Designing ultra-personalized product service systems

Citation for published version (APA):

Nachtigall, T. R., Mironcika, S., Tomico Plasencia, O., & Feijs, L. M. G. (2020). Designing ultra-personalized product service systems. *CoDesign*, 16(4), 274-292. <https://doi.org/10.1080/15710882.2020.1842454>

Document license:

TAVERNE

DOI:

[10.1080/15710882.2020.1842454](https://doi.org/10.1080/15710882.2020.1842454)

Document status and date:

Published: 29/11/2020

Document Version:

Publisher's PDF, also known as Version of Record (includes final page, issue and volume numbers)

Please check the document version of this publication:

- A submitted manuscript is the version of the article upon submission and before peer-review. There can be important differences between the submitted version and the official published version of record. People interested in the research are advised to contact the author for the final version of the publication, or visit the DOI to the publisher's website.
- The final author version and the galley proof are versions of the publication after peer review.
- The final published version features the final layout of the paper including the volume, issue and page numbers.

[Link to publication](#)

General rights

Copyright and moral rights for the publications made accessible in the public portal are retained by the authors and/or other copyright owners and it is a condition of accessing publications that users recognise and abide by the legal requirements associated with these rights.

- Users may download and print one copy of any publication from the public portal for the purpose of private study or research.
- You may not further distribute the material or use it for any profit-making activity or commercial gain
- You may freely distribute the URL identifying the publication in the public portal.

If the publication is distributed under the terms of Article 25fa of the Dutch Copyright Act, indicated by the "Taverne" license above, please follow below link for the End User Agreement:

www.tue.nl/taverne

Take down policy

If you believe that this document breaches copyright please contact us at:

openaccess@tue.nl

providing details and we will investigate your claim.

Designing ultra-personalized product service systems

Troy Nachtigall, Svetlana Mironcika, Oscar Tomico & Loe Feijs

To cite this article: Troy Nachtigall, Svetlana Mironcika, Oscar Tomico & Loe Feijs (2020) Designing ultra-personalized product service systems, CoDesign, 16:4, 274-292, DOI: [10.1080/15710882.2020.1842454](https://doi.org/10.1080/15710882.2020.1842454)

To link to this article: <https://doi.org/10.1080/15710882.2020.1842454>

Published online: 29 Nov 2020.

Submit your article to this journal [↗](#)

Article views: 197

View related articles [↗](#)

View Crossmark data [↗](#)

Designing ultra-personalized product service systems

Troy Nachtigall^{a,b,c}, Svetlana Mironcika^a, Oscar Tomico^{a,d} and Loe Feijis^a

^aIndustrial Design, Eindhoven University of Technology, Eindhoven, The Netherlands; ^bSocio-Technical Design, Aarhus University, Aarhus, Denmark; ^cFashion Research and Technology, Amsterdam University of Applied Science, Amsterdam, The Netherlands; ^dIndustrial Design Engineering, Elisava, Barcelona, Spain

ABSTRACT

Design games are rarely used to design shoes but data and emerging digital fabrication systems are rapidly changing how designers make things. We envision a near future where shoes are personalised using algorithmic, parametric, and generative systems that are data-driven. In this article, we describe and deploy a design game for shoes to help designers create circular Ultra-Personalised Product Service System. Designing such products (that include services supported by systems that last over product lifetimes) presents a multitude of challenges; product challenges in negotiating design considerations, service challenges in customer journeys and systemic challenges in creating data flows. The UPPSS game was designed to help scaffold designers in confronting these challenges. The UPPSS game was deployed with 16 industrial design students over nine weeks where shoes, services, and systems were all made using code to program personalisation systems. Each participant wrote a reflection on the process. The reflections were analysed to see how the design game resulted in facing the challenges and learnings of a UPPSS. Conclusions are presented from the challenges and opportunities confronted in the game, and what it meant to the emerging practices of designing a UPPSS.

ARTICLE HISTORY

Received 16 April 2020
Accepted 22 October 2020

KEYWORDS

Design game; Ultra-Personalised Product Service System; shoe-making; research through design; models of production

1. Introduction

Previous research on computational composites (Vallgård and Redström 2007), meta-materials (Ion et al. 2017), and data-driven design (Bogers et al. 2016), has shown how data and materials can be crafted together to form new kinds of artefacts and products. At the same time, emerging technologies are enabling new possibilities in personalisation as services (i.e. Benford et al. 2018; Zoran 2015; Magrisso, Mizrahi, and Zoran 2018). A future of co-designed product service systems is emerging thanks to computational materials and emerging fabrication technologies. These systems can be described as an evolution, transforming from traditional vertical production systems, to horizontal service-oriented systems, and then to circular Product Service Systems (PSS) as seen in Figure 1.

A theoretical model that embraces the combination of data and digital production is the Ultra-Personalised Products and Services interpretive framework proposed by the Dutch Technical Universities. This model describes Ultra-Personalised Products and

Figure 1. Data in design increasingly allows for the creation of circular product service systems. These go beyond vertical product design systems and horizontal service design systems.

Services as ‘(1) Products in which personal data is obtained before use – such as 3D scans – and (2) products in which the data is obtained during use’ (Stolwijk and Punter 2018). Previous work (Nachtigall, Tomico, Wensveen, and Wakkary 2019) has shown that design of Ultra-Personalised Products and Services as a product service system results in an interpretive framework: Ultra-Personalised Product Service System (UPPSS). The focus of this article is to explore how to support industrial designers with a design game to transition to this new form of design. In short, a UPPSS is a personalised, multi-stakeholder PSS that embraces four primary phases: Co-Analysis, Co-Design, Co-Manufacturing, and Co-Use.

Training industrial designers to design a UPPSS has many challenges. We scaffold these challenges using a design game inspired by embodied experience (Wilde, Vallgård, and Tomico 2017) for the product design, a customer journey (Lemon and Verhof 2016) for the service design and data flow (Ward 1986) for the system design. The application domain of shoes was chosen because there is a large opportunity for personalisation, both aesthetic and functional, which interests both industry and academia. Several examples of bespoke personalisation in companies such as Adidas (Piller, Lindgens, and Steiner, 2012), Nike, United Nude, and many others. Academia considers systems of shoe personalisation (i.e. Piller, Lindgens, and Steiner, 2012; Weerasinghe and Goonetilleke 2011) and their history (Ball and Rollinson 1935; Greene 2018). Moreover, shoes were the first wearable computer (Mann 1997) and continue to fascinate HCI as a rich location for data (Schirmer et al. 2015, Feijs, Nachtigall, and Tomico 2016).

We explored the value and possibilities of teaching how to design a UPPSS using a design game. We evaluated 16 industrial design students’ understanding of UPPSS design by analysing their reflections after playing the game using inter-coder agreement. From the findings, we draw conclusions about how the game supported the creation of a UPPSS, offer suggestions to the UPPSS interpretative framework, and offer reflections upon the emerging design practice of Ultra-Personalisation in PSS involving co-analysis, co-design, co-manufacturing, and co-use.

Key to the game was creating a first-person embodied perspective of shoemaking to support meaningful learning and valuable reflections. Participants who engage in an experience can translate material usage to memory making (Tsai and Van Den Hoven 2018). While this meant that the game took weeks to complete, living with a prototype

has been shown to be key to understanding a research product (Desjardins and Wakkary 2016; Mackey et al. 2017).

2. Related work

Dourish (2017) discussed how data can be like a material. But using data as a design material to support personalisation it is not an easy task. We can find examples of data used like a design material in computational composites (Vallgård and Redström 2007), Meta-Materials (Ion et al. 2017), and data-driven design (Bogers et al. 2016). There have also been frameworks developed that suggest how to act on data (Forlizzi 2012) at the forefront of design and HCI research. Based upon earlier explorations into product ecologies (Forlizzi 2012) and on research done on PSS (Tukker 2004), Ultra-Personalisation grows out of the research done into embodied smart textile services (ten Bhömer, Tomico, and Wensveen 2016).

Designing the game required not only understanding the complexities of multi-stakeholder collaboration but also the challenges of the data/material relations (Nachtigall, Tomico, Wakkary, and Van Dongen 2019) as found inside the different phases of a UPPSS system: Co-Analysis, Co-Design, Co-Manufacture, and Co-Use. Co-Analysis is the process of understanding the needs of the person in different forms of data, including multiple expert opinions. Co-Design in UPPSS is a generative process that algorithmically negotiates the parameters of the wearer to the design considerations of the object being made. Co-Manufacture is the process of fabricating the object being made, often in a distributed location, yet geographically close to the wearer. Co-Use is the process of using the object over its lifetime with the data feeding forward into the system for all stakeholders to use. See Table 1 for a summary of the product, service, and system challenges in UPPSS.

Table 1. An interpretive framework of the challenges and learnings faced when making a shoe-based UPPSS (extracted from Nachtigall, Tomico, Wakkary, and Van Dongen 2019) used to form a classification schema to evaluate the UPPSS game.

Product Challenges/Learnings		Service Challenges/Learnings		System Challenges/Learnings	
Adapting Algorithms (AA)	Negotiation of design considerations in code	Reading the Body (RB)	Personalisation can mean personalised sensors	Saving and Storing the Data Trail (SS)	Ideal vs actual
Manufacturing Misinterpretation (MM)	Limits of the current technology	Profiling Predicted Use (PU)	Potential for self -directed machine learning	Quantity and Scaling Up (QS)	Profile the thing, not the person
Standardising Material Behaviour (SB)	Ideal vs actual	Understanding Behaviour (UB)	Temporal composites	Comparing Data (CD)	Designers need data
Mechanical Sensing Material Structures (MS)	Active vs passive monitoring	Adding Sensing (AS)	Multi-purpose hybrid material geometries	Storing and Decoding Use (SD)	Understanding temporal composites as material

2.1. Addressing product challenges and opportunities

In a UPPSS, objects can be made algorithmically based on the parameters encoded from digital data captured from wearers' bodies. In the co-design phase, encoded parameters are algorithmically negotiated using design considerations. To make the designs ready for fabrication, data from algorithmically generated objects are transformed (into code) for digital co-manufacturing.

The process of co-design in the game should confront specific challenges. Parametrically generating shoes for a specific feet and style requires *adapting algorithms* (AA) to negotiate design considerations (Nachtigall 2017). Researchers are already applying specific geometries such as selective buckling (Paulose, Meeussen, and Vitelli 2015) in programmable materials (Vallgård et al. 2017), using algorithms to make flexible shoe soles (Feijs, Nachtigall, and Tomico 2016), and creating dynamic behaviours (Ballagas, Ghosh, and Landay 2018). Algorithms translate these materials into dynamic forms (Frens 2006) using computational co-design (Malakuczi 2017).

However, the results are not always what was expected. *Manufacturing misinterpretations* (MM) are unintended results that can appear when the limits of the technology are reached. To overcome these situations, the game needs to create a designerly understanding, i.e. human-material interactions (Giaccardi and Karana 2015) or how materials evoke a material conversation (Karana et al. 2016). It can also be seen as process-led material-based research that leads to design innovation (Marr and Hoyes 2016).

The game takes into account another challenge in co-design which is *standardising material behaviour* (SB). When using data like a material, the behaviour of the material needs to be understood. We see these opportunities already being addressed in the form of research products (Odom et al. 2016) where specific requirements (inquiry-driven, finish, fit, and independent) allow the product to be deployed for long periods over product lifetimes. Additionally, other challenges include creating consistent and uniform results when digital fabrication technologies have a different precision than industrial manufacturing. Real-time feedback and feedforward data can already be seen in concrete 3D Printing (Wolfs et al. 2018) which illuminates new opportunities for UPPSS digital fabrication.

Finally, UPPSS requires data to be created by the resulting products. While traditionally been done with electronics, e.g. (Hertenberger et al. 2014), *mechanical structures for material sensing* (MS) allow mechanical (Zheng and Do 2018), biological (Steiner et al. 2018), meta-material (Amorim, Nachtigall, and Alonso 2019) and chemical (Kao et al. 2017) sensing to produce data. The game has to help designers close an input – output loop to make UPPSS circular.

2.2. Service challenges

The process of understanding personalisation needs of a wearer using different forms of data and multiple expert opinions, starts in the Co-Analysis phase. In this phase, a relationship with the user is being developed, and the service challenges of UPPSS revolve around the customer journey. In shoe design, it shifts towards an intimate embodied relationship with the wearer that requires management and trust.

The game should support starting the process of UPPSS (and following iterations) with a *reading of the body* (RB). There are many methods to gather data about the foot

and wearer (Nibedita et al. 2010). An analysis of the wearers' data provides a profile at a moment in time. Challenges are deeply rooted in the variability of body shapes (Griffin, Compton, and Dunne 2016). Additionally, the process of reading the body should carefully consider user experiences and users' willingness to share own private body-related data with designers (Mironcika et al. 2020). Yet, new opportunities include using images to create body sizes (Mok and Zhu 2018) and convert these into digital fabrication (Hong et al. 2018).

Closely related is capturing of a movement or action (or a series thereof) of the foot described previously as *Understanding Behaviour (UB)*. This could include context data points about the social dimensions of where a shoe is worn. Alternatively, anthropomorphic data on how the user strikes the heel and progresses to the talon could be used as human locomotion is complex (Hagman 2005). This complexity and how it translates to materials are described in detail by Vertommen et al. (2011). The game should help designers to bring that understanding of the body into the design.

UPPSS requires the storing of data across time with many points of comparing how the designers expected the object to be used. The game should provide an opportunity for *profiling predicted use (PU)*. The designer can then compare it against the actual shoe use in the future. This can be found in predicting the needs for the shoe with, e.g. machine learning (Nácher et al. 2006), or using the data to predict life events of the wearer such as puberty (Busscher et al. 2011). It would even become more complex if we adopt a model using distributed manufacturing.

In building a system with data, there is a challenge to generate the right kinds of data described as *adding sensing (AS)*. Sensing in shoes is commonly performed electronically (Shenck and Paradiso 2001) or from other places on the body (Skach et al. 2018). Yet there is an opportunity to achieve this with materials that change as part of a computational system, as seen in DuoSkin (Kao et al. 2016), Grow Kit (Steiner et al. 2018), and the EVA Mocassin shoes (Nachtigall 2017). The game needs to help designers understand how to collect data.

2.3. System challenges

Research into system design spans decades (Norman 1986). Software and stakeholders face challenges and opportunities as seen in the data flow of a UPPSS process. The system challenges can be observed when creating an overall picture of how the data and material interact in UPPSS (Nachtigall, Tetteroo, and Markopoulos 2018).

Co-Use is the process of using the object over its lifetime, with the data feeding forward into the system for stakeholders to use that data for creation of new objects or services. *Saving and storing the data trail (SS)* is often used in app design and social media design, not physical objects. Much like home health devices now track patient health (Habibović et al. 2018), designers of UPPSS have an opportunity to record data at many points during the analysis, design, manufacture, and use of the object. The game should support that data is shared and used with many stakeholders. This can be seen in the current way usage statistics are impacting software development (Dinner, van Heerde, and Neslin 2015). In UPPSS, data are created and stored for at least the product or service lifetime. Questions of data security and privacy become important as well (Wetzels et al. 2018)

The game needs to help designers take a personal experience into a larger system. Artisan shoemakers make bespoke personalised shoes using implicit craftsmanship. When making shoes with data, new challenges, and opportunities for *quantity and scaling up* (QS) arise. The form, behaviour, and aesthetic can be understood as data. New opportunities emerge such as monitoring, control, optimisation (Porter and Heppelmann 2014). Challenges include the costs of digital fabrication (Baumers et al. 2016) and the integration of craft and technology to move from mass customisation to mass personalisation (Wang et al. 2017).

Machine learning has opened up the possibility of *comparing data* (CD) from predicting iterations and users. UPPSS is driven by generational (Reiss and Stricker 2013) and multi-user comparison via pattern recognition and machine learning (Bishop 2006) at a design system level (Yang 2018). The game needs to help designers understand these opportunities.

UPPSS depend upon data and should be clear in the game. *Storing and decoding use* (SD) is fundamental to the iterative generations of UPPSS. We see the importance of that data in data-enabled design (Bogers et al. 2016) as well as the lifespan nature in temporal composites (Valgarda et al., 2015). Hybrid Reassemblage (Zoran and Buechley 2013) provides a unique window into the possibilities of generational iteration with materials.

3. Creating a co-design game for UPPSS

Design games have been shown to drive innovation and knowledge creation, especially in Service Design (Hannula and Harviainen 2016). Hannula & Harviainen have shown games are effective at dealing with the challenges of integrating products in service systems (Hannula and Harviainen 2016). Moreover, card games have specifically demonstrated a capacity to deal with large amounts of complex challenges (Lucero et al. 2013). The UPPSS game we created was intended to scale up a personal shoe-based crafting experience into a co-designed multistakeholder UPPSS. The game was inspired by other design games already used in service design that deal with multiple stakeholder co-design sessions (Kirsikka and Mattelmäki 2014).

The game board (fig. 2) was adapted from the theoretical UPPSS model, representing the UPPSS phases and enabling data/material transitions described in 'Unpacking Solemaker into a model for UPPSS' (Nachtigall, Tomico, Wensveen, and Wakkary 2019). The game board is a circular system with phases of Co-Analysis, Co-Design, Co-Manufacture, and Co-Use in the corners. Between the 'Co-' phases are enabling transitions of encode, materialise, profile, and monitor. Encode enables Co-Analysis to become Co-Design by making the data compatible with the parameters needed to generate. Materialise enables Co-Design to become Co-Manufacturing by making the data ready for digital manufacturing processes (which may be distributed). Profiling enables Co-Manufacturing to become Co-Use by remembering the data from all previous phases for later comparison and predicting the lifecycle of the object. Monitor enables Co-Use to become Co-Analysis by taking the data from the object (and use) and making it available for analysis.

Cards representing stakeholders, objects, characteristics, phases, actions, and values were created (see Figure 2). Each card had a simple icon and empty space where

Figure 2. The UPPSS game board and cards being used to create PSS Customer Journeys and Data Flows for an Ultra-Personalised shoe platform.

stakeholders were encouraged to add new icons and descriptions when needed, as suggested in “Efficiently Inefficient: Service Design Games as Innovation Tools“ (Hannula and Harviainen 2016). The cards were created for stakeholder teams to have open conversations about customer journeys and dataflows so opportunities could be explored in the process.

A series of questions were formulated as part of the gameplay to help the stakeholder teams approach PSS elements (see Figure 3):

- (1) Who is involved in the process?
- (2) What are the other objects involved in the processes areas (Boxes)?
- (3) What happens in between each phase? Where is the data? How does the data change (i.e. formats)?

Figure 3. Examples of the icons created for the UPPSS game that describe stakeholders, objects, design considerations, phases, actions, and values in a general way that is modifiable.

- (4) How and when is the ‘fit’ (physical, social, behavioural) of the shoecontrolled?
- (5) Are there places when changing one aspect will break another? Add a negotiation card to that moment and quickly note what happens.
- (6) Consider the board as a system. What is difficult and what would make the process better? Identify challenges and opportunities in the product, service, and the system.
- (7) Walk through the system again to see what can be streamlined, modified, or changed.
- (8) Create a customer journey and data flow from the cards on the board.

4. Deploying the UPPSS game

The game was used as the main teaching tool with second- and third-year bachelor students ($n = 16$) from a course on digital craftsmanship in an industrial design programme. Of the students, eight were female, eight were male. Their brief was to design a shoe personalisation UPPSS. As the course started, each participant made and wore their own pair of digitally fabricated shoes for a week (see [Figure 4](#)). Then, participants formed into groups of four and played the UPPSS game. Using findings from the game (see [Figure 3](#)) and the worn shoes experience (see [Figure 4](#)), the participants created customer journeys and data flow diagrams that represent a complete designed UPPSS (see example [Figures 5](#) and [6](#)). The final version of the shoes, customer journeys, and data flows were critiqued at the completion of an eight-week process. Participants then wrote a reflection which was coded by the researchers.

4.1. Inter-coder classification using an interpretative framework

To understand the effect of the UPPSS game, an inter-coder agreement method was used (Kjeldskov and Paay 2012; Tetteroo and Markopoulos 2015; Nachtigall, Tetteroo, and Markopoulos 2018). Using [Table 1](#) as an interpretative framework classification schema, an abbreviation was given to each challenge. Two coders (PhD candidates working within

Figure 4. Game participants designed with code, manufactured, personalised, and wore shoes using algorithms, Processing, and the ONEDAY open source shoe toolkit (Nachtigall et al. . 2019).

Figure 5. Example customer journey and data flows that illustrate an UPPSS created by a participant using the game.

Figure 6. Another example UPPSS customer journey and data flow created by a participant using the game.

UPPSS) read each reflection and coded each sentence if a classification was apparent; only one classification allowed per sentence. No classification was also possible. If more than one classification was present, coders negotiated the classification that seemed more important in context. After classifying one page of text, the coders compared classifications. When

disagreement was found, classification was debated until consensus was reached with no time constraint. Each coder's classification and final agreement were recorded for analysis.

5. Results

From the participant ($n = 16$) reflections 1474 sentences were considered. The categories from the interpretative framework (Table 1) were found in 753 (51%) of the sentences. Product challenges represented 384 (51% of found classifications), service challenges represented 215 (29% of found classifications), and system challenges represented 154 (20% of found classifications). The inter-coder agreement for the classifications was 0.76 using Cohen's kappa. This is found to be sufficient reliability to draw results (Muñoz and Bangdiwala 1997). Representative sentences of each category were selected for qualitative analysis presented in Table 2.

6. Analysis

It is clear from the inter-coder analysis of the reflections on the use of the game that the interpretative framework's challenges and learnings (see Table 1) were addressed by the students. All challenges and learnings had at least four classifications and as many as 179. We looked for references to the game itself in the reflections and found them in the

Table 2. A summary of challenge classifications found in participant reflections upon the game using inter-coder analysis.

product, system and service challenges and learnings and in the four UPPSS phases, namely Co-Analysis, Co-Design, Co-Manufacture, and Co-Use. Examples from each phase and PSS category are presented in Table 3. We found evidence of all UPPSS phases in PSS categories, but some were more present.

From the game reflections, the product challenges and learnings (Table 2) were best represented in the UPPSS phases of co-design and co-manufacturing (Table 3). The challenge of mechanical sensing material structures was the least represented. The concept that material ‘wear and tear’ forms part of a computational system was difficult for the participants. Finding four reflections in the *Mechanical Sensing Material Structures* is still nominally sufficient.

We found the game explicitly mentioned in the service challenges and learnings (Table 2), primarily represented in the co-use and co-design phases. Moreover, from the service challenges, *Adding Sensing*, *Profiling Predicted Use* and *Reading the Body* were well addressed by the participants.

The system challenges and learnings (Table 2) were mostly found in Co-Analysis and Co-Manufacture (Table 3) yet had the least classifications. There is evidence of the role of the game, especially when *Comparing data*, *Saving and Storing the Data Trail*, and *Quantity and Scaling up*.

7. Discussion and conclusions

Working with data as if it is a material is a complex challenge. It is especially true when we look to a future of complete product service systems that are personalised with that data. Via the UPPSS design game, we confirmed that the challenges and learnings from the interpretive framework can be taken into account. We found the UPPSS design game helped participants work together to create complete customer journeys and data flows that open up the gateway to future production systems. The game allowed the participants to take the experience of digitally crafting a pair of shoes and scale it into a PSS platform. One of the teams was so successful that members went on to build the website P-16 ‘To illustrate our service and learn more about implementing processing.js – and I created a website’. It is also interesting to note that in many of the reflections, the game influenced either the product, service or system levels or multiple of them at the same time. P4 – ‘Now the shoe is not as flexible and it still looks nice. I had to change my initial design, a little bit to fit in with our shared service design’. This also helps to confirm that the UPPSS model works. It allowed the participants to pick up and work with abstract ideas. Each participant and stakeholder team did it in a different way and developed their own methods and knowledge.

While the results show the potential of the game in supporting the making of future production systems, it also shows that although difficult, data and algorithms became a fluid part of the designer’s toolkit. The ramifications of small decisions by a diverse team of stakeholders were made apparent by the UPPSS game, which allowed participants to have a clear mental picture of how the process would change the co-designed shoe and supporting service.

The game captured some elements of stakeholder relationships that the original interpretive framework did not encompass. Service design emerged from the relationship of people with computational things but has been shown to understand stakeholder interaction (ten Bhömer et al. 2013). Future work into the UPPSS, the game, and other future systems should look to better

Table 3. A summary of key sentences found in the participants' reflections organised by UPPSS phases (Co-) and Product Service System (PSS) Challenges and Learnings.

Product	Service	System
Co-Analyze		
Adapting Algorithms: "Using this algorithm, I wanted to create a shoe that basically folds perfectly to the shape of your foot." - P2	Reading Body: "After this the feet are scanned, pressure and 3D, to gain data about the feet and make a perfect shoe." - P12	Comparing Data: "In the meantime sensor data from the pressure sensors on the uppers are compared to the optimal values for people with comparable features (weight, height, shoe size, etc.)." -P5
Mechanical Sensing Material Structures: "Also, the option of a printable paper model to check what size the customer needs, will be available." -P8	Reading Body: "It will start measuring (the foot) with an app on your phone as soon as you wake up and start your first activity." -P14	Comparing Data: "The next step is to make a decision on which input data (mouse input, weather data, etc) will it be used to generate the personalised pattern design." -P6
Mechanical Sensing Material Structures: "I also found that you can gain a lot of information about a persons' foot by looking at the shoes after wearing them for a certain amount of time." - P12	Understanding Behaviour: "In order to get a good impression of the differences with my normal sneakers and to find possible design opportunities, I wore the shoes for four full days."-P13	Comparing Data: "The first time I wore shoes that I made myself (the leather ones) I had difficulty pointing out what was and wasn't pleasant about the experience. On top of that I did not know how to translate specific points into design changes" -P8
Co-Design		
Adapting Algorithms: "I learned a lot of basics for using mathematical functions to generate form, but I am not yet able to create these alone from scratch." -P5	Profiling Predicted Use: "When the customer is fully finished with designing, they will see a realistic render of what the design will look like." - P3	Saving and Storing the Data Trail: "There you can create an account that manages the customer's current and old shoe designs, number of walked steps and unlocked designs." - P6
Adapting Algorithms: "Now the shoe is not as flexible and it still looks nice. I had to change my initial design a little bit to fit in with our shared service design." -P4	Profiling Predicted Use: With this design, I wanted to create an ultra-personalized shoe in which design would not be obvious for everyone but would be very important and precious for a user himself. - P9	Quantity and Scaling Up: "The main objective for our service system was to keep it modular but not too complicated. We made the dataflow with the website in mind; we transformed all the functionalities from the site into data objects."-P16
Standardizing Material Behaviour "Code can be very abstract and designers need to know what will happen to the real material if they manipulate the code." - P5	Adding Sensing: "This game gave me the idea to let customers of the service platform play with the contrast by letting them change the density of the vector markings on the top of the upper and on the back." - P13	Comparing Data "When the customer is ready for ordering the shoe, the metadata is imported and it will check if they have walked enough steps in order to really order it." - P4
Co-Manufacture		
Manufacturing Misinterpretation "while trying to make some material explorations with some scrap leather, faced a lot of problems with setting up the proper functions for the laser cutter and despite asking for help every time a new error was there." -P6	Understanding Behaviour: "With my hands I could feel that there actually was more resistance in the heel, the place where the cells were smaller." - P8	Storing and Decoding Use : "I made sure that the output of the code is a pdf file that can be sent to a laser cutter immediately, without the need of changing the scale or removing things in Adobe Illustrator." -P13
Manufacturing Misinterpretation: "For the actual realization, another material would be needed." -P3	Adding Sensing: "First the contours are made from the 3D scan using the convex hull method (projected from the feet) and the preference list of the user. In that scan the position of the sensor are also included, which will be used for the first order of Voronoi cells." -P5	Quantity and Scaling Up: "I not only wanted to make the patterns needed for the shoe, but I also tried to look at how the code would be integrated in a real service platform."-P13
Standardizing Material Behaviour: "With different densities, materials, placements and stitches could see what would suit best for this project." - P4	Understanding Behaviour: "The leather was quiet stiff which made it rub against my feet, which resulted in an unpleasant/painful experience while wearing.:" - P7	Quantity and Scaling Up: "I found that making the data flow helped me visualize what would have to be done in the code and therefore I will make one before I start on big codes."- P5
Co-Use		
Adapting Algorithms: "From an ethical perspective it is important that you keep the privacy of these people in mind and that you give them a pleasant experience."-P5	Reading Body: "Then they get a socks sent home that they have to wear for a week. In the socks pressure sensors can be found. Over the period they gather pressure data to compare with the data of 'healthy people' to define where and how much extra support should be." -P5	Saving and Storing the Data Trail: "When choosing my shoe, they will first have to create an account, or login with an already existing one." -P6
Adapting Algorithms: "The original idea was to let the customers poke their own (designed holes) in the vector marked area. However, the vector marks were not deep enough to be able to do this." - P3	Adding Sensing: "Even when the shoe has already been received and worn, there is an option of sending the shoe back to enhance its design, for a small fee." -P12	Storing and Decoding Use: "All stakeholders are also sources of data."-P10
Adapting Algorithms: "I think it is important from both a business and an ethical perspective to make sure that the customer have a pleasant and safe leeway from the start of deciding to purchase it to the actual use."-P5	Adding Sensing: "After again checking if they've walked enough steps, they will need to pay a small fee and send the shoe back to the address that appears on the screen." -P6	Comparing Data: "The user can use the shoes for themselves or choose to evaluate them in their regular check-ups with their podiatrists. After three months the user gets one last questionnaire to evaluate the customer satisfaction." -P5

capture these interactions and define stakeholder roles better. This could include templates for the data flow and customer journey that might allow for greater analysis.

The UPPSS board itself represented a static framework. It needed to be more dynamic allowing for the changing of the board (system) itself. We saw the frustration in a few of the reflections P15 – ‘Without having the group service platform, my customer journey probably would have been completely different’. In the future, the Co-Analysis, Encoding, Co-Design, Materialise, Co-Manufacture, Profiling, Co-Use and Monitoring phases could be in independent boxes allowing participants to manipulate the system framework. This would have helped participants like P6 who said ‘The design will be updated and again sent back to the customer.’ indicating a possible different process.

Data remained challenging for the participants. The concept that materials can make data as part of the process was difficult to find in the reflections. This was tied to the fact that the circularity of bringing the data from the shoe back in the process was poorly represented. The game allowed conceptually detailed and contextually rich first-person experiences. We look forward to adding actions to the UPPSS game to address qualities such as sustainability that may help participants make the process more circular resulting in iterative shoes.

Finally, while no other examples of inter-coder analysis of personal reflections were found, the data validates the game, was created using this method, and lead to effective research. Analysis showed the transmission of the ideas of UPPSS and indeed, although it was key to our understanding that we captured the quotes that informed the analysis.

8. Implications and future work

The language used by the students especially in the ‘System’ Challenges/Learnings points to a possible future of highly automated data flow and fast production flow, but extremely adaptive with respect to changes in the data and the user’s wishes. In fact, the technology to implement this is ready: more and more production machines are data-driven and allow each product to be unique. Digital embroidery, laser cutting, laser engraving, printing and computer-controlled knitting are just available, only sewing for assembly lags behind. But in present-day factories, one can still see streets of parallel embroidery machines, all stitching the same designs, dozens of machines side-to-side, day after day. It is like being in the early Bronze age: the first bronze tools still being copies of the old Neolithic tools (axe heads, hammers, etc.). It takes centuries for humanity to use bronze for refined works of art and precision instruments. We envision a world where designers can make individual things for individual people.

On the user side, the creativity and the desire to have personalised products are in place, but the only way for an individual to have them realised is either bespoke/haute couture tailoring (for the happy few), or it is DIY (using craft-style home equipment). There is a lack of access to powerful machinery and the software of ultra-personalisation is hampered by a wilderness of proprietary file formats and tools. Most creatives outside the mass-production industry are forced to work with the well-known versatile but inefficient what-you-see-is-what-you-get (WYSIWYG) software. In the participant designs, the power of open-source programming environments is demonstrated. The shoes are generated by a compiler (like in electronics, where a chip designer deploys a silicon compiler). We envisage a future where efficient production is no longer the opposite of ultra-personalisation; the realisation of this future will take time, however.

Figure 7. Possible distributed and localised future models discovered during the research. These systems go beyond current systems and create a new class of systems. These systems are ubietous in that they are personalised to specific place and time; the opposite of ubiquitous.

The technology is no longer the bottle-neck, but there are other bottlenecks, notably the complexity, and rigidity of the present-day fashion industry.

Co-Designing with the opportunities and challenges of a UPPSS creates new opportunities for future production systems. In showing that these challenges can be solved, each group created a different localised solution. Taken as a whole, the four systems developed seem to illustrate that there is a possibility for distributed and localised systems (see Figure 7) that could be called *ubietous*, as in the opposite of ubiquitous. More work is needed to look at current approaches to socio-technical systems of production (Figure 1), i.e. how data can transition these away from *ubiquitous* systems to ultra-personalised, localised, and distributed *ubietous* systems. The result is move from vertical production processes based on an extractive economy to a local, open, distributed, and circular, hinting at a regenerative co-designed economy. But to accomplish Ultra-Personalisation requires a new kind of stakeholder group that is capable of understanding data as a core constituent material to create circular systems and beyond.

Acknowledgments

Special thanks to Chet Bangaru, the students of the Digital Craftsmanship course, Stephan Wensveen, Eva Klabalova, Henry Lin, Bart Pruijboom, Kristina Andersen, Max Pirsky, The Footwearist, the ArcInTexETN programme and all members of TU/e's Wearable Senses and dSearch Labs.

Disclosure statement

No potential conflict of interest was reported by the authors.

Funding

The project received funding from the European Union's Horizon 2020 research and innovation programme under the Marie Skłodowska-Curie grant agreement no. 642328.

ORCID

Troy Nachtigall <http://orcid.org/0000-0002-2136-1214>

References

- Amorim, D. J. N., T. Nachtigall, and M. B. Alonso. 2019. "Exploring Mechanical Meta-material Structures through Personalised Shoe Sole Design." In *Proceedings of the ACM Symposium on Computational Fabrication*, 1-8. New York: ACM. doi:10.1145/3328939.3329001.
- Ball, J., and H. Rollinson. 1935. *Boots and Shoes: Their Making, Manufacture and Selling, Volume VI Bespoke Bootmaking*. Edited by F. Y. Golding. London: New Era Publishing.
- Ballagas, R., S. Ghosh, and J. Landay. 2018. "The Design Space of 3D Printable Interactivity." *Proceedings of the ACM on Interactive, Mobile, Wearable and Ubiquitous Technologies* 2 (2): 1-21. doi:10.1145/3214264.
- Baumers, M., P. Dickens, C. Tuck, and R. Hague. 2016. "The Cost of Additive Manufacturing: Machine Productivity, Economies of Scale and Technology-push." *Technological Forecasting and Social Change* 102: 193-201.
- Benford, S., B. Koleva, W. W. Preston, A. Angus, E. C. Thorn, and K. Glover. 2018. "Customizing Hybrid Products." In *Proceedings of the 2018 CHI Conference on Human Factors in Computing Systems*, 1-12. New York: ACM. doi:10.1145/3173574.3173604.
- Bishop, C. M. 2006. Mixture Models and EM Algorithm. <http://mlg.eng.cam.ac.uk/tutorials/06/cb.pdf>.
- Bogers, S., J. van Kollenburg, J. Frens, and T. Djajadiningrat. 2016. "Data-enabled-design: A Situated Exploration of Rich Interactions." In *Proceedings of the 2016 ACM Conference Companion Publication on Designing Interactive Systems*, 45-48. New York: ACM. doi:10.1145/2908805.2913015.
- Busscher, I., I. Kingma, F. H. Wapstra, S. K. Bulstra, G. J. Verkerke, and A. G. Veldhuizen. 2011. "The Value of Shoe Size for Prediction of the Timing of the Pubertal Growth Spurt." *Scoliosis* 6 (1): 1. doi:10.1186/1748-7161-6-1.
- Desjardins, A., and R. Wakkary. 2016. "Living In A Prototype: A Reconfigured Space." In *Proceedings of the 2016 CHI Conference on Human Factors in Computing Systems - CHI '16*, 5274-5285. New York: ACM. doi:10.1145/2858036.2858261.
- Dinner, I. M., H. J. van Heerde, and S. Neslin. 2015. "Creating Customer Engagement Via MobileApps: How App Usage Drives Purchase Behavior." [Tuck School of Business Working Paper No. 2669817]. doi:10.2139/ssrn.2669817.
- Dourish, P. 2017. *The Stuff of Bits: An Essay on the Materialities of Information*. London: MIT Press.
- Feijs, L., T. Nachtigall, and O. Tomico. 2016. "Sole Maker: Towards Ultra-Personalised Shoe Design Using Voronoi Diagrams and 3D Printing." In *Proceedings of SMI'2016 Fabrication and Sculpting Event (FASE)*, edited by K. Polthier, J.A. Baerentzen, E. Akleman, 31-40. ISAMA. <http://igs2016.mi.fu-berlin.de/proceedings/fase2016/papers/1.pdf>
- Forlizzi, J. (2012) "The Product Service Ecology: Using a Systems Approach in Design." In *Proceedings of the 2nd Conference on Relating Systems Thinking and Design (RSD2)*, 1-27. Oslo: The Oslo School of Architecture and Design.
- Frens, J. 2006. "A Rich User Interface for A Digital Camera." *Personal and Ubiquitous Computing* 10 (2-3): 177-180. doi:10.1007/s00779-005-0013-z.
- Giaccardi, E., and E. Karana (2015, April). "Foundations of Materials Experience: An Approach for HCI." In *Proceedings of the 33rd Annual ACM Conference on Human Factors in Computing Systems*, 2447-2456. New York: ACM. doi:10.1145/2702123.2702337.
- Greene, E. M. 2018. "Metal Fittings on the Vindolanda shoes: Footwear and Evidence for Podiatric Knowledge in the Roman World." In *Shoes, Slippers, and Sandals*, edited by S. Pickup and S. Waitepp, 310-324. London: Routledge.
- Griffin, L., C. Compton, and L. E. Dunne. 2016. "An Analysis of the Variability of Anatomical Body References within Ready-to-wear Garment Sizes." In *Proceedings of the 2016 ACM International Symposium on Wearable Computers*, 84-91. New York: ACM. doi:10.1145/2971763.2971800.
- Habibović, M., E. Broers, J. Piera-Jimenez, M. Wetzels, I. Ayoola, J. Denollet, and J. Widdershoven. 2018. "Enhancing Lifestyle CHANGE in Cardiac Patients through the Do CHANGE System

- (‘Do Cardiac Health: Advanced New Generation Ecosystem’): Randomized Controlled Trial Protocol.” *JMIR Research Protocols* 7 (2): e40. doi:[10.2196/resprot.8406](https://doi.org/10.2196/resprot.8406).
- Hagman, F. 2005. *Can Plantar Pressure Predict Foot Motion*. Eindhoven, NL: Eindhoven University of Technology. doi:[10.6100/IR597100](https://doi.org/10.6100/IR597100).
- Hannula, O., and J. T. Harviainen (2016, May). “Efficiently Inefficient: Service Design Games as Innovation Tools.” In *Service Design Geographies. Proceedings of the ServDes. 2016 Conference* (No. 125, pp. 241–252). Copenhagen: Linköping University Electronic Press.
- Hertenberger, A., B. Scholz, B. Contrechoc, B. Stewart, E. Kurbak, H. Perner-Wilson, . . . K. Kuusk. 2014. “2013 E-textile Swatchbook Exchange: The Importance of Sharing Physical Work.” In *Proceedings of the 2014 ACM International Symposium on Wearable Computers: Adjunct Program*, 77–81. New York: ACM. doi:[10.1145/2641248.2641276](https://doi.org/10.1145/2641248.2641276).
- Hong, Y., P. Bruniaux, X. Zeng, A. Curteza, and K. Liu. 2018. “Design and Evaluation of Personalized Garment Block for Atypical Morphology Using the Knowledge-supported Virtual Simulation Method.” *Textile Research Journal* 88 (15): 1721–1734. doi:[10.1177/0040517517708537](https://doi.org/10.1177/0040517517708537).
- Ion, A., L. Wall, R. Kovacs, and P. Baudisch. 2017. “Digital Mechanical Metamaterials.” In *Proceedings of the 2017 CHI Conference on Human Factors in Computing Systems*, 977–988. New York: ACM. doi:[10.1145/3025453.3025624](https://doi.org/10.1145/3025453.3025624).
- Jacobs, J., D. Mellis, A. Zoran, C. Torres, J. Brandt, and J. Tanenbaum. 2016. “Digital Craftsmanship: HCI Takes on Technology as an Expressive Medium.” In *Proceedings of the 2016 ACM Conference Companion Publication on Designing Interactive Systems*, 57–60. New York: ACM. doi:[10.1145/2908805.2913018](https://doi.org/10.1145/2908805.2913018).
- Kao, C. H. L., B. Nguyen, A. Roseway, and M. Dickey. 2017. “Earthtones: Chemical Sensing Powders to Detect and Display Environmental Hazards through Color Variation.” In *Proceedings of the 2017 CHI Conference Extended Abstracts on Human Factors in Computing Systems*, 872–883. New York: ACM. doi:[10.1145/3027063.3052754](https://doi.org/10.1145/3027063.3052754).
- Kao, H. L., C. Holz, A. Roseway, A. Calvo, and C. Schmandt. 2016. “DuoSkin: Rapidly Prototyping On-skin User Interfaces Using Skin-friendly Materials.” In *Proceedings of the 2016 ACM International Symposium on Wearable Computers*, 16–23. New York: ACM. doi:[10.1016/j.matdes.2009.12.021](https://doi.org/10.1016/j.matdes.2009.12.021).
- Karana, E., E. Giaccardi, N. Stamhuis, and J. Goossensen. 2016. “The Tuning of Materials: A Designer’s Journey.” In *Proceedings of the 2016 ACM Conference on Designing Interactive Systems*, 619–631. New York: ACM.
- Kirsikka, V., and T. Mattelmäki. 2014. “Design Games in Codesign: As a tool, a Mindset and a Structure.” *CoDesign* 10 (1): 63–77.
- Kjeldskov, J., and J. Paay. 2012. “A Longitudinal Review of Mobile HCI Research Methods.” In *Proceedings of the 14th International Conference on Human-Computer Interaction with Mobile Devices and Services*, 69–78. New York: ACM.
- Lemon, K. N., and P. C. Verhoef. 2016. “Understanding Customer Experience Throughout the Customer Journey.” *Journal of Marketing* 80 (6): 69–96.
- Lucero, A., J. Holopainen, E. Ollila, R. Suomela, and E. Karapanos. 2013. “The Playful Experiences (PLEX) Framework as a Guide for Expert Evaluation.” In *Proceedings of the 6th International Conference on Designing Pleasurable Products and Interfaces*, 221–230. doi:[10.1145/2513506.2513530](https://doi.org/10.1145/2513506.2513530).
- Mackey, A., R. Wakkary, S. Wensveen, and O. Tomico. 2017. ““Can I Wear This?” Blending Clothing and Digital Expression by Wearing Dynamic Fabric.” *International Journal of Design* 11 (3): 51–65.
- Magrisso, S., M. Mizrahi, and A. Zoran. 2018. “Digital Joinery for Hybrid Carpentry.” In *Proceedings of the 2018 CHI Conference on Human Factors in Computing Systems*, 1–11. New York: ACM. doi:[10.1145/3173574.3173741](https://doi.org/10.1145/3173574.3173741).
- Malakuczi, V. 2017. “Raising New Opportunities for the Next Economy by Exploring Variable User Needs for Computational Co-Design.” *The Design Journal* 20 (sup1): S581–S588. doi:[10.1080/14606925.2017.1353005](https://doi.org/10.1080/14606925.2017.1353005).

- Mann, S. 1997. "Wearable Computing: A First Step toward Personal Imaging." *Computer* 30 (2): 25–32. doi:[10.1109/2.566147](https://doi.org/10.1109/2.566147).
- Marr, A., and R. Hoyes. 2016. "Making Material Knowledge: Process-led Textile Research as an Active Source for Design Innovation." *Journal of Textile Design Research and Practice* 4 (1): 5–32. doi:[10.1080/20511787.2016.1255447](https://doi.org/10.1080/20511787.2016.1255447).
- Mironcika, S., A. Hupfeld, J. Frens, and S. Wensveen. 2020. "I Am Not an Object: Reframing 3D Body Scanning for Co-Design." In *Proceedings of the 2020 CHI Conference on Human Factors in Computing Systems*, 1–6. New York: ACM. doi:[10.1145/3313831.3376352](https://doi.org/10.1145/3313831.3376352).
- Mok, P. Y., and S. Zhu. 2018. "Precise Shape Estimation of Dressed Subjects from Two-view Image Sets." In *Applications of Computer Vision in Fashion and Textiles*, edited by W. K. Wong, 273–292. Oxford: Woodhead Publishing. doi:[10.1016/B978-0-08-101217-8.00011-7](https://doi.org/10.1016/B978-0-08-101217-8.00011-7).
- Muñoz, S. R., and S. I. Bangdiwala. 1997. "Interpretation of Kappa and B Statistics Measures of Agreement." *Journal of Applied Statistics* 24 (1): 105–112. doi:[10.1080/02664769723918](https://doi.org/10.1080/02664769723918).
- Nácher, B., S. Alemany, J. C. González, E. Alcántara, J. García-Hernández, S. Heras, and A. Juan. 2006. "A Footwear Fit Classification Model Based on Anthropometric data (No. 2006-01-2356)." [SAE Technical Paper No. 2006-01-2356]. doi:[10.4271/2006-01-2356](https://doi.org/10.4271/2006-01-2356).
- Nachtigall, T. (2017, September). "EVA Moccasin: Creating a Research Archetype to Explore Shoe Use." In *Proceedings of the 2017 ACM International Symposium on Wearable Computers*, 197–202. New York: ACM. doi:[10.1145/3123021.3123077](https://doi.org/10.1145/3123021.3123077).
- Nachtigall, T., D. Tetteroo, and P. Markopoulos. 2018. "A Five-Year Review of Methods, Purposes and Domains of the ISWC." In *Proceedings of the 2018 ACM International Symposium on Wearable Computers - ISWC '18*, 48–55. New York: ACM. doi:[10.1145/3267242.3267272](https://doi.org/10.1145/3267242.3267272).
- Nachtigall, T., O. Tomico, and R. Wakkary. 2019. "Oneday Shoes: A Maker Toolkit to Understand the Role of Co-manufacturing in Personalization." In *Proceedings of the Thirteenth International Conference on Tangible, Embedded, and Embodied Interaction*, 105–115. New York: ACM. doi:[10.1145/3294109.3295637](https://doi.org/10.1145/3294109.3295637).
- Nachtigall, T., O. Tomico, R. Wakkary, and P. Van Dongen. 2019. "Encoding Materials and Data for Iterative Personalization." In *Proceedings of the 2019 CHI Conference on Human Factors in Computing Systems*, 1–12. New York: ACM. doi:[10.1145/3290605.3300749](https://doi.org/10.1145/3290605.3300749).
- Nachtigall, T. R., O. Tomico, S. Wensveen, and R. Wakkary. 2019. "Unpacking Solemaker into a Model for UPPSS." In *Proceedings of the 4th Biennial Research Through Design Conference*, 1–16. Delft and Rotterdam. doi:[10.6084/m9.figshare.7855817.v2](https://doi.org/10.6084/m9.figshare.7855817.v2).
- Nibedita, R., Y. F. Zhang, A. Khandual, and A. Luximon. 2010. "3D Foot Scan to Custom Shoe Last." *Special Issue of International Journal of Computer and Communication Technology* 1 (2–4): 14–18.
- Norman, D. A. 1986. "User Centered System Design, User Centered System Design." Boca Raton, FL: CRC Press. doi:[10.1201/b15703](https://doi.org/10.1201/b15703).
- Odom, W., R. Wakkary, Y. K. Lim, A. Desjardins, B. Hengeveld, and R. Banks (2016). "From Research Prototype to Research Product." In *Proceedings of the 2016 CHI Conference on Human Factors in Computing Systems*, 2549–2561. New York: ACM. doi:[10.1145/2858036.2858447](https://doi.org/10.1145/2858036.2858447).
- Paulose, J., A. S. Meeussen, and V. Vitelli. 2015. "Selective Buckling via States of Self-stress in Topological Metamaterials." *Proceedings of the National Academy of Sciences* 112 (25): 7639–7644. doi:[10.1073/pnas.1502939112](https://doi.org/10.1073/pnas.1502939112).
- Piller, F. T., E. Lindgens, and F. Steiner. 2012. "Mass Customization at Adidas: Three Strategic Capabilities to Implement Mass Customization." SSRN. doi:[10.2139/ssrn.1994981](https://doi.org/10.2139/ssrn.1994981)
- Porter, M. E., and J. E. Heppelmann. 2014. "Spotlight on Managing the Internet of Things—how Smart, Connected Products are Transforming Competition." *Harvard Business Review* 1: 1–23.
- Reiss, A., and D. Stricker. 2013. "Personalized Mobile Physical Activity Recognition." In *Proceedings of the 2013 International Symposium on Wearable Computers*, 25–28. New York: ACM. doi:[10.1145/2493988.2494349](https://doi.org/10.1145/2493988.2494349).
- Schirmer, M., J. Hartmann, S. Bertel, and F. Echter. 2015. "Shoe Me the Way: A Shoe-based Tactile Interface for Eyes-free Urban Navigation." In *Proceedings of the 17th International Conference on Human-Computer Interaction with Mobile Devices and Services*, 327–336. New York: ACM. doi:[10.1145/2785830.2785832](https://doi.org/10.1145/2785830.2785832).

- Shenck, N. S., and J. A. Paradiso. 2001. "Energy Scavenging with Shoe-mounted Piezoelectrics." *IEEE Micro* 21 (3): 30–42. doi:[10.1109/40.928763](https://doi.org/10.1109/40.928763).
- Skach, S., A. Xambó, L. Turchet, A. Stolfi, R. Stewart, and M. Barthet. 2018. "Embodied Interactions with E-textiles and the Internet of Sounds for Performing Arts." In *Proceedings of the Twelfth International Conference on Tangible, Embedded, and Embodied Interaction*, 80–87. New York: ACM. doi:[10.1145/3173225.3173272](https://doi.org/10.1145/3173225.3173272).
- Steiner, H., S. Kang, A. Roseway, and R. Banks. 2018. "GrowKit: A Kit for Organisms to Promote Personalized STEAM Learning." In *Extended Abstracts of the 2018 CHI Conference on Human Factors in Computing Systems*, 1–1. New York: ACM. doi:[10.1145/3170427.3186605](https://doi.org/10.1145/3170427.3186605).
- Stolwijk, C. C. M., and M. Punter. 2018. *Going Digital: Field Labs to Accelerate the Digitization of the Dutch Industry*. Den Haag: TNO.
- ten Bhömer, M., C. E. Brouwer, O. Tomico, and S. A. G. Wensveen. 2013. "Interactive Prototypes in the Participatory Development of Product-Service Systems." In *Proceedings of the 3rd Participatory Innovation Conference*, edited by H. Melkas and J. Buur, 36–42. Lahti: Lappeenranta University of Technology.
- ten Bhömer, M. T., O. Tomico, and S. Wensveen. 2016. "Designing Ultra-personalised Embodied Smart Textile Services for Well-being." In *Advances in Smart Medical Textiles*, edited by L. van Langenhove, 155–175. Oxford: Woodhead Publishing.
- Tetteroo, D., and P. Markopoulos. 2015. "A Review of Research Methods in End User Development." In *International Symposium on End User Development*, edited by P. Diaz, V. Pipek, C. Ardito, C. Jensen, I. Aedo, and A. Boden, 58–75. Cham: Springer.
- Tsai, W. C., and E. Van Den Hoven. 2018. "Memory Probes: Exploring Retrospective User Experience through Traces of Use on Cherished Objects." *International Journal of Design* 12 (3): 57–72.
- Tukker, A. 2004. "Eight Types of Product-service System: Eight Ways to Sustainability? Experiences from SusProNet." *Business Strategy and the Environment* 13 (4): 246–260. doi:[10.1002/bse.414](https://doi.org/10.1002/bse.414).
- Vallgård, A., and J. Redström (2007, April). "Computational Composites." In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, 513–522. New York: ACM. doi:[10.1145/1240624.1240706](https://doi.org/10.1145/1240624.1240706).
- Vallgård, A., L. Boer, V. Tsaknaki, and D. Svanæs. 2017. "Material Programming." *Interactions* 24 (3): 36–41. doi:[10.1145/3057277](https://doi.org/10.1145/3057277).
- Vallgård, A., M. Winther, N. Mørch, and E. E. Vizer. 2015. "Temporal Form in Interaction Design." *International Journal of Design* 9 (3): 1–15.
- Vertommen, H., E. De Raeye, S. Bukenbergs, R. Sevit, W. Dewindt, and L. Peeraer. 2011. "The Development of Methods and Procedures to Determine the Dynamic and Functional Properties of Sports Shoes." *Footwear Science* 3 (sup1): S159–S160. doi:[10.1080/19424280.2011.575870](https://doi.org/10.1080/19424280.2011.575870).
- Wang, Y., H. S. Ma, J. H. Yang, and K. S. Wang. 2017. "Industry 4.0: A Way from Mass Customization to Mass Personalization Production." *Advances in Manufacturing* 5 (4): 311–320. doi:[10.1007/s40436-017-0204-7](https://doi.org/10.1007/s40436-017-0204-7).
- Ward, P. T. 1986. "The Transformation Schema: An Extension of the Data Flow Diagram to Represent Control and Timing." *IEEE Transactions on Software Engineering* SE-12 (2): 198–210. doi:[10.1109/TSE.1986.6312936](https://doi.org/10.1109/TSE.1986.6312936).
- Weerasinghe, T. W., and R. S. Goonetilleke. 2011. "Getting to the Bottom of Footwear Customization." *Journal of Systems Science and Systems Engineering* 20 (3): 310. doi:[10.1007/s11518-011-5171-0](https://doi.org/10.1007/s11518-011-5171-0).
- Wetzels, M., I. Ayoola, S. Bogers, P. Peters, W. Chen, and L. Feijs. 2018. "Consume: A Privacy-preserving Authorisation and Authentication Service for Connecting with Health and Wellbeing APIs." *Pervasive and Mobile Computing* 43: 20–26. doi:[10.1016/j.PMCJ.2017.11.002](https://doi.org/10.1016/j.PMCJ.2017.11.002).
- Wilde, D., A. Vallgård, and O. Tomico. 2017. "Embodied Design Ideation Methods: Analysing the Power of Estrangement." In *Proceedings of the 2017 CHI Conference on Human Factors in Computing Systems*, 5158–5170. New York: ACM.
- Wolfs, R. J., F. P. Bos, E. C. van Strien, and T. A. Salet. 2018. "A Real-time Height Measurement and Feedback System for 3D Concrete Printing." In *High Tech Concrete: Where Technology and*

- Engineering Meet*, edited by D. Hordijk and M. Luković, 2474–2483. Cham: Springer. doi:[10.1007/978-3-319-59471-2_282](https://doi.org/10.1007/978-3-319-59471-2_282).
- Yang, Q. 2018. “Machine Learning as a UX Design Material: How Can We Imagine beyond Automation, Recommenders, and Reminders?” In *AAAI 2018 Spring Symposium on Designing the User Experience of Artificial Intelligence*. Palo Alto, CA: AAAI Press.
- Zheng, C., and E. Y. L. Do. 2018. “Mechamagnets: Tactile Mechanisms with Embedded Magnets.” In *Proceedings of the Twelfth International Conference on Tangible, Embedded, and Embodied Interaction*, 57–64. New York: ACM. doi:[10.1145/3294109.3295622](https://doi.org/10.1145/3294109.3295622).
- Zoran, A. 2015. “Hybrid Craft: Showcase of Physical and Digital Integration of Design and Craft Skills.” In *SIGGRAPH '15: ACM SIGGRAPH Art Gallery*, 384–398. New York: ACM. <http://dl.acm.org/citation.cfm?doid=2810185.2810187>
- Zoran, A., and L. Buechley. 2013. “Hybrid Reassemblage: An Exploration of Craft, Digital Fabrication and Artifact Uniqueness.” *Leonardo* 46 (1): 4–10. doi:[10.1162/LEON_a_00477](https://doi.org/10.1162/LEON_a_00477).
- Zuckerman, O., and M. Resnick. 2003. “A Physical Interface for System Dynamics Simulation.” In *CHI'03 Extended Abstracts on Human Factors in Computing Systems*, 810–811. New York: ACM. doi:[10.1145/765891.766005](https://doi.org/10.1145/765891.766005).