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Intertwining Material Science and Textile Thinking: Aspects of Contrast and Collaboration

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Abstract: The current research of eTextiles tends to focus on integrating new functionalities into textile structures in a technology-driven manner. Meanwhile, we approach the development of eTextiles through utilizing interdisciplinary practice-based materials research for creating new types of textile-integrated actuators. Our study aims to shed light on how interdisciplinarity and especially the interphase between scientific thinking and practice-based research can create added value both through contrasts and mutual alignments. Based on interviews of researchers working in that intersection, we have identified some key factors concerning specifically the eTextile environment: differences in ways of thinking, intertwining concepts, common practices, and the need for a certain degree of individual autonomy. Overall, we advance the understanding of the inner workings of interdisciplinary projects and how to better facilitate them, as well as provide some concrete ideas of how this type of research should be supported.

Keywords: interdisciplinarity; practice-based research; eTextiles; material development

1. Introduction

Novel smart materials enable discrete integration of varying functionalities into the very structure of textiles, opening numerous possibilities for how we experience and interact with technologies around us. However, smart material development tends to be driven by engineering aspects, while textile design knowledge is sparsely utilized. Textile knowledge is needed for designing structurally, tactually, and visually versatile textiles, which are qualities essential for how the textile is experienced by individuals. This also provides the foundation for interweaving *active materials* in which the functionality, such as actuation, can be programmed, as well as conventional textile materials that can be seen as passive materials, that do not react to external stimuli. In textile-based actuation, the properties of passive textile materials are often neglected (Sanchez et al., 2021) due to the lack of inclusion of textile-specific expertise from the early phases of material development. Yet, these properties are fundamental for optimizing the textile structures to maximize the motion of active textile materials, as well as for pleasing sensorial experiences of the users (Townsend et al., 2020).

Intertwining the bodies of knowledge from experimental material science and textile design through smart textile material research collides two distinct ways of approaching knowledge creation: scientific thinking and practice-based textile thinking. Thus, it is important to acknowledge that these two disciplines embrace different modes of knowing, which in turn influence research experimentation, evaluation, and decision making. Experimental material science is based on scientific thinking (Berland, 2011), regarded as an objective process consisting of iterative cycles of hypothesis formulation and hypothesis testing through experiments, leading to results independent of their producer. It can be seen as “a dialogic practice in which individuals compare disparate ideas in order to make sense of the question under study” (Berland, 2011; Driver et al., 2000). In practice, this relies on heavy backgrounding from previous studies, careful planning of design of experiments (DOE), and iteration or experiments based on findings and reflection on literature. These findings are, in specifically material science, verified by different characterization and analytic tools to ensure robust results.

Practice-based research, on the other hand, generates new knowledge through creative practice and its outcomes. It acknowledges the influence of embodied knowledge and reflective practice in knowledge creation, and a delicate, partially subjective relationship between the researcher and research outcomes (Candy and Edmonds, 2018). This research specifically applies practices from textile craft and design, which are grounded in textile thinking, i.e., "the understandings developed through the practice of using textiles to explore new concepts and design challenges" (Lean, 2020). Textile thinking is characterized by embodied knowledge of materials and sensitivity to the materiality and structures of textiles (Phillpot and Kane, 2016), and rooted in recurring engagement in the reflective process of making (Schön, 1983). It unfolds in different textile activities, alternating between objective (i.e., choice of fabrication) and subjective thinking (i.e., haptic and aesthetic choices), requiring all three mental states: cognitive, affective, and conative (Igoe, 2021, p.127-139). Although experimentation is at the core of both experimental materials science and practice-based materials development, the semantic differences, in what is meant by “experiment” and “hypothesis” are noteworthy

We intend to understand how these two different approaches, practice-based textile thinking and empirical scientific thinking, contrast and collaborate within interdisciplinary material science research, through investigating a specific case of developing novel actuators for eTextiles (textiles with added electrical functionalities). This study has been conducted as a part of the ModelCom-project which aims to develop yarn-like actuators and design concepts for modular shape-changing textiles capable of interacting with their environment through simple movement patterns. The development is based on modifying coiled yarn thermoactuators with different surface coatings, coupled with traditional textile construction techniques. For the fabrication and optimal integration of these actuators, interdisciplinary work involving people with materials science and textile backgrounds is essential. The project was initiated in 2019 by a material scientist (Author 3) with previous interdisciplinary background, aiming to bring textile-specific knowledge into smart textile material development from the start. During the project, the areas of expertise have been complemented by textile craft, textile design, eTextile design, and polymer physics and chemistry. The project will be completed in 2025, the progress of the current research is illustrated in Figure 1.

The study reported in this paper is conducted parallel with the material development process. The findings are based on interviewing the interdisciplinary research team members on their experiences, supported by the analysis of the process documentation. The findings indicate that shared practices located at the intersection of the collaborating fields can create a transitional space of development, enabling the complete integration of disciplines. In addition, supporting the feeling of autonomy when crossing the disciplinary boundaries, and acknowledging the differences in orientation to knowledge creation have been identified as crucial factors for interdisciplinary success. Finally, these findings help to identify pitfalls in the current working methods, where working together tends to not reach all the potential synergy.

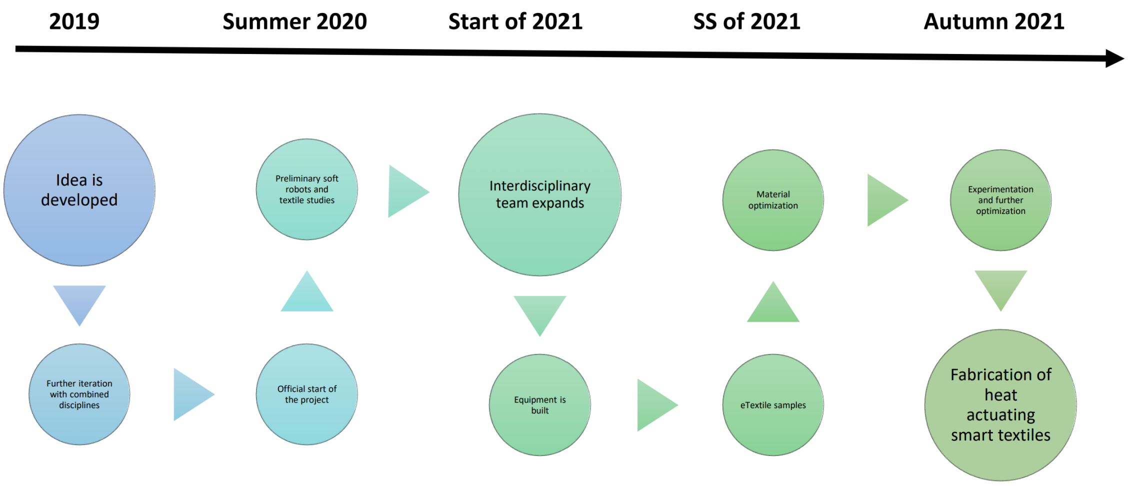

Figure 1 Timespan of interdisciplinary material development.

2. Implementation of textile design practices into smart material development

Researchers in material science are increasingly engaging in varying forms of interdisciplinary collaboration with the field of design which can enrich the material research by proposing new perspectives for interpreting scientific discoveries through design thinking and practices (Langella, 2021). For example, in biomaterial development, collaborations between science and creative practices are enabling researchers to access the research possibilities beyond the disciplinary boundaries of biochemistry and design (Groth et al., 2020; Camere and Karana, 2020). Research on materials experience (Karana et al., 2015b) underlines the interdisciplinary collaboration between material science and design professionals to steer the focus of the design and development process on *"the experiences people have with and through materials"*. Examples of successful collaboration applying a material driven design approach (Karana et al., 2015a) range from creating material sets for communicating sensorial properties of materials (Wilkes et al., 2016) to designing with under-developed smart materials (Barati et al., 2019). The approach provides suggestions for collaborative materials development, utilization of material samples and demonstrators to support communication, and bridging disciplinary gap between material scientists and designers.

While material-driven design focuses on designing applications for materials under development, textile thinking can aid in tackling material-specific challenges through exploiting distinct characteristics related to the understanding of textile materials, structures, and construction methods (Philpott and Kane, 2016). In eTextile research, the importance of including textile design expertise in the development team has been highlighted by several authors. For example, both Devendorf et al (2020) and Heiss et al (2016) have noted that equal collaboration between technological, design and craft knowledge can introduce technical innovations only attainable through textile thinking, and lead to better usability and more human-centered outcomes. The necessity to include characteristics of textile thinking (Philpott and Kane, 2016) has also been discussed in the context of developing shape-changing interfaces for tactile interaction. Townsend and others (2020) deemed eTextiles as an enhanced sensory experience compared to traditional fabrics, emphasizing the idea that the additional functional elements cannot exist as separate add-on entities but as an integral part of the textile system.

Although the previous research highlights the need for interdisciplinary cooperation, typically the point of departure for design-driven approach is when the functional material has been partially or completely established. The aim of including design and textile expertise has been to search and ideate potential applications (Du et al., 2018), focus on the material experiences through prototyping with the material (Barati et al., 2019) or to combine textile designers and engineering knowledge about eTextiles in the same innovation space (Townsend et al., 2020). Contrary to this, our research focuses on including an interdisciplinary approach from the early phases of the development of smart textile material where no requirements are imposed by the tentative application. We aim to understand the collaborative nature of interdisciplinary material development, and how that can inform decision-making in a process that is inherently situated at the intersection of material science and textile design.

3. Methods

For this study, we interviewed all eight members of a research team on their experiences in combining material science and practice-based textile design methods in an interdisciplinary material development process. The interviews consisted of personal meetings and a group discussion. The titles that the team members are addressed with, and their professional backgrounds are shown in Table 1. In addition to this, we occasionally use *textile experts* to refer to Textile designer, eTextile designer and Handicrafts expert, and *material scientists* to refer to Interdisciplinary engineer, Polymer chemist and Engineering student.

Table 1 Members of the interdisciplinary research team.

Title	**Background**	**Role**	**Working time allocation**
Project leader (Author 3)	PhD Applied Physics	Principal investigator, budgeting, and leading research efforts	Full-time (10/2019 - now)
Interdisciplinary engineer (Author 2)	BSc Material Science, interdisciplinary studies combining engineering and design	Material development and facilitating interdisciplinary collaboration	Alternating full-time and part-time (6/2020 - 8/2021)
eTextile researcher (Author 1)	MA Textile Design, specialist in woven eTextiles	Knowledge on eTextiles, textile thinking and practice-based research methods	Part-time (10/2019 - now)
Textile designer (Author 4)	MA Textile Design	Experience in woven 3D textile structures	Full-time (1/2021 - now)
eTextile designer	BA Contemporary Design, specializing on industrial and textile design	Textile prototypes and test setting	Periodically (9/2020 – 5/2021)
Handicrafts expert	Craft teacher, specialist on traditional threading techniques	Yarn manufacturing development	Full-time (1/2021 - now)
Polymer chemist	MSc Chemical Engineering	Synthetization of actuator materials and study of coating	Periodically (1/2021 - now)
Engineering student	Chemical engineering bachelor student	Optimization of the actuator structures	Seasonal (Summer 2021)

Authors 1 and 2 conducted semi-structured interviews with three of the team members (Textile designer, eTextile designer, and Handicrafts expert), who were intimately involved in the material development activities. The semi-structured interviews focused on their role in the interdisciplinary process and the acts of making during material development. As the interviewers also engaged in the practice-based material development process, it situates the researchers in a twofold position of being a researcher and an object of research (Candy, 2018). Authors 1 and 2 utilized these personal experiences to inform the interviews, inspired by Leigh (2021). In addition, seven of the team members (excluding the Handicrafts expert) participated in a group interview to discuss their experiences in interdisciplinary collaboration. The team members were asked to reflect on their experiences while the process was first discussed in chronological order, concluding in an open-ended discussion where participants contemplated different aspects of the interdisciplinary process. The discussion was facilitated by Authors 1 and 3, and the session lasted for 2 hours. The discussion provided us with additional information on the different modes of thinking applied in the interdisciplinary process, to deepen our understanding of the themes identified from the semi-structured interviews.

The audio files of the interviews were transcribed and analyzed abductively by identifying themes emerging from the data (Braun, 2019). The analysis was conducted by Authors 1 and 2, and started by using open coding (Flick, 2014) for labeling excerpts of text. The second level of analysis focused on drawing connections between the codes, which resulted in identifying three central themes emerging from the data. The first theme evolved from identifying the types of thinking applied in the research process and understanding which specific practices are built upon those. Secondly, theme of frustration and evaluation started to emerge, as participants had identified different points of dissatisfaction within their individual and the communal process, and the success criteria for evaluation of the work between the different modes were remarkably different. Finally, a theme around common practice was identified as an example for successful interdisciplinary collaboration and communication.

In the interpretation, the identified themes were organized according to how different types of thinking appeared during the material development process, how the different approaches were contrasting and conflicting, and how the team members successfully managed knowledge sharing and common methodologies in interdisciplinary collaboration. The classified themes were further discussed by Authors 1, 2 and 3. This also provided the basis for mapping the distinct phases of the research process. To gain more comprehensive understanding of the interdependencies of varying shared and field-specific research activities, the interview insights were complemented with analysis of the process documentation including several individual projects, collaborative practices, and facilitated brainstorming sessions. As a result, the working process of the project was depicted in a reflective description and process diagram, which was further discussed with all the authors.

4. Findings

The findings of this study include a reflective take on the interdisciplinary material development process (illustrated in Figure 2), in addition to the themes identified within the interdisciplinary team interviews and discussions. The themes of the interviews are divided as follows: Chapter 4.1 focuses on exemplifying how the different types of thinking were intertwined, 4.2 presents the aspects of the different working styles and ways of thinking diverting from one another, and finally 4.3. gives an example of a common practice created by knowledge sharing and different methodologies forming a new combined discipline.

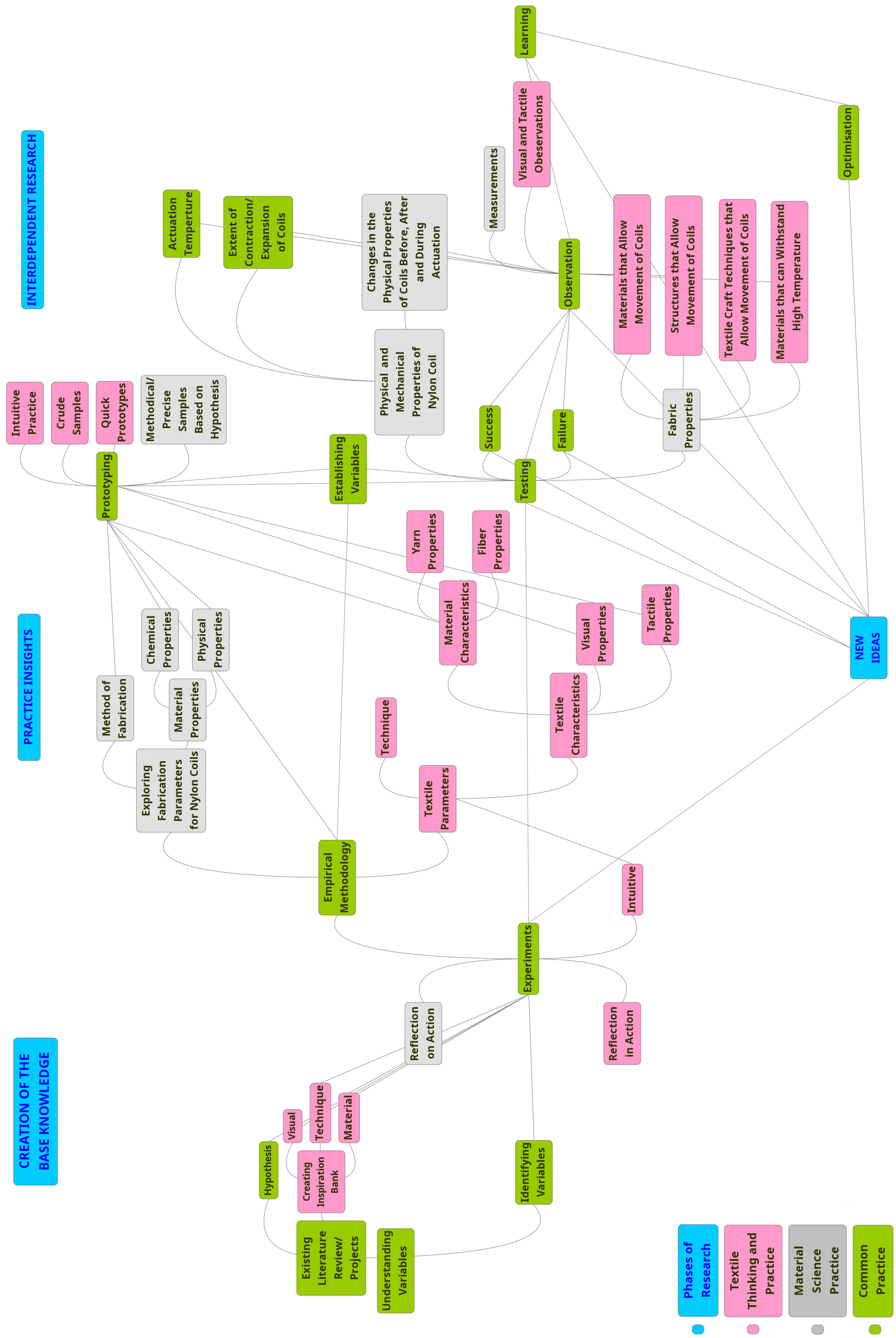

Figure 2. Mind map depicting the research process integrating different modes of thinking and practices. The map has been assembled based on the interviews that identified key phases and activities within the research process.

Based on our interview data and the supporting process documentation, the overall research process followed three identifiable stages: creation of the base knowledge, implementation of practice insights, and interdependent research progress. The base knowledge was built on the work of Haines and co-authors (2014), focusing largely on the material science and material design perspectives. In the implementation stage, the fabrication process created a common ground of interaction between textile design and material science experts. This phase centered on nylon actuator development and preliminary textile integration which made it possible to conduct two prototyping stages simultaneously: optimization of the material and textile integration. For textile prototypes, hand weaving was selected as the textile construction method due to the stable structure of woven fabrics. The first samples were handwoven on a dobby loom with 16 shafts, but this limited the possibility of designing complex weave structures. To address this issue, the following samples were handwoven on a TC2 Digital Jacquard loom which was conducive to designing more diverse structures. The prototypes focused on mapping the domain of woven textiles to identify potential variables that are relevant for actuator integration. Different depictions of the material optimization and textile integration are presented in Figures 3-7. The parallel prototyping in combination with the development of the coiling equipment (Figure 8) in the interdisciplinary collaboration led to the third stage: interdependent research progress. As each of the stages built upon the knowledge gathered from the previous ones while increasing in complexity and feasibility, the different facets of material study, prototyping and function optimization became interdependent on one another.

4.1 Interweaving scientific and textile thinking

As exemplified in the reflections on the material development process, the types of thinking for each specific field in this project started from very different places. Material scientists approached the development on a relatively abstract level, highlighting theory and hypotheses. The Interdisciplinary engineer described how they approached material development through grounding understanding on existing theories on the subject, forming a hypothesis, and trying the hypothesis through systemic testing by fabricating different samples. The Handicraft expert and the Textile designer, in turn, emphasized the meaning of various aspects of textile thinking, especially its embodied nature and analytical approach to textile structures as ways of making sense of the material development process.

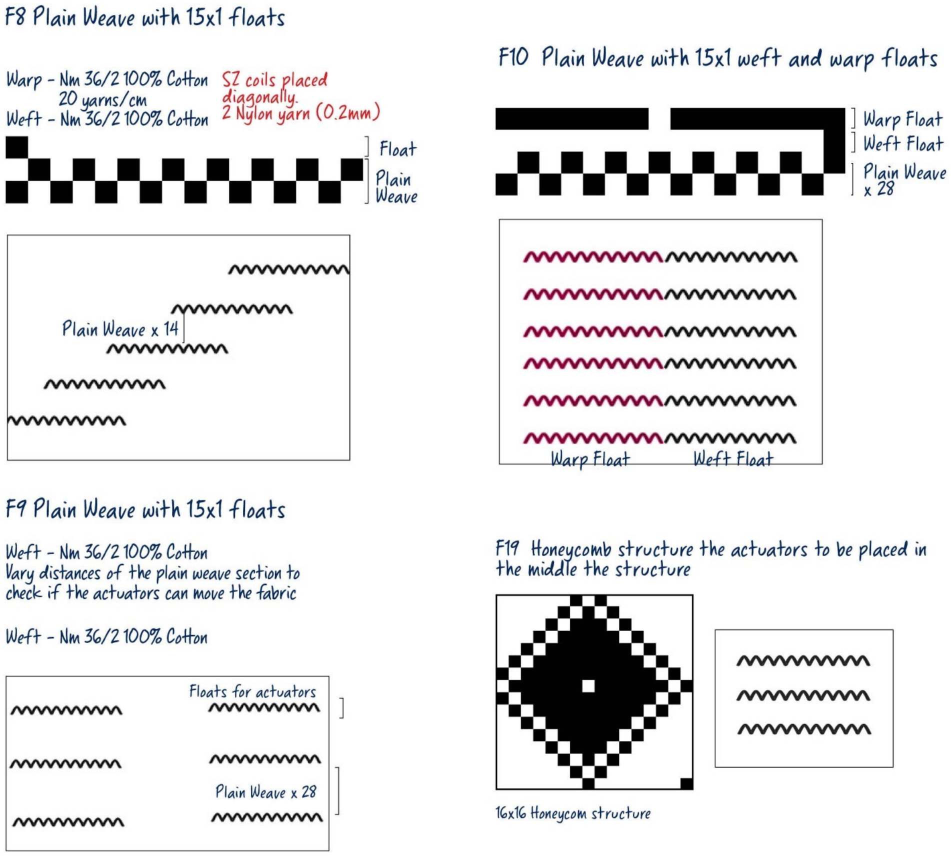

Figure 3. Sketches and ideation of weave structures and coil placements before weaving.

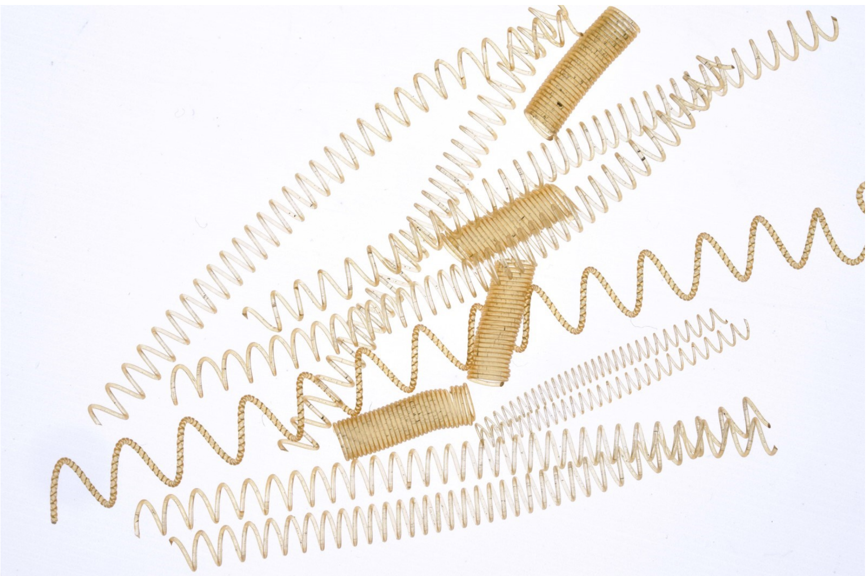

Figure 4. Coil samples with varying diameters, twists and number of plies.

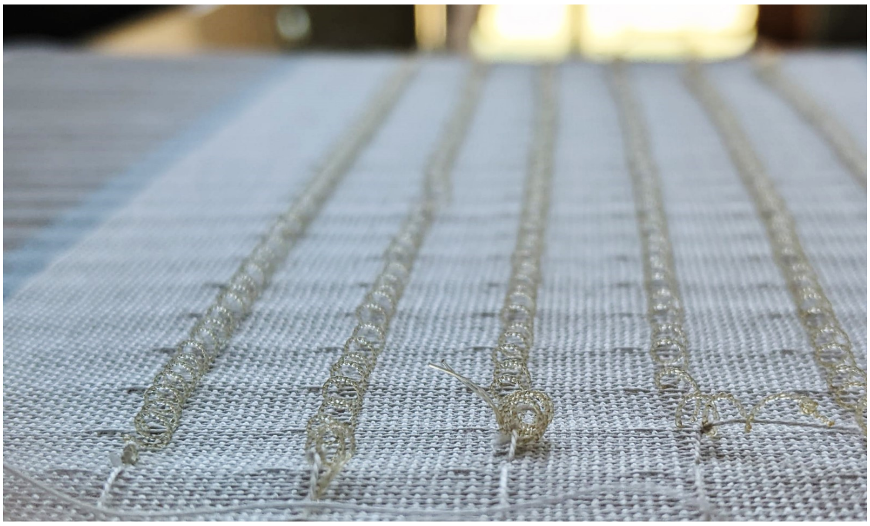

Figure 5. Fabric sample F6 on the loom. The fabric is woven with SZ, 2ply nylon coils and cotton yarns.

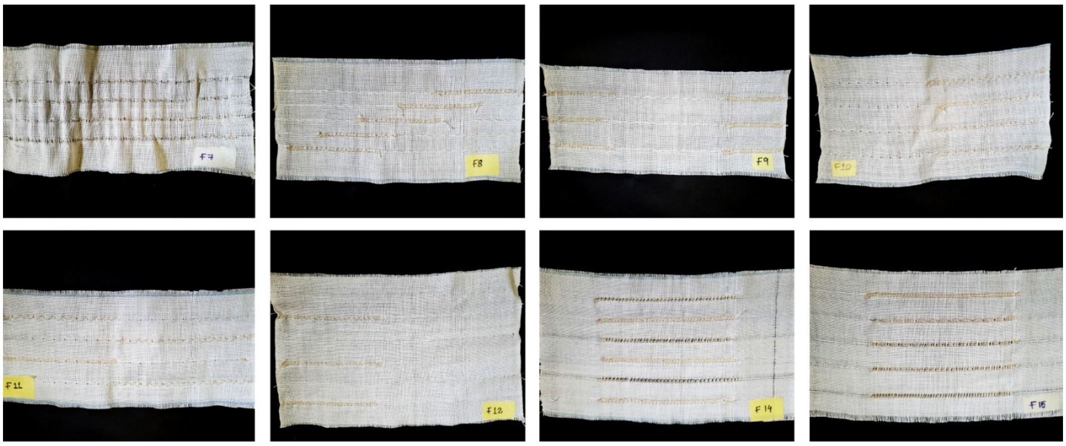

Figure 6. Woven fabric samples with varying float structure for nylon coils and placements.

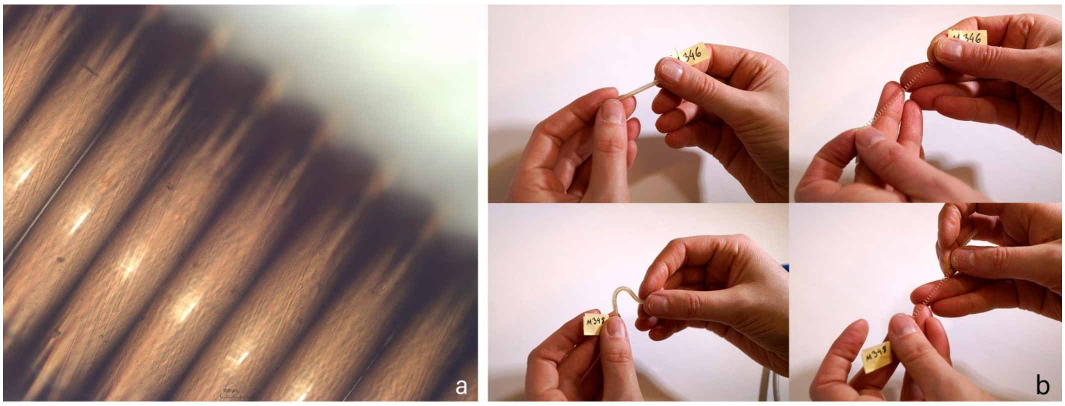

Figure 7. Images of different methods of observation. (a) microscopic image of the coil examining its structure. (b) Textile designer observing the stretching capacity of different coils through tactile observation.

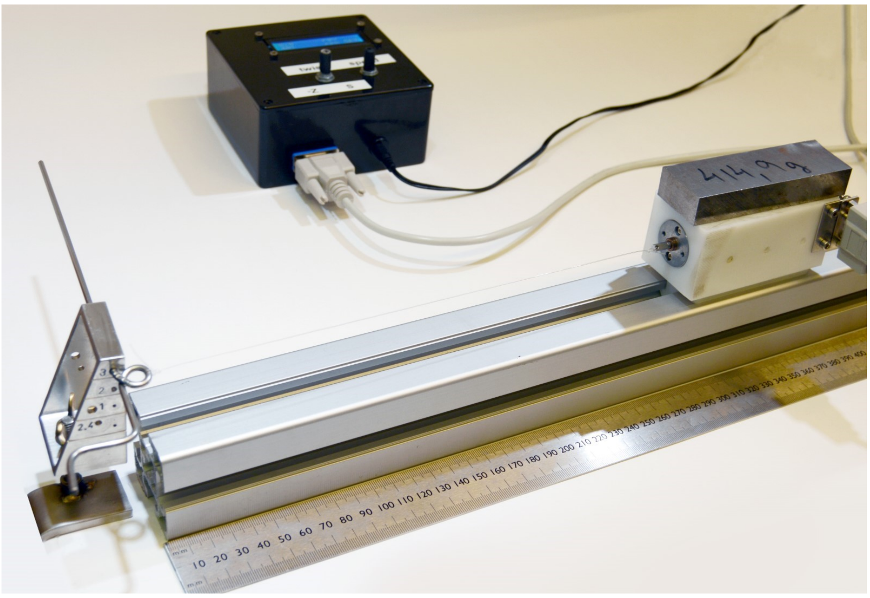

Figure 8. The twisting and coiling equipment developed and further modified for optimizing the coil making process by the handicraft expert.

Sometimes this led the material scientists and textile experts to approach the situation differently and define contradictory goals for their research activities. An exchange between the Interdisciplinary engineer and the Textile designer revealed how the material scientists aimed to explain the material behavior thoroughly, whereas textile experts aimed to rapidly harness the material behavior for applying it in textile sample prototyping. When describing a testing situation of woven actuators, the Interdisciplinary engineer emphasized the point of excitement being connected to starting point of understanding. For Textile designer, in turn, the same results fueled further ideation and were used to inform the following generative iterations. Thus, the researchers evaluated the process from their distinct perspectives and as a result, material scientists and textile experts made different observations regarding material variables. For example, the first woven actuator samples were deemed unsuccessful from the material science viewpoint as the implementation was not providing the desired actuation. The textile design perspective viewed this as an insight into the relevant textile parameters, such as weight of the materials and suitable float lengths, informing the next steps in the development process leading to successful iterations.

4.2 Contrasts and conflicts in different ways of thinking

Intertwining the different ways of thinking was at times conflicting. As the rigor of scientific research was applied to all the research activities, that at times caused frustration among textile experts. Both the Handicraft expert and the Textile designer expressed that focusing intensively on optimizing the coiling process and experimenting with the basic variables while keeping textile structure and material variables constant, limited their ways of approaching material development through their own creative practices. As the reflective process triggers new ideas, restraining the creative approach to sample fabrication sometimes blocked innovative ideas from surfacing. Thus, the textile experts at times felt being stuck on testing the basic parameters before being capable of moving towards more complex textile structures, resulting in a decreased sense of autonomy. On the other hand, material scientists expressed frustration related to a need for rigorous testing and more specificity in the 'rapid prototyping' process. As the Interdisciplinary designer expressed it, making a proper research plan and sufficient testing was essential to understanding and directing the material behavior, instead of focusing on single experiments and deriving conclusions from those. This difference manifested into worries about safety issues during the development of the equipment and testing setup, as well as confusion about the evaluation of success and research goals of the project. The clear difference in perspective, where textile designers focused on generative experimentation and material scientists on understanding, clashed when testing was conducted in different ways with no common standardization.

Another conflict involved researchers going over their interdisciplinary capacity and working with expectations completely outside their expertise. For example, the Interdisciplinary engineer expressed how the capacity to understand another discipline and its working methods in a short period of time was deemed unsuccessful, and relief was expressed when collaboration progressed further and involved people with the required skillsets. Similarly, the Textile designer described how the theoretical approach on understanding the material behavior was deemed unsuccessful and could not substitute the embodied knowledge of the nylon-based actuator material gained through experimentation. Thus, restraining one's capability to apply their specific ways of thinking, posing similar expectations for field-specific evaluation, as well as requiring working off from one's competence area will lead to feelings of frustration and insufficiency.

4.3 Interdisciplinary interphase: best practices for successful knowledge sharing

Team members utilized varying tactics to overcome the challenges caused by differing ways of approaching research. One of those tactics was naturally evolving shared practices, which were situated at the intersection of material science and textile thinking. Most often the team members mentioned how the act of coiling became an activity that was utilized to share knowledge and support communication. Coiling in this context is the process of first twisting nylon yarn to achieve tension and maximizing the material's capability for thermal expansion, and secondly coiling this twisted yarn on itself or onto a mold to geometrically induce linear actuation. All the team members, except eTextile researcher and Project leader, engaged in making coils right after joining the research team. The act of coiling, either through engaging in it or by observing others, became a common ground enabling two-directional knowledge sharing between professionals from different disciplines. For textile experts, it provided understanding of the material behavior as a point of departure for the textile exploration, whereas for material scientists it was the point where the material optimization is coming towards its outcomes and provided context about the textile materials and where the development was heading. The shared act of coiling was also utilized to level the understanding of experts from different fields: *"I [Interdisciplinary engineer], Engineering student and Handicrafts expert, we had this, I guess like, standardization day where we all made some samples, and we could observe the different ways of working with the same equipment and explain to each other why we are doing these certain things while working with the equipment."*

Also, including textile expertise in the empirical material research phase and being able to participate in the material development before it transitioned to the textile integration phase was considered beneficial. That enabled the textile experts to understand the material behavior and gain embodied knowledge of its properties. The scientific approach was also considered to provide structure for the practice-based approach. The interplay of controlled empirical research and textile thinking supported defining and examining the key parameters in a manner that produced relevant data for further experimentation of feasible actuating textiles. The empirical research approach also provided the textile experts with a more objective perspective on their own practice, in comparison to the typical design process. This steered the focus on the very nature of active and passive textile materials, which enabled engagement with the material completely, giving rise to new ideas, material possibilities and different techniques, such as hand embroidery and tablet weaving. These handicraft practices opened possibilities of manipulating and altering the nylon coils in the processes of making and hence creating functionally varying samples enabling also versatile sensorial experiences.

5. Discussion

The study presented in this paper investigated how practice-based textile thinking and empirical scientific thinking collaborate within interdisciplinary material science research. We presented the major differences in thinking between textile designers and material scientists in the context of smart material eTextile development, and how those ways of thinking conflicted and collaborated, especially during common practice.

5.1 Understanding through common practice

Communication between disciplines is one of the major challenges in interdisciplinary work already well-recognized in literature (Wilkes et al., 2016). As most research activities of material scientists and textile designers tend to be field-specific, natural knowledge transfer points need to be found in their intersection. We noticed that including the experts from different fields in the transition phases when research activities are intersecting eases the communication in multiple ways, as experts can utilize shared activities for learning the necessary information to be transferred. Philpott and Kane (2016) have described how engaging professionals from different fields around a practical activity that combines skills and methods from different disciplines can support communication, lower barriers, and enable more direct knowledge transfer. This resonates with Groth and others (2020), and their notion of highlighting hands-on practices and shared cognitive activities as enablers of successful collaboration.

In our study, the actuator fabrication served a similar purpose and became the essential phase enabling the smooth transition between different disciplines. As an activity, coiling embodied two perspectives: for material scientists, it is the point of material optimization on a tangible level and for textile experts the point of departure for textile experimentation. It also equally combined methods from both disciplines, triggering textile thinking for planning further steps for textile integration, as well as informing material scientists on the research needs of adjustments. Hence, it naturally evolved into a shared practice and common ground for knowledge transfer. Thus, we second the idea of Philpott and Kane (2016) and Groth and others (2020) that interdisciplinary collaboration demands common practices and environments available to all disciplines and enabling this should be one of the major focus areas within the research.

5.2 Dismissing universal and absolute interdisciplinary

Although searching for shared space for joint activities supports successful collaboration, the research environment should also advance the feeling of autonomy. Based on the insights shared by the textile experts, we identified two key factors contributing to their motivation: first, acknowledging the specific characteristics of textile thinking, and secondly, reconsidering the role of a designer in the process. The typical role of a designer in interdisciplinary material research is often directed towards designing applications for the material under study (e.g., Karana et al., 2015a). As textile thinking is oriented towards the materiality and structures of textiles, we observed that deviating from the application-focus allowed textile experts to engage into reflective process with the material. Thus, eliminating the adaptability of materials to industrial processes and adopting a more intuitive and craft-oriented approach in the beginning stages of research can produce new understanding of the material possibilities. For example, some serendipitous moments occurred while the Textile designer was hand weaving the textile samples. This craft-approach led into unintentional misplacement of the coils, resulting in unexpected observations, and identifying new research directions. This indicates that the variables of textile integration in creative process cannot be hypothesized in a comparable manner as in scientific research and suggests, that utilizing more open-ended exploration may result in new findings.

Thus, we would like to point out the need for commonly acknowledged methodological framework that equally validates the different types of thinking involved in the research process. From our perspective, interdisciplinary practice-based material research should aim for creating equal space for empirical research and creative practice to enable both verifiable and serendipitous findings to surface and recognize the reflective and embodied thinking appearing across the different research activities. In practice, this would mean two things: first, reserving space and time of the experts for uninterrupted individual work in addition to the collaboration and facilitation of common practices, and secondly, allowing room for different forms of exploration that support empirical and practice-based approaches on knowledge creation from project leadership perspective.

5.3 Giving space for inclusive evaluation

The distinct approaches to knowledge creation also pose questions regarding the evaluation of the outcomes of different research activities. In our study, this was especially evident when researchers from different disciplines were describing successful achievements and failures. For example, the textile samples that did not result in observable actuation as planned were deemed failures from the perspective of actuator material development. Although the actuators were not optimized for textile integration, from textile design perspective these findings were noted to be crucial for developing the passive characteristics of the woven samples towards functional woven actuators. Barati and co-authors (2019) discuss the interdisciplinary aspects of working with underdeveloped smart materials, emphasizing the dual role of material demonstrators in increasing understanding of material capabilities, and supporting communication between material science and design disciplines. Similarly, we observed that prototyping through textile exploration was a requirement for understanding the dynamic qualities and performance of the functional material, as well as the passive characteristics of a woven textile.

Thus, the prototypes underwent various means of evaluation, including subjective and reflective methods, and empirical evaluation. As material science is inherently driven by empirical evaluations aiming to hypothesize and theorize its assumptions and outcomes, acknowledging the reflective and embodied methods for evaluation may be challenging, whereas a practice-based approach may find the rigor of scientific experimentation constraining. All in all, we would like to point out the importance of understanding and acknowledging these separate ways of evaluation instead of assuming a homogenous methodology and establishing common standardization for the experimentation that covers all the different evaluation criteria. In conclusion, it is essential to understand how different variables and material characteristics are being evaluated through the lenses of different disciplines, and for what purposes the different material demonstrators are developed for.

5.4 Facilitation of interdisciplinarity

In our findings, cognitive integration and aiming to thoroughly understand the research landscape of other researchers was deemed important – and quite often, the barrier of different disciplinary terminology needed negotiation. On the methodological level, one of our main observations is that "borrowing" the methodology of a neighboring discipline is already applied in our practices, but it often goes without verbal acknowledgment. Especially in the case of materials science, although it is lacking the established methods for reflection upon the process of making, we note that in our view, a lot of activities utilize embodied understanding of the material without any formal documentation or dissemination. Trying to verbalize one's practice is thus crucial for recognizing this partially silent methodological interdisciplinarity. Also, validating the responses of other work group members was considered essential for working communication. These observations thus second the existing literature on highlighting communication aspects.

As our final contribution, we state that interdisciplinary research processes can be further facilitated by (1) identifying and establishing common shared practices (and related physical spaces), (2) ensuring the time and space for individual creative autonomy in exploration, and (3) taking the evaluation process of the work into negotiation, where all contributors assume equality without an a-priori set application focus. As one potential limitation to generalizing this approach, we note that a flat hierarchy enabling all this might be more difficult to implement for significantly larger working groups.

6. Conclusion

In this contribution, we elucidate how practice-based textile thinking and empirical scientific thinking contrast and collaborate within interdisciplinary material science research. The research is conducted through qualitatively analyzing both the interviews of a core research team, involving professionals from textile design, material science, handicrafts, and polymer chemistry domains, as well as viewing the whole research project from a systemic perspective. Our findings indicate that different ways of knowing can co-exist in a research team and beneficially contribute to the advancement of the research goals – however, we see our most important contribution as the identification of key impediments originating from different backgrounds. These consist of not giving enough exploratory research space for design researchers, and on the other hand implementing rapid prototyping action within a study on material behavior, as well as the inability to acknowledge the differences in ways of thinking and negotiating those differences in, e.g., evaluation. As a next step of our research, we envision strategies for amending these conflicts to achieve an even more seamless interdisciplinary working method. Awareness of these key questions can be essential for any research program aiming to involve contributors from other disciplines.

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7. References

Barati, B., Karana, E., & Hekkert, P. (2019). *Prototyping Materials Experience: 13*(2), 19.

Berland, L. K. (2011). Explaining Variation in How Classroom Communities Adapt the Practice of Scientific Argumentation. *Journal of the Learning Sciences*, *20*(4), 625–664. https://doi.org/10.1080/10508406.2011.591718

Braun, V., & Clarke, V. (2019). Reflecting on reflexive thematic analysis. *Qualitative Research in Sport, Exercise and Health*, *11*(4), 589–597. https://doi.org/10.1080/2159676X.2019.1628806

Camere, S., & Karana, E. (2018). Fabricating materials from living organisms: An emerging design practice. *Journal of Cleaner Production*, *186*, 570–584. https://doi.org/10.1016/j.jclepro.2018.03.081

Candy, L., & Edmonds, E. (2018). Practice-Based Research in the Creative Arts: Foundations and Futures from the Front Line. *Leonardo*, *51*(1), 63–69. https://doi.org/10.1162/LEON_a_01471

CohenMiller, A. S., & Pate, E. (2019). A Model for Developing Interdisciplinary Research Theoretical Frameworks. *The Qualitative Report*. https://doi.org/10.46743/2160-3715/2019.3558

Devendorf, L., Arquilla, K., Wirtanen, S., Anderson, A., & Frost, S. (2020). Craftspeople as Technical Collaborators: Lessons Learned through an Experimental Weaving Residency. *Proceedings of the 2020 CHI Conference on Human Factors in Computing Systems*, 1–13. https://doi.org/10.1145/3313831.3376820

Driver, R., Newton, P., & Osborne, J. (2000). Establishing the norms of scientific argumentation in classrooms. *Science Education*, *84*(3), 287–312. https://doi.org/10.1002/(SICI)1098-237X(200005)84:3<287::AID-SCE1>3.0.CO;2-A

Du, J., Markopoulos, P., Wang, Q., Toeters, M., & Gong, T. (2018). ShapeTex: Implementing Shape-Changing Structures in Fabric for Wearable Actuation. *Proceedings of the Twelfth International Conference on Tangible, Embedded, and Embodied Interaction*, 166–176. https://doi.org/10.1145/3173225.3173245

Groth, C., Pevere, M., Niinimäki, K., & Kääriäinen, P. (2020). Conditions for experiential knowledge exchange in collaborative research across the sciences and creative practice. *CoDesign*, *16*(4), 328–344. https://doi.org/10.1080/15710882.2020.1821713

Haines, C. S., Lima, M. D., Li, N., Spinks, G. M., Foroughi, J., Madden, J. D. W., Kim, S. H., Fang, S., de Andrade, M. J., Göktepe, F., Göktepe, Ö., Mirvakili, S. M., Naficy, S., Lepró, X., Oh, J., Kozlov, M. E., Kim, S. J., Xu, X., Swedlove, B. J., … Baughman, R. H. (2014). *Artificial Muscles from Fishing Line and Sewing Thread*. *343*, 6.

Heiss, L., Beckett, P., & Carr-Bottomley, A. (2016). Redesigning the Trans-disciplinary: Working Across Design, Craft and Technological Boundaries to Deliver an Integrated Wearable for Cardiac Monitoring. *Proceedings of the 2016 ACM Conference on Designing Interactive Systems*, 691–699. https://doi.org/10.1145/2901790.2901794

Igoe, E. (2021). *Textile Design Theory in the Making*. Bloomsbury Visual Arts. https://doi.org/10.5040/9781350061590

Karana, E., Barati, B., & Rognoli, V. (2015a). *Material Driven Design (MDD): 9*(2), 20.

Karana, E., Pedgley, O., & Rognoli, V. (2015b). On Materials Experience. *Design Issues*, *31*(3), 16–27. https://doi.org/10.1162/DESI_a_00335

Langella, C. (2021). Design and science: A pathway for material design. In *Materials Experience 2* (pp. 259–277). Elsevier. https://doi.org/10.1016/B978-0-12-819244-3.00001-6

Lean, M. (2020). *Materialising data experience through textile thinking* [Thesis, Royal College of Art]. https://researchonline.rca.ac.uk/4443/

Leigh, J., & Brown, N. (2021). Researcher experiences in practice-based interdisciplinary research. *Research Evaluation*, *rvab018*. https://doi.org/10.1093/reseval/rvab018

Philpott, R., & Kane, F. (2016). 'Textile Thinking': A Flexible, Connective Strategy for Concept Generation and Problem Solving in Interdisciplinary Contexts. In *Craftwork as Problem Solving*. Routledge.

Sanchez, V., Walsh, C. J., & Wood, R. J. (2021). Textile Technology for Soft Robotic and Autonomous Garments. *Advanced Functional Materials*, *31*(6), 2008278. https://doi.org/10.1002/adfm.202008278

Townsend, R., Bang, A. L., & Mikkonen, J. (2020). Textile Designer Perspective on Haptic Interface Design: A Sensorial Platform for Conversation Between Discipline. In N. Streitz & S. Konomi (Eds.), *Distributed, Ambient and Pervasive Interactions* (pp. 110–127). Springer International Publishing. https://doi.org/10.1007/978-3-030-50344-4_9

Wilkes, S., Wongsriruksa, S., Howes, P., Gamester, R., Witchel, H., Conreen, M., Laughlin, Z., & Miodownik, M. (2016). Design tools for interdisciplinary translation of material experiences. *Materials & Design*, *90*, 1228–1237. https://doi.org/10.1016/j.matdes.2015.04.013

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