co-Ability
Aligned arguments for the dissolution of a human “centre”

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Chapter III.

co-Ability Methodology

The chapter that follows presents and elaborates on an applied statement of the theoretical position of co-Ability, already discussed in the second chapter, and investigates the reasons why user-friendliness appears to come second behind the desire to help improve the experience of being human for the impaired.

To study the trajectories between Disability studies and Design culture perspectives, the application of practical design experimentation 'through' a single case study of prosthesis design with situated discursive co-design method is a reliable instrument. In the present chapter, I first talk about the RtD inquiry residing in the method and process of design practice. To understand the relation between the design process and the academic research, I discuss RtD to map out and develop a viewpoint of where this study stands in the realm of the research world. The novel knowledge-finding approach is not merely artisan as it attempts to relink academic theory and everyday real-life actions; it also wants to discover communicable scientific knowledge linked to the epistemology of the practice. It was hypothesised that digital craft combined with the unused disability potential specifically scrutinized through the argumentative RtD lens can lead to a better understanding of human-centred normative visions of our world.

To provide context to the design process, I present the single, in-depth prosthetic case study in which the research settled. The research introduces Luca Szabados as one of the key characters to settle the social situation and investigate her personal experiences within her real-life context. The process represents research into design innovation with situated variables and open-research questions allowing to change hypothesis predictions. In the prosthesis design process, the various entities analysed as key players are essential to the subject. A discursive prosthetic design is significant because it creates a connection with the general viewer by presenting the project's argument without emphasizing the result of a terminal design production as an absolute masterpiece. To articulate unclear and unimagined possibilities of an emerging reality, the prosthesis artefact does not follow past and recent tendencies of interpreting a corresponding anatomical body part. The form of a prosthesis does not need to be based on a bio-normative body model and does not need to be an artificial interpretation of a biological limb. Design research does not necessarily involve projects that lead to a market-ready artefact in which science and art meet and expand to the extent of design problems' boundaries. To recall Sennett's famous saying 'making is thinking' in the co-design process, I present the information gathered in the detection and production of data followed by the interpretation. The practice-oriented creative skills of digital craft analysed with rigorous science criticality address disability beyond identity politics and activism. The material conditions of digital craft are considered to be a process instead of a product. Consequently, it is understandable why design is more than an interface between a material object and its use. Another ground upon which this notion was popularly theorised was the manifestation of 'head' and 'hand' + 'materials' + 'tools' in the context, critically addressing the transversal form of non-synthetic understanding of the relational bond that connects us. As such, this text maps out and builds up a view of the co-Ability concept and formulates the understanding of co-Ability. It seeks to uncover the paradox in the dichotomous endeavours interplaying in body representations with the potential of leading substantial alteration in the overall perspective in which the problem is viewed (Bargar and Duncan, 1982). In connection to co-Ability 'I would suggest that the body representations are actually linked to the understanding of the bodily experiences of an individual, and it leads me to think it can be a description of the primary understanding of the world as well' (Dezső, 2019).

The public's perception of a socially responsible designer should not only be received when a designer plays an essential role in the process of social intervention. Concluding the chapter, I focus on another part of the framework: the question of interpretation and presentation of such research process analysing how art and science work together to inform the public on scientific information.

Research through design or craft?

In the first chapter, I clarified the term Research through Design. It was essential to understand the terminology in earlier chapters. Yet, at the same time, it still requires a more detailed examination to detect the position of this particular research and how it connects to the practice. Right from the beginning of the doctoral research, I found it essential to map out and pinpoint the approximate position of this research in the world of clashing opinions. This map supported the understanding of the novel methods applied in knowledge generation throughout the last five years. To best present, the process calls for clarification where design research stands here, so I have to define which actions are connected and how the methodologies are related. Before the doctoral study, my work was concentrated on product design or artistic projects. The two disciplines were separated by different processes, network connections, and artefacts, but with this study, the academic aspects are finally incorporated into the process.

As a designer doing academic research, I felt as if I was an artistic researcher sometimes questioning the scientific quality of the quest, and I was curious to find the correct answers. So, what is the relation between science and art? What does it mean to do artistic research? Is artistic research or design research happening here, or is it scientific research? Can it fall in all categories at the same time? If yes, what does that mean in terms of execution, and what are the methodological guidelines, discussions in this matrix of research definitions?

To begin, I would like to interpret how design practice presented in this text is related to artistic practice. On the one hand, design is an actual manifestation of tangible objects, products, or even a system, that is so to say in general, all 'things' that are artificially made. On the other hand, however, it is also a process or a method, which is closer to the meaning used in this chapter. In Design Research, the focus is on the latter meaning, on an approach of thinking and action. Rather than a retrospective and factual analysis of a final ideal object, the prosthesis prototype design is transformative in nature and provides context to this study.

How this text looks at design is not equal to the perspective of artistic or non-artistic aspects. Nevertheless, the predominant digital object making design activity refers to industrial design more than design engineering in additive manufacturing, considered a non-artistic form of design (Eder, 2012; Flurscheim, 2014; Julier, 2013; Tjalve, 1979).

The main future of design held here is the situated nature in our everyday life culture: 'design relentlessly intervenes into the quotidian world so that it becomes our world and we become in it' (Julier et al., 2019). The situated nature of design in our quotidian world is in reflective symmetry with how our moral and social values steer our behaviour on a daily basis. Combining the situated nature of design with a convivial situation of disability is the predominant perspective viewed here, with special emphasis on how it reforms everyday life culture. The conceding relation between society and market is often intricated in design history, recalling the Arts and Craft movement that mostly stood for the opposition of industrialised capitalism, as a 'critical stance towards the state of the market and capitalist product culture as such' (Julier et al., 2019). The criticality of craftmanship is also a part of digital craft movements or, in other words, 'maker movement' with 'technological developments that endow consumers with productive power' (Knott, 2013). The joint affiliation between craftmanship and technology is supported by a craftsman's 'right approach, skills and mindset' (Campbell, 2016). The manual skill-set and practised excellence combined with visual thinking of digital media can expand the perspectives of traditional making practices (McCullough, 1998). Based on these previews, the 'tight-knit cooperation between artists and craftsmen' (Julier et al., 2019) helps to understand the extent to which this academic design research is an artistic process. An artist's investigative skills may not be recognised as a direct application and manifestation of grounded research with subjectively informed interpretive analysis of cultural theory (Bennett et al., 2010). Still, interpretive and creative approaches of grounded research encompassed in scientific research are beneficial to qualitative inquiry, and mixed methods will positively impact the academy in the future.

So, after all, the question remains; What is research? The UNESCO defines research and experimental development (R&D) as follows: '[it]comprises creative and systematic work undertaken to increase the stock of knowledge – including knowledge of humankind, culture and society – and to devise new applications of available knowledge' (UNESCO Institute for Statistics (UIS), 2008). This is an implication of not yet knowing. A theoretical or experimental work of investigation aiming at new/novel answers based on original concepts and hypotheses with an uncertain outcome. 'Science', 'design', 'disability', and 'technology' have a common aspect in being somewhat homogenous; therefore they trespass the boundaries of categories, and also represent variations in methods and paradigms in the shared common cultural everyday space. The knowledge generated by the present transdisciplinary research manifests the complex taxonomy of embodied perspectives, insights gained from material artefacts, communal experiences that can future-orientally reflect on the fundamental and theoretical aspect of science, and the usefulness of applicability design practitioners' and education community.

Prosthetic case study and repositioning the initial theory

To investigate through personal values and situated concerns, the research settled on a case study project for studying the instance of the designing process of prosthesis design. Articulation information embedded in the artefacts is part of the activity of the inquiry, including implicit and tacit knowledge-based data that are rarely verbally articulated. Prosthesis prototyping provides the possibility of creating a set of 'boundary objects' within design discussions which include latent perspectives carried out. In particular, the in-depth single case study was chosen because of personal interest in an individual with a contextual situation. The embedded part of the investigation, the design tool of prothesis, leads to theory building of co-Ability in social innovation.

The locus of the investigation built up by a single design case was initiated in 2016 at the 'MOME enable design tour' workshop, where I got introduced to Luca Szabados to create a prosthetic design as 'an empirical inquiry that investigates a contemporary phenomenon within its real-life context' (Yin, 2003).

Luca's left lower arm is missing due to a congenital disability. She is a visual designer artist who primarily creates puppets for artistic performances. After being introduced to each other, we started to discuss what kind of prosthesis she needs and how she manages her daily routines. At this early exploratory stage of the case, the initial theories (she needs a prosthesis) and the initial questions (what does she really need?) were challenged by her representation of independence and creativity and her responses to my questions.

Right at this initial stage of her situation at the workshop, we clarified she does not need a prosthesis; moreover, she doesn't like to 'wear' one due to its weight. Also, she finds it weird and uncomfortable to move around with a prosthesis, often bumping into other objects. Her answers were surprisingly different from my anticipation: she questioned the design intention, inviting more questions to understand her personal needs and interests, redirecting the design process and the research trajectory altogether. The situated setting of the discussion was supportive on both sides: we had the genuine mutual intention to understand how the two opposite intentions can be matched. The discussion was extended to explore further the necessary details and specifics on how she manages smaller daily two-handed tasks were covered. “Disabled people are often outstanding problem solvers because they simply have to be creative. Life for disabled people is a continuous series of challenges to be overcome” (Miller et al., 2004).

The particularity of the initial situation provided directions to further discussions and physical investigations; the framework of the doctoral research allowed to reposition the initial theories to elaborate it by novel critical/reflexive design discourses.
We established together that ‘both the aesthetic value for people around her and the somaes-

Figure 10: Luca Szabados at her workshop. Photo by Andras Ladocsi. Photo by Andras Ladocsi.

thetic experience in her freedom of movements were limited with classical prosthetics’ ‘she definitely wouldn’t need a prosthesis for her daily routine’ (Dezső, 2019).

Based on her reflections, we explored special occasions where she would appreciate a prosthesis. The work situation was the selected occasion in Luca’s routine when the performance could be improved by a designed aid. This is an exciting concept since all people prefer to enhance their work performance. We all prefer improved tools and environment to work with, not only for comfort but for higher performance and higher success. ‘By keeping an eye on the concept of inclusion, we focussed on improving the ability to work instead of pushing aesthetics to the fore. As a key situation for Luca, we defined the problems of using a cutter while working because this work exercise requires that she use two hands – when Luca is holding the cutter in her intact hand, the support she provides on a single point of the paper with her elbow stump is insufficient. If the surface to be cut is not supported properly, the cutting will be imprecise while the supporting elbow stump might be wounded too, which is more prone to injuries already’ (Dezső, 2019). Supporting the performance with the cutter is a short-term usage with a simple mechanical aspect. It does not require cybernetics or bioengineering as many prosthetic designs offer on the market with unaffordable price ranges for a simple customer.

A desktop 3D printed prosthetic tool can meet the surfaced requirements of producing a simple and affordable personalised prosthetic tool for improving work performance for Luca. By using the selected technology, some specifications also had to be considered, which I will describe in detail later in this chapter.

As part of the functional selection and technological details, one key feature of the design-led research question develops further. The design data, such as the prosthesis prototypes presented here lend themselves exceptionally well to narrative analysis. From this point of view, I was interested not only in what Luca said and did but in how she expressed herself to examine the forms and the functions of narratives. To match the necessary function, the prosthetic tool prototypes differed from an anatomical biosimilar prosthesis to a hand. The new aesthetic questioned the visual message transmitted by it, questioning how a prosthesis should look like. Longmore argues in several essays on disability as a matter of appearance as function in media images and screening stereotypes. The symbolic character of disability is dominant in media culture (Longmore, 1987).

A prosthesis functioning as a social symbol and a political emblem for oneself, the distinction between aesthetics and usability is blurred, or as Jauss discusses, ‘aesthetics just is the usability of an admittedly special kind’ (Jauss, 1982). ‘The design is a broad exploration of the problems of communicating information, ideas, and arguments through a new synthesis of words and images that is transforming the "bookish culture" of the past. An exploration of the problems of construction in which form and visual appearance must carry a deeper, more integrative argument that unites aspects of art, engineering and natural science, and the human sciences’ (Buchanan, 1992). Based on the earlier literature review of disability studies, a prosthesis that looks like an anatomical hand but is not able to function as an upper limb, the question arises: what kind of information does it communicate to the public and to the user? ‘Do I care more about social inclusion, or is it more important to sensitise the society? How should I eliminate the influence of stigma and divergence of the negative perceptions of difference (deviance) and their evocation of adverse responses (stigma)’ (Dezső, 2019)? The most valuable situation for Luca was her work situation. In (a) socio-cultural context (where), a disabled person is excluded from the commercial workflow with designed tools and environment; the(ir) inclusion is to adapt a tool to the environment instead of to adapt a person to the environment. In this case, the adaptive mechanism could be not for a disa-

Figure 11: Testing prosthesis prototypes with Luca. Photo by Andras Ladocsi.

Figure 12: Luca Szabados testing prosthesis prototypes. Photo by Andras Ladocsi.

bled person but the environment, ergo, so it is only reasonable to ask: Why should it look like a human body part? Should I form an anatomical hand, or should I transform the 'bookish culture of the past'? Strangely, the futuristic transhuman nature of the prosthetic developments are connected to the 'bookish culture' that follows the old expectation of an anatomical hand? If I do not follow the past and recent tendencies of anatomical hand design, am I calling the prosthesis an artefact to help articulate unclear and unimagined possibilities of an emerging reality (Bessant and Maher, 2009)?

'Based on Richard Buchanan's 'conceptual repositioning' theory, if I am changing the 'bookish culture' – in this case, the usual and expected shape of the lower arm prosthesis –, it will communicate a new status. Suppose the shape of the prosthesis does not follow the anatomy of the lower arm and the hand, and even differs from it significantly. In that case, it can emphasise the stigmatising expectations of the bystander. The important point in this context is that the expertise I was focusing on is a kind of knowledge that is practical and centred exclusively on Luca's experiences as a matter of principle. In this case, Luca's tacit knowledge guided the design, whereas I was in charge of transforming it to explicit wisdom so that it could be implemented. Her experience could also be called 'embodied knowledge' to emphasise the role of bodily abilities and capacities. Considering the pattern to change society's stigma, we can find a changing set of placements defined by shapes, actions, and thoughts. The shape of the prosthesis was defined by the actions for which it is being used, which, at the same time, produces a placement in representation. The boundary of this placement gave me a context or orientation to thinking, and the application generated a new perception. A person with a prosthesis – the materiality of the body – is invigorated in the given interaction. With further research, I analysed the nature of human rationality, subjectivity, and consciousness in the cross-disciplinary section of design culture and disability studies.' (Dezső, 2019).

In this research, I had no intention to make comparisons within other case studies to develop perhaps a causal theory based on measuring variables in the different settings of the various design projects. The goal was to know how Luca Szabados, in her everyday settings, interpreted 'her inside experience' and compare it with the literature study's 'outsider understanding' during the prosthetic design case study. The co-design process offered the ideal option for conducting in-depth analysis in one design's settings. In social science, addressing the meaningful character of social action using interpretive methods is appropriate. The historical debate between the positivist view of the natural sciences on valid knowledge contrasting it with the interpretive paradigm of social reality has been present since the nineteenth century. I do not intend to represent all critical points of the debate, but as an essential part of these opposing views, the tangible goes along with the objectivity. At the same time, self-reflectiveness leads to qualitative research (Travers, 2001). I would argue the tangible in craft experiences, and artistic research rarely goes along with objectivity. Instead, it is connected with a personal interpretation of an experience. When it is combined with the tangible experience of a person missing an upper limb, it can lead us to explore the implicit knowledge hidden behind social prejudices about abilities.

The rarity of this case study submerged in moving from the classical linear supplier/consumer model for research into design innovation with variables situated in this design research with open research questions avoiding hypothesis predictions. Luca's response to my initial idea and further works functioned as a 'Part of a 'critique from within' posed by a person with a disability with personal (implicit and explicit) knowledge of the situation, the prosthesis prototypes as 'object for discourse' were positioned as a basis for reflection in and upon the design. Ideas may be central, such 'objects that talk back' require the use, reflection, and action, through their very physical presence, materiality, and craft' (Mazé, 2007). The participants in the case study project were Luca Szabados (a highly creative independent artist with congenital disability) and me as a researcher/designer digital crafting the artefact with digital craft technology and the prosthetic prototypes guiding reflections through non-verbal modelling media. The experimental attitude of the following qualitative case study work provided space for understanding relationships between phenomena and theory. 'How we learn from the singular case is related to how the case is like and unlike other cases we know, mostly by comparison' (Stake, 2005).

Figure 13: Luca Szabados testing prothesis prototypes. Photo by Renáta Dezső.

"Making is thinking"

Processing data by forming and testing

If the prosthesis is not corresponding with the anatomical reference body parts, what form should it have? How should we proceed to form a prosthesis? What should other major differentiation from a traditional prosthesis be considered here? Differing from an accustomed prosthesis design also involves the intention to produce a low-cost and short-term use prosthesis tool, something that can be damaged in use without any stress and is easily reproducible if needed without high economic demand. 'Technology puts time central to 'Material practice', present 'return to things', 'temporal form', temporality of materials, use, and change, inflected by concepts such as becoming, making, and futurity' (Mazé, 2007). Furthermore, economically Luca's personal needs are very similar to any other person. All she wished for was affordable aid. Cost efficiency should be a part of the discussion when it comes to prosthetic development. We should consider the appropriate low-cost technology aligned with some bottom-up tendencies and contrast it with the recent highly funded bioengineering and cybernetics research developments in prosthetic design. In this respect, the discourse on cybernetic and organic attributed to the work of Donna Haraway's "Cyborg Manifesto" could deliver important arguments (Haraway, 1987). As I mentioned earlier, the philosophical question of aesthetics is an important consideration when it comes to prosthetic design, and low-cost fabrication technology offers new aesthetical appearances, too. Margolin and Margolin discussed that as the 'broader understanding of how to design for social need might be commissioned, supported, and implemented' when the 'population in need' is connected with 'design for development', the ideas are often borrowed from 'alternative technology movement, which has promoted low-cost technological solutions' (Margolin and Margolin, 2002). The digital craft process is based on isolating the minimal and most easily detectable parameters that can support to choose a specific action of material interception. In order to hold a flat-surfaced material completely steady, the number of fixing points must be increased at least to three, which quickly leads to an idea of a three-pod shaped form. Forming of such a shape was driven by the three primary parameters: functional aspect, time-based aspect, and the technology offered.

Design process step-by-step

1. The preliminary idea was an initiative with the best intention to design an ideal prosthetic supported by a university workshop for ideation. Similar to the recent tendencies of top-down problem formulation, the problem formulation focused on creating an ideal personalised prosthesis supported by digital technology.
2. Next, we discussed Luca's personal needs with her, which resulted in the conceptual repositioning of the initial task of problem-solving to the new objective of the research, considering the situativity in a case study aiming to generate new knowledge explored with research through design.
3. Closely listening to Luca's experiences and suggestions, the need for a general prosthetic was challenged as a 'bottom-up' initiative. In order to move forward, we defined together with a key function that can be supported by a prosthesis design I described earlier.
4. In order to start to develop a prototype and test its defined function, there was an important aspect to manage. I had to collect the exact stump measurements for prosthetic fitting, and it became apparent that three main options represented three different techniques for the initial ergonomic reasoning. The simplest possibility was an analogue process to measure the stump with a ruler or tape. After the measurements, the collected data could be inserted manually into the CAD modelling software. The second option was to use a traditional technique of plaster casting, which is a precise and feasible process without digital technology in place, but in order to enter the collected data in digital design, it is required that we reverse engineer and freeze the shape of the stump only in one position at the time. The third option was to use contemporary 3D scanning technology with direct digital data collection, which we did not have on the spot. In this case, the simplest and best option was the first one for various reasons. Ergonomically accurate measurement couldn't be precise and fixed in one body position since the elbow stump, like many other parts of the

human body, is a moving body part that changes shape and forms with movement. To comprehend the complexity of the measuring problem, Luca provided feedback right away. It was easy to select the most appropriate method to give a good estimate based on her feedbacks and my previous experience with 3D scanning and reverse engineering. At an early stage of the 3D scanning of the human body, the average micromovements challenged this accurate technology. 3D scanning geometric features of a static object with precision is much easier than a human breathing chest or a standing body that require spatial alignment in the calculation. Luca's elbow stump movements impose modifications that are much larger than a breathing chest. As a result, the alignment calculations should provide free space to be integrated into the object. To obtain comfort for Luca, the precision of the measurement was of secondary importance, so the classical tape measuring method was sufficient. The freedom of body movement in interaction with an object became more valuable in the design. This small task of measuring the physical aspects also questioned how feasible is it to consider a rigid object as a prosthetic attached to a non-rigid human body? The attachment between an object and a person questioned the idea of a fixed long-term connection. I wondered if the design should consider a short-term fastening connection instead of a permanent and lasting prosthesis integration. It also intrigued me; how long should the prosthetic be attached to the human body? Since the interaction occurs not only between the body and object (prosthesis) and in body-prosthesis-other object interactions. A prosthesis primarily is a tool to interact with another object. Therefore, the additional question of whether this primary aspect varies between a prosthetic leg and a prosthetic hand or other prosthetic parts remained.

5. The first meeting with Luca Szabados repositioned the initial theory and represented possible future comparative directions to fuel theoretical reflection on possible oppositions to this case study. The different demands for design in upper limb prosthetics and lower limb prosthetics need to be further explored. Also, another aspect affects the design process: Luca's condition is congenital. Her needs and reflections differ from a person with an acquired disability based on his/her self-concept and body recognition.

Figure 14: Luca Szabados at her workshop on the left, and prototypes to test on the right. Photo by András Ladocsi.

6. Main parameters of initial forming:

- The selected function is a mechanical aspect initially focusing on a single body motion, improving cutler use to hold a flat-surfaced material on three points. It opposes emulating the entire lower limb and hand functions to create complex body motions in terms of the limbs' external surroundings.
- Time-based aspects: short-term use. The design is enacted to the body only for the duration it is needed for cutting. The prosthesis should be easy to put on and off with one hand, or as later during the development we found out, it is even better not to fix the object on Luca or have an automatic fixing option like a click on/of the mechanical system of the hinge and joint. On a positive note, short-term usage does not require an ecosystem of hardware (equipment necessary for digital data input) to adapt the tool to the body, and the comfort of the surface material is less determinative, allowing a more straightforward object creation out of one material.

Figure 15: Short term usage supported by easy adaption to the upper limb stump. Photo by András Ladocsi.

- Technology-led aspects: computational workflow and structural efficiency
    - For cost efficiency, desktop 3D printing is used for prototype manufacturing.
    - The limitations of desktop 3D printing show as we worked with a rigid material called PLA; also, the size and detail limitations are significant compared to professional 3D printers.
    - The material is the media. Micromechanical structures can influence flexibility property on a rigid material property and also improve the body-object per formance. The leading art and technology inspirations in micromechanical structures are the works from Studio Bitonti–UNIQ orthopaedic and pros thetic products (http://studiobitonti.com/), Nervous System co-founders Jessica Rosenkrantz and Jesse Louis-Rosenberg (https://n-e-r-v-o-u-s.com/about_us.php) and Behnaz Farahi (http://behnazfarahi.com/) works. At the same time, the physical limitation of desktop technology does not allow micro-sized geometry and sophisticated material geometry. In light of such implications, it is still possible to alter the material's geometrical configuration with the strategic selection of geometry to showcase dynamic behaviour such as flexibility, thus improving the body-object performance

Figure 16: Various versions of the flexible side parts. Photo by Marcell Kazsik.

    - Assemblage: Desktop printing workflow offers the possibility to create an interlocking design, which we can use as an advantage in the shape of a pre-assembled bearing to support some of the body dynamics. Also, the elements cannot be larger than the size of an average 3D printer's bed size to conform to the needs of assembling the elements.
    - I follow a designer-based iterative development in computational design workflows, as opposed to a self-organisation process of Morphogenetic Design (Hensel et al., 2012). I propose a classical designer-based surface CAD modelling technique to support the development process of discursive situated design without using a parametric algorithm or generative design (Soddu, 1994).

Figure 17: A basic set of assembly. Photo by Marcell Kazsik.

Figure 18: Set of assembly. Photo by Marcell Kazsik.

- Body-object interaction requires obtaining the best surface quality of the printed pieces. For this reason, the prints needed to have the least possible support material enacted to them. Due to the FDM printing technology, the printing process requires us to print a support structure that can be removed with physical effort leaving a rustic surface behind that can harm the human skin.

Figure 19: Set of the printed elements before assembly. Photo by Marcell Kazsik.

7. The primary phase of CAD modelling began after the first reflective discussion and the collection of real-world, measured data. The digital design method allowed to further analyse and visualise pre-collected real-world data. The initial digital models I first used for 3D production were testing the timing and calculating the possible assembly and other predictable physical elements. Aesthetic as a direct goal was not present at this stage.
8. The secondary phase of design development was based on digital data physicalising (Bader et al., 2018; Hogan et al., 2016; Jansen et al., 2015). The design 'activities focused on building physical manifestations of data, where some variable is mapped onto a physical artifact, are uniquely well-suited to scaffolding a process and exposing' for interaction to generate the next steps (Bhargava and D'Ignazio, 2017). This phase appeared and reappeared before and between the real-life testing with Luca. The process is similar to traditional crafting actions, which are rarely described in detail; the difference in digital crafting is the presentable data transfer within technological elements (computer, 3D printer machine) and humans. Some data code is readable only to the 3D printer, the artificial element, but not the human (python code to prepare to print). The code is textualised information generated by the 3D printer preparation software that helps the machine create physical objects from digital data.

In other words, the 3D image of a form created in the 3D modelling software is the visualisation of the pre-collected and designed digital data; the 3D printed forms are the physicalisation of the created data (Bader et al., 2018). Both the visual and physical representations of data are untestable and comprehensible to humans. But in the transferring process between the visual and physical, the information data are textualised and are altered into the 3D printer movements, and they are not understandable for an untrained eye. After each printing session, the printed parts need hand-crafted post-production, like detaching it from the printing plate, removing the support material from the surface, assembling elements etc. Sensing the physicalised material data through movements of the hand while moving the printed parts helps feedback simultaneously form the prosthesis's structure further. This activity supports two important sensual activities: the animated vision and the exploratory tool of touch (Ballard, 1991). Dana H. Ballard's animated vision paradigm research investigates ways in which fast, fluent, and adaptive responses can be supported by computationally less intense routines – routines that intertwine sensing acts and movements in the world. We see the information from the world during a movement and we change our action by considering that information. Based on A. Clark's description, we use touch to explore surfaces also as an action-involving cycle in which fragmentary perceptions guide further explorations (Clark, 1989). I would say I used the moving sensorial touch to understand not only the surface but the internal parameters of the material, such as morbidity, stiffness, relative weight, etc. Animated vision and animated touch are the tools for using the extended organs of physiology in the material world beyond our body.

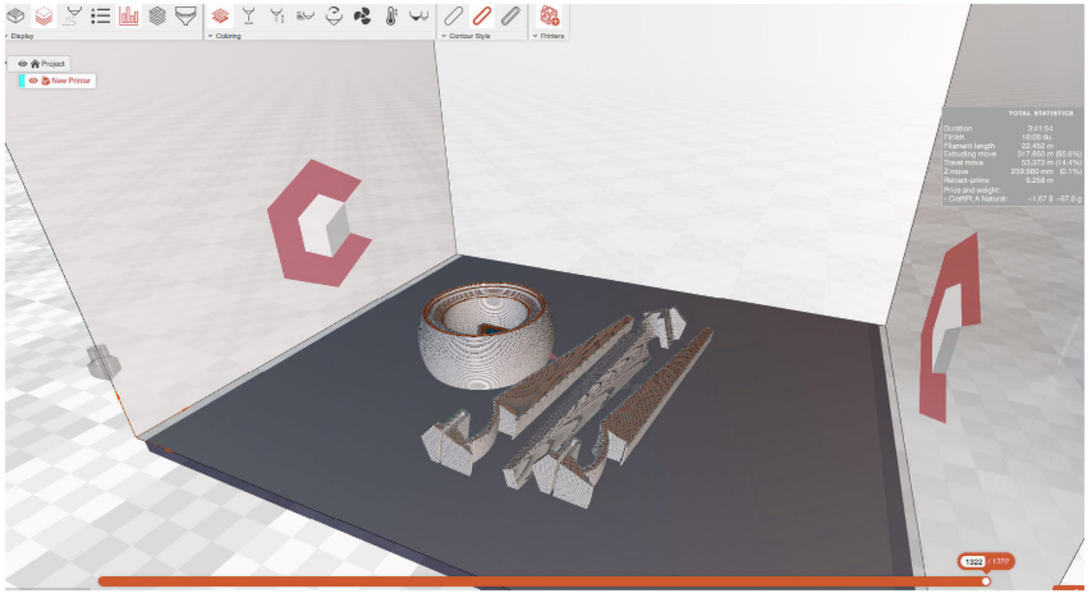

Figure 20: 3D printing setup without any supports

In this creative craft process, the designer can use the real-world prototype as its own best-structured information source (instead of a text-based information data source like in other sciences) and visit and revisit the real-world material scene as the idea of the envisioned design changes and develops. The process requires the experienced nature of the movements in the material scene and involves subjective illusion into the motor-loop-specific perceptual adaptation. Paul Dourish (1999) explained the unfolding nature of situations when Heidegger argued the ontological structure of the world not given, not there to be found, discovered, or revealed, but arisen through interaction, through unfolding (Dourish, 1999). So, the prototypes hold a probe and reprobe material data structure; the information to improve the prosthesis prototypes are developing while action-oriented touch and vision generally extend the perception.

In other words, the two modalities of explorative touch and vision in craftworks are a parallel modality of the (body) image and (body) schema in self-recognition, that is, conscious and unconscious or 'online' and 'offline', implicit and explicit representations during a creations process (Carruthers, 2007). Body image and body schema will be discussed later in adaption to sensing the body.

The described process also begs for the question: can a single case study be considered as a qualitative research method with quantitative data collection and analysis in the digital crafting process? If the answer is yes, is this case study with co-design prototyping a mixed method that combines qualitative research, grounded theory, and meaningful variation in quantitative secondary data presented in the artefacts?

9. When the testable prototype became ready for use, we once again met Luca for usability testing. The initial tests were not in a real-world environment, but Luca received one prototype for more extended independent real-world testing at her workshop. Several prototypes were tested at the meeting to see the proportional aspect, fragility (some had cracked). I valued her short-term feedback and returned to change the design. The reflective discussions' main and returning physical characteristics focused on her comfort in moving around with the object. She generally needed the prosthetic tool for 5-30-minute-long periods, so I genuinely was interested to see if there is a need to soften the surfaces of this rigid PLA plastic. Another section of interest in function was how the prosthetic could be fixed on her elbow stump or arm, and generally, the process of attaching it onto it. Especially the take-on take-off processes were significant: they were not supposed to be too complicated since it could have reduced the satisfaction of use, which might have resulted in Luca not using it at all. Later in the process, she suggested not to fix the prosthetic at all to her stump and have an option of fast docking, which was an interesting proposal considering a traditional prosthesis. During the observation of the ordinary use of physical and material things in focus, our attention was drawn to details within embodied action, situated interaction, and social practices.

Figure 21: Luca Szabados testing the prototypes. Photo by András Ladocsi.

Evidence data in artefacts

The research argument is supported by the evidence provided by the data of prosthesis prototypes. This evidence is generated through the application of the design research methods in the social context of disability studies in the form of the production of material objects, which is given to establish the point in question. Data (plural, singular 'datum') of the material object become information when produced, tested, and interpreted in the social contexts of the case study.

Various methods will generate multiple types of artefacts: for example, an artistic method may yield personal interpretations or expressions; research for design with market-focused development would represent a market-ready product; research about design and traditions would result in a representation in objects of material culture or practice. 'Different types of research method can provide different kinds of evidence which, when seen as a whole, can provide a 'rich picture' of the issue being investigated' (Gray and Malins, 2004).

In this section, I present the two analytic themes of the prototypes reflecting on a selected function to provide support for Luca and make the limitations my choice of data imposed below explicit. To define two restricted data sets in the creation process, I focused on supporting a flat surface with 'tripod support' and the imitation of the 'grasp' with attachable modular grip elements. I describe the roadmap of the development and reason for the details of technical feasibility. In order to do so, I employ several methods like illustrative drawings from the 3D models in addition to photographs of the 3D printed objects themselves. Finally, I present the evidence after it has undergone Luca's testing.

Figure 22: 3D printed artefact in use. Photo by András Ladocsi.

Figure 23: 3D printed prototype, photo by Marcell Kazsik

Tripod support: the central theme for the prototypes

Using a cutler is a typical task for Luca, and in order to improve her working quality, stable support of a flat surface on a table would serve her well. The function is not a tripod grasps describing a grip on a pencil, but tripod support of a flat surface such as a paper on a table which can be moved by the cutler pressure.

One of Luca's main movements with her elbow stump is putting pressure against different surfaces, even towards the side of her chest when she needs to hold an object. The force of the elbow stump is central to her lower arm. This direction has led the prototypes' shape to have a centre line and all elements symmetrical.

The tripod support works as a tool that is used for seconds or minutes while cutting. Adapting it to the body is not only temporary but it also extends Luca's lower arm only when it is in function/use. When the cutler is used, Luca's visual focus is on the surface to cut, and she adapts the place of the tripod support by her other hand without looking at it. For this reason, I added a tangible outer surface to the central element.

As for the critical technical aspects to design, it was important to build the 3D printed parts of the tripod support with interlocking elements. The probe and reprobe method were executed faster when the design without external material for assembly was tried. In further development it had a leading role in the design and also in thepersonal printing process. No use of glue or screw to fix the parts could have been obtained with proper interlocking shapes and gaps for movements. The central part of the design was ideated from one-ball rotational bearings as the movable components were printed in one. The mathematics required to determine element sizes according to the resolution of the desktop 3D printer and the correct gaps between components were critical. We can say that the three legs and the upper closing smooth surface naturally serve as the interlocking elements that build the whole object together. There are three size variations that can adapt to the height of a table Luca is using in her workshop, since she has a standing table and a sitting table as you can see on figure 26.

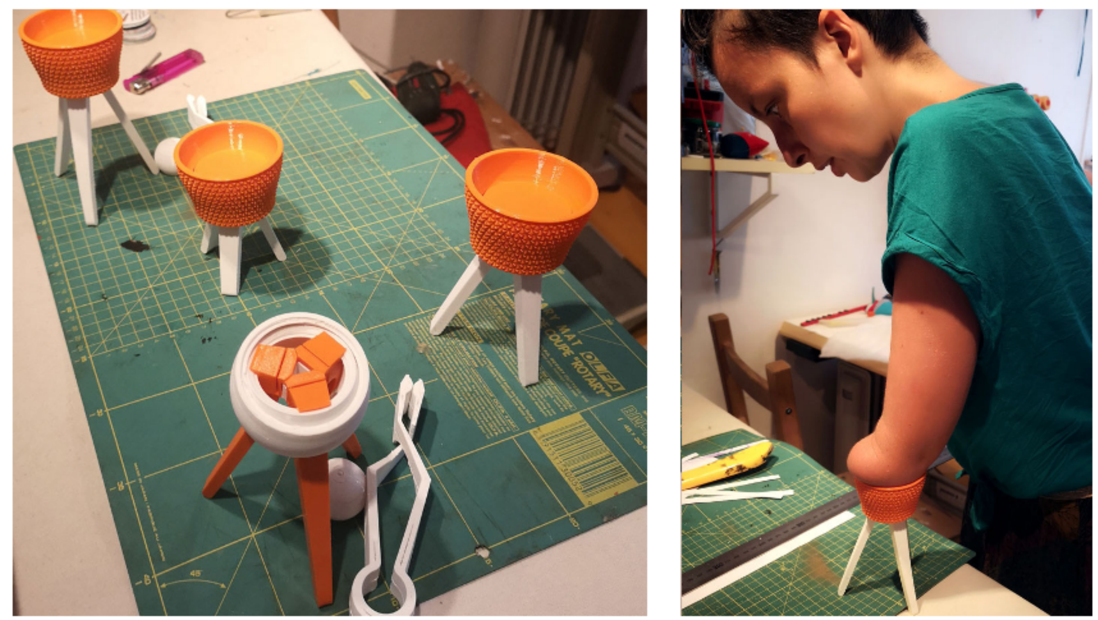

Figure 24: Size testing. Photo by Renáta Dezső.

Figure 25: Tripod support movement by Luca. Photo by Renáta Dezső.

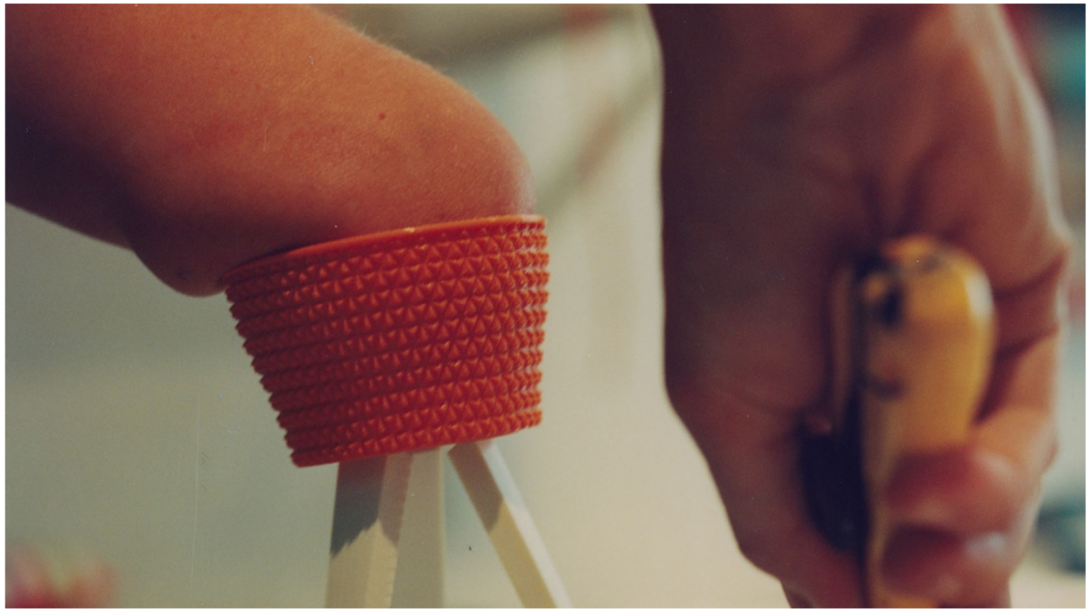

Figure 26: Flexible connection with the elbow stump. Photo by András Ladocsi.

Figure 27: Luca Szabados testing the prototypes. Photo by András Ladocsi.

Figure 29: Leg development series. Photo by Marcell Kazsik

Figure 30: 3D printed bearing gear with the tangible exterior. Photo by Marcell Kazsik.

Figure 31: Try and Error versions. Photo by Marcell Kazsik.

Figure 32: Various versions of the prototype. Photo by Renáta Dezső.

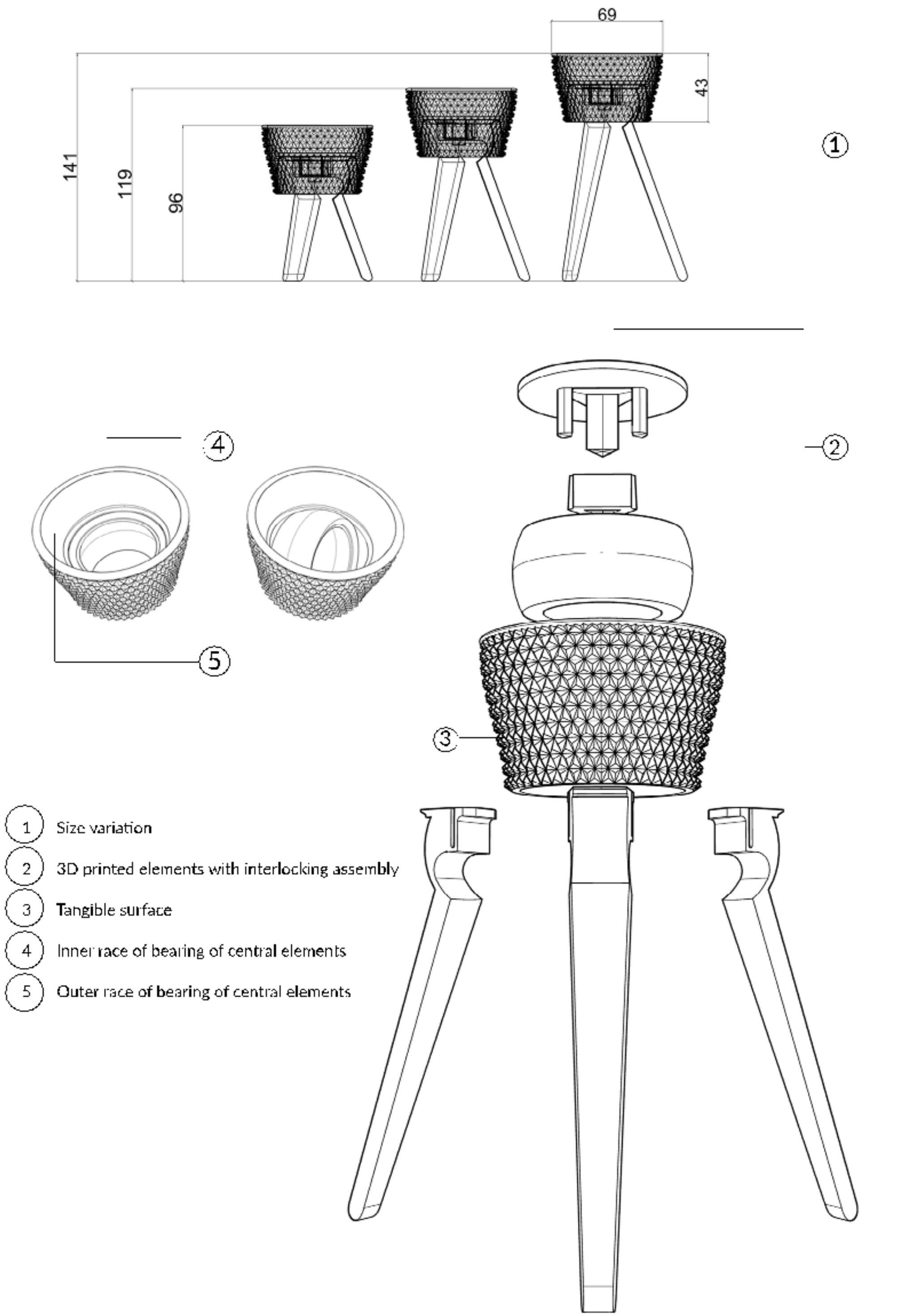

Figure 33: Exploded view and assembly with the centre element with tangible outside surface and bearing feature with the necessary gap to be able to move but printed as one piece.

Figure 34: Luca Szabados cutler use with the prototype. Photo by András Ladocsi.

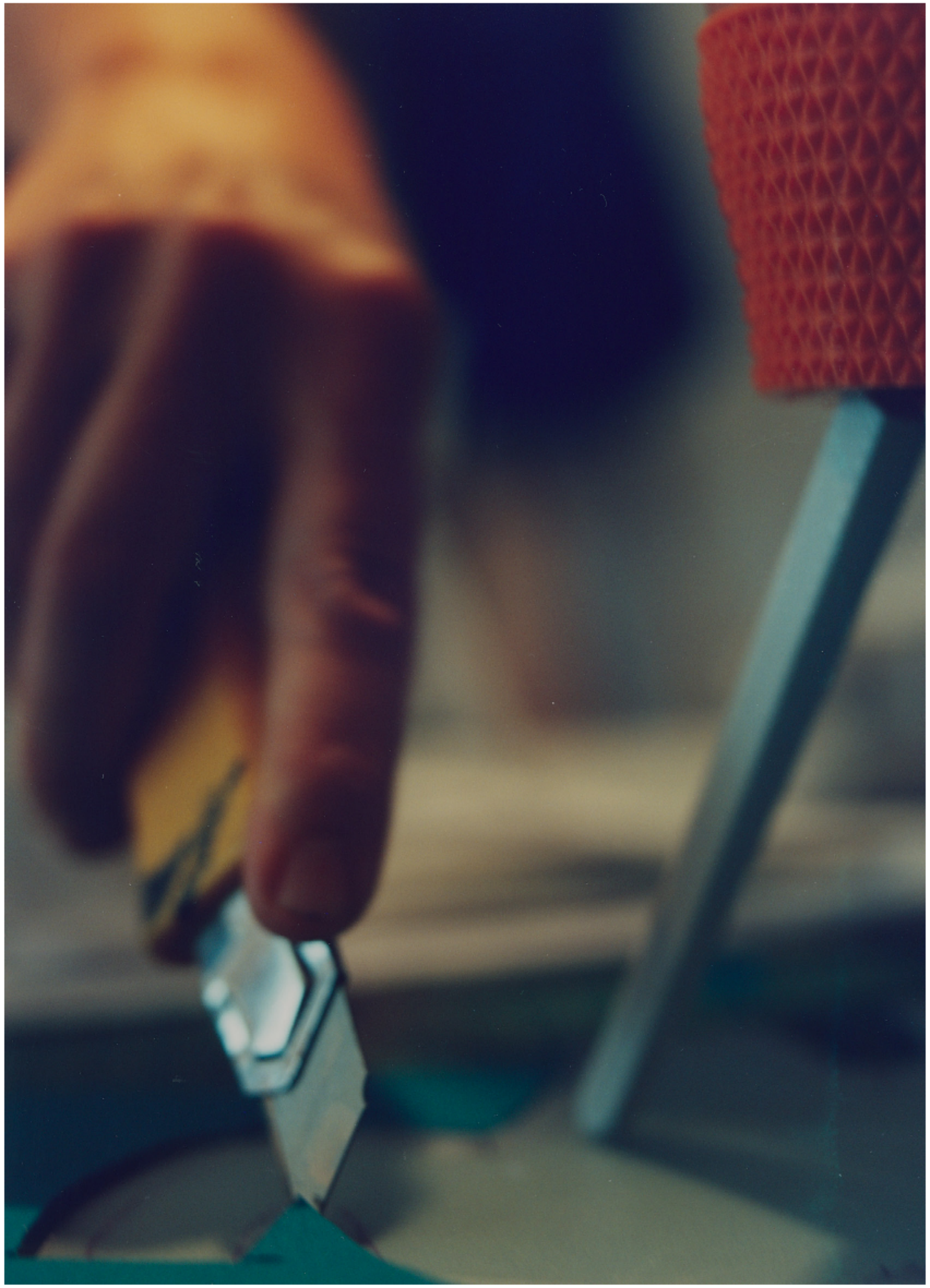

Figure 35: Hand and prosthesis side by side. Photo by András Ladocsi.

Modular grip:

We continuously returned to the question of what else could be useful for Luca as a prosthetic; what are the situations where an artificial tool can be useful for her? There are several small situations, mainly activities that relate to preparing a meal or social involvement such as card games or beauty routines such as nail colouring or hair drying.

The secondary sets of constructing elements support the structure of prosthetic development. The structure contains three elements:

- A side piece is an element that is connected with the elbow stump. It helps to fix the prosthetic. It was necessary to have an easy fitting that can be managed on the spot – An adaptive mechanism towards the human body.
- A modular element to connect with a particular object or a surface. This element adapts to the required function and object – A modular adaptive mechanism towards the outer world.
- A central bearing piece is an element in-between the other two to support the assembly, provide flexibility, and constitute possible modular variations – A fixed element in size and form.

All are made for short-term use, where a prosthetic tool could be used for 1-30 minutes. To adapt for independent application of a prosthetic tool to Luca's elbow stump, I developed a flexible side piece that is easy to attach or detach to the outer face of the central bearing element. The ideation originates from the double Gaussian curvature laser cutting wood technique. The designed set of side piece elements allowed Luca to quickly and simply fix the prosthetic to her elbow stump and quickly release it in seconds. Also, the flexibility of the features following Luca's arm movements without limiting discomfort was supported by the shape of the sidepieces bending in one and two directions while lightly increasing in stiffness and load capacity. To put it on was practically a second long movement, while at the same time, it allowed Luca to handle lightweight objects with the prosthetic tool on. The technical challenge in the side elements was to design a rigid fabric into a flexible one. I had not used parametric programming but classical Rhinoceros 3D modelling. The CAD modelling and the 3D printing workflow allowed me to improve as I learned from failed attempts to find a three-dimensional solution based on a variety of hinges. It was crucial to understanding some generic analytic themes of the prosthetic prototypes, such as the representation of the engineering aspect of the design, which does not comprehend the complexity of uncertainties and ambiguities of social context. The exploration of the diversity of a social phenomenon resulted in a large number of prototypes with various levels of execution.

In this case, the other side of the central bearing part is designed for possible modular assembly for further development and for adaptive pieces in the future. The logic of the design follows the same structure as the tripod support design logic. Once they are locked in place, the interlocking tree part forms a bearing bed for modular adaption. The external modular elements had a single ball as rolling elements locked into the bearing bed.

Once the main part of the modular grasp prosthetic tool is assembled, any newly developed function is easily attachable and detachable into the main centre piece. Two versions are presented below for the flat grip function. One is a general autoclip forceps; the second is a large mouth clip for card games specially made for Luca's request.

The roadmap of the details in the artefact suggests that I highly relied on my previous design experience in ideation and in the development of critical elements; meanwhile, I needed to be open-minded and critical about the prototypes, recognizing that whilst there were corroborating forms of solutions, there were ill-fitting models even for 3D printing and

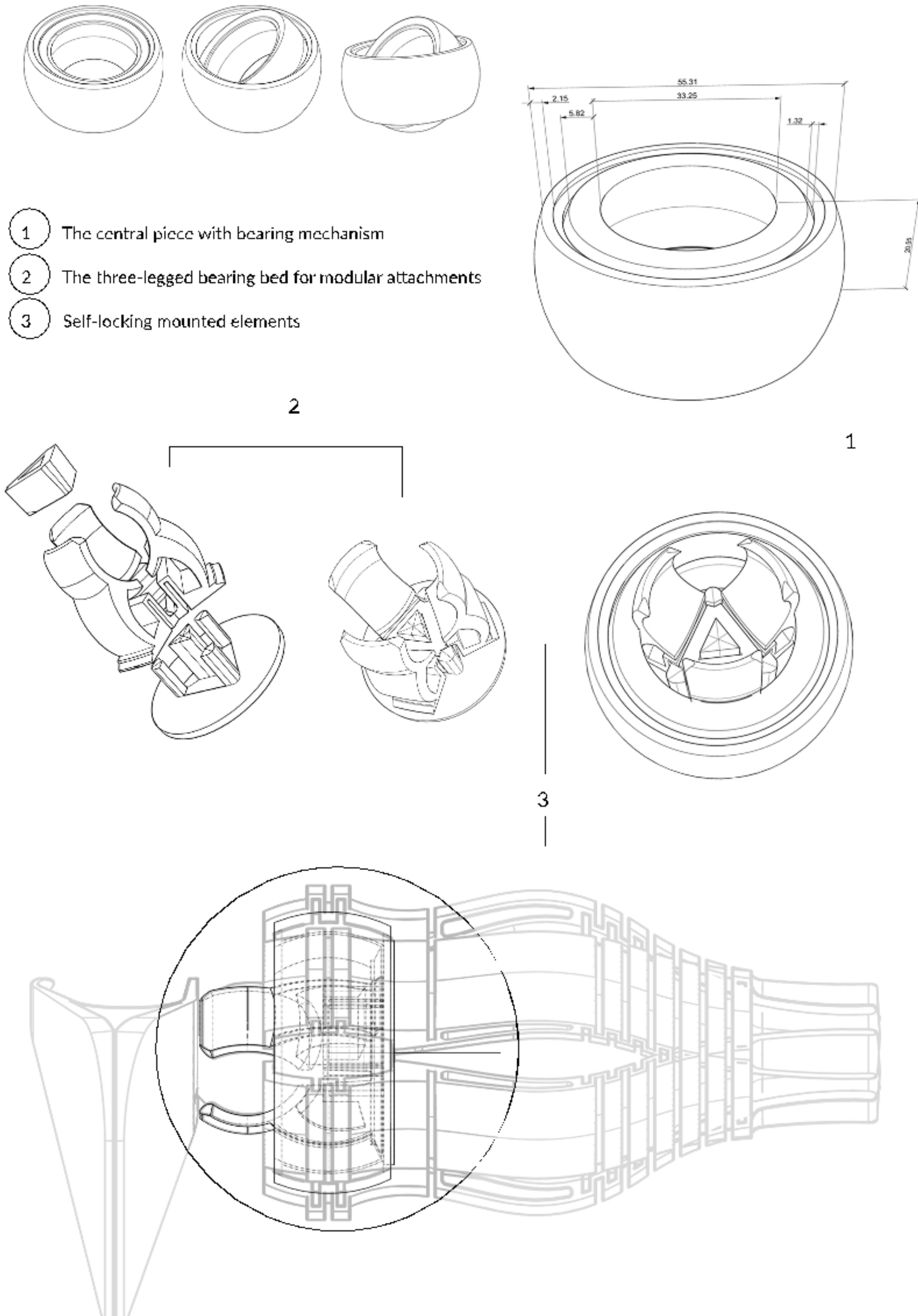

Figure 39: The main elements of the modular central piece.

Figure 36: Flexible adaption on the elbow stump. Photo by Renáta Dezső.

Figure 37: Modular element for card games. Photo by Renáta Dezső.

Figure 38: Flexible adaption for card games and support. Photo by Renáta Dezső.

Figure 40: Close-up of the modular attachments. Photo by Marcell Kazsik.

for usability testing as well. It is essential to acknowledge and illustrate the reason behind this. In some development phases there were obvious opportunities to try out another CAD model and/or a new 3D printing method, or just to take the findings for further testing and discussion.

The primary and secondary data of information both affected the evidence/artefact development. Primary knowledge already publicly exists on 3D printing. I also had several years of experimenting on various desktop printing to have primary sets for constructing research of the details.

Printability issues in the design to adhere:

- Applying a flat surface on each element for the initial layer defining the built orientation to ease the printing is a simple task that turns into a complex problem in connection to a biological form of a human body.
- FDM printed parts may require support structures to print successfully since a new layer is built upon a solid scaffold. The goal was set to model features on the prosthesis that does not require support with overhangs that are less than 45 degrees. As an effect, the printing time is shortened, and it is without detrimental impact on the surface from the support. Also, the post-processing time is shortened, which allow fast prototype testing time around. As far as the aesthetic side is concerned, its result is a visually different shape than a form from subtracting or moulding technologies. Therefore, it was not merely a technical and functional decision but also a designer issue since I decided to develop the form representing the attributes and aesthetic of the technology.
- Topology optimization means using an optimal method to minimize a part's mass while maintaining structural integrity constrained within a set of limits of printability. The optimization during various stages of the design process allows a more detailed design to be obtained. Since it is not a 'one click' process, the functional prototype testing process was easily aligned with the effort of optimization.
- Interlocking printing assemblies with moving parts in a single built. The orientation of the assembly on the built platform is affected as well.
- Lattice hinge design to improve the flexibility of the solid plastic material. Lattice hinges are a set of parallel, overlapping cuts that divide a solid shape into thinner, linked sections in an array of parallel divisions that determine flexibility in the material properties by geometry. They also affect the orientation of the building platform.
- 0,3-0,5 mm clearance for interlocking fit between elements
- 1,2mm minimum wall thickness in a single wall
- Easy assembly, easily mountable mechanism
- In FDM technology, the minimum future is<2mm; the desktop printer does not allow more minor details and precision models.

The transactions with the three-dimensional data were produced, shaped in turn by Luca's personal experience, the designer's ideas, and the analytic procedures of the research. The knowledge is the outcome embedded in the data of the artefacts affecting the transactions within the design and the social world, shaped by the methods of co-design inquiry for a 3D printed prosthetic artefact. Analysing the design process from contrasting angles communicates the complexity of the subject, encourages the exploration of alternative strategies in the design and also stimulates the sensitive appreciation of complexity and variety as Coffey and Atkinson suggest: 'The more we examine our data from different viewpoints, the more we may reveal-or indeed construct-their complexity' (Coffey and Atkinson, 1996).

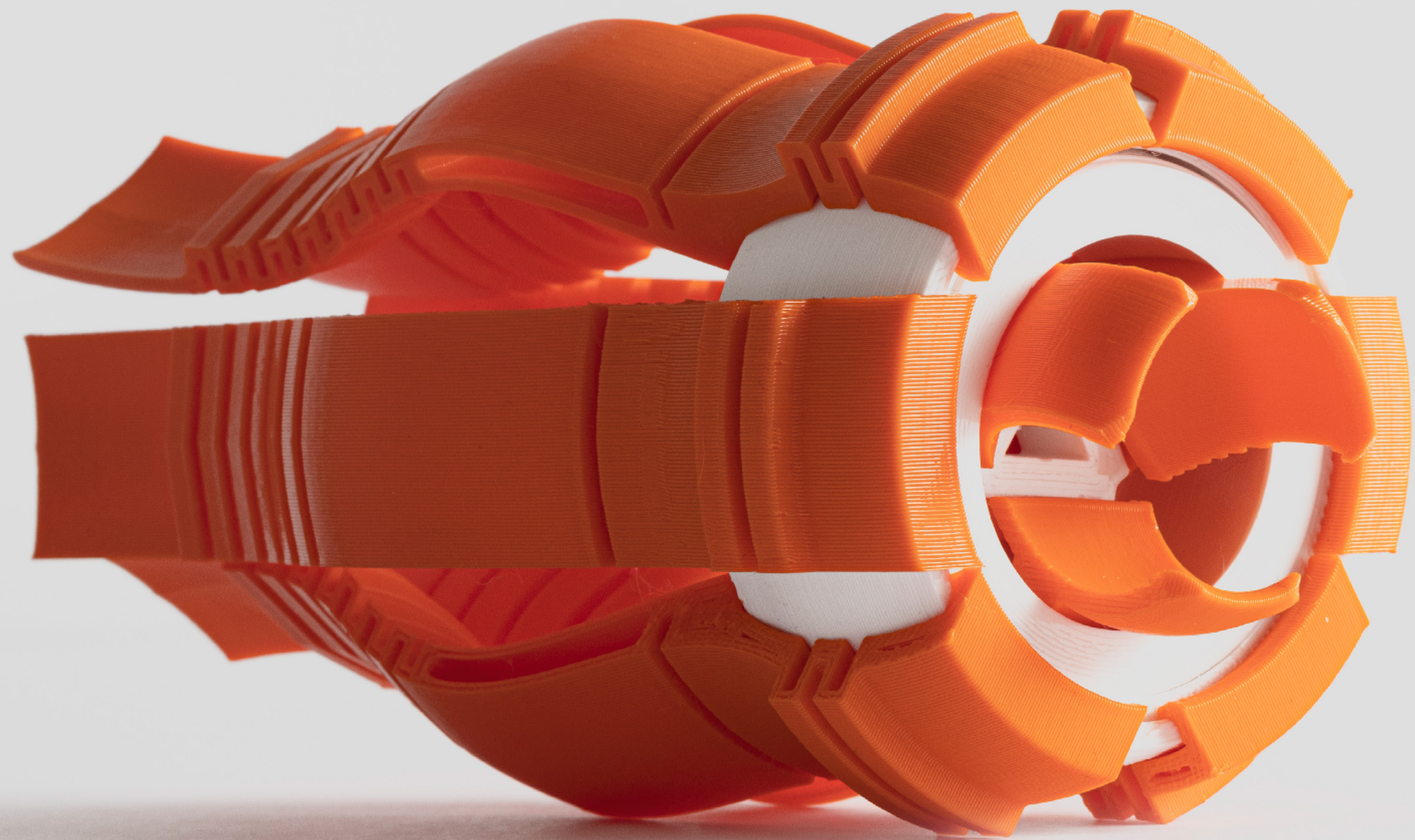

Figure 41: The modular grasp basic structure 3D printed and assembled. Photo by Marcell Kazsik.

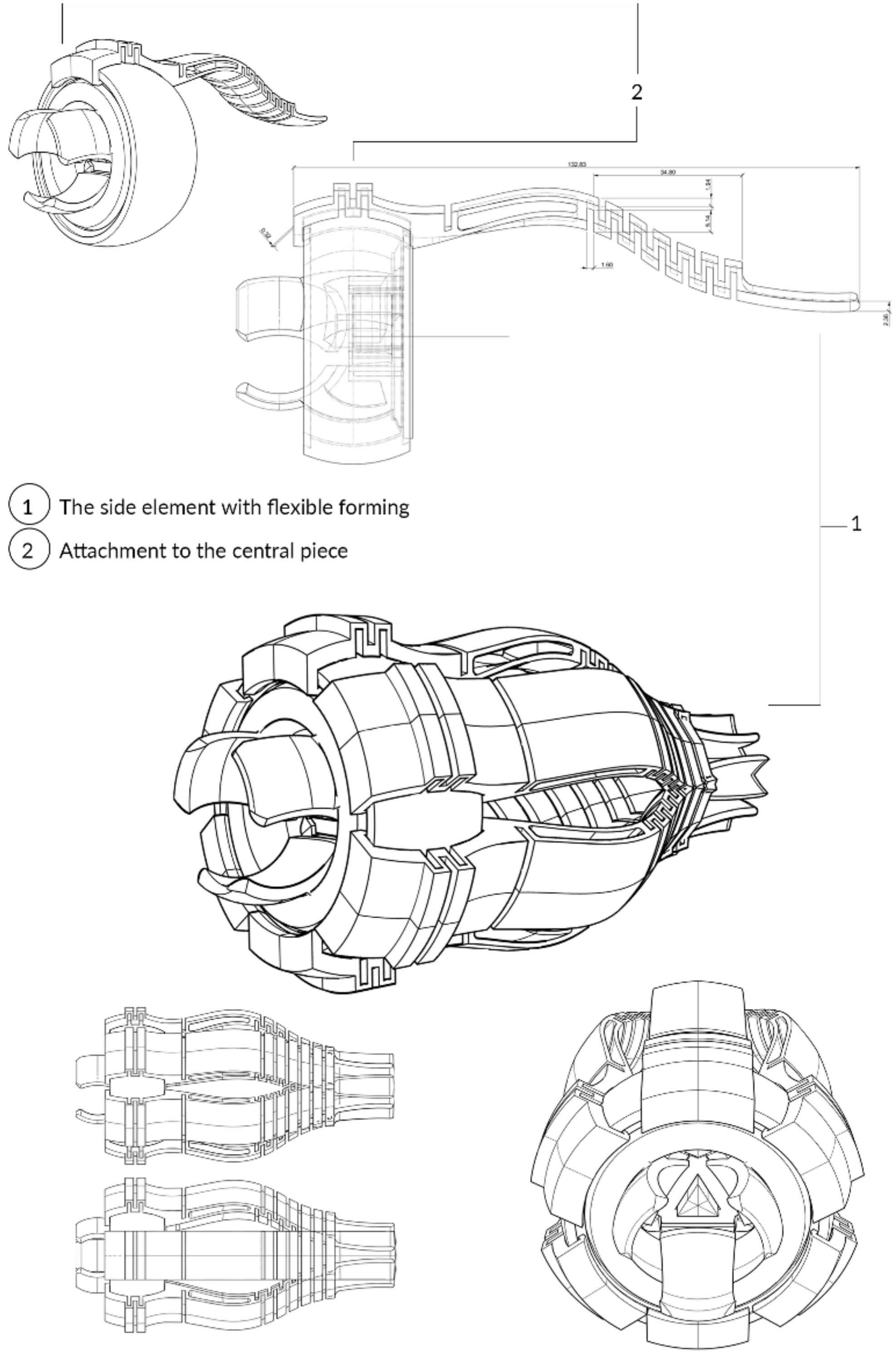

Figure 42: The modular grasp basic structure assembled.

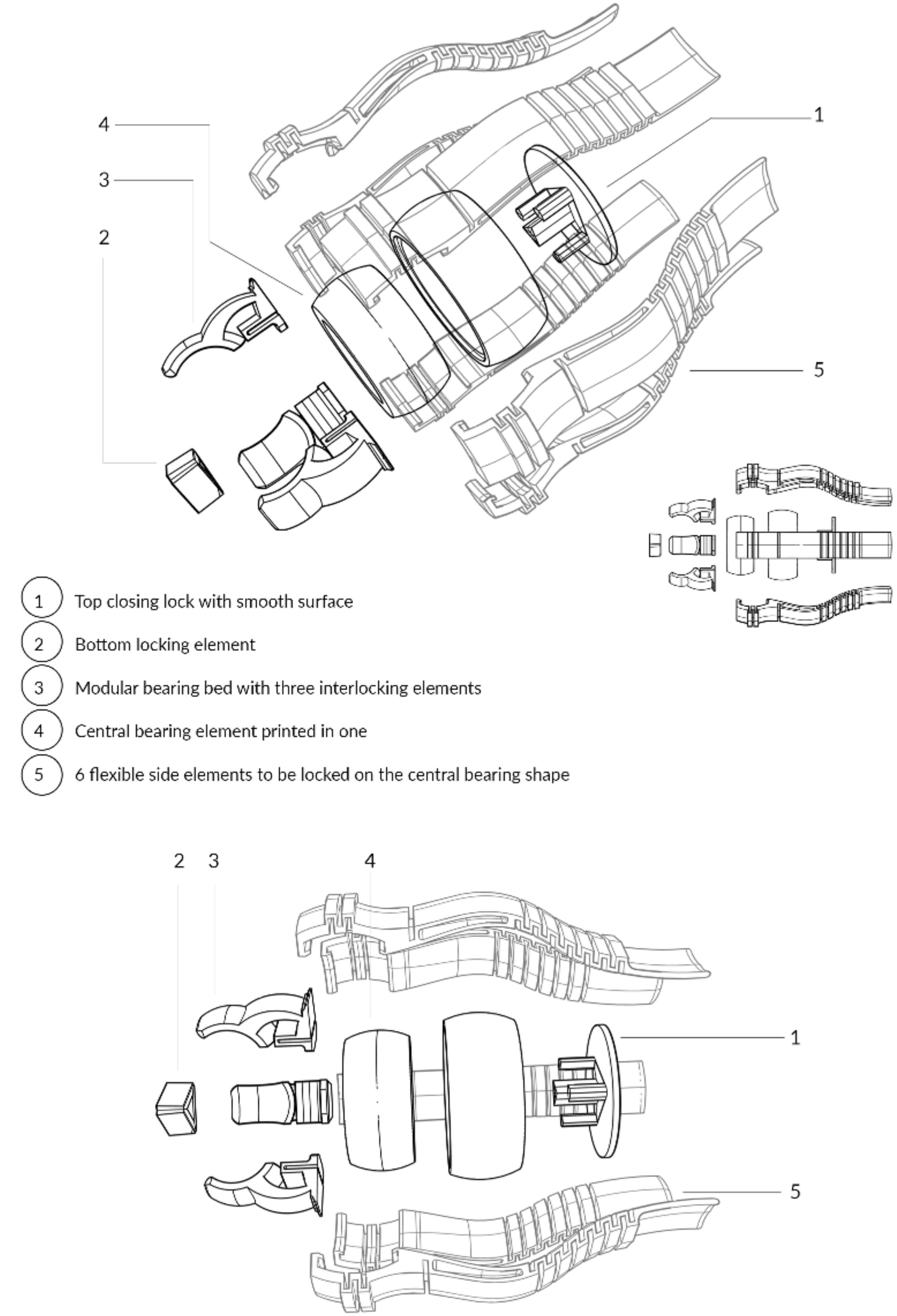

Figure 43: Exploded view of the central part of the modular model

Figure 44: 3D printed modular grasp central pieces with attachments. Photo by Marcell Kazsik.

Figure 45: Prosthetic prototypes are waiting for testing. Photo by Renáta Dezső.

Figure 46: Luca Szabados testing the prototypes. Photo by András Ladocsi.

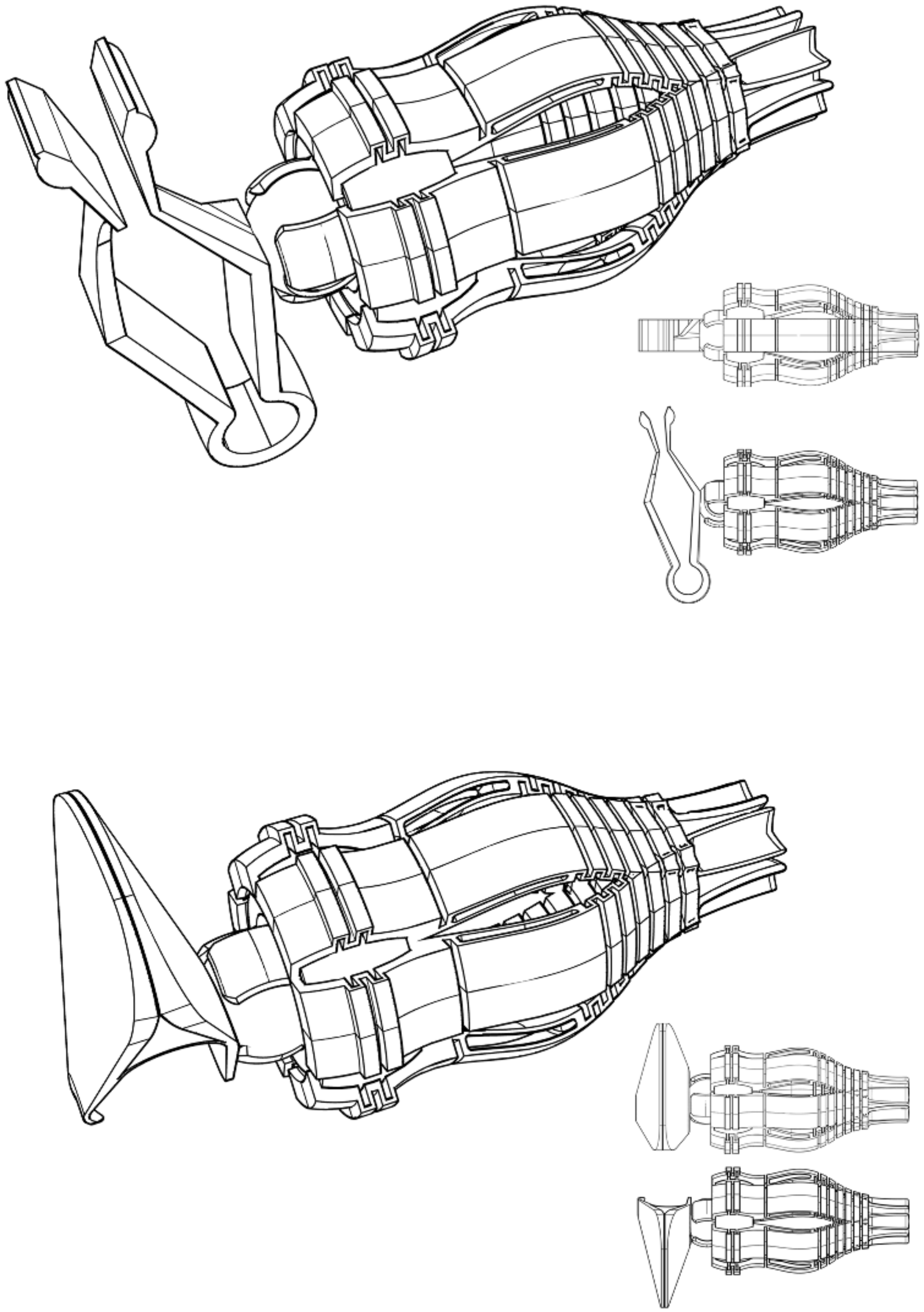

Figure 47: Two modular grasping elements attached to the central piece.

Figure 48: 3D printed attachable forceps. Photo by Marcell Kazsik.

Figure 49: 3D printed attachments. Photo by Marcell Kazsik

Figure 50: 3D printed forceps positioning. Photo by Marcell Kazsik.

co-design process to co-Ability concept

In this chapter, I reflect on the methodology of the design process, on what was done during the making and the testing processes. The thoughts and reflections here follow an earlier logical initiation already described in the previous chapter. Co-design was not a pre-selected, desired method at the beginning of the research. It only appeared by considering a specific design territory that combines craftsmanship and digital technologies driven by disability studies, but as it turned out, co-processes could initiate a new epoch with immense effects on the everyday life of the 'common person'. My interest has grown in understanding what could happen if we considered that cultural artefacts were produced by those no longer invested in maintaining human superiority in culture and politics? With the methodological approach of the co-design framework, I point to the junctures where technology, bodies, and cultural theory intersect. The presented co-design processes account for a decentralised soft assembly in which disability, technology, and design act as equal partners determine co-Abled formations.

Working with Luca, we became partners in design development to find solutions with a shared goal and with our own specific skills contributing to the design process with solid constraints of direct cooperation (Visser, 2006). At our first meeting, Luca's initial responses instantly clarified that my design practice greatly relies on her feedback and her specific needs. During the rapid prototyping of designs in recent years, amidst a wide range of social problems, co-creation and coproduction approaches developed for innovation to incorporate the user's needs in workaround solutions (Bessant and Maher, 2009; Bevan et al., 2007; Ehn et al., 2014). The interaction modality helped to connect the designed prototypes with Luca's everyday life settings, including non-verbal and often implicit personal and socio-political symbols. On the one hand, this design process with the prototypical exploration of future possibilities and practices mediated and supported the redefinition of a possible reality with new social, economic, or political roles for all society (Björgvinsson, 2008). Disability identity is already channelled in the form of language or symbols such as enacting, communicating, or negotiating, all of which are often stigmatising indicators in social, everyday-life contexts. In this case, the parallel methodology to Discourse Analysis (DA) originating from linguistic studies with critical and semantical aspects in co-design led to a deeper understanding and innovative perspectives (Starks and Trinidad, 2007). The proposed cycle of prototypes and the design process present a 'plausible' set of concepts. Luca's viewpoint often added a contrasting account, moving the analysis further by connecting it all to the theoretical research work. The uniqueness of this doctoral research is embedded in the conceptual density of the chosen project because the validity of theories can change concerning contemporary social reality. Disability as a personal trait is dynamic. Disability studies and design culture progressively change, and so does digital technology. As various conditions change in such a case study project in the future, at any level of the conditional matrix affects the outcome. Barney Glaser and Anselm Strauss developed the grounded theory in the late 1950s. They undertook a scientific study of the human being with theoretical propositions to predict future events (Travers, 2001). Throughout the course of (designing) the prototypes in the case study project, the analytic approach was 'a general method of (constant) comparative analysis' (Glaser and Strauss, 1999), similarly to the Grounded theory in social science where 'the approach is often referred to as the constant comparative method' (Strauss and Corbin, 1994). The common ideology of design suggests that the designer develops the idea of an object and then anticipates the creation process in mind. The practical part is where the pre-computed and evaluated procedure is executed. To reflect on digital craft methods in making and observing objects and processes, I present reflections on my own practices. Instead of interpreting as a designer what is observed to conclude in focused terminal design development, it was the constant production of design prototypes that worked as a statement of the concept later verified by testing and discussing with Luca. While Luca did not always explicitly know how to translate her preferences into the object, I was the designer who completed the act of translation-interpretation by designing the prototypes further (Ventura and Shvo, 2017). This co-creation cycle was not only between the designer (me) and the person with a disability (Luca): the same cycle appeared in working with digital manufacturing technology. This methodological approach of co-design framework depicts the morphological interrelation of technology, bodies, and cultural theory.

After developing the 3D model from earlier data, the direct testing in the prototyping process began. Understanding a framework to analyse the role of emergent knowledge in digital craft practice was incipit rather than explicit. Many years of experience in additive manufacturing allowed me to do shorter turnaround cycles. These cycles are the co-creation phases with digital manufacturing. The implicit, pre-embedded knowledge of digital manufacturing makes the testing cycles almost subconscious; due to its physical nature, it is not easily transferred when the format of sharing is text-based, but the long printing hours and the errors in printing render it explicit again. Digital craft and the traditional craft technique are based on a collection of routines like sensing, acting, and moving. During these activities, the mind is predominantly focused on bringing an object into life with the help of direct contact with a specific material. The craft is built by action sequences performed in space and time, while the supplement is built on reliable environmental properties. It is like scaffolding upon external material structures with digital technology as an action-and-context-specific external control structure that guides the digital craft practitioner.

For example, in the traditional craft practice of glassblowing, a glass designer works in complex and effective feedback loops between movement and bodies of materials: the timing is inextricably interwoven with the glass transformation temperature, and the material is indirectly connected to the practitioner, and the material data is detected through the tools used.

Figure 51: Gergely Pattantyús glassblowing at MOME Tech Park.

As described by Andy Clark in his book 'Being There: Putting Brain, Body, and World Together Again', there are a variety of ways in which cognition might exploit real-world action so as to reduce the computational load for the mind (Clark, 1989). He means that scaffolding is where the bodily dynamics involve external memory-store from the material world and soft assembly, and then decentralised problem solving occurs. In order to learn about the world and the materials, specific actions are performed during the crafting exercise and the mastery knowledge itself is often acquired in an action-specific way with interaction modalities. Scientifically speaking, it can be viewed as 'sloppiness', 'chaos', or 'opportunism', but in the development, the risk of error and uncertainty has the essential function just as in science 'in the development of those very theories which we today regard as essential parts of our knowledge. These deviations, these errors, are preconditions of progress. Without 'chaos', no knowledge. Without a frequent dismissal of reason, no progress' (Feyerabend, 2010).

Figure 52: Gergely Pattantyús glass artist and lecturer and James Carcass glass artist and invited lecturer at MOME Tech Park, Luca Szabados prosthetic prototype testing at her workshop. Photo by Renáta Dezső.

As I described in the earlier chapter, a 'co-designerly' way of knowing through digital-craft work involves bodily dynamics and the use of simple kinds of external memory stores (Cross, 1982). To understand the working procedures better, it is essential to dwelling on errors, just as Richard Sennett states in 'The Craftsman' (Sennett, 2008). Studying the errors of the external material structures support change and development. It is implied that working with digital fabrication technology is necessary to have indecision and material learning. Error and failure are important, because that is the leading way of truly understanding a developing form or object.

Heidegger's famous example of the broken hammer provides access to the present-at-hand (as opposed to ready-at-hand) and hence to abstract philosophy and a scientific stance towards discussing the network between artefacts, entities, interactions, and systems such.

> 'The less we just stare at the hammer-Thing and the more we seize hold of it and use it, the more primordial does our relationship to it become, and the more unveiledly is it encountered as that which it is as equipment…' 'If we look at Things just 'theoretically', we can get along without understanding readiness-to-hand. But when we deal with them by using them and manipulating them, this activity is not a blind one; it has its own kind of sight, by which our manipulation is guided and from which it acquires its specific Thing character' (Heidegger, 1962)

Errors do not just render an 'invisible' tool suddenly visible, but they redirect the focus onto what matters in the situation. During iterative changes supported by errors, the practitioner often only remembers the present-at-hand situations with the design. This raises a few questions: how might a relationship between 'head' and 'hand' + 'materials' + 'tools' manifest itself in the context?

In the object-oriented discursive co-design actions described earlier, the interaction modalities with the material help shape the forms of the prototypes. At the same time, the prosthesis prototype also renders the maker conscious and shapes the person's thoughts by leaving the generally invisible elements visible when presenting 'errors' during the process. The ideal prosthesis, in Heidegger's terms ready-at-hand, is the one that fits seamlessly or invisibly into a meaningful network of actions, purposes, and functions. Being part of one's action becomes part of 'oneself', 'one's body', part of a domain of 'ownness' or 'mindedness'. Meanwhile, according to Heidegger's terms, the created discursive prosthetic prototypes in this process are present-at-hand, providing reflection, improvisation, and developments by delivering errors. The forms of the prototypes are not waiting there all along to be discovered, and they do not look biosimilar to an anatomical hand. The co-design process is an involved, embodied action loop in which key elements act innovatively through collections of moments ready-at-hand process.

Based on Heidegger's philosophy, there is a discussion about the double life of equipment, the tool in action when it is invisible, and the tool presenting error and rendering conscious visibility. I would suggest the two modalities should not be based on the existence of a tool or material but should be based on human perceptions. In the previous chapter, I analysed the parallel modality (animated vision and exploratory tool of touch) between exploring the environmental data and the self-awareness that can lead to understanding the world around us according to how we understand ourselves. The two dominant binary modalities are in opposition, cooperating in recognising information.

'Co-design assemblages allow us to ask important questions about power, authority and resistance. However, while the co-design process assembles a multi-componential model with a design goal, it also represents a formally unstructured attitude that is instead managed by a shared philosophical understanding. Co-Ability is a new concept and a new productive, ethical relation that is not a definition of how people work together with others towards a shared goal – instead, it offers an interpretation of how we, biological/artificial, human/nonhuman, elements/networks become relational in a complex manner that connects us to the multiple. In this condition, shared competence is a distributed phenomenon rather than an individualised trait. Our understanding of the actors involved in design practice will deepen if normative power is not exercised. The understanding of co-Ability is grounded on posthumanist philosophy and critical disability studies outlined by scholars such as Rosi Braidotti (2013) (2017); McRuer (2016); Goodley (2014) (2017); Goodley & Lawthom (2009); Campbell (2012); Wolfe (2009); Meekosha and Shuttleworth (2009); Shildrick (2009) (2015); Liddiard (2014); Mallett & Runswick-Cole (2014); Ranisch & Sorgner (2014). The concept of co-Ability contributed from the perspective of disability studies and that of design culture offer alternatives for the dominant 'humanist man' (Braidotti, 2013). The term co-Ability is not the opposite of the term "disability", nor is it the contradiction of ability. This term applies to the relational matter of our world. Many posthuman transformations already occur every day across the globe since our life is technologically mediated daily. Our physical spaces and the social spaces liaise by networked computational media' (Dezső, 2019).

Co-Ability is a transformative language engaging directly with the reauthoring perspective on social architecture and roles stuck in 'contested concept of humanity' to 'approach humans as embedded in a network of relations between humans and non-humans' (Trigt et al., 2016). It brings a new social ecosystem built on relational autonomy conditioned by the social relations in which individuals are embedded to enable life to flourish (Winance, 2016). Relationality means not to think beyond disability or opposition of humanity but to reconsider the domination of any elements and represent the reciprocal interaction in forms of meaning-making and sense-making in everyday practices.

How can the structure of embodied knowledge in perceptual awareness be related to body-centred human norms in society? By investigating the reciprocal relationship between new technology in prototype fabrication and unfolded new ideas, the notion of the spirit of posthumanism appears to be directly questioning how contemporary technologies contribute to the powerful social or philosophical repercussions in human life. The ways in which knowledge is formulated after the genuine question of what it means to be human. The politics of technology render it invisible and seamlessness to blend into the fabric of everyday life (Forlano, 2018; Weiser, 1999). It is easy to dismiss the material realities of technologies, including the ways in which they are entangled with human bodies, environmental resources, and political economies or the ways in which they embody our ethics and values. When the material realities of technology are explicitly studied, we can reconsider human co-evolution with technology that repositions and reinterpret what it means to be human amongst nonhuman actors. The relational posthuman model greatly expands our understandings of the multiple agencies of technology. There are related concepts of the posthuman perspectives that differ in many aspects, such as the non-human, the multispecies, the Anthropocene, the transhuman, and the cybernetics theories. By using the critical approach in posthuman studies to exceed human-centred norms, I address the repertoire of experiencing reciprocal connectivity in the Rosi Braidotti sense (Braidotti 2013). Posthumanism integrates human and non-human actors in the networks that share equal agency when it comes to participating in actions with shared competence. Liberal notions of autonomy are equally crucial in our value systems: responsibility, self-determination, solidarity, community bonding, social justice, and principles of equality supported by humanism. To bring us towards exploring co-Abled formation further, the interpretations of 'online' and 'oine', or a conscious–unconscious representations of the body, can help (Carruthers, 2007).

In the case study design process, the question is as follows: why do we want to make a prosthesis that looks biosimilar to an anatomical hand-worn long-term when the actual function does not need such a complex form? Is it connected with our mental representation of the body considering another person or ourselves?

'Since 1905, when Bonnier first introduced the term "schema" to refer to the spatial organisation, almost all neurologists have agreed on the existence of mental representations of the body' (Vignemont, 2010). We have a radical recognition of bodily functions (e.g., health span, longevity), cognitive and emotional capacities (e.g., intellect, memory), physical traits (strength, beauty), and behaviour (e.g., morality). On the basis of the affirmation of specific traits, there is the relational matter of considering another person or our self' (Dezső, 2019). The self-aware knowledge of our body is linked to the body-image, which is a mental model joined to all affective, cognitive type elements traced in our body (Molinari and Riva, 2004). 'In addition, Vignemont (2010) says that the body image can be applied both to one's own body and to someone else's body' (Dezső, 2019).

After Ungerleider and Mishkin established the well-grounded theory of the Perception–Action model (Mishkin et al., 1983), Paillard distinguished the main dualistic aspect "the identified body" (le corps identifié) and "the situated body" (le corps situé) (Paillard, 1991). The body-image is connected to our perceptual body identification and recognition, and based on it, the body parts are judged predominantly in a visual manner. We build the concept of the whole by including information on the organisation of the elements that are relatively structurally stable (Dijkerman and de Haan, 2007). Changing a visually stable body image is fairly difficult, as it is preserved even when a situation is changing the actual body (Vignemont, 2010). Most commonly, the natural changes appear with age, such as the change in hair colour, tone of body parts, etc. Traumatic changes like amputation call for a more radical restoration of body image 'applied both to one's own body and to someone else's body'. Luca is missing her upper limb by a congenital disability, and the concept of her own body image is developed in self-recognition through her personal history at an early age. An external viewer's self-body image concept develops differently than Luca's, so when one recognises that the organisation of Luca's body parts is different from their own structure, they tend to assume the need for radical restoration with a biosimilar looking prosthesis. In this analysis, the 'body-image is related to the body-centred human norms in society. Ideals of bodily appearance that are impossible for most people to achieve are cunningly promoted as the necessary norm, thus condemning vast populations to oppressive feelings of inadequacy that spur their buying of marketed remedies' (Bordo, 1993; Dezső, 2019).

Luca's refusal of a classical prosthesis was not based on looks or on how it helps her visually blend into society. Her response focused on bodily experiences such as weight or how a prosthesis is disturbing and causing changes in body movements or brings discomfort. Her answers lead to viewing the action-oriented body representation that is constantly updated by an action called body-schema. The information about what is 'necessary for body motions such as posture, limb size, and strength' based on implicit elements traced in everyday actions (Dijkerman and Lenggenhager, 2018). In the complex phenomena of body-schema, we often encounter the 'motocentric' knowledge when an embodied; embedded agent/object/prosthesis prototype is acting as an equal partner in adaptive responses to the environment, which draws on the co-Abled resources of mind, body, and world. It is intimate correspondence feedback and interactions that follow the rhythm of the object and the body.

With the help of the various data embedded in the artefacts, the prosthetic prototypes for this study were collected over a period of five years. In the early context of the case study – during the first year of the co-designing process – we were unaware of co-Ability theory being embedded in the process (Glaser and Strauss, 1999). After becoming aware of co-design mechanisms and the critical disability studies, we discussed co-Ability in the design context with Luca. 'Memory note taking' was in the digital design and remained close to the design process. In this period, the article on co-Ability practices was published at the 8th biannual Nordic Design Research Society (NORDES) conference at Aalto University, Finland (Dezső, 2019). Following the process, more abstraction was built directly upon the prototypes revisiting cycles to be checked and refined by designing further prototypes.

I defined four sets of elements that interact on three different levels 'to articulate the co-design assemblage in layers of theories, competence and body of entities that establish a principle of relevance for knowledge' (Dezső, 2019).

'Keyplayers' as non-static and changeable entities in the co-design process:

- The disability entity is based on Luca bringing her implicit knowledge of bodily mechanisms. On the disciplinary level, she represents the complex socio-political aspects of disability.
- The entity of Design culture embedded in the designer participating with First-Person-Perspective (1PP) (Höök et al., 2018; Tomico and Wilde, 2016; Tomico Plasencia, O. et al., 2012; Wilde et al., 2017). As a disciplinary, I add design culture in the doctoral research. 'Within RtD, the researcher and the objects created are entwined and cannot be separated, establishing knowledge through this relationship' (Isley and Rider, 2018).
- Digital technology represented by the desktop 3D printing process that has the potential of personalised low-cost object production in digital fabrication. On a disciplinary level, it was imperative to add computational technology and human-computer interaction (HCI) into the discussion (Dourish, 1999; Zimmerman et al., 2007; Zimmerman and Forlizzi, 2014).
- Artefacts as a media – mediating messages through the material reality of a prosthesis. The prototypes embodied a collection of mediated messages addressing social, cultural and technological insights in the artistic artefacts. Usually, the created forms take on existence as an entity whose meaning is determined by the character of the theoretical gaze to which it is subjected and by the explorative movements that are in use. Adopting the perspective and experiences of a digital craftsman, it differs from an observing interpreter of objects.

No partners in key elements alone had the independent knowledge to develop the prosthesis prototypes. The morphological suspension of distinctions in established institutional and professional boundaries in a design project with several key players such as designer and user, or technology and human, artificial and biological can generate novel approaches. Actor-network researchers (Dolwick, 2009; Latour, 2007, 1999) suggest that socio-material political assemblies collectively intervene with people, the artefact, and the process. All key players are small independent actors in a relationship for agile and open collaborative innovation supporting shared competencies.

It would have been more complicated to manage fast turnarounds with complex professional printing technology. The small independent infrastructural level stabilised the cultural practice with open innovation, and stability was brought by not being expected to become entrepreneurial with an extensive, corporation-like system. The morphology of co-ability can be described by the changes of the network-shaping character in certain situations (prototype creation, prototype testing, discursive reflection, literature review etc.). The morphing is activated by one or more members in a continuously transactional network. In this case study, the network and the described morphology is aligned with similar aspects of disability and co-design, both distinct, unstable in context and in time, presenting a never-ending process allowing divergence and change in key aspects.

As it is presented in this section, the research theory on co-Ability and the design activity constantly informed each other through the application of design practice and reflective discourse.

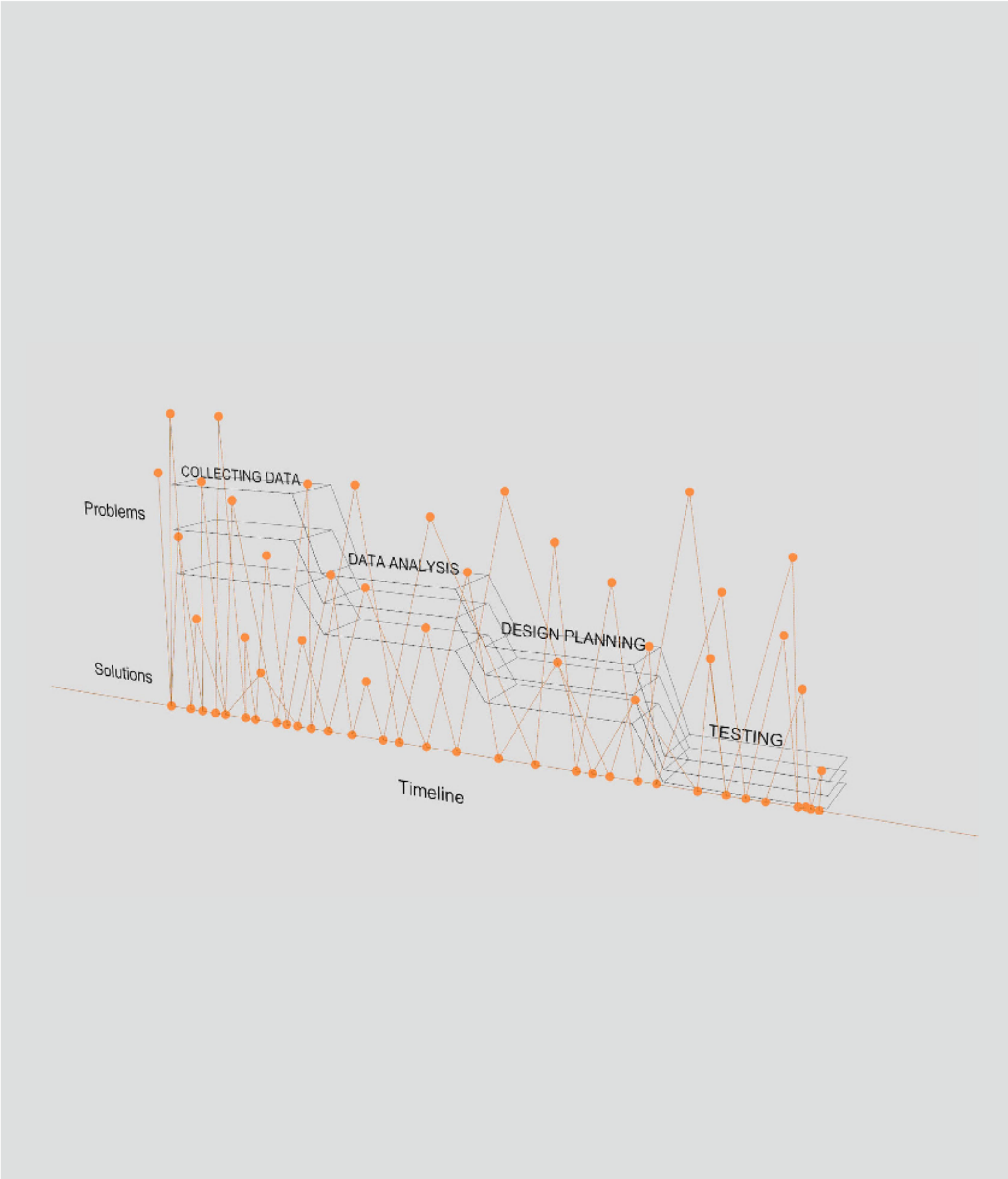

Figure 53: Pattern of the cognitive activity of the designer in co-design – 'jagged' line opportunity-driven approach (Conklin, 2005).

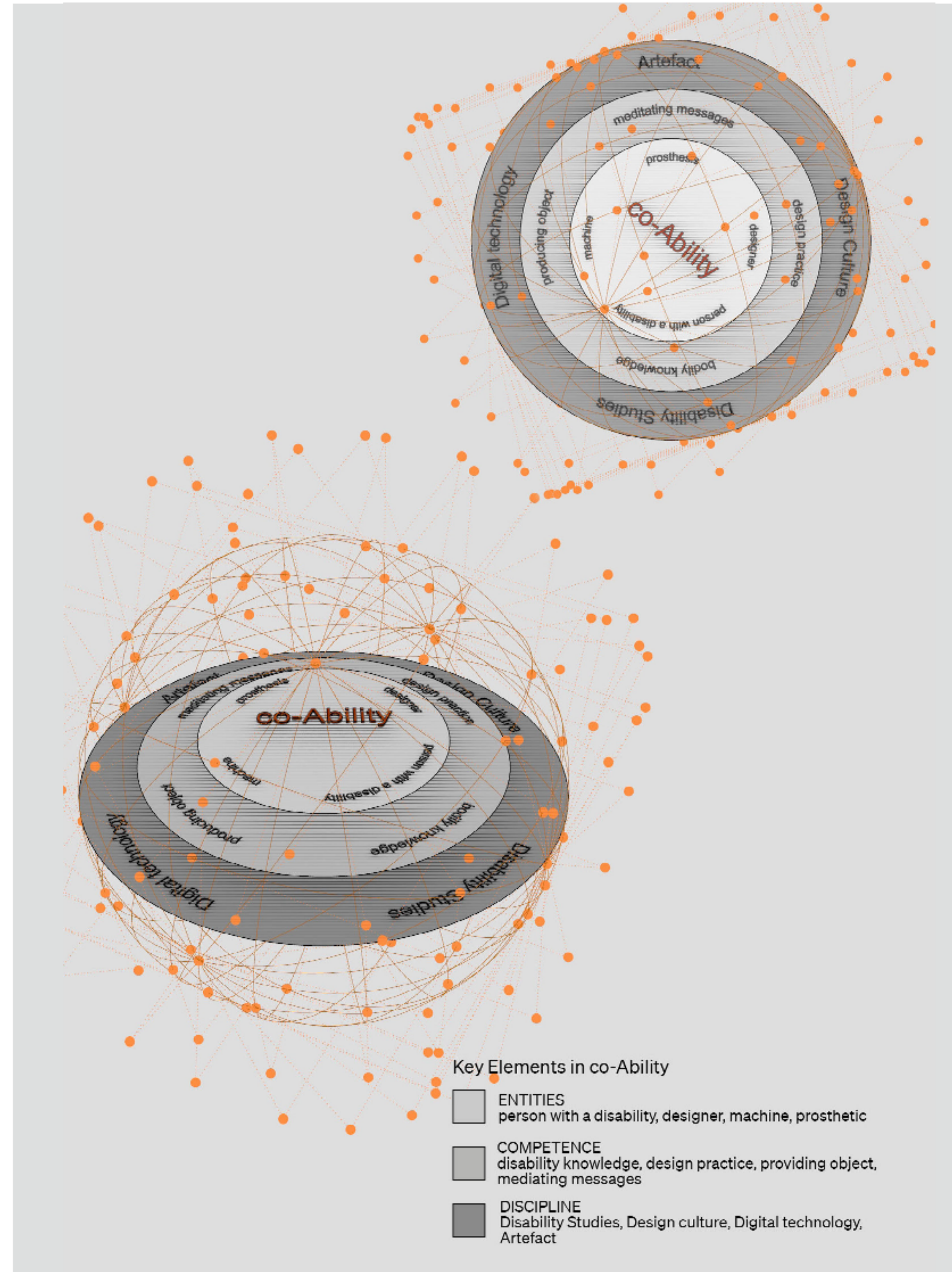

Figure 54: The key players, co-Ability assemblages in levels of disciplines, competence and entities. The yellow dots and the trajectories of the movements represent the patterns of activity as 'jagged line opportunity-driven approaches' described in Concklin works on co-design approaches (Conklin, 2005).

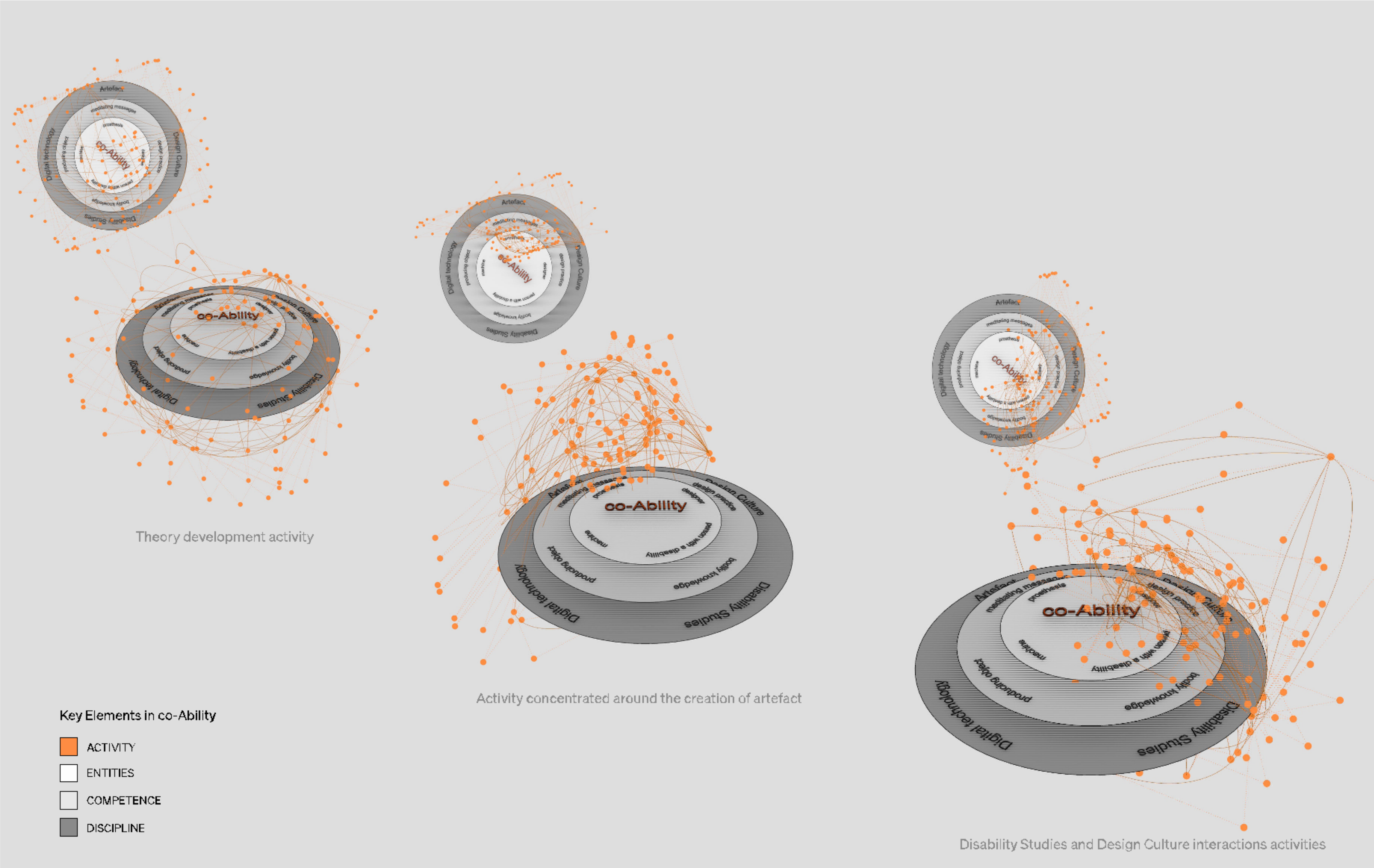

Figure 55: The morphologically changing aspects represented in co-Ability assemblages.

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