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Method& Critique *Frictions and Shifts in RTD*

Unpacking Solemaker into a Model for UPPSS

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Abstract: Solemaker research is a collection of four RtD projects related to personalized shoemaking. Across these projects, we created 272 material samples that explore how to make shoes that are digitally fabricated for the individual. This shoe personalization system utilised soft materials, 3D printing, digital embroidery, laser cutting and our own digital tools. Achieving Solemaker meant hundreds of material samples for only a few research products; all were algorithmically generated. Our work exemplifies a change in making and craft practices through digital fabrication. In design theory, this is encapsulated in a model of digital personalization known as Ultra Personalized Product Service (UPPS). To investigate these links in the context of our material and making approach, we compared our hybrid craft practise to the model of UPPS using a system of physical boxes. We unpacked our work into boxes representing the model. This afforded ways to map projects together by means of a common language. This resulted in previously unseen connections, new understandings of the theoretical model, and new enabling transitions between model pillars. We present our unpacking "material sample boxing" process, a refined definition of the model, and the "physicalised" enabling transitions between the UPPS model stages.

Keywords: Personalization; Shoemaking; Digital Fabrication; 3D Printing; Design Practice and Theory; Ultra-Personalized Product Service Systems

Nachtigall, Tomico, Wensveen, Wakkary | EVA Moccasin Data Generating Shoe. [Nachtigall and Klabalova]

Introduction

Design practice and theoretical models almost always differ. Theoretical models cannot express the subtlety and nuance of practice (especially when the practice is creating personalized objects, such as shoes). Many design practitioners and researchers are dubious of theoretical models. This is summarized well in the words of Watkins about theoretical models being like toothbrushes (Watkins 1990). Yet, case studies can inform a theoretical model (Binder and Redström 2006). To this end, we describe our practice of personalized digitally fabricated shoemaking. We then unpacked all our physical samples into boxes and analyzed our finding using the theoretical model of Ultra Personalized Products and Services (UPPS). This included intermediary knowledge created during the process.

Our research into ultra-personalisation, fig 1, started by observing how a bespoke shoemaker investigates a client's current shoes before making a new pair, fig. 2. This inspired us to design a system where the shoes themselves create a data trail for the next pair of shoes. There was no road-map for making shoes this way. Digitally personalized shoemaking provided a new rich area of practice. Bespoke shoemaking inspired this research practice as the shoes are highly personalized to the foot, movement and style of the wearer. The artisan shoemaker has a deep, often implicit, understanding which inspires a great deal of trust in the skill and taste of the artisan.

Data seemingly cares little for the material that makes it or the person that is manipulating it. Programmers usually create tools for large numbers of people with little concern for the individual or the materiality of the data. We joined bespoke shoemaking with computer programming creating a system of personalized shoemaking with a data driven back end. Designing a system that scaffolds bespoke craft with data driven technology was no easy task. The materials, tools and techniques were invented by us and/or highly experimental when we started in 2015. Over two years and four projects, 272 samples, 3 demonstrators, and 4 research products we digitally manufactured data driven bespoke shoe.

Making each sample required a great amount of effort and many stakeholders. At the end of the project we "unpacked" (Storni 2012) the entire process into boxes. This allowed us to look at the theoretical model of Ultra-Personalized Products and Services from our practitioner's eyes. While the UPPS model had peripherally informed our process, our first hand, practiced based research allowed us to fill the gaps between practice and theory. We literally compared our practice to the theoretical UPPS model by placing every sample we could find in our studio into physical boxes representing the different steps of the UPPS model. We found gaps that helped us to refine and redefine the UPPS model including adding enabling transitions.

Theoretical Background & Related Work

Shoemaking is a complex practice. It can be executed by a single artisan in a small studio or by large companies with thousands of workers in far off factories. The side of shoemaking that relates to our work is personalization, a topic of interest to shoemakers of all sizes. This interest in personalization is historical seen in "Boots and shoes: Bespoke Bootmaking." (Bell 1937) or "Metal fittings on the Vindolanda shoes" (Greene 2018). Our research and practice was inspired by visits to shoemakers, shoe museums and archaeological sites to understand shoemaking practice. We also studied personalization in large scale shoemaking. Adidas, Nike, Under Armour, Reebok, Ecco, United Nude, Desma, HP and many others are making attempts at personalized shoes. We can see these in papers such as or "Getting to the bottom of footwear customization" (Weerasinghe & Goonetilleke 2011) or "Mass Customization at Adidas" (Piller 2012)

Figure 1. Spike Shoe Photo: Troy Nachtigall An example of our previous work in 3D printed shoes that inspired us to write software to make shoes without 3D models.

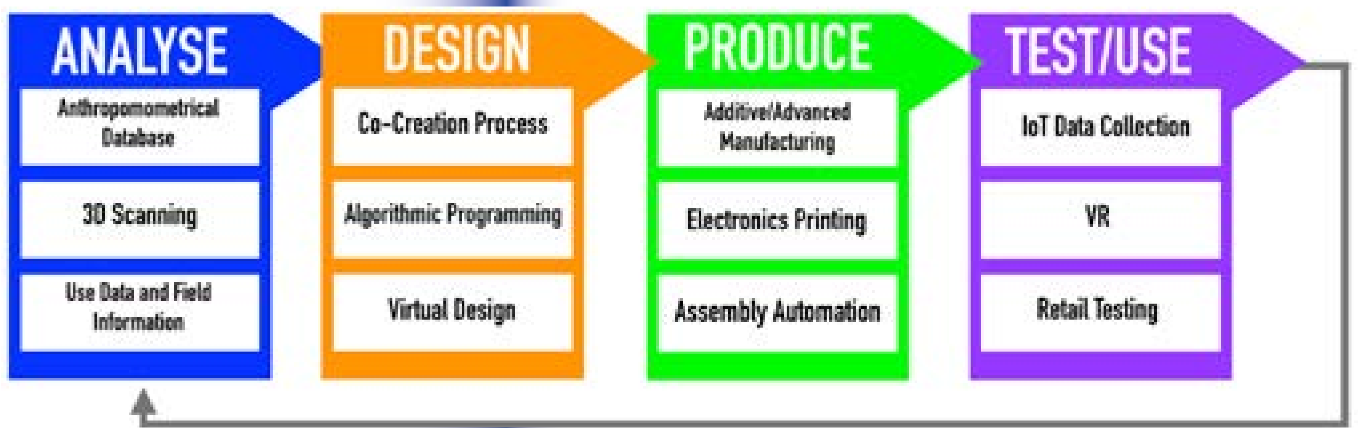


Figure 3. Original UPPS Model extracted from a presentation by Click NL. An example of the original theoretical UPPS model proposed by the UPPS Field Labs projects supported by the 3TU Technical Universities of The Netherlands.

Unpacking (Storni 2012) inspired us as a way to deeply look into an object and its making. Storni looks deeply into a designed object that have constituents and aspects. Unpacking for Stroni is a way to "provide a perspective on design practices that allows us to focus on the movements and the transformations that lie behind products" (Storni 2012). We build upon Storni by making unpacking a process of boxing. Grouping the samples by movements and transformations of the material & data in each sample to create a new kind of annotated portfolio (Bowers 2012).

Research Products unlike research prototypes, are inquiry-driven, finished, fit, and independent (Odom et al. 2016). These objects are typically created as single pieces or small batches to actively be used in everyday life. Research products often resemble artisan products but are inquiry-driven. We worked in a style resembling bespoke shoemaking with digital tools to make shoe research products which were worn as part of the research process.

Encoded Materials use new kinds of flexible materials, making the digital fabrication of personalized shoes increasingly possible as seen in our previous work "Towards Ultra Personalized 4D Printed Shoes" (Nachtigall et al. 2017). Material Science and HCI shown data defining how internal structures bend and flex (or don't) in recent research such as "selective buckling" (Paulose et al.2015), "metamaterials" (Ion et al. 2016), "programmable materials" (Vallgårda 2017), "personal fabrication" (Baudish and Muller, 2017), "using algorithms" (Feijs et al. 2016) and "dynamic behaviours" (Ballagas et al. 2018).

Ultra Personalization. Digital tools and techniques for making personalized products have reached a level of precision that allows the personalization of the form, material, and behaviour of a shoe (Nachtigall et al. 2018). Adding systems of foot scanning, cloud services, and use sensing enables a new form of mass-personalization. This mass-personalization takes place inside of a data-rich environment that concentrates on the needs of the user. We find researchers and practitioners calling this "Ultra-Personalization". We find examples in "Designing ultra-personalized embodied smart textile services for wellbeing'" (Bhomer et al. 2016), eLearning (Hutchison & Mitchell 2010) and the medical domain (Trifiletti Showalter 2015). There are examples that suggest ultra-personalization is an important next step; "Styling evolution for tight-fitting garments" (Kwok et al. 2018), and "Optimal design for additive manufacturing: opportunities and challenges" (Doubrovski et al. 2011).

Figure 2. Visiting bespoke shoemaker Mario Bemer Photo: Troy Nachtigall. Mario Bemer demonstrating how he builds a bespoke shoe in his Florence, Italy studio.

Ultra-Personalized Products and Services (UPPS) was a theoretical model for personalization that we encountered during our practice based research. The UPPS theoretical model proposed by the 3TU Dutch Technical Universities. UPPS explains personalized products and services as a system of Analyse, Design, Produce, Test/Use (Ahsmann 2015), fig. 3. We see UPPS being used in a series of field labs around the Netherlands, where it is defined 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 & Punter, 2018). The goal of UPPS is stated as "The development of radical new product propositions for the manufacturing industry through the innovative use of data and by making products fully customized." (Stolwijk & Punter, 2018).

A Flexible Design Practice

While we had the theoretical UPPS model roughly in mind during our design practice, there was always the feeling that our practice was more complicated than what the UPPS model expresses. This wasn't surprising as theory cannot fully understand the richness of practices or contexts. Nonetheless, we kept exploring how to use data to analyze, design, make, and profile shoes; all while encoding data for more shoes. In a series of four iterative design projects we created 272 samples, fig. 5. This included four pairs of fully wearable shoes, one foot scanning pressure pad, a material demonstrator and 266 other material samples/failures. These samples were made over two years. We scanned feet, programmed software, created printers (and other digital fabrication machines) and wore the generated product to understand the how and why of digitally fabricating personalized shoes.

This practice included the algorithmic programming of each of the samples detailed in our previous work (Feijs et al. 2015). No off the shelf 3D modelling software was used, rather we programmed the material to achieve detailed control over internal flexible structures by hacking the gCode language (Kramer 1994). Our earliest samples are seen in figure 4. GCode is little more than X,Y, Z coordinates with a move command G1, a speed variable F (usually in millimetres per minute) and an E extrusion variable. A line of gCode typically looks like "G1 X10 Y20 F300 E4.57. This roughly means move to the point AT 10mm by 20mm at 300mm/minute (slowly) and extrude 4.57mm of filament along the way. The most basic algorithm of the software is calculating the distance between two points to define how much material to extrude (§which took many hours and people to perfect). We arrived at the software through a combination of theoretical calculations and practical samples. In our practice the 3D printer stopped looking like a "printer" and started to seem like a computer-controlled hot glue gun. In time, the 3D printer more resembled a TNT (non-woven) textile loom. We increasingly found our hands inside the printer making changes while printing. TPE and TPU flexible filaments created complex structures that bent and flexed (or didn't) in specific ways. Thin wall geometries being very soft and flexible.

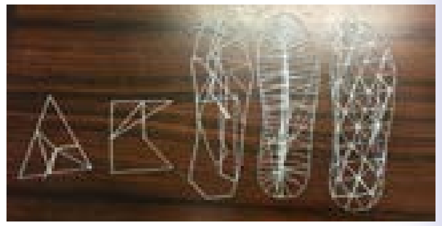


Figure 4. Early work: printed samples showing development of our own software to make gCode for flexible filament FDM 3D printers.

Geometries that fill a space with 45% or more seeming solid and strong. Combining hard and soft properties mathematically in code allowed us make shoes that are fit to the individual in terms of comfort, support, flexibility, and aesthetics. We described developing these design considerations in our previous work (Nachtigall et al. 2018). In the next section we present how we created a system of foot scanning, shoe design, shoe manufacturing and use monitoring that resulted in a wearable shoe that collected data to make more shoes. While other research into encoded materials was informing our work, we chose a first hand hybrid craft experience. We developed our own algorithms and material structures and explored the relationship between data & material. What resulted was a research product (shoe) that provided data and a rich context about the RtD research process.

Figure 5. Making Samples. A selection of the 272 samples created during the four projects.

Four Design Practice Projects

From Analysis to Design - SoleScan, fig. 6, was a project to create a sensor capable of revealing the shape and pressure of a loaded foot. It was made using digital embroidery technologies. SoleScan was designed to show footprint as 2D foot dimension outline and pressure as a 3 mm 3D image. The software visualized and recorded data of the footstep on the sensor. This project taught us that there are many different kinds of feet, beyond the length and width of the foot. We saw many outliers in terms of shape (especially height) and pressure balance from the 400+ scans at a public exhibition. High arches, large big toes, and small toes confused the system. We adjusted for these on the fly, but we had to also change the scanning process to capture the full weight shift in a footstep. Even if we thought we knew how complex the feet of all the people, we ended up realizing the footstep was far more complex than expected when turned into data.

Figure 6 Analysing the Foot. Photo: © Bart van Overbeeke. The SoleScan foot scanner revealing the pressure of the users foot.

From Design to Manufacturing - Solemaker, fig.7, was a project to create software for 3D printed shoe soles and laser cutting shoe uppers. Solemaker was designed to allow a user to co-design the size (footbed), the aesthetic (tread), support and comfort (density) of a shoe sole. In Solemaker we learned to negotiate design considerations with geometry and algorithms. We wrote code directly into machine gCode instead of using slicer software (slicer software take a 3D model and transforms it into the .gCode that a 3D printer needs, like Microsoft Word generating a postscript file but for a specific printer). This required different kinds of .gCode for different 3D printers. We faced challenges as materials or colours (of the same material) had different flexibility and density. This required creating a unique relationship between the specific material and data controlling it.

Figure 7. Manufacturing Shoes Photo: © Bart van Overbeeke. Printing shoe soles on modified commercial and self made 3D printers

From Manufacturing to Use - Solemaker.io, fig. 8, was a project to gather the data from the analysis, design and manufacture of the personalised shoe. The project allowed website users to stand on the SoleScan and have a shoe dynamically generated via an algorithm for their foot. The shoe sole could then be modified in a design interface and complete the process with a gCode file for 3D printing. At the same time, it would generate the uppers needed to laser cut leather (or similar material) for the shoe. Solemaker.io brought together the various modules needed to make a fully functional demonstrator. Solemaker.io served as the database for all the data and shed light on the idea that machine learning can be used to understand shoes over large populations.

Figure 8 Designing the shoe. Photo: © Bart van Overbeeke. An early version of the Solemaker.io software being used to design the tread of shoe sole

From Use to Analysis - EVA Moccasin, fig. 9, was a project to explore sensing and aesthetics in a parametric shoe. The project was built on top of Solemaker and added sensing to the sole of the shoe. A new shoe construction was used to explore alternative solutions and add 3D printing on the leather shoe upper. The printed sole was inserted into a moccasin construction to make the sole replaceable and avoid stitching the sole to the upper. Different methods of sensing were explored using electronic and mechanical sensing. Sensors were internally printed inside the sole structure to collect personalized data about the wearer. EVA Moccasin showed multiple ways of sensing inside shoes to make the next shoe more personalized.

Figure 9. EVA Moccasin. Photo: Troy Nachtigall. A Shoe that is generated from footstep data. The shoe records data during its lifetime of use for future shoes

Research Methodology: Material Sample Boxing

Theoretical research models can often be like maps drawn by people listening to stories from others who went somewhere (or didn't). In our research, we went there, described it in detail, and updated the "map". This meant programming shoes with code, data, digital fabrication and soft materials. This was a new way of making shoes when we set out. Designers, artisans and other practitioners know that understanding a craft requires making numerous swatches and samples. This is especially true when engaging in a process creating a new form of craftsmanship. Making this process explicit is often very challenging for practitioners. Only once we had accomplished making a full shoe (that also recorded data) were we were able to utilize the embodied complexity of all the created samples to explore our practice and the UPPS model in a profound way. Our aim was to provide a complex picture of our practice and what it meant to the UPPS model.

Previous to the research we visited bespoke shoemakers, fig 2. and started to make shoes using digital fabrication as seen in our prior work "Towards Ultra Personalized 4D Printed Shoes" (Nachtigall et al. 2017) or the 'Spike Shoes' in figure 1. This attracted us to the model of UPPS in figure 3 (step 1 in fig. 10). The UPPS model informed our design practice as we created the four projects described in the previous section resulting in the 272 samples in figure 5 (step 2 of figure 10). Working with a graphic designer we created the icons in figure 11 to help describe our practice while making the samples in the projects (step 3 of figure 10). As we completed our practice of shoemaking we realized that the small line connecting Test/Use to Analyze in figure 3 was more significant than previously thought. In figure 10 step 4, we used the icons to describe how the shoes from the Eva Moccasin (fig. 9) made data to make more shoes in a circular system. It was at this time that we changed the labels of the UPPS system as well. We added "Co-" to the stages making them Co-Analyze, Co-Design, Co-Manufacture and Co-Use. We made this change because of the number of stakeholders involved in every project. Using a person's data made them a specific stakeholder. Programmers, designers, digital fabrication specialists,podiatrists and others were all involved in the system. We were all users of the data. Thus, the person we were making the shoes for came to be called the wearer. Throughout findings we use the "co-" terms to communicate the aspect of multi-stakeholder collaboration required in this hybrid craft.

Unpacking into boxes In order to better understand the model and our practice, we created a series boxes labelled with the UPPS model phases: co-analyze, co-design, co-manufacture and co-use (figure 12a). The practiced based design researcher scouted the studio and collected 272 samples (swatches, failures, demonstrators, research products) and considered the material, code, behaviour, manufacturing process, stakeholders and that each embodied. He placed the samples in the box that represented them best (figure 12). Sorting many of the artefacts was a frustrating process even though he had direct experience with the code and creation of every sample, artefact, and research product.

Many of the samples (more than half) fit into two boxes. After much consideration the samples were forced into a single box (figure 12b). The contents of the boxes are shown in figure 12c. Storni in "Unpacking Design Practices" (Storni 2012) only unpacks a single item. We had hundreds that came from all over our system. Our process was more like reverse engineering, an archaeological excavation and a dumpster dive. All at the same time happening in our own studio. We

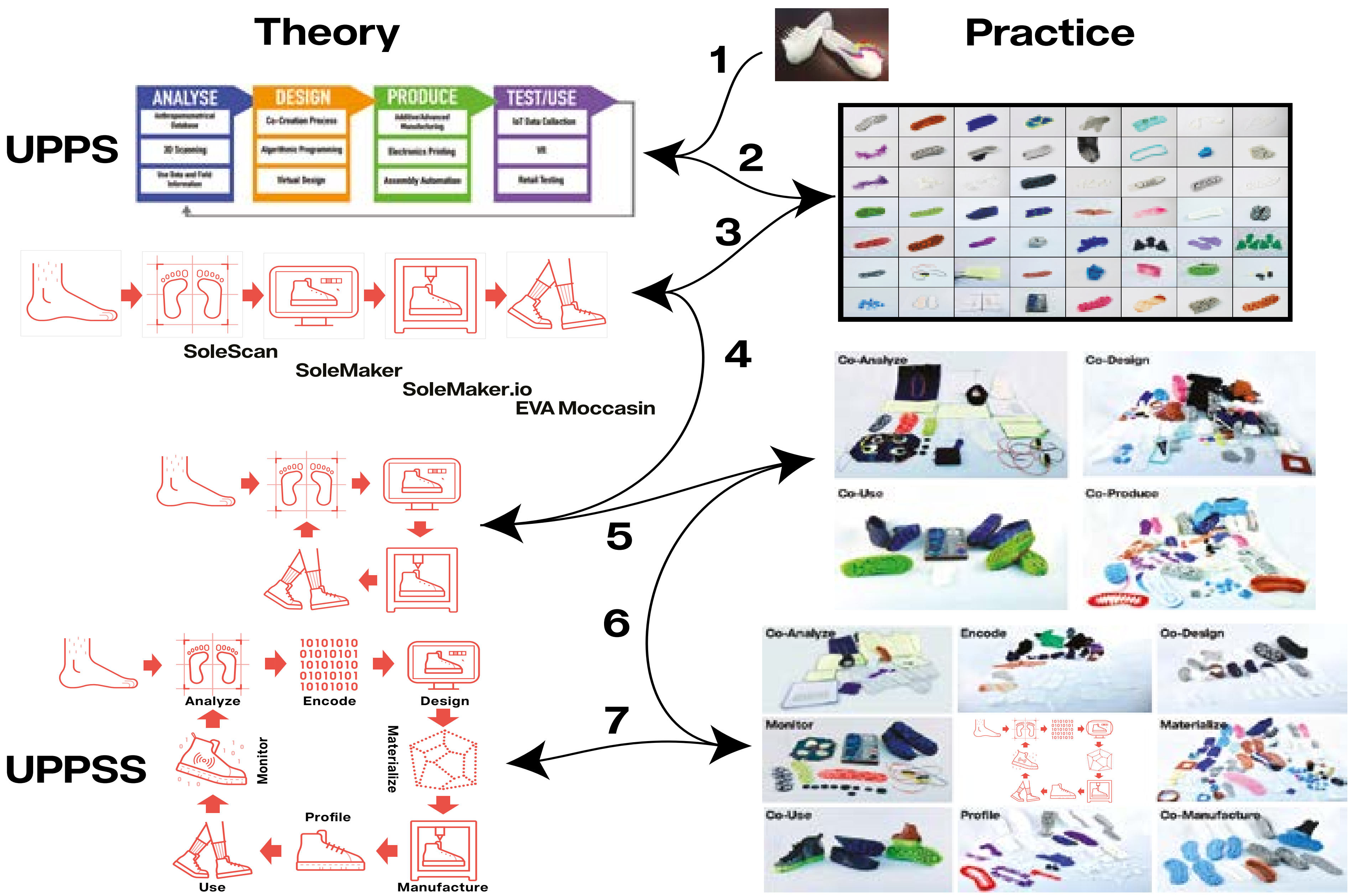
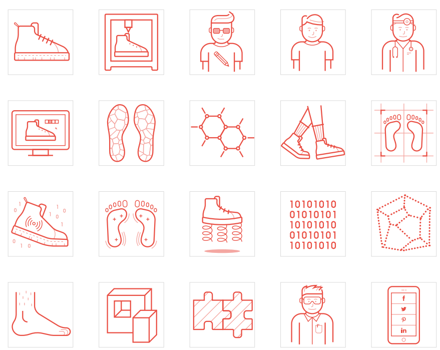


Figure 10. (Above) Mapping the Methodology. A map of the relationship between our shoemaking practice and the UPPS theory

Figure 11. (Below) Illustration: Max Pirsky A series of icons created to describe our shoemaking practice.



took inspiration from annotated portfolios, which Bowers describes as "a means for capturing the family resemblances that exist in a collection of artefacts, simultaneously respecting the particularity of specific designs and engaging with broader concerns." (Bowers 2012). We realised that there were transitions between the boxes (step 6 figure 10). The in-between samples enabled transitions between them. We developed icons and names for the transitions (step 7 figure 10). In the following section we present our findings and example samples from each stage. We detail our process of unpacking in greater detail, and describe the enabling transitions we discovered via a series of examples.

Findings:

From the 272 digitally fabricated samples we created, we selected a sample from each box that exemplifies that stage of the UPPS model. The following findings show the intermediate design knowledge (Höök and Löwgren 2012) between the practice and model. As described above, we started with boxes for each of the UPPS model stages and sorted all of the samples into the boxes, fig 12. Following is an example of each box.

Figure 12 Unpacking the samples into the Analyze, Design, Produce and Use boxes. a. Boxes were made b. All the samples were meticulously unpacked along with their source code. C. Final Groupings of the first unpacking.

Figure 13. Foot Pressure Pad. This sample is made from 100% polyester fabric, conductive ripstop nylon, rivets/snaps, polyester embroidery threads, 4mm cork sheeting and industrial spacer fabric, Eletrosola 4x0 071, a Cypress CY8CKIT-050 5LP,and Standard Electronic Headers. It was created on a Brother PR655 digital embroidery machine using soft textile techniques. Software was written in Processing and Matlab. The sensor samples at 20 Hz over a 16 x 8 matrix resolution revealing 4mm of 3D form.

An Example of Co-Analysis #263 Foot Pressure Pad, fig. 13, was made in the SoleScan project to parametrize the footstep and size of the user. It is a prime example of the co-analyze stage. The capacitive sensor revealed the foot size and footstep pressure of feet up to a men's size 47 EU. It was exhibited at a public exhibition where more than 400 feet were scanned. The sensor worked well with feet and shoes. This example is made on digital embroidery technology. Making the sensor required an electronic engineer capable of programming, a podiatrist, two digital fabrication specialists and the practice based design researcher.

Discussion In using the foot pressure pad to scan hundreds of feet we realized there is an extreme complexity in the analysis process. Many outliers were found in the process and the software required many updates. A very close stakeholder relationship was needed. Moreover, revealing the foot pressure using capacitive distance sensing was very accurate. There was a serious challenge in converting the entire footstep data (an image over time) into single parameters for the generative Solemaker design software. This sample worked great as co-analyze, but presented problems as we transferred the data to the design software.

An Example of Co-Design: # 236 Variable Density Sole, fig 14, was the first wearable pair of shoes made in the Solemaker project with variable density sole treads and flexibility. The software was heavily edited to add an interface that allowed each cell to be selected and the density set manually. The parametric data from SoleScan was not yet added. This sample represents the co-design phase because it shows how the software could be used to personalize the tread by a user. The practised based design researcher and digital fabrication expert did the vast majority of the programming with the computer scientist advising. This sample marked a point where many of the involved stakeholders began showing initiative.

Figure 14. Variable Density Sole. This sample was made from FilaFlex Silver TPE-s Filament on a handmade Prusa i3 with a 0.4mm nozzle fabricated specifically for shoe manufacturing. The shoe upper is made from 100% Technical polyester with a waterproof performance finishing. The dynamic density soles were written in Processing.

Discussion It is clear that we would have designed the system differently if had we known how SoleScan would parametrize the footstep. Adding tread tools increased the software complexity as many arrays managing the math were needed. Changing the internal geometric structures added a significant amount of rendering time and .gCode file size (megabytes instead of kilobytes). Because of its complexity, we had to re-tune our algorithm to negotiate the behaviours we were programming. This sample worked well, but lead to a vast number of problems in the co-manufacturing phase.

An Example of Co-Manufacture: # 113 Bend and Flex Sole, fig 15, shows how we made the shoe soft or hard, floppy and stiff in specific places (treads, footbeds, sidewalls) using specific mathematical geometries. This project required the practice based design researcher and two digital fabrication specialists work countless hours to perfect the software & hardware relationship. The relationship had to be established per machine, filament, and filament colour. This required adding parameters and code to account for these differences. Additionally, changes in ambient temperature, humidity and other contextual variables could change the co-manufacturing reality.

Figure 15. Bend and Flex Sole. This sample is made from FilaFlex Silver TPE-s Filament on a handmade Prusa i3 Slem Silver with a 0.4mm nozzle fabricated specifically for shoe manufacturing. The sole was created using the Solemaker software. A new technique for negotiating support and flexibility was created.

Discussion As with many manufacturing processes, there is a large difference between the ideal computer model and the actual output. When 3D printing for dynamic behaviour the differences can change the amount of bend and flex (and other design considerations) dramatically. For example, we created parameters for colour differences per printer as more transparent filaments create a softer behaviour versus the opaque filaments. Dealing with this complexity showed us that a system can become large and complicated unless we give a local digital manufacturing specialist the tools to be able to adjust the software to a specific printer in a specific colour on a specific day.

An Example of Co-Use: #188 Brown Knit Shoes, fig 16, were digitally fabricated and worn for a four month period on the streets of Berlin. These shoes exemplify co-use as they were a fully functioned as a pair of shoes worn as a research product. The code was written by a computer scientist working with the practice based design researcher and a digital fabrication specialist. The style and behaviour of the shoes were designed by a shoe designer and the practiced based design researcher. The experience of making and wearing these shoes inspired the making of the EVA Moccasin.

Figure 16. Brown Knit Shoes. This sample is made from FilaFlex TPE-s Filament on a handmade Prusa i3 3D Printer with a 0.4mm nozzle fabricated specifically for shoe manufacturing. The leather is 3mm thick vegetable tanned leather. It was laser cut and etched on a Trotec Speedy 300 laser cutter The sole and uppers were created using the Solemaker software.

Discussion Wearing the personalized shoes for an extended period of time taught us how the shoes behaved during a long day. The shoe had personalized flexibility,comfort and support but there was too much flexibility and not enough comfort. The shoes performed well in the fall season but, as the temperatures became sub zero Celsius, the material became stiffer and harder. In wearing these shoes the soles began shaping to the foot and discolouring where the foot applied pressure to the ground.

There is something between the boxes

Unpacking the samples into the boxes was a long and challenging process. Reflecting on our sorting revealed a struggle with over half of the samples which fit into at least two boxes. In discussing the difficulty with fellow authors we realised that a majority of the design happened in connecting the data from one box to the next. Apparent in the data & material relationships was that many samples illustrated how we connected the phases of UPPS together. Many sample connected one phase of UPPS to another phase. These in-between phases seemed to represent a large amount of the involved stakeholders' time and effort. Icons, then descriptors about what we saw happening were assigned to these spaces. These descriptors are as follows:

Materialization enabled the array data of co-design to become the .gCode of co-manufacturing. As we see in sample #113 Bend and Flex Sole, fig 15, the code behind the object enabled the 3D printer to create the object. Encoding enabled the footstep data SoleScan to be used as a parameter to algorithmicly generate the sole treat densities previously seen sample #236 Variable Density Sole, fig.14.. In the data, this was a transition from a Matlab file to a compressed .json file. Monitoring enabled the data of co-use to become co-analysis. The Eva Moccasin was able to make data for co-analyze as seen in sample #188, fig.16, which gave us new insights in how this could be done. Once the entire process was completed, the importance of the space between co-manufacturing and co-use became apparent. Profiling enabled co-manufacturing to become co-use. We needed to store the data about the foot pressure from the co-analysis, how the user changed the shoe design, and the details including errors about co-manufacturing. This would allow a detailed system to track the shoe use data against the profiling data as we see in #113 Bend and Flex Sole, fig 15.

We named these physical spaces between the boxes enabling transitions as we discussed how the samples could fill the spaces. We unpacked each sample a second time and placed it in the box or space between the boxes, as seen in fig. 17. We report specific examples of artefact samples that exemplify the spaces, fig. 18, and discuss why each is in that space.

Figure 17. Unpacking the samples into the boxes and spaces between the boxes realizing the enabling transitions that connect the boxes.

Figure 18 New family of groupings added in the second Unpacking resulting in enabling transitions

An Example of the Enabling Transition of Encoding: # 38 The Heel imprint in a shoe heel, fig 19, was made to increase the comfort of the shoe. The outline and footstep pressure data was used to create a softer geometry, allowing the foot to sink in and be supported. This required encoding the footstep into parameters that the co-design software could use to generate the sole. This example shows the moment when we effectively integrated the outline of the foot, but the pressure data failed as we attempted a soft gradient of material.

Discussion This sample is one of fifty-two where we needed to perfect the code and data transitioning from co-analysis data to the co-design software. This transitioning required numerous hours achieve. During the public demonstration of the system we found many problems caused by outliers such as very high arches, over fitting caused by over personalizing to a single person, and a miss calibration of the upper and lower boundary parameters. Some might compare this phase to debugging software, but something more fundamental was happening in the function of the overall system. An understanding was being created between two complex systems. We had to learn to deal with outliers that caused unexpected behaviour in the negotiation of design considerations of the sole.

An Example of the Enabling Transition of Materialization: # 58 Open Footbed, fig 20 shows one of the many errors between code and manufacturing. The gCode geometry needed to be printed on the 3D printer. In this example we were negotiating the comfort of the sole against the robustness of the shoe. Changing a single parameter for comfort in the co-design software resulted in the opening of the entire footbed. It was not what we were looking for, but inspired many other geometries.

Discussion Materialization was the single most represented enabling transition with more than 100 sample failures. These represent the difficulty of programming 3D printing geometries that are negotiating design considerations for form, behaviour and aesthetics. One of the most notable peculiarities from these samples is that a 3D printer modified for flexible filaments behave more like a knitting machine. The tension is a game of pushing flexible filament at the exact right speed, too little and nothing comes out, too much and things get blocked up thus nothing comes out.

An Example of the Enabling Transition of Profiling: # 113 Into the Spaghetti, fig 21, is a dramatic result of what happens when the 3D printer under-extrudes (fails to deposit enough material). We worked with many different printers in the materialization process: commercial and hand-made. Each kind of 3D printer has slightly different initialization code, bed size, and nozzle size. Occasionally, the wrong printer, material, or colour profile was used. Each printer has its own way of behaving, even if two are the same brand and model. Moreover, the direction of travel of the print head and sequence of print features in specific gCode geometries caused over and under extrusion of material. This changed the behaviour of what we had programmed.

Discussion Creating data for new shoes meant that the precise details of the co-manufacturing exist in a profile. The flaws in co-manufacturing often did not render the shoes unwearable, they needed to be recorded as a baseline for co-use. Profiling remembers the multitude of variables so that each shoe can be understood individually. It was important to track this small internal flaws for co-use sensing as it could affect the behaviour of the shoe over time. This would become very important as we added mechanical sensing for co-use.

Figure 19. Heel imprint. Made from FilaFlex Clear 75a soft TPE-s Filament on a modified Ultimaker 2 with a 0.8mm nozzle. The heel footprint seen is a composite pressure image created by the SoleScan software, written in Matlab. Solemaker software then generated the heel of a shoe with a softer density in the heel area to make the footbed more comfortable. Difficulties connecting the two software parameters resulted. An encoded composite was added to correct the problem.

Figure 20. Open Footbed: This sample is made from FilaFlex Clear 75a soft TPE-s Filament on a Prusa i3 Slem Silver with a 0.4mm nozzle that was fabricated specifically for shoe manufacturing. It is discoloured from the printer nozzle running too hot. This sole is a prime example of selective buckling support mixed with open cell breath-ability to keep the shoe from overheating.

Figure 21. Into the Spaghetti This sample is made from Ninjatek Cheetah TPU Conductive ETPU Filament on a modified Ultimaker 2 with a 0.8mm nozzle. It was generated using the Solemaker. A profiling error resulted in the under-extrusion.

An Example of the Enabling Transition of Monitoring: # 265 Wear and Tear Demonstrator, fig 22,was made in the Eva Moccasin project where we learned that monitoring data over the co-use of the shoe was vital. A demonstrator was created to show how both electronic and mechanical sensing could be added to the shoe as describe in "EVA Moccasin: creating a research archetype to explore shoe use" (Nachtigall 2016). The enabling transition of monitoring collects and carries data from the use of the shoe back into co-analyze .

Discussion Monitoring during co-use allows for a complex picture of the varying activities that were undertaken while wearing the shoes. While this data generally reflects day to day walking, special activities such as dancing and tennis can create very specific data. The data gathering in the monitoring phase is not just beneficial in co-analysis to make the next shoe, it can indicate needs in a full closet of shoes.

Discussion and Conclusions

The four Solemaker projects came together as a complex system for making personalized shoes that make the data trail to make more shoes. By unpacking into boxes we came to the following conclusions.

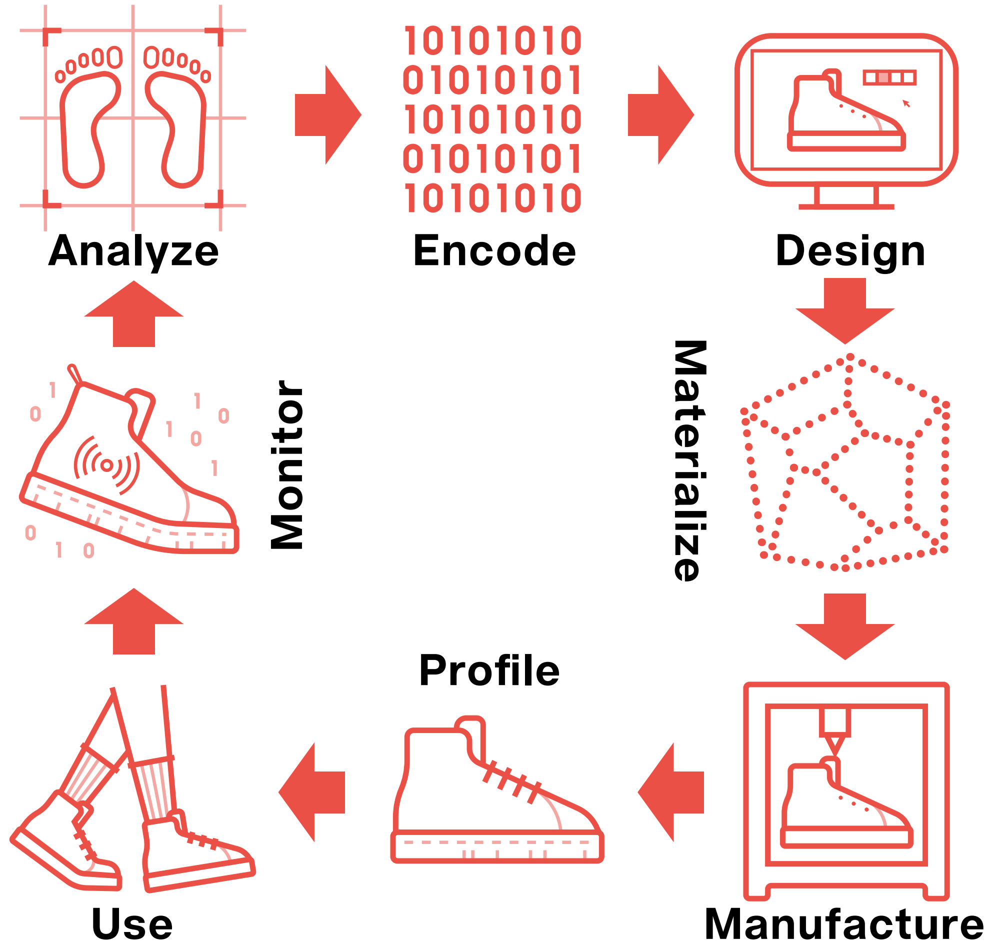
The UPPS model contains enabling transitions that connect the stages of UPPS proposed in (Ahsmann 2015). The four enabling transitions presented show that the model lacked a level of description relating to the data back-end of the system. The new model is a circular process of co-analysis, encode, co-design, materialize, co-manufacture, profile, co-use and monitor. The enabling transitions were equally important as the rest of the stages. In designing the system, the enabling transitions required more time than the existing stages. As stakeholder practice was embodied in the samples, these newly defined stages could be integrated in the model with a high level of detail. Encoding makes explicit the way a physical thing and/or its behaviour becomes parametric data for co-design. Materializing makes the negotiation of data needed to transition from a digital construct to one that can be digitally fabricated into a thing. Profiling remembers the data about the thing and strategically proposes a use for the object based on its strengths and limitations. Monitoring shows the importance of carefully planning and setting up the collection of data that will loop back into analysis.

The UPPS model is a cooperative process. Many stakeholders, including the wearers whose data were used, were involved in every sample that sorted into the UPPS model. It is important that the definitions of UPPS reflect that importance. We conclude that the stages of UPPS could be re-coined to reflect this stakeholder relationship: Co-Analyze, Co-Design, Co-Manufacture, and Co-Use. We use Co-Manufacture instead to Produce (from the original model Ahsmann 2015) as Co-Production carries a strong definition that includes the entire production process (sourcing, manufacture, etc.) seen in marketing research (Jiménez et al. 2013).

A better naming of the practice and process of UPPS is Ultra-Personalized Product Service System (UPPSS). In the four projects we quickly observed that designing an UPPS is the creation of a system with: a complex interplay of data and materials, a series of services that the stakeholders interact with, and enabling transitions that interface the stages of UPPS together. The change from UPPS to UPPSS creates a model that depicts the practice of designing a system that creates the products and services. In line with the research done in Product

Figure 22. Wear and Tear Demonstrator. This sample is made from FilaFlex 85a TPE-s and Ninjatek Cheetah TPU Conductive ETPU Filament on a modified Ultimaker 2 with a 0.8mm nozzle. A teensy 3.2 and neopixel ring provide user pressure feedback from the ETPU sensor. Mechanical sensing is shown in abrasive colour change and linkage breaking available for the public to handle.

Figure 23. A Model for UPPSS : Based upon our practice of personalized shoe making, we arrive at a model of UPPSS that is a system that includes enabling transitions.



Service Systems (PSS), the UPPSS model thus considers all stakeholders, infrastructure, resulting products and services at the same level (Tuckker 2004). This also reflects a move from a vertical production to a horizontal collaborative setting like that shown in "Designing Smart Textile Services through value networks, team mental models and shared ownership" (Bhomer et al. 2012). Figure 23 summarizes the new UPPSS model.

The way in which we unpacked the complexity of our samples into boxes is also a methodological contribution to RtD and unpacking (Storni 2012). Unpacking a large number of samples builds upon the idea annotated portfolios, capturing groupings of artefacts under specific labels and reflections (Bowers 2012). Unpacking and boxing our understanding of the data and materials behind each and every sample helped us to acknowledge and revise the UPPS model. We made the model more descriptive based on our personalized digital shoemaking practice. Thus, supporting the validity of that model. At the same time, the model provided inspiration to create intermediary knowledge of designing a system that creates shoes using a data & material relationship.

Finally, this paper provides a complex picture of practice in digital craftsmanship. The enabling transitions shown here are a description of encoding data and materials to behave in specific ways. The encoding is based upon a scaffolding of a bespoke craft with digital technology. The practice often required crafting the behaviour the sole in data and material simultaneously. Even if Solemaker never made a second pair of shoes for the same person, the data could make other shoes better which is important for design.

Future Work

More than 100 pieces of .gCode did not print. The meaning of the materialized data that didn't print could also be important. Perhaps creating a system that tracks the designers practice in a form of sub-version control (eg. git or mercurial) could assist in understanding data that does not materialize. We observed a deep relationship between the data and material in the system. It is important to investigate how data & material form a new relationship and answer why it is important. It's seems highly possible that a new discipline is emerging with a new material understanding

Developing the circularity of the model in a deeper way would also bring more understanding to the how and why of personalization. The model needs to be generalized for design researchers and practitioners in personalization. We intend to use the developed model as a departure point for design, perhaps in the form of a game. The UPPS Field lab (www.UPPS.nl) has proposed their own change to the UPPS model by adding a stage of collect to the theoretical model. We see this more as a enabling transition which may be a better term for what we interpreted as monitor. Also, as the model is a system, product service system research and cybernetics research may be able to provide more insights.

Finally, the practice of digitally crafting personalized shoes and other objects has many facets to be explored. We invite other practitioners to use join us in personalizing objects form, behaviour and aesthetic to create an individual everyday design.

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