods can potentially be more versatile and applied to broader situations (Kurze et al., 2019). However, the terminology often used to present methods and tools like toolkits is inconsistent, making it challenging to map previous tools (Peters et al., 2020).

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Some examples of toolkits and co-design approaches include the IoT Design Deck 2.0 for co-designing connected products and services in multidisciplinary teams (Dibitonto et al., 2019), the MappingTheIoT Toolkit for helping multidisciplinary teams design IoT products (Vitali and Arquilla, 2018), the IoT Design Kit for aiding creatives in exploring and defining connected products (Roeck et al., 2019), the Un-Kit for assisting older adults with the exploration of sensors and actuators to create IoT applications (Ambe et al., 2019), the IoTgo Toolkit (Rizvi, 2021) for supporting teens and end-users in the ideation and creation of smart things by exploring, ideating, reflecting, programming and prototyping IoT applications, and the Tiles Toolkit, a card deck of 110 cards intended to help people ideate during workshops (Mora et al., 2017). This last toolkit can be combined with electronics during workshops for rapid prototyping (Gianni et al., 2018), where participants can ideate augmented objects (e.g., "smart shower"), and expert developers write the code and make it available to the participants.

Besides toolkits, there are also frameworks for tangible interactions (Hornecker, 2010), educative card decks such as MakerCards that help teach circuitry and electronics (Luong, 2021), pedagogical tools that help students design products (Briard et al., 2023), toolkits for children like the SNaP model which assists and guides children through exploration, ideation, programming and prototyping (Roumelioti, 2022), and other toolkits specialised in specific domains, like the IoT4Fun prototyping tool that helps teams develop smart toys (Wheler et al., 2020). Outside academia, we acknowledge the IoT Service Kit (Brito and Houghton, 2016), a board game that includes 3D printed tokens, blueprint maps and cards that help create IoT services through the process of (re)arranging tokens on a blueprint map.

We derive inspiration from previous work but take a perspective that does not require programming and focuses on assisting adult participants in improving their work processes and environments. With our approach, we aim to enable participants to explore and experience IoT to understand what capabilities and limitations the IoT technology can offer them. In this respect, IoT toolkits that include physical artefacts with embedded sensors and output blocks are widely available on the market. Some examples include LittleBits, SAM Labs and MESH. These toolkits are usually developed to support STEAM activities for children so they can familiarise themselves with using sensors and electronics.

3. Method

To observe the Karakuri IoT toolkit and method in use by participants, the researchers (a PhD student, a senior researcher in lean production and a professor in computer science) organised six co-design workshops onsite with the manufacturing partner. This paper focuses on the first two workshops, each of which were attended by the same eight (8) participants. These two workshops lasted approximately three hours and were facilitated on consecutive days.

Our contact person held the role of change leader in the organisation. This contact, based on previous discussions and presentations of the research project, suggested inviting production leaders to the workshops as participants. The main reason for this was that the manufacturing organisation was in the process of creating new initiatives regarding production improvements, lean production and digitalisation, and production leaders were expected to become more active in those aspects in the coming four months. Before the workshops, our contact sent an invitation to ten production leaders (eight attended) based on the personnel's availability.

The first workshop commenced with a presentation round, where each participant said a few words about their role in the organisation and previous experiences and whether or not they had any prior knowledge of IoT and programming: the participants had not heard the term IoT before, did not have any prior experience with programming, but were familiar with the capabilities of a sensor.

Data collection consisted of handwritten notes taken by two researchers who facilitated the workshops (the first two authors), role-play recordings by participants, pictures taken during the workshops, the outcomes of each activity (e.g., filled templates, ideas in post-it notes, etc.) and the notes taken during the reflective session at the end of the workshops.

After each workshop, the three researchers held a debriefing session to reflect on the aspects observed about the toolkit and the method. Then, the PhD student (senior interaction designer) analysed the empirical material attending to aspects of *material interactions* and the skill of *material sensitivity* (Wiberg, 2018), combined with the five qualities —perception, conception, externalisation, knowing-through-action and mediation— of instruments of inquiry (Dalsgaard, 2017).

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4. The Karakuri IoT toolkit and method

The toolkit comprises paper tokens, a game board (canvas stage), instructions for each method step, and sensors (see Figure 1). Each paper token has information printed on both sides, including a token name and an icon selected from the FlatIcon online library. The paper tokens are divided into five different colour-coded categories: eight people tokens (purple), sixteen industrial tokens (orange), twelve sensor tokens (blue), eight notification tokens (green) and blank tokens (white). The sensor tokens include duplicates and consist of *button*, *movement detection*, *brightness*, *microphone*, *temperature*, *motion*, *camera*, *location*, *colour*, *QR code*, *distance* and *pressure* tokens. The notification includes duplicate tokens and contains *LED*, *speaker*, *phone*, *tablet*, *smartwatch*, *screen* and *scoreboard*. Lastly, the industrial tokens represent various industrial elements often found in manufacturing environments. The industrial tokens (and the people and blank tokens) do not contain any names, with the intention that participants can use the representations of the tokens more ambiguously to suit their scenarios.

Figure 1. Figure A depicts some materials of the Karakuri IoT toolkit with the MESH sensors and app. Figure B shows participants exploring a conceptual solution using the paper tokens

The instructions include brief descriptions with suggested times and recommended material from the IoT toolkit for each method step. They also include other material, like infographics describing each sensor, activity templates, and further instructions that link to videos created by the researchers that provide in-depth descriptions of the generation of conceptual solutions and proof of concept steps. The sensors used are a commercial product named MESH that includes a companion app with a drag-and-drop interface to help configure "if this, then that" behaviours and contains seven modules: *button*, *LED*, *move*, *motion*, *brightness*, *temperature and humidity*, and a *general-purpose input/output* (GPIO).
The method (see Figure 2) guides the use of the IoT toolkit to help participants explore, brainstorm, describe, enact, prototype and discuss IoT manufacturing improvement opportunities through six steps: Introduction to IoT, Demystifying IoT, Brainstorming Improvement Ideas, Factory Tour, Generation of Conceptual Solutions (see Figure 1B) and Creation of Proofs of Concept.

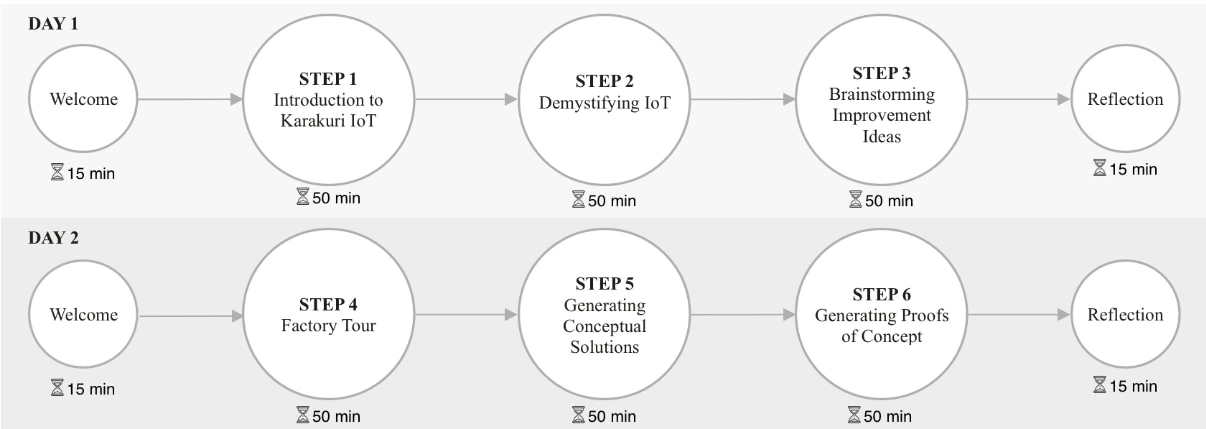

Figure 2. Summary of the main steps in the Karakuri IoT method

The first method step introduces the Karakuri IoT project and what IoT is, providing examples of IoT products and applications in the industry. Step 2 aims to demystify IoT and help participants familiarise themselves with IoT by exploring the MESH sensors and performing three different challenges inspired

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by MESH's "Computational Thinking Basics" guide ("MESH", 2021), such as detecting when a screw box is nearly empty and sending an automatic notification to the supplier. This step aims to encourage participants to explore the sensors, configuring simple "If this, then that" behaviours in the companion app, investigating the thresholds of sensors under specific constraints (e.g., the motion or light sensors' sensitivity) and considering alternative locations for the attachment of sensors. Then, in Step 3, the researchers introduce the Karakuri IoT toolkit by presenting each toolkit element and facilitating a brainstorming activity aimed at creating improvement opportunities with IoT. Firstly, participants are given time to think individually and write down their ideas on post-it notes. Next, the participants present their ideas to each other and discuss them in groups of four. To end the first day, the participants sort their ideas according to their perceived value, recording a role-play of the most promising ideas.

To start the second day, a guided tour of the manufacturing environment is scheduled with the intention of allowing participants to discuss their improvement ideas in the corresponding key factory locations. Unfortunately, due to manufacturing restrictions, visiting the factory in this study was impossible, so we compensated for the lack of this activity by allotting more time to the remaining activities. In Step 5, each group of participants starts by reviewing the most promising ideas from the previous day and explores them more deeply. The participants can use the paper tokens representing sensors and notifications to explore and more specifically describe the interactions that would happen and how they would consume the information. The participants are given time to rehearse and document the idea in a scenario through video recording. Lastly, the participants receive a box of MESH sensors to generate proofs of concept (Step 6). They can substitute the paper token representations of sensors for the MESH sensors included in the kit. Then, the participants record the role play of the scenario with the created prototype. If the participants finish early, they pick the next promising idea and repeat the generation and prototyping steps. Each workshop is concluded with a reflective session, where participants can provide feedback about the method, the toolkit, and aspects explored during the workshop.

5. Results and findings

The two groups of four participants could brainstorm five opportunities (see Table 1) to improve the factory (five videos), conceptualised five solutions with IoT technology (five videos) and made three proofs of concept (three videos). To reach such outcomes, the participants first explored the problem space using paper tokens to describe the opportunity. The tangibility of the tokens enabled participants to role-play scenarios by moving them along the canvas board from a bird's-eye perspective. In such role-playing, the participants moved the character tokens in particular ways to depict how the character would walk from one place to another and interact with the environment. The participants also used gestures, such as pressing an imaginary button when using the *button token* (see Figure 4B) or shaking sensor tokens to depict when a sensor is triggered. In such role-playing, the participants made different sounds to complement the gestures and movement of tokens. For example, making sound steps, "beeps" (when receiving notifications) or ambient sounds such as an elevator arriving.

Table 1. Summary of problems and ideas recorded by participants during the workshop

1. Detect and notify when material is delivered from the warehouse to the workshop. 2. See when the department might be running out of trolleys. 3. Detect and display empty parking spaces for trolleys.	4. Detect pallet weight and sort pallets according to their correct placement on different floors. 5. Detect low level of powder material and notify when it is time to refill it. Be able to display different thresholds: 75%, 50%, 25%.

To explore the problem and possible solutions, the participants made drawings of schematic factory locations, usually with boxes and circles. Such drawings, in the form of diagrams, were vital to the externalisation of the different places where the action happens. Such initial drawings were usually expanded upon or amended later by participants once they had rehearsed a scenario for the first time. For example, new locations would be drawn on demand to place the sensors where the participants would expect to detect an event in the factory, and the participants drew new locations to represent

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where people would receive notifications. Occasionally, such drawings were augmented with arrows or drawings to represent interactions or complementary drawings showcasing a part of the environment.

The participants were asked to create prototypes with the sensors, configuring simple "if this, then that" behaviours and exploring the threshold of sensors to be able to trigger them in the role play of the scenarios. Substituting the paper tokens with sensors triggered new discussions for participants, especially regarding whether they had chosen a suitable sensor to solve the problem, whether the sensor could detect a specific event, and preferences on how participants would receive notifications. Combining the sensors with the paper tokens allowed participants to role-play and trigger the sensors, for example, triggering the *motion sensor* with a *box of material token*. However, the participants experienced some limitations with the toolkit, as not all the sensors represented on the paper tokens were included in the MESH box. The participants often solved this challenge by using paper tokens or by using a different sensor and simulating the interaction with that sensor to trigger the expected event. The participants did not create a proof of concept for Ideas 2 and 3 from Table 1. The second idea relied on a camera streaming so that industrial workers could see when the department might run out of trolleys, so no sensors from the toolkit were required. For the third idea, the participants used the LED tokens to indicate empty parking spaces, but it is unclear how they would detect an available space (from the video, it seems that they refer to an internal system). To exemplify the method and IoT toolkit, we describe the first improvement idea more deeply in the following section.

5.1. Case example: Notifying when the material arrives at the workshop

Initially, the group of participants started by discussing the opportunity for improvement. The participant who suggested the idea knew more about the problem, so this participant described the problem in more depth, providing details about the production line, work processes and the main challenge the participant observed: the participant and other colleagues often need to check whether or not the material has arrived at the workshop, disrupting their flow of daily operations (see Figure 3).

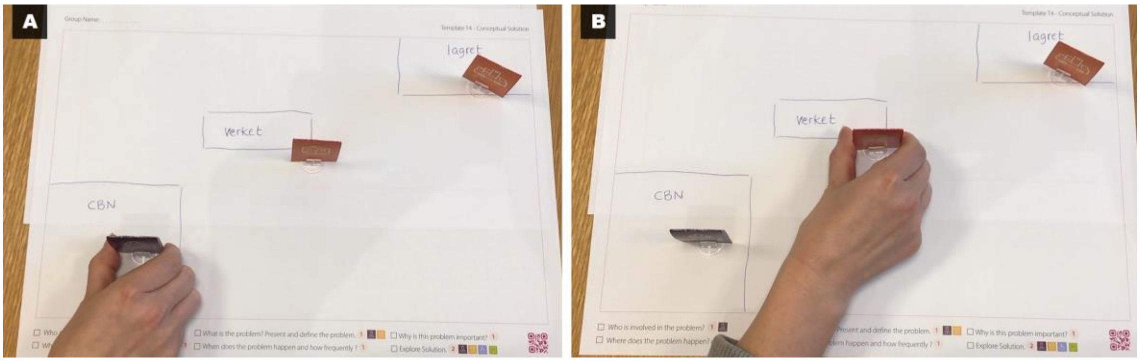

Figure 3. Participant role-plays the improvement opportunity scenario

After this explanation, the other participants in the group asked questions about the problem, for example, inquiring if the material usually arrives during a particular time of the day and whether the driver could send a message or call to notify them that new material has arrived. The participant answered that it was hard to know when the material was coming; sometimes, it was not the same driver, and each time it could be a different person working in the workshop, depending on shifts. During this back-and-forth dialogue, the participants explored the paper tokens, finding tokens that could be of interest to describe the problem. After some minutes, the participants selected a few tokens placed next to the canvas stage. Then, the participant (the one with the idea) drew pictures depicting the locations of the factory with boxes showing where the action of role-playing would take place (see Figure 3).

In each box, the participant wrote down the factory location, placed a character token to showcase where this participant works ("CBN") and placed two different industrial tokens in the factory workshop ("verket") and the warehouse ("lagret"). After some discussion among the group, the participant proceeded to describe the problem, moving the *character token* and the *material token* to role-play the problem description scenario:

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“Here we have [person’s name] [Figure 3A], here we have a warehouse lift [Figure 3B], and here we have the warehouse that delivers materials to the workshop. The problem is that [person’s name] doesn't know when the material will be delivered here [workshop]. [Person’s name] has to run and check several times a day to see if the material has arrived, which means that it disrupts the rest of the daily operations. So it would be perfect if there were a notification that would alert [person’s name] when the material has been delivered to the workshop.” - *Participant*

Then, the participants emptied the box of all remaining tokens and discussed potential solutions. A participant picked a *button token* and suggested the driver should press it when the material has arrived. Such a button could be installed next to the warehouse lift. The participants kept exploring, and new questions emerged: How would the participant with the idea like to be notified? Would it be with sound (*sound token*)? With a mobile notification (*mobile token*)? By a lamp installed in the participant’s workspace (*lamp token*)? The participant preferred both a lamp and a phone's message:

“The solution to [person’s] problem should be that when the warehouse delivers material to the plant [Figure 4A], they press a button [Figure 4B], which causes a lamp to light up in the department, and you get a notification on your phone." - *Participant*

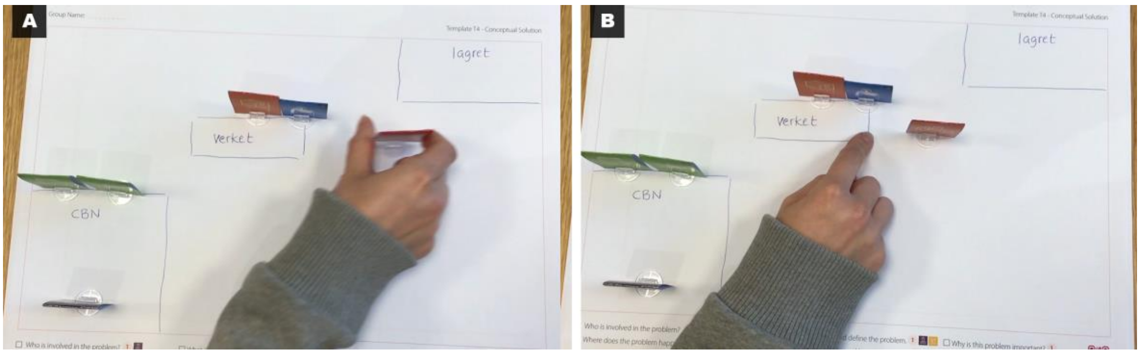

Figure 4. Participant role-plays a scenario with the conceptual solution

Afterwards, the participants opened the MESH box and retrieved the button and LED modules. The participants had some practice with the sensors during the demystifying step of the workshop, so one participant established the logic that when the button is pressed, the LED should turn on (see Figure 5B). Then, the participants discussed the scenario and aspects of the LED notification, like where to place it and which light colour to choose. Lastly, the participants proceeded to role-play the solution:

“When the warehouse has delivered the material, they press the button [Figure 5A]. The lamp lights up, and a notification appears on the phone [Figure 5B].”

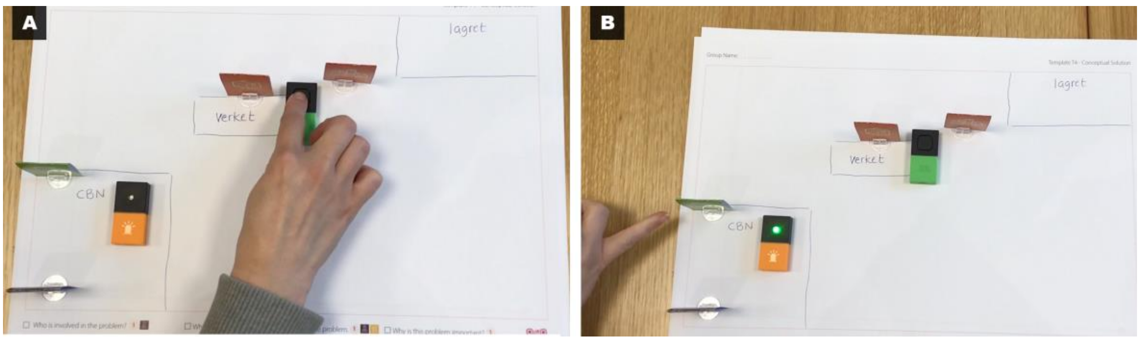

Figure 5. Participant role-plays the final solution with a working prototype

6. Discussion and future work

The research summarised in this paper started with the following research question: What materials and methods can support the transition from idea generation to IoT proofs of concept? We answered this

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question by presenting the Karakuri IoT toolkit and method, exemplifying with two co-design workshops how this solution can be facilitated to reach proofs of concept of IoT improvement opportunities and describing one case example in depth. In this section, we draw upon the instruments of inquiry qualities —perception, conception, externalisation, knowing-through-action and mediation— (Dalsgaard, 2017) and notions of material interactions (Wiberg, 2018) to discuss the results.

The Karakuri IoT toolkit guided participants to open the design space and explore the representations depicted in the paper tokens while hiding aspects that were not included in the toolkit, masking some of the complexities often present in the design of IoT systems, such as electronics knowledge, soldering and programming (perception quality). These mediations between the participants, the tokens and the sensors (mediation quality) guided the participants to explore various combinations. Such combinations created meaning (knowing-through-action quality) towards exploring, conceiving and communicating improvement opportunities and potential IoT solutions (conception quality), revealing positive and negative aspects to discuss and revise with other participants. Such explorations were reinforced through role-playing scenarios and discussions, where the enactment of participants externalised and revealed new contextual aspects of the opportunities and solutions. Such contextual aspects (externalisation quality) included key locations and movements of workers in the factory, discussions about where workers expected to consume information, information necessary for workers, and actions that the workers would perform once they were notified, which further revealed and externalised aspects of existing workflows and intentions about how participants could integrate the solution within their current ways of working. Participants could document some of these externalised contextual aspects by recording role plays of their improvement opportunities, conceptual solutions and prototypes.

In the context of designing IoT systems, we see that the Karakuri IoT toolkit and method can help cultivate the skill of material sensitivity, defined as the ability to "carefully consider how different materials could be brought together in the design of an interactive system" (Wiberg, 2018). To cultivate this skill, people need to understand the available materials at hand, the properties of such materials and how such different materials can be combined to create relationships with each other when designing an interactive system (Wiberg, 2018). To better understand the materials, we included sensors in the toolkit and activities to help participants familiarise themselves with IoT as a design material with a demystifying step. Some of the aspects participants explored during workshops included concepts related to sensor capabilities, sensor thresholds and configurations, setting the logic of "if this, then that" behaviours, and how contextual and ambient aspects can emerge to trigger sensors in unwanted and unexpected ways. In the transition to prototyping a proof of concept, combining sensors with the paper tokens enabled participants to work iteratively, revealing specific aspects of how the IoT system could work once integrated into the factory. For example, this prototyping and enactment step included discussions about unwanted aspects (e.g., alarm sounds in noisy environments), preferences on how to be notified and how often, and priorities on how such notifications need to be communicated.

As an overall reflection, to support ideation with IoT, we recognise the strength of support tools like card decks when it comes to exploring and guiding the first stages of the double diamond (Kurze et al., 2019). However, for the transition towards conceptualisation and prototype creation with IoT, we see that the business origami method is well suited to the dimensions of IoT and can contribute to the augmentation of card decks, as rearrangement tokens representing people, sensors and notifications on a canvas board aids collaborative explorations and discussions about IoT opportunities. This aspect of business origami aligns with the IoT service toolkit (Brito and Houghton, 2016) that, to our knowledge, lacks an academic presentation and argumentation. The business origami method can be augmented with the inclusion of sensors that do not require programming so that participants can familiarise themselves with the technology through reflective challenges, understand some of the opportunities and limitations the sensors offer, and prototype their ideas to discover potential unknowns. Augmenting the ideation process with electronics aligns with previous work, such as the Tiles IoT Toolkit (Gianni et al., 2018; Mora et al., 2017) or the SNaP Toolkit (Roumelioti, 2022); however, our case deviates from the focus or need of programming. Another difference is that we tested the Karakuri IoT toolkit and method on professionals (instead of students or children) to improve their work processes and environments. We found, in this process, that documentation is valuable to participants and managers as a starting point for potential next steps, and this has led us to reflect on what might further support the externalisation

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and documentation of their knowledge. Especially because their job activities are interrelated with other roles in production, and each activity and process is part of a workflow.

Lastly, we identified some limitations we aim to address in future iterations. Firstly, the sensors available in the toolkit and the configuration options are very limited and might demand imagination from participants as they adapt their role-playing to such restrictions. We see the need for a more comprehensive analysis of the sensors to be included in the toolkit, attending to the main properties of IoT as a design material and what aspects the sensors need to support in order to help participants reveal unknown dimensions of their solutions. Secondly, participants might not be familiar with specific production lines and the manufacturing processes of their colleagues. To compensate for this lack of contextual knowledge, we recommend including the fourth step of the method —which we unfortunately could not test— where participants have the opportunity to tour the manufacturing environment and explain the opportunity within context. Thirdly, more varied roles in the workshops, such as operators, technicians, and managers, can provide richer details on contextual aspects, strategic thinking, and potential ways to integrate ideas for IoT improvements in the factory. Lastly, we lack a validation stage for testing more refined iterations of the prototypes in the manufacturing environment.

7. Conclusion

This paper presented the Karakuri IoT toolkit and method, developed to enable people in the early design stages to ideate, conceptualise, role-play and create proofs of concept improvements for their work environments and processes. We tested the Karakuri IoT toolkit and method in two workshops at a tooling manufacturing company in Sweden. During the workshops, eight (8) production leaders used the IoT toolkit and method to explore the problem space from a bird's-eye view, rearranging paper tokens on a canvas space to discuss, among many other aspects, IoT opportunities and the potential solutions, what sensors to use and where to place them, how and when sensors can be triggered, who would consume the generated information and what actions would be taken based on the information received. The participants augmented such rearrangement of tokens by drawing schematic locations of the factory, helping them to externalise the contextual aspects of the scenarios created. The resulting scenarios were role-played on the canvas using the paper tokens, contributing to participants' shared view of the problem and the desired solution. As outcomes, the participants presented video-recorded role plays of their ideas, solutions and proofs of concept. We analysed the empirical material from a theoretical perspective of instruments of inquiry and material interactions, concluding that the Karakuri IoT toolkit and method can help participants cultivate the skill of material sensitivity and support the early stages of design, enabling people with no prior knowledge of IoT, programming and electronics to be active creators of improvement opportunities with IoT for their work activities and environments. This view of engaging industrial workers acknowledges them as creators who can shape their working landscape, potentially creating more sustainable industrial jobs.

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