Open-Ended Design. Explorative Studies on How to Intentionally Support Change by Designing with Imperfection

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Proefschrift ingediend tot het behalen van de graad van
Doctor in de industriële wetenschappen: industrieel ontwerpen

UNIVERSITEIT GENT

Vakgroep Industriële Systemen en Productontwerp
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Faculteit Ingenieurswetenschappen en Architectuur
Academiejaar 2017 - 2018

ISBN 978-94-6355-061-1
NUR 656
Wettelijk depot: D/2017/10.500/96

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“Design is non-attachment and total engagement.
Design is control and uncontrollable.”

H.G. Nelson and E. Stolterman, (2012)

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SUMMARY

Design can be seen as the process of creation of what is not there yet, but what is *ought to be* in the future. In other terms, design is an intentional act that aims at modifying future reality. One of the main problems of this complex process is the gap that is spontaneously created once the product, from being ideal and belonging to the design space, becomes tangible encountering the real environment (which could be of production, distribution, use, maintenance, etc.). Products are in fact anything but static, predictable or under control. They are dynamic entities, that break down, age, and are – sometimes – being personalized and modified. These variated modifications occurring in products (in time, often because of use dynamics) have been here defined as *change*. Changes occurring in products ultimately change also the perception we have of them, leading to either disruptive or beneficial scenarios. If disruptive changes are not contained and beneficial ones are not supported, they might provoke early products' abandonment, with negative implications (for example, in terms of sustainability). In fact, even valuable design outcomes face rejection: on the one hand top-down standard solutions – created *for all* – might not reach the goodness of fit that is required, while on the other hand bottom-up local solutions – created *for one* – are hard to be adapted, because of their very contextual nature. In both cases problem can be recognized on that these design outcomes are generally not designed with a *"real use" perspective* (that occurs in time) and, in case they are, it is often under the belief that *only expected things will happen*.

To bridge this gap between design space and real environment a constant engagement and interaction between products and different stakeholders is adovocated.

This process has been here defined as conversation, to underline as this mutual exchange of information can be seen as a learning process. Most importantly active engagements that occur in the design-after-design space are aimed at. In other words, the design outcome changes thanks to the contact with (non-)human actors of the products' ecology. This is what has been defined as re-appropriation. In fact, every actor provokes change and eventually learns what conserves and what evolves in the designed outcome. In return, this experience can change the perception that the actors have of the design object. This mutual change, a real conversation, can be seen as second-order cybernetics. It occurs in time and is rarely considered during the design process, being hardly predictable.

Open-ended Design is here proposed as possible approach to facilitate the conditions for this conversation to happen, and has been defined as a design outcome that is able to change, according to the changing context. Open-ended Design can also be defined as suboptimal, error-friendly, unfinished, *wabi sabi*, contextual, context-dependent and is characterized by its inner flexibility due to the voluntary incomplete definition of its features, also defined as its *imperfection*. This unfinished aspect of the design outcome regards only those specific design attributes that, deeply relating with the real environment, cannot be fully imagined and that have been defined as context-dependent. Whilst this concept is grounded in software development (i.e. Wikipedia programming system is explicitly inspired by the wabi sabi approach), it is still hard to transfer it into hardware and low tech solutions, both bottom-up and top-down.

The here presented research is explorative and adopts qualitative research methods deeply related with the design practice. A research through design approach was used to answer the following general question: What is the role, value and potential of change in industrially designed products? This question was successively divided into: (1) How can the phenomenology of *change*, occurring in industrially designed products, be described? (2) How can we intentionally support change in those products?

The goal of this research is to provide more insights in the phenomenon of change in design, by creating a theoretical framework of reference and a better understanding of possible methods to tackle this challenge, and by putting these two worlds in communication. The exploration is articulated in six main studies:

- Study 0 (*post factum, observation*) analyses existing industrial products [+100] that already embed ingenious ways to meaningfully embrace potential change in design, for example products that consider – from the design stage – out-of-control possibilities of breakage, ageing, re-purposing, ..., of the initial design. These cases have been collected (work in progress: open-ended-design.com) and analyzed, till the creation of a set of ten lenses that support the understanding of the complex dynamic of change. The ten lenses (What changes? Why? When? Where? How much? How fast? With which goal? Who is changing the product? Is the change reversible? How many products can be produced?) have been matched with a set of possible answers raised from the analysis. By merging the ten lenses it is possible to identify unique approaches to Open-ended Design, defined as the two extra "How lenses": How do you support change (defined as *mechanism*, for example smart connections, oxidation, etc.)? How do you put your design outcome in the market (defined as *strategy*, for example industrial DIY toolkits, vanishing acts, etc.)? These last two lenses represent the unique result of the creative process, and depend on many different aspects such as the designers' skills, possible business models, technologies availability, etc.

- Studies 1-4 (*ante factum, anticipation*) have been built upon 70+ originally developed cases. The work observed – step-by-step – how to generate solutions for diffused but yet diverse needs. Specifically, it firstly experimented how to create design outcomes (specifically assistive devices) that, even by responding to the same need, require different configurations. This was done first with an off-line and proximal community (Study 1) and then with an on-line and distant one (Study 2). We then explored how to identify and to elaborate the needed open-endedness of certain design attributes in order to support identified potential change (Study 3) and finally we focus on understanding how to bring such design outcomes to the market, without losing their capability of addressing the needs of each, as opposed of one or of all (Study 4).
- In Study 5 we reached a closure, unifying our understandings into an Open-ended Design methodology created to support designers while dealing with potential change in design. The outlined pathway is not rigid in its structure, and doesn't aim at being prescriptive. It is mainly grounded on the iterative learning process of the dynamic observation of the real context and anticipation of what can changes and what conserves in the design outcome. The anticipation is materialized in form of Open-ended Design outcomes and the shift from observation to anticipation is supported by the ten lenses, outcome of Study 0. In this final study the proposed methodology has been tested, opening up possibilities of future developments and applications.

We can conclude that designers can finally be involved in different open conversations with technologies, networked societies and users that give them new possibilities of engaging with previously un-related stakeholders and their contexts. Designers are no longer forced to think only in terms of standardization and top down approaches where design *solutions* are given. They are challanged to explore the design outcomes in their dynamic nature, which is time-related, out-of-control and un-disciplined, but still possible to anticipate by an intentional design act. Finally, Open-ended Design is a work that aims at triggering reflections on the way we – as humans – interact with products that is, ultimately, the way we participate at creating a more or less sustainable world. For this reason, we consider it fundamental to participate (with this research) to the on-going conversation about change in design, acknowledging that designers can intentionally support change in order to try to steer reality to its better status. In concrete terms we highlight that imperfections, meaningfully designed, have the potential of reinforcing or balancing spontaneous changes in design objects. Important is to highlight that, being the anticipated change potential per definition, with our Open-ended Design we are not providing a solution, but rather a way to better rephrase the problem and learn through a constant observation of reality to which we have to keep *conversing*.

SAMENVATTING

Design kan worden gezien als een proces waarbij men tracht te creëren wat er nog niet is, maar wat er zou moeten zijn in de toekomst. Met andere woorden, design heeft als doel het bewust aanpassen van de toekomstige realiteit. Eén van voornaamste problemen van dit complexe probleem is de kloof die spontaan ontstaat eens het product, initieel toebehorend aan de design-ruimte en daardoor als ideaal voorgesteld, tastbaar wordt en in contact komt met zijn reële omgeving (dit kan tijdens productie, verdeling, gebruik, onderhoud, etc. zijn.) Producten zijn in se allesbehalve statisch, voorspelbaar en controleerbaar. Integendeel, ze zijn dynamische entiteiten die stuk gaan, verouderen en soms aangepast of gepersonaliseerd worden. Dergelijke veranderingen die de producten ondergaan, veranderen uiteindelijk ook onze perceptie ten opzichte van hen, wat zowel kan leiden tot gunstige alsook vernietigende scenario's voor de verdere levensloop van het product . Als enerzijds de vernietigende veranderingen niet worden ingeperkt en anderzijds de gunstige niet worden bevorderd, kunnen ze er dus voor zorgen dat gebruikers zich sneller zullen ontdoen van het product, met negatieve implicaties tot gevolg in termen van bijvoorbeeld duurzaamheid. In feite lopen zelfs verschillende ontwerpmethodes, die op het eerste zicht echter waardevol lijken in deze optiek, toch het gevaar geconfronteerd te worden met afwijzing: de top-down standaard oplossingen – design for all – slagen er vaak niet om de vereiste bruikbaarheid te bereiken voor elke unieke gebruiker. De bottom-up, lokale oplossingen – design for one – zijn dan op hun beurt weer heel moeilijk aanpasbaar door hun sterk contextuele aard. In beide gevallen kan er worden vastgesteld dat een deel van het probleem schuilt in het feit dat bij deze ontwerpmethodes het *aspect tijd* niet in acht wordt genomen. Indien dit echter wel gebeurt, wordt er vaak

van uitgegaan dat *alleen verwachte zaken zullen gebeuren*.
Om deze kloof, tussen de ontwerp-ruimte en de reële omgeving, te overbruggen, wordt er uiteindelijk gepleit voor een constante betrekking van de actoren, die we definiëren als conversatie. Hierbij wordt er voornamelijk gericht op conversaties die zich voordoen in de design-na-design-ruimte. Dankzij deze conversaties, die worden gezien als een tweede-orde cybernetica, is iedere actor in staat om getuige te zijn, en daardoor ook om te leren, van wat er wel en niet verandert in de ontworpen oplossing. In feite, de oplossing zelf wordt juist dynamisch en veranderlijk door het contact met de (niet-)menselijke actoren van het volledige systeem van het product. Het beseffen van het bestaan van deze veranderlijke variabelen gebeurt pas na een bepaalde tijd en is daardoor soms zelfs *ondenkbaar* tijdens het design-proces. Dit is wat we *re-appropriation* noemen.

Open-ended Design wordt hier voorgesteld als een ondersteuning voor het faciliteren van de voorwaarden voor de vorming van deze conversaties en wordt gedefinieerd als een ontwerpmethodes die in staat is om te veranderen en zich aan te passen naargelang de veranderende context. Open-ended Design kan verder nog gedefinieerd worden als suboptimaal, error-friendly, onafgewerkt, *wabi sabi*, contextueel, context-afhankelijk en wordt gekarakteriseerd door zijn intrinsieke flexibiliteit die te wijten is aan de vrijwillig incomplete bepaling van zijn kenmerken, ook wel gedefinieerd als imperfectie. Het onafgewerkte aspect van de ontwerpoplossing richt zich alleen op juist die specifieke ontwerpattributen die sterk gerelateerd zijn met de reële omgeving, die werden omschreven als context-afhankelijk. Desalniettemin dit concept al aangewend wordt in de ontwikkeling van bepaalde software (b.v. de programmatie van Wikipedia is expliciet geïnsipireerd op de Wabi Sabi filosofie), blijkt het nog steeds moeilijk om dit toe te passen in hardware en low tech ontwerpoplossingen.

Het hier voorgestelde onderzoek is exploratief van aard en bevat kwalitatieve onderzoeksmethodes die sterk gerelateerd zijn met de ontwerppraktijk. Een onderzoek naar en via ontwerpmethodes werd gehanteerd met de bedoeling om een antwoord te vinden op volgende algemene vraag: Wat is de rol, de waarde en het potentieel van verandering in industriële producten? Deze vraag werd achtereenvolgens onderverdeeld in: (1) Hoe kan de fenomenologie van verandering, voorkomend in industriële producten, beschreven worden? (2) Hoe kunnen we intentioneel die verandering in dergelijke producten ondersteunen?

Het doel van dit onderzoek is om meer inzichten te verschaffen in het fenomeen van verandering in design, door zowel het creëren van een theoretisch referentiekader alsook een beter begrip van mogelijke methodes die deze uitdaging aangaan. De exploratie is onderverdeeld in zes hoofdstudies:

Study 0 (*post factum, observation*) analyseert bestaande industriële producten, die in meer of mindere mate en op soms ingenieuze wijze reeds het idee van verandering in design, al dan niet bewust, omarmen en toepassen. Dit zijn producten die bijvoorbeeld open staan – al van bij de ontwerpfase – voor de oncontroleerbare veranderingen veroorzaakt door het stukgaan van het product, het verouderen, hergebruik van het initiële design, etc. Deze cases werden verzameld (work in progress: open-ended-design.com) en geanalyseerd om zodoende een set van tien lenzen te creëren die de ontwerper moeten ondersteunen bij het begrijpen van deze complexe dynamiek van verandering. De tien lenzen zijn (Wat verandert er? Waarom? Wanneer? Waar? Hoeveel? Hoe snel? Met welk doel? Wie verandert het product? Is de verandering omkeerbaar? Hoeveel producten kunnen worden geproduceerd?) werden verbonden met een reeks mogelijke antwoorden gebaseerd op de analyse zelf. Door het samenvoegen van deze lenzen bekomen we unieke manieren om Open-ended Design toe te passen. Deze werden vervolgens gedefinieerd als twee extra lenzen: Hoe ondersteun je verandering (gedefinieerd als mechanisme, bijvoorbeeld slimme verbinding, oxidatie, etc.)? Hoe pas je deze aanpak toe in de markt? (gedefinieerd als strategie, bijvoorbeeld industriële DIY toolkits, het spontaan doen verdwijnen van iets, etc.)? Deze lenzen representeren het unieke resultaat van het creatieve proces en in feite berusten ze op verscheidene, andere aspecten zoals de skills van de ontwerper, het business model, beschikbare technologieën, etc.

Studies 1-4 (*ante factum, anticipation*) is opgebouwd uit 70+ origineel ontwikkelde cases. Er werd nauw en stap-per-stap opgevolgd hoe in deze cases oplossingen werden gegenerereerd voor gediversifieerde maar uiteenlopende noden. Specifiek werd er in eerste instantie geëxperimenteerd hoe bepaalde ontwerpoplossingen moesten bedacht worden (voornamelijk hulpmiddelen voor mensen met een beperking) die hoewel deze allen beantwoorden aan eenzelfde nood, toch verschillende configuraties bleken nodig te hebben. Dit werd eerst uitgevoerd met een offline en nabije groep gebruikers (Studie 1) en daarna met een online en verafgelegen groep. (Studie 2) Daarna werd er geëxploreerd hoe we de nodige openheid konden identificeren en uitwerken van bepaalde ontwerpattributen met als doel het ondersteunen van potentiële verandering (Study 3). Uiteindelijk concentreerden we ons op het begrijpen van hoe zulke ontwerpaanpakken in de markt kunnen worden toegepast, zonder dat ze hun mogelijkheid verliezen om te beantwoorden aan de noden van elke, unieke gebruiker, in tegenstelling tot design-for-all of design-for-one.

In Studie 5 convergeerden we naar een besluit, waarin we de begrippen en kennis verenigden tot een Open-ended Design-methode die de ontwerper moet ondersteunen en leren omgaan met de potentiële verandering in design. Deze uitgelijnde methode is niet rigide, noch strikt qua structuur en dient niet als voorschrijvend te worden aanzien. Het is voornamelijk gebaseerd op het iteratieve leerproces van de dynamische observatie van de reële context en de anticipatie van wat kan veranderen en wat behouden blijft binnen de ontwerpaanpak. De anticipatie wordt gematerialiseerd onder de vorm van een Open-ended Design-aanpak en de verschuiving van observatie naar anticipatie wordt bekomen door de tien lenzen, die eerder werden beschreven. In deze studie werd de methode getest, waardoor nieuwe mogelijkheden ontstonden met het oog op toekomstige ontwikkelingen en toepassingen.

We kunnen concluderen dat ontwerpers nu eindelijk kunnen betrokken worden in verschillende, open conversaties met technologieën, samenlevingen en gebruikers die hen nieuwe mogelijkheden geven om een dialoog aan te gaan met stakeholders en hun context die initieel niet (of nauwelijks) gerelateerd waren. Ontwerpers worden niet langer gedwongen om te denken in termen van standardisatie en top-down benaderingen waarbij ontwerp*oplossingen* opgedragen worden. Dit laat hen toe om de dynamische aard van hun nieuwe aanpak te exploreren, die tijdsgerelateerd is, oncontroleerbaar en ongedisciplineerd, maar waarbij het desondanks nog steeds mogelijk is om te anticiperen en daarvoor dus te ontwerpen met de intentie om de veerkracht van de creaties te verhogen. Uiteindelijk is het doel van Open-ended Design het triggeren van reflecties op de manier waarop wij als mens intraheren met producten wat uiteindelijk op zijn beurt vertelt hoe wij bijdragen aan een meer of minder duurzame wereld. Voor deze reden zien we het als fundamenteel om (met dit onderzoek) te blijven deelnemen aan de huidige en voortdurende conversatie over verandering in design, ook om te erkennen dat ontwerpers bewust de verandering kunnen ondersteunen om zo een verbeterde realiteit te bekomen. Concreet willen we het belang van zinvol ontworpen imperfecties beklemtonen, die potentieel in staat zijn om de balans van de spontane veranderingen in het design object te versterken. Tenslotte is het belangrijk op te merken dat we met Open-ended Design geen oplossing voorschotelen, maar eerder een manier waarmee we het probleem herformuleren en leren door een constante observatie van de realiteit waarin we moeten blijven *converseren*.

CHAPTER 1

INTRODUCTION AND OVERVIEW

Products change. They age, break down, are personalized. Products are dynamic entities, as well as is our perception of them. Changes happen when we bring products from the design space, *where they are thought to be*, in contact with the real environment, *where they are used and emerge* (Nelson & Stolterman, 2012)(Wakkary & Maestri, 2008). These changes are not always predicted, and even predictable, by the designer. Therefore, it is common to perceive the two contexts – referred here as: the design space and the real environment, distant and profoundly different. This perception is well spread among the scientific community too (Hermans, 2014)(Risdiyono & Koomsap, 2011)(van der Bijl-Brouwer & van der Voort, 2014)(G. Fischer, Giaccardi, Ye, et al., 2004).

Importantly, the dynamic nature of products, has big impacts on the products' life performances and lifespan: sometimes it leads to the production of early stage waste, or to products failure, while other times leads to products improvements, for example by reaching higher functionality, and postponing the end of life (see **Chapter 3, Foundations**). In **Figure 1.1** some daily examples of dynamic products' *attributes* are displayed: (a) the ceramic cup accidentally fell and broke, (b) the computer's buttons have different texture according to how intensively they have been used, (c) the painting of the facade is brighter where protected from the sun, (d) the plastic signs on the facade are deformed because of the sun, (e) the more the *moka* has been used the better taste is perceived, (f) Giulietta statue in Verona, Italy, shows where it has been touched by the tourists who were hoping for good luck.

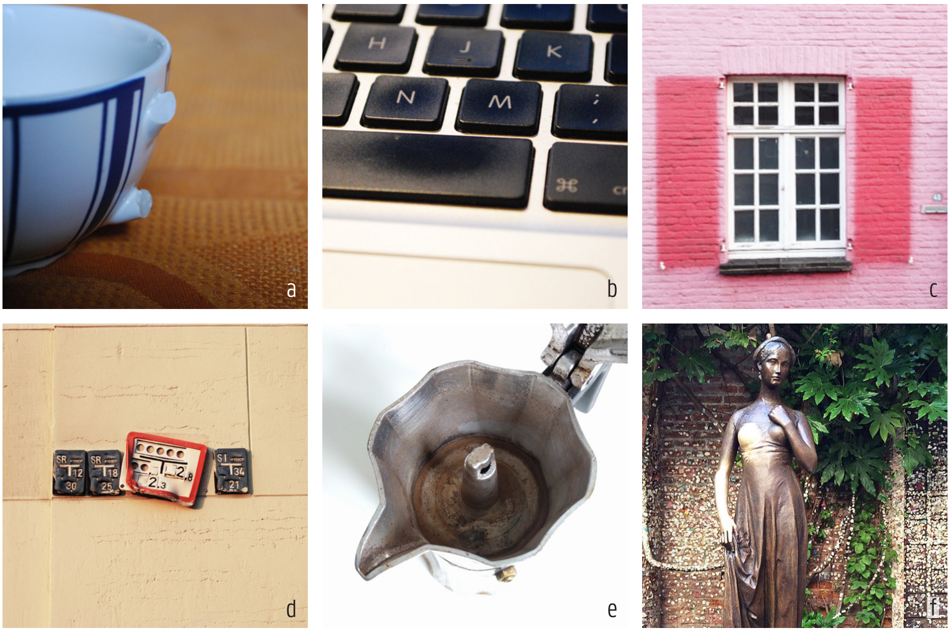


Figure 1.1. Examples of change in products, occurred because of daily use

In **Figure 1.2** some examples of some dynamic *interpretations* of products are reported: (a) the broken cup is repaired with Sugru® (sugru.com, last accessed on June 2017), (b) the clothespin is used to close the food package, (c) the walls are used to deliver messages, (d) a concrete piece triggers sympathy in the observer, (e) a breakfast bowl is used to contain flowers, (f) the bicycle rack hosts a kayak. While in the first list of examples changes occur because of the daily use, in the second list what changes is the possible interpretation of the products themselves, often showing the creativity of the users. In both cases, everyone can probably think about different examples for similar phenomena of change in products.

Why, then, do we tend as designers to think of our products as stable entities? Why do we often design gathering information from abstract constructions of a specific situation, or from controlled environments, more similar to laboratories than reality?

Of course, many historical reasons support this design mindset, generally inducible to the need for standardization, high volumes, average dimensions, average needs, simplification, top down dynamics, etc. Somehow, historically, the *design space* was considered enough to satisfy the *real environment*. On the contrary, in every introduced example change can be experienced as the difference between the same product while located in one or the other space. In a simplified description of the two

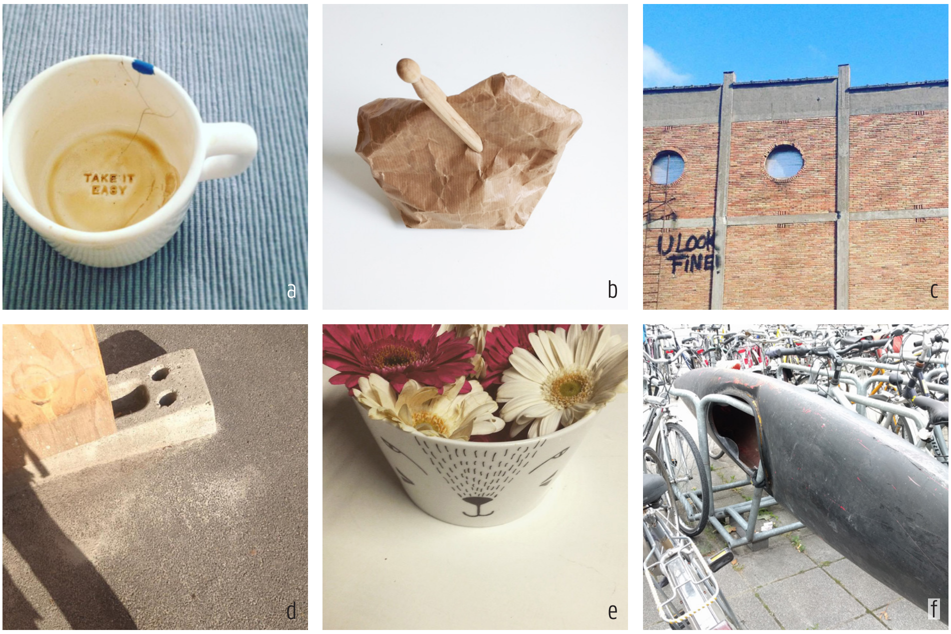


Figure 1.2. Examples of change in products, occurred because of extra-ordinary use or interpretations

"spaces", created through the use of general dichotomies, we could state that: while the design space is abstract, standard and stable, the concrete environment is, *per definition*, unique in nature and dynamic in time and space (Nelson & Stolterman, 2012). The design space often refers to the truth (meant as repeatable and replicable scientific knowledge), while the real environment is unique and therefore unrepeatable. This because the design space is proximal and under control, while the real environment is distant and out-of-control. The design space aims at simplifying and recognizing problems as tame, while the real environment is complex and characterized by wicked problems (Rittel, 1972)(Buchanan, 1992). The design space defines use in the "design time", *through design* (designing for use before use), and the real environment defines use *through use*, in the "use time", better defined as "design after design time" – since it doesn't only refer to the use stage, but also production, distribution, end of life, etc. (Ehn, 2008)(Björgvinsson, 2008)(Redström, 2008). These concepts are listed in **Table 1.1**.

The gap between design space and real environment is ultimately the gap between the designer and the "user" (meant here in its possible broader meaning, i.e. end user, producer, distributor, etc.). Many attempts have been done in order to bridge this gap, but often they refer to the front-end of the design process as, for example, by adopting generative tools, user center design methods, participatory design, etc. (Couvreur, 2016)(Lim, Stolterman, & Tenenberg, 2008)(Sanders & Stappers,

Design space	Real environment
abstract	concrete
standard	unique
stable	dynamic
true	real
proximal	distant
under control	out of control
simple	complex
use through design	use through use

Table 1.1. Possible dichotomies used to distinguish the design space from the real environment

2008).
Goal of this research is, in boarder terms, to support the *conversation* between the (different, but coexisting) spaces of design space and real environment, in order to bridge the gap that sometimes make them distant and conflicting.

1.1. Open design

Nowadays the conversation about these two spaces can have a renewed and more profound value for designers. We are witnessing, among others, the impact of the post-industrial and anthropocene ages. The centrality of the human being, and the need for a more sustainable design approach, combined to the development of new democratic and accessible technologies, have disruptive consequences on the way we design (Igoe & Mota, 2011). More participatory and inclusive ways of designing have been reached, often supported by more open design processes. Open design is an emergent phenomenon that plays a crucial role in the current design landscape. It can be defined as democratic, accessible, connected with users involvement dynamics (Maldini, 2014), wisdom of crowds (Surowiecki, 2004) and ultimately sustainability (Thackara & John, 2011)(Manzini, 2010). The creation of Open design is also deeply linked with the spread of internet, digitalization and digital manufacturing technologies (Hermans, 2015). Open Design products are characterized by the "free distribution, documentation, permitted modifications and derivations of it [the design specifications]" (see: opendesign.org, last accessed on June 2017). In other words, open design embraces and supports the cultural disruption that provokes the pivotal shift from the production *for the masses* to the design (distribution and production) *from the masses* (Bas, Lucas, & Roel, 2011).

In this perspective we can notice the connection between our main goal and open design. Furthermore, open design is created to embrace diversity, and acknowledges the need for a new paradigm, where the standardization leaves place for the uniqueness provided by every single user, eventually expressed by a collective voice (Thackara & John, 2011).

In other words, open design is made to support change under two points of view: the cultural change of opening-up the design solutions by sharing them with unknown stakeholders and the physical change, the actual modifications *meant* to occur on the product itself as expression of the specific environment. This constant interaction can be seen as a sort of *conversation* (see **Chapter 3**) occurring between users and the products themselves. In every conversation, in fact, actors deliver and receive information in a "chain of events" that can be interepreted as a learning process. Similarly, users interacting with products are (more or less ocnsicously) changing the products themselves accordingly. Consequently, this change is delivered back to the user, in form of feedback (see **Chapter 3**, **Paragraph 3.6**). The word *meant* is intentionally used to underline a problematic area: in reality open design is easy to be accessed by users, but it becomes more complex when the goal is to adapt it and to physically change it (Cruickshank & Atkinson, 2014). Thinking back about the previous cases of change in products of daily use, we could wonder: how is it possible that a design intentionally made open, is not providing more support for such changes to happen? In the design documentation, in opendesign.org, we can read:

> "The embodiment must include design documentation, and it must allow distribution of design documentation as well as manufactured form. Where some embodiment is not distributed with design documentation, there must be a well-publicized means for downloading the design documentation, without charge, via the Internet. The design documentation must be the preferred form in which a designer would modify the embodiment (e.g. native file format used to create the design document). Deliberately obfuscating design documentation is not allowed. Intermediate forms (e.g. read only documents, G&M codes for machined parts, or STEP translations of model files) are not allowed."

It is noticeable that the main focus is about the ease of transparently distributing the design, rather than the ease of changing it (only the sources format is mentioned as facilitating aspect). To conclude, the adaptation of the design still requires specific skills and knowledge to the point of compromising the users' intervention capability and motivation, as explained afterwards (Fogg, 2009)(Von Hippel, Ogawa, & de Jong, 2011)(Cruickshank & Atkinson, 2014).

1.2. Open-ended Design

The ease to modify and to create derivations on the shared projects can play a crucial role in sustaining the diversity of local contexts, the engagement of laypersons and the democratization of the design act itself. By questioning this ease in the context of *traditional design* and even, sometimes, of open design, we sketched – thanks to the here presented research – the landscape of another related phenomenon: Open-ended Design, which reaches different areas of intervention. The term Open-ended Design has been defined, in **Chapter 4, Investigations, Study 3** as follows.

> Open-ended Design (OeD) is a design outcome able to change, according to the changing context. Open-ended Design, can also be defined as suboptimal, error-friendly (Manzini, 2010), unfinished, Wabi Sabi (Juniper, 2011) contextual, context-dependent and is characterized by its inner flexibility due to the voluntary incomplete definition of its features, also defined as its meaningful imperfection. In fact, only the design attributes that cannot be fully predicted by the designer should therefore be left open-ended. In this view, the real context (of production, use, mainteinance, etc.) is invited to participate to the product emergence and definition.

This can happen unintentionally (from the designers' point of view), as in the examples of **Figures 1.1** and **1.2** or it can be supported by an intentional design act, which often means to leave the product intentionally incomplete and imperfect under some aspects. The second case refers to Open-ended Design and is the main focus of this work (see **Chapter 4, Investigations**). For this reason, Open-ended Design (**Fig. 1.3 c**) aims at being different from the *ideal design* (**Fig. 1.3 a**) (the one created as stable in time and space) but should not be mistaken with open design (**Fig. 1.3 b**), as it will be explained in detail throughout the whole dissertation. Briefly, as you can see in **Figure 1.3**, the dashed lines are used to represent something that is not yet defined in reality, an ideal status, abstract in nature. In this way, the ideal design is represented as completely dashed, while the open design is normally a representation of very practical cases that have already been generated in reality, and shared with the online community in their practical and material aspects. For Open-ended Design only few design

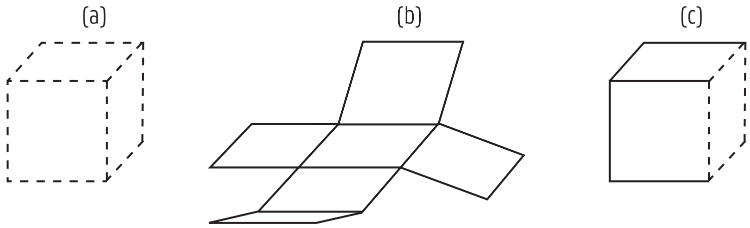


Figure 1.3. (a) Ideal design , (b) Open design, (c) Open-ended Design

attributes remain undefined, which are the attributes that will (potentially) emerge only once the design outcome is put in contact with the real environment (of production, distribution, use, etc.). In other words, the dashed line of (c) is its intentional imperfection. To better understand the general context of Open-ended Design a parallelism with open-ended questions could be made. For example, in such questions there is no definition *a priori* of the possible answers so that the respondent is free to answer with his/her own means (words, tools, mental structures, etc.). Open-ended questions are often used for exploratory research, and it is thanks to their openness that the researcher can learn other things, different than the ones already anticipated. The same applies to Open-ended Design, as described later. Three practical examples of design solutions definable as open-ended are reported in **Figure 1.4**. First (a) a social house that is unfinished, in order to let the users complete it. This doesn't only increase the emotional value, but also the initial market value (elementalchile.cl, last accessed on June 2017). Second (b) a material developed and sold in small kits, made to repair or upgrade objects. In this case, the broken or not functional product can live longer with positive impacts in terms of sustainability (sugru.com, last accessed on June 2017). Last (c) a big centerpiece in ceramic. In the event of a fall the decorations, small holes in the fragile materials, become the starting point of the breakage creating smaller bowls still usable (paoloulian.it, last accessed on June 2017). In all the three cases it is clear as the designers embraced and supported processes occurring in the real environment, the design-after-design time, trying to facilitate them (in case of positive change, such as personalization) or to make them less disruptive (in case of negative changes, such as rupture). Additionally, we could see Open-ended Design as a designed solution that, once in contact with the real environment, can change giving more clear feedbacks to -for example- the user, supporting a learning process itself. To better understand this concept, it could be interesting to move back to the very definition of design, as the complex process of creation of what is *not there*, and what is *ought to be* (Nelson & Stolterman, 2012). For this process to happen, a constant interaction between the two *spaces* (design and real environment) is needed. This interaction, compared previously to an actual conversation, has the goal of diminishing the gap between these two spaces. Focusing on the actual responses of the products, this interaction can only take place in time and in the real environment.

Figure 1.4. Three examples of products that could be seen as Open-ended. (a) Incremental Houses: unfinished houses meant to be finalized by the users (a project by Elemental), (b) Sugru®, a flexible material that can repair almost everything (a project by Jane and FormFormForm) and (c) Una seconda vita, a vase that, in the event of an accidental fall, is designed to become something else (a project by Paolo Ulian)

Thanks to this conversation, which can be seen as second-order cybernetics (see **Chapter 3, Foundations**), every actor involved learns about what conserves and what changes in the designed solution once immersed in the real environment. This conversation can occur, per definition, only in time and in the real context. To facilitate the conditions for this conversation to happen, which is ultimately a design act done *by others*, a second-order design is advocated (Dubberly & Pangaro, 2015)(Krippendorff, 2007). The definition by Dubberly (2015, p. 5) of second-order design as "[The signage system] is never completely finished, never completely specified, never completely imagined. It is forever open." gets close to the concept of introducing a meaningful imperfection in the designed outcome. Such meaningful imperfection has the crucial function of facilitating this communication, occurring with (possibly unknown) *others*, in the use after design stage (Redström, 2008).

1.3. Relevance and motivations

What is described in this manuscript is not a new phenomenon. In reality, every single product changes, from its ideal status, while in contact with the real environment (from production to end of life). In all the cases, the broad and complex product ecology – meaning the sum of interactions between (non-)human actors with the design outcome – is determining constant changes (Forlizzi, 2007). We experience then the dynamic nature of products, and we witness how by changing – in time – they tend to dynamically move from the "abstract" context of design and the "real" context of use (Hermans, 2015). Two main bridging processes can be seen as dynamics were change in products brings *better performances*, and therefore could be *facilitated* by a design act, and cases where change brings to *lower performances*, and therefore could be *limited* to non-disruptive scenarios by the same design act. This is what we will later define as the "controversial nature of change", which influences the way we perceive products, our behavior towards them and leading ultimately to more or less sustainable scenarios. In fact, if we – from this perspective – analyze the two behaviors of consumerism and accumulation, we can easily notice as they both deny the possibility for change to occur. Change, in fact, can be seen as a *spontaneous process*, which is something that occurs in the time-evolution of every system, and that brings it to a more stable energy state (second law of thermodynamics). Spontaneity implies that the process *can* occur, without *necessarily* occurring, which means necessity, and not sufficiency. Traditional design often struggles in trying to contrast the spontaneous processes of change, or even ignores them completely. Open-ended Design, on the contrary, sees change as inevitable, and suggests strategies to support it. And, even if change in design is not a new center of study, we perceive that the current design scenario is ready to adopt it in a more structural and practice-based manner. This research collocates itself in the stream of publications represented mainly by: Eternally yours (Thackara et al., 2004), The Design Way (Nelson & Stolterman, 2012), Opening-up Design (Hermans, 2015), Meta-design (Gerhard Fischer & Giaccardi, 2006), Error-friendly and Slow Design (Manzini, 2012)(Strauss & Fuadluke, 2008), however five aspects need some further specifications.

1. Focus on low tech, tangible products. This research doesn't engage with Smart technologies and Virtual realities, as some of the previous works do. It mainly focuses on the products materiality and the physical interaction we can have with them. Reason for this choice has to be found in the awareness that adaptations, modifications and personalization of online products are possible and, even more importantly, pervasive in our daily life. One famous example is Wikipedia (**Figure 1.5**), that explicitly uses a programming approach inspired by *wabi sabi* and therefore based on the concept of imperfection as valuable design attribute (see **Chapter 3, Foundations**). Wikipedia serves us as starting benchmark, eliciting the question: how can we transfer the dynamic nature of Wikipedia on a physical and therefore tangible product?

Figure 1.5. Wikipedia, an open-ended virtual product

2. Design practice as method of the research. This research is deeply grounded in the practice of design. "Research through design" (Koskinen, Zimmerman, Binder, Resdstöm, & Wensveen, 2012) and "participatory design" have been adopted as methodologies to create knowledge (see **Chapter 2, Research Method**) and to re-organize the reality concerning the phenomenon of change in design.

3. Goal of originally bridging academic theory with design practice. The focus on practical examples and case studies is motivated by the intention to overcome the lack of practical examples verifiable in some previously cited related works. In fact, scientific articles dealing with intentionally imperfect, un-finished, sub-optimal outcomes often provide strong theoretical support, but lack practice-based insights, fundamental for the design practitioners on how to design to support change (Dix, 2007). Viceversa, it is the intent of the study to provide theoretical frameworks useful to help the designers with a "knowledge for action" during the design process. Specifically, the works introduces a methodology that characterizes objectives, techniques, and processes for creating new design outcomes. This methodology advocates the engagement with Participatory Design actions, that could be conducted in many forms becoming sometimes User-centered ones, waste-centered, etc. depending on the specific context. In other terms it is supported by a "blend of more than one systemic methodology" (K.M. Adams, 2015) all focused on the identification and management of change in design.

4. Main focus on design-after-desgin dynamics. While previously cited works about open design and, more generally, about end users' contribution in the design process, in form of co-creation and participatory design (Sanders & Stappers, 2008), often focus on the design phase (*front end* phase) and/or production phase (co-production and personalization), which can be defined as the design time, or use-before-use phase. Open-ended Design focuses also on the use time, or better design-after-design dynamics (Ehn, 2008)(Björgvinsson, 2008)(Gerhard Fischer & Giaccardi, 2006).

5. Focus on "relevant design" cases. This thesis starts from reflections about sustainability, in form of more resilient and efficient products, able to embrace different contexts – and therefore to change - without *failing*. Several case studies have been used and generated ex-novo. The originally developed ones can be grouped in two main topics: assistive devices and urban farming, both considered as *relevant* and sustainability driven (McDonagh & Thomas, 2010)(Despommier, 2013). These two fields have been chosen for several reasons later described in detail, here summarized as their peculiar and evident aspects of strongly depending on specific (and always different) contexts and users' needs. Anyhow, these fields have been used as examples to describe more general understandings applicable to different contexts as well.

Finally, this work can also be seen as a continuation of the PhD *Adaptation by product hacking* by Lieven de Couvreur (Couvreur, 2016), with which shares part of the theoretical framework and some practical cases, with an attempt of moving from the co-construction of do-it-yourself assistive devices *for one*, to the design conversation (through design) with more and possibly unknown stake-holders, creating devices *for each*. In some ways what de Couvreur sees as prototype, becomes in the Open-ended Design framework a real product, which keeps the same qualities of being "shared (tangible) language between all stakeholders" and primarily learning devices.

1.4. Research questions

To conclude, a first general question has guided and centered the whole research process.

General question (GQ)
What is the role, value and potential of change in industrially designed products?

To better understand the complex landscape of change in design, explorative and dynamic ways of researching have been utilized. This landscape resembles the structure of a tree, where the trunk constitutes the main topic of *change* in design, the roots the main foundations and the branches the more specific ways for change to become manifest in products, also definable as *strategies*. Starting without hypothesis, but rather from the observation of the apparently unorganized mass of leaves (in form of case studies), this explorative research aims at better understanding the observed phenomenon, by relating it to an architecture of connected branches and roots.

Ultimately the research attempts at proposing a unified Open-ended Design method that bridges the more abstract foundations (the roots of this work explored in form of researches, methods and frameworks), with the design practice and manifestation (the leaves). A visualization of these concepts is reported in **Figure 1.6**.

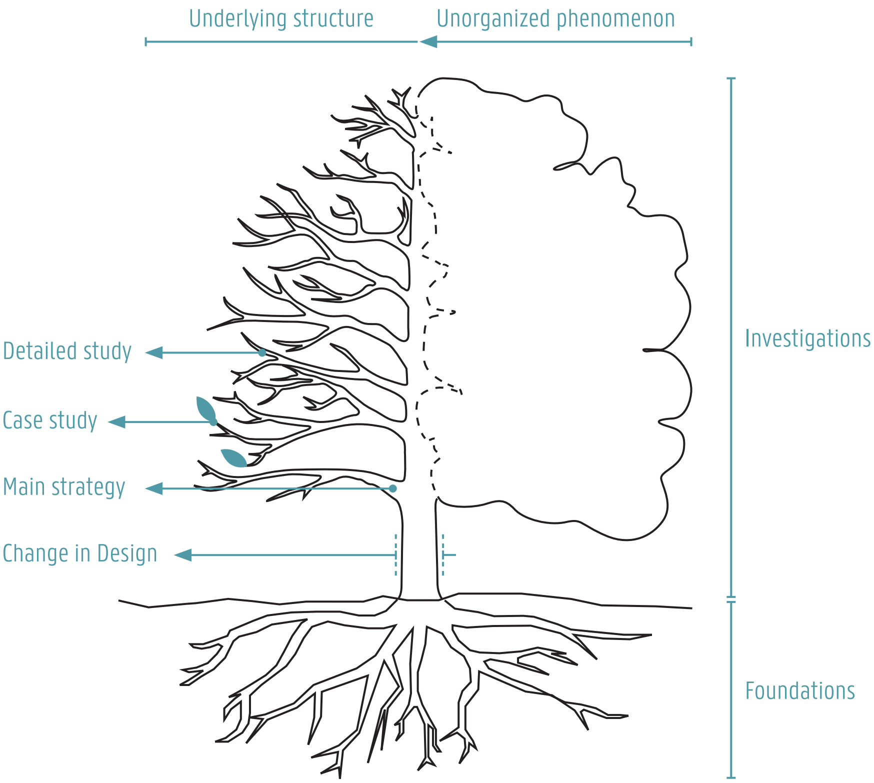


Figure 1.6. The structure of the research can be metaphorically compared with a tree. The leaves represent the observable phenomenon of change, visible in our daily life (see Figure 1.1 and 1.2). The branches give structure and support to this phenomenon, while the roots represent the main theoretical foundations

In other words, as visible in **Figure 1.7**, the here presented work focuses on (a) describing the structure of the tree, both in terms of branches (specific strategies to deal with change in design) and roots (the theretical foundations of those strategies) and (b) on helping the sharing of knowledge between roots and branches.

A set of investigations were developed in order to explore these two aspects. Other investigations, also developed during this work, have pointed on the contrary to very specific strategies to support change. For example, as in **Figure 1.8**, with regard to the strategy of Traces, signs accumulated by materials in time, we explored the change in sensorial perception and emotions occurring in aged plastics (Nobels, Ostuzzi, Levi, Rognoli, & Detand, 2015). It is a decision of the author to not fully include these specific explorations in this manuscript, as stated afterwards in the Reader's guide section. The list of these very specific explorations is reported in **Chapter 7, Termination**.

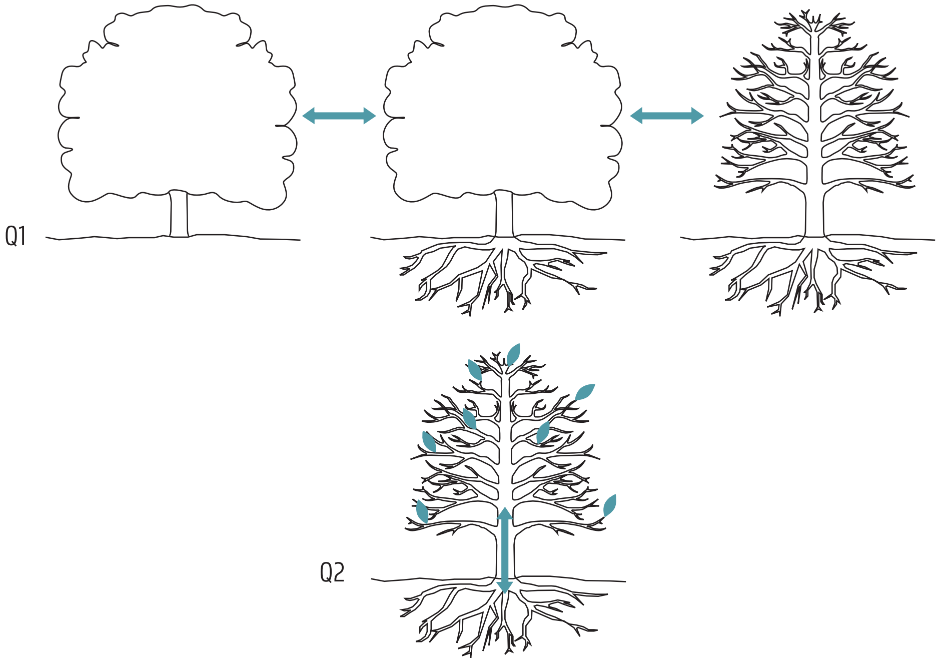


Figure 1.7. Two main goals of this research. (Q1) To understand the "hidden" structure beneath change in industrial products, as reported in Chapter 3, Foundations and (Q2) to put in communication the foundations with the design practice, by developing original explorations, as reported in Chapters 4, 5 and 6, Investigations

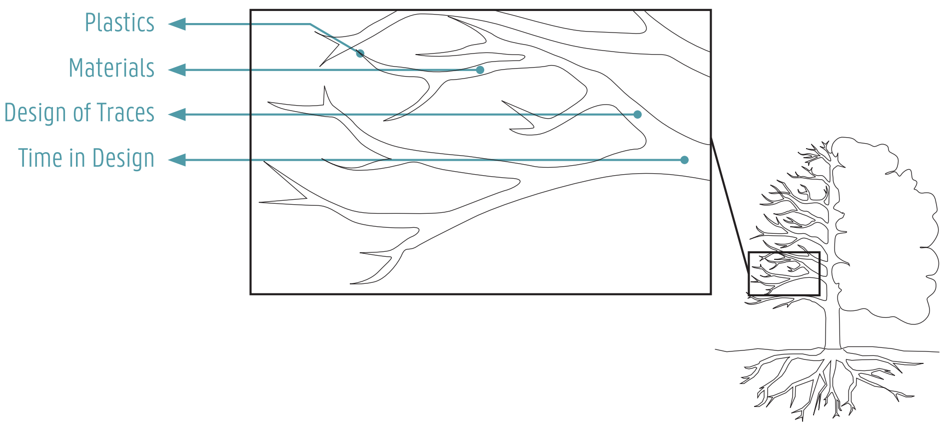


Figure 1.8. Every branch represents a possible strategy for Open-ended Design (such as the inclusion of time in form of traces, modularity, vanishing products, etc.). In this figure one example of a detailed research path, from including time in the designed solution to its emotional value when applied to plastics, is represented

In order to explore the General Question (GQ) more specific questions were phrased and reported in the following pages.

Question one (Q1)
How can the phenomenology of *change*,
occurring in industrially designed outcomes, be described?

As seen in **Fig. 1.7** (a), Q1 is concerned with understanding the structures and principles of change in design, and answers the basic questions of "Why / What / When / Where / Who / How … changes in industrial design products?". Its main goal is to sketch the landscape of this phenomenon by collecting and analyzing existing cases (more than 100), all representing good examples of products able to trigger and/or support dynamics of change. Also **Chapter 3**, **Foundations** gives some answers to Q1, providing a framework of relevant theories and related models. The research, in this phase, tries to isolate every design aspect in order to understand what can bring an additional value when the product moves from idea to real (Kleinsmann & Valkenburg, 2008). This part of the research, represented in **Figure 1.9** as a magnifying glass that helps in understanding and re-organizing an existing phenomenon, has been defined as **Post Factum**, **observation**, **Study 0**.

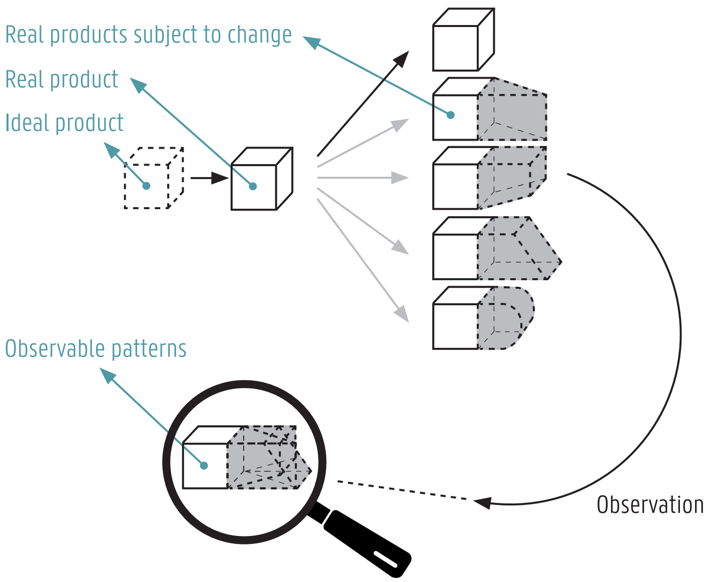


Figure 1.9. Reality of dynamic products observed and re-organized through the "lens" of change

Main result of the exploration around Q1 is, apart from the collection of the existing cases themselves, the definition of ten lenses, through which it is possible to look at the Open-ended Design phenomenon, in order to better understand it. At the same time the second fundamental question (Q2) of this research aims at understanding how to intentionally create and manage Open-ended Design solutions, *ex novo*.

Question two (Q2)
How can we intentionally support change in industrially designed outcomes?

As seen in **Figure 1.7** (b), Q2 is concerned with understanding the strategies and methods to support change in design, both by facilitating it when positive and limiting its possible disruptive scenarios. Q2 has been explored mainly though original investigations, therefore can be defined as **Ante Factum, anticipation, Study 1-5** and it answers the specific following sub-questions, also represented in **Figure 1.10**.

(a) How can we co-design with small offline communities with diverse needs?
(b) How does the re-appropriation of our co-design outcomes occur?
(c) How can we understand and anticipate what conserves and what changes in our designed outcome?
(d) How can we bring to the market our co-designed outcomes, without losing openness?
(e) Can the combined and iterative method of anticipation and observation become a learning process?

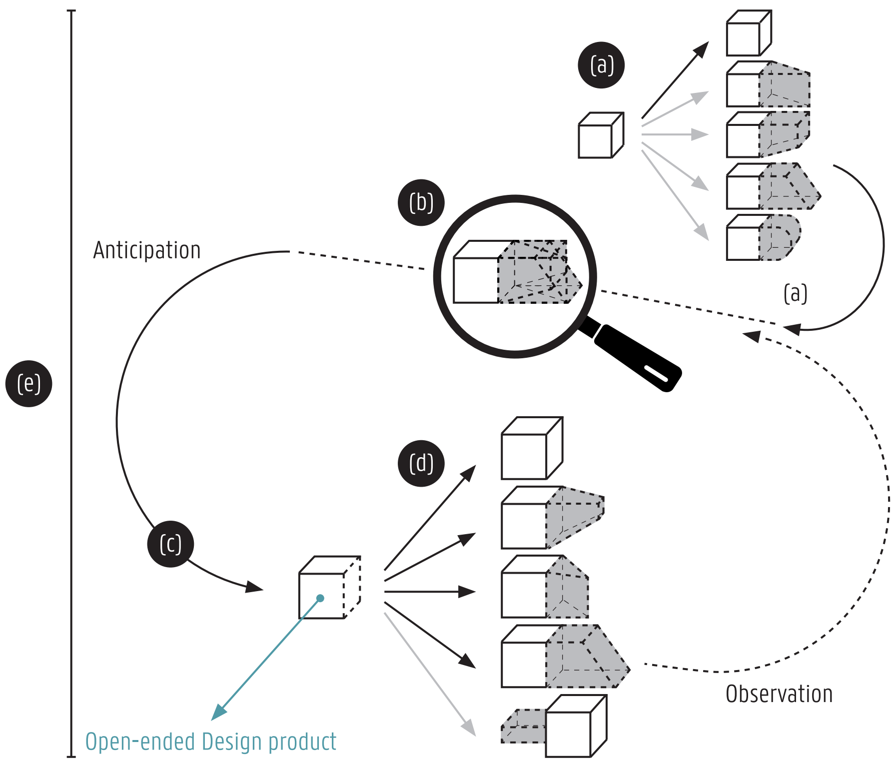


Figure 1.10. Question two articulated in the four sub-questions

These questions represent the core structure of this dissertation, especially under the operative point of view: they supported in fact the design of the investigations themselves. To conclude, it is important to mention again as in all the presented questions there have been no hypothesis to be confirmed or rejected, but more open observations around the identified phenomenon. In the following pages these questions will be specified in more detail, being the skeleton of the whole research.

1.5. Readers' guide

The structure of this dissertation is represented in **Figure 1.11**. The work is divided into five main parts. While **Chapter 1** provides an introduction and overview of the whole research, **Chapter 2** focuses the attention on the way the research is conducted and how the knowledge is created. **Chapter 3** introduces the main foundations of the work: sustainability, change, conversation and imperfection in design. **Chapters 4, 5 and 6**, core of this research, have been defined as **Investigations** and report on the main investigations conducted to explore the main research questions one and two. This part consists of six tudies: cases collection and analysis (**Study 0, Post factum, Chapter 4**) and 4 original cases (**Studies 1 to 4, Ante Factum, Chapter 5**) and a closing experiment that unifies the previously gathered insights (**Study 5, Chapter 6**). Finally, **Chapter 7** summarizes the main results, and pro-poses a discussion about the whole work and sketches opportunities for future research.

Some Studies have been already published in form of book, journal articles, conference proceedings and website, as specified in the introduction of every chapter. Because of the dynamic nature of this exploration, the presented papers have been reworked, refocused and extended, when needed. The general structure of scientific articles is anyway preserved, to support the advantage that every Study could be read separately, according to the reader's interests. For the same reason, also the Studies not yet published have been written following the same self-conclusive structure. Only the foundations (or state of the art), the one common among all the studies, have been merged and presented in **Chapter 3**. The only limitation of this structure is that some concepts have been necessarely repeated, especially the ones reported in the introduction sections.

At the end of the manuscript, in **Chapter 7**, the most relevant case studies used for this research have been listed, highlighting the main achievement followed by their realisation. Some of these are projects which haven't found space into this manuscript, because of the high specificity of the focus.

1.5.1. Graphics and schemas

In this book various graphics, in form of *design schemas* can be found. Design schemas are utilized to "form particular representations or aspects of ideal things out of a cloud of possibilities, in support of a divergent or expansive process of inquiry" (Nelson & Stolterman, 2012, p. 7). Schemas are therefore tools to simplify and explain otherwise complex phenomena. Their goal is to facilitate the reading of the manuscript, and to support the application of the introduced concepts both for the practice of design and the design inquiry.

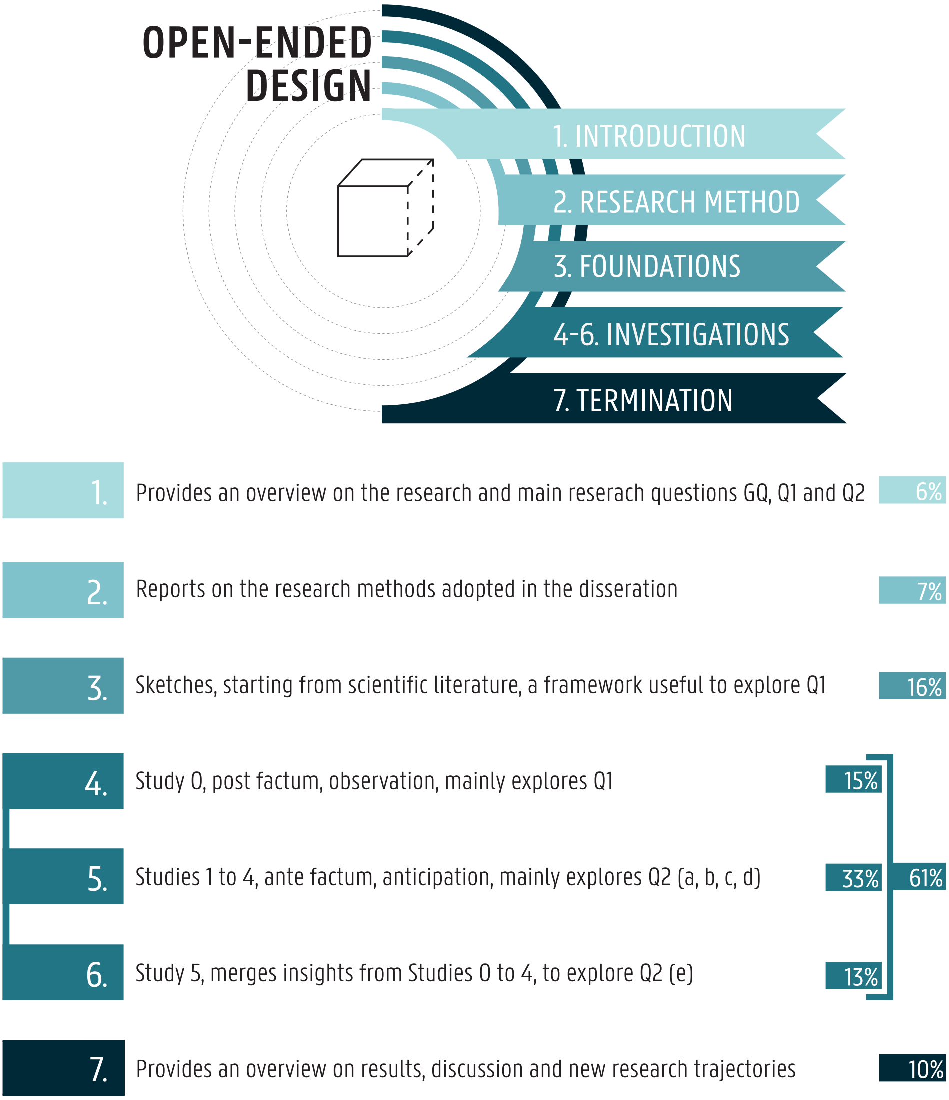


Figure 1.11. Structure of the manuscript and summmary of the contents

CHAPTER 2

RESEARCH METHOD

This dissertation has an explorative nature and builds upon several empirical studies, it can be therefore defined as practice-based research or research through design (Zimmerman, Forlizzi, & Evenson, 2007). The *design practice* constitutes both the field of exploration and its mean as described afterwards. For this reason, researchers and designers involved in this study, were constantly asked to personally engage in design activities (Nelson, 1994), referring with these terms to the process of consciously creating outcomes that previously didn't exist, and the outcomes themselves, as design is both process and artifact (Nelson, 1994). Every design activity ends in fact with the introduction of the created outcome into the real environment, which ultimately aims at reshaping reality, following the paradigm of *what is not there*, and what is *ought to be*. In other terms, aims at reshaping reality towards a better status, since "being a designer means being an optimist" (Manzini, 2009, p. 4)(Fallman, 2007)(Nelson & Stolterman, 2012). The conducted explorative process has been fundamentally divided into three parts:

- **Foundations (Chapter 3)**
- **Investigations (Chapter 4, post factum, observation, Study 0)**
- **Investigations (Chapter 5, ante factum, anticipation, Studies 1 to 4)**
- **Investigations (Chapter 6, ante factum, anticipation, Study 5)**

Case study research and, more generally, *research through design* have been adopted as main methodologies; reasons, dynamics and consequences of this choice are reported in detail in the following pages. Evaluation methods, data collection techniques, and other important aspects of the research are also briefly described in this chapter. For more details regarding each specific study we refer to see **Chapters 4, 5** and **6**.

2.1. A research to grasp reality

Design activities often aim at solving very complex problems (Dubberly & Pangaro, 2015). These problems can be seen as "wicked", meaning problems that cannot be solved and not even represented (or *modeled*) in reductionist ways or adopting linear causality, more typical for traditional sciences (Rittel & Webber, 1973). The exploration of wicked problems cannot be limited to an "ultimate test" since many explanations for the same problem can be found. Furthermore every explanation cannot focus on dichotomies, such as "true or false" kind of statements, since these problems should be recognized in their dynamic nature. *Change*, and change in design, seen as consequence of design cause and intention (Nelson, 1987), and therefore at the very heart of the design process itself (Nelson & Stolterman, 2012), can be seen as a wicked problem because of its dimension, dynamics and consequences. Change becomes manifest only in *time and space* and can be recognized as the difference between two statuses, or conditions, of the same thing. In this dissertation, the two starting statuses refer to the ideal design space and the real environment (see **Table 1.1, Chapter 1**), in other words change is the *coming into existence* and its continuation, in time, as *evolution* of the designed product itself. While the ability to change and the unfinished structure of the artifacts is embraced by academic activities (Fallman, 2007), there is often a lack of practical examples and strategies to tackle this complex problem while designing new artifacts.

Design and practice-based research are both generative. Specifically, this research has been based on design activities that become, together with their end-results, the main objects of study. Furthermore, the artifacts made for this research acquire the added value of – once exposed to the real environments – triggering and sustaining processes of change. All the interactions, discussions, re-appropriations occurred *because of* the objects of study, also represent crucial aspects to be considered. The products become themselves *learning objects* and, in this perspective, they share characteristics with prototypes (E. B. Björgvinsson, 2008)(Ehn, 2008). The contact between products and environments implies a change that involves all the actors and the reality we are exploring, that is therefore never static or true, but dynamic and ongoing (Nelson & Stolterman, 2012). In literature *design research artifacts* and *design practice artifacts* are sometimes distinguished (Koskinen, Zimmerman, Binder, Resdstöm, & Wensveen, 2012)(Zimmerman et al., 2007). The main reason has to be found in the role played by the different market perspectives, in fact while design practice artifacts are meant to be commercially successful, design research artifacts often focus on the intent of creating specific knowledge, and only secondarily (and not necessarily) on the market potential of the end results. In this dissertation this aspect has been kept into consideration. Our first goal is the understanding of the phenomenon of change in design from the perspectives of design practice and de-sign methods. And to do so, we think of designing as an activity leading to an "outcome which can be seen as a solution that defines the problem(s), in contrast to the way we normally think of a problem leading inexorably to the solution" (Glanville, 2007, p. 1179). Nevertheless, a glimpse to the related business models has been caught. This aspect has just been sketched in **Chapter 5, Study 4** and will require future explorations.

As introduced in **Chapter 1**, no hypotheses have been drafted before starting the research. On the contrary, observations of daily phenomena of change led to attempts of anticipations, embodied in the main research questions. This choice is rooted in the concrete and complex nature of the design practice and can be seen as an attempt to understand, starting from the "ultimate particulars" (Nelson & Stolterman, 2012), dynamics and characteristics of an observed phenomenon. This positioning of the research is not new for the design culture (Zimmerman et al., 2007)(Manzini, 2010) and is based on the distinction between the two possible focuses for academic explorations: the *true* and the *real*. In **Figure 2.1**, a representation that shows relations between true, real, universal and ultimate particular is displaced.

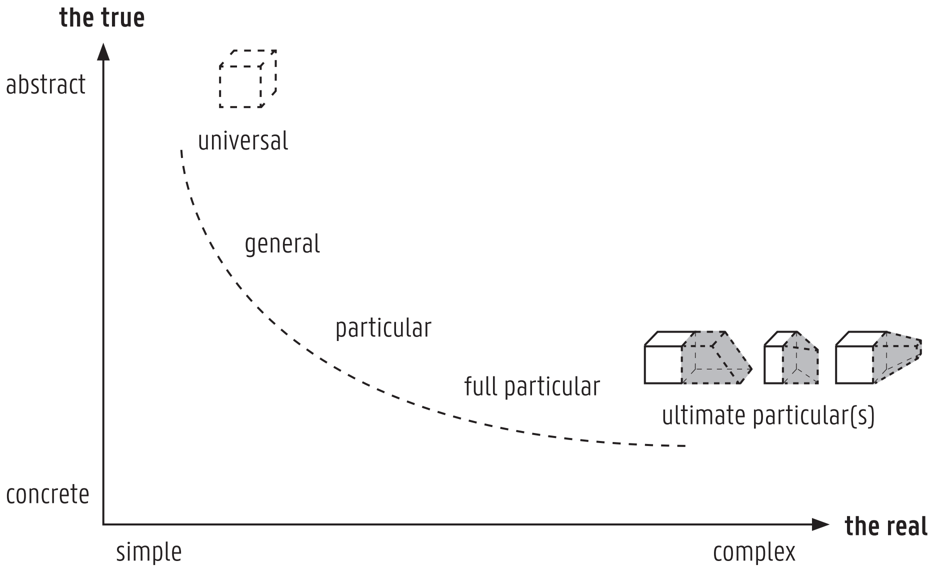


Figure 2.1. Universal to ultimate particular. Image adapted from (Nelson & Stolterman, 2012)

Design is a discipline that developed its own terms and rigorous culture, deeply rooted in its reflective practice of implicit intuitive processes developed by practitioners (Cross, 2001)(Schön, 1983)(Nelson, 1994)(Manzini, 2009). This results in a radical shift from some typical paradigms of scientific research, here briefly listed. For example, on the one hand traditional sciences (also when applied to certain design issues) focus on the search for *true* definitions, meant as repeatable, always eliciting the same results. This can be translated into a quantitative approach. On the other hand, design research (especially when practice-based and focused on the design process or method) focuses on the description and understanding of the *real* aspects of the exploration, meant as repeatable, but always leading to *contextual* results, since design deals with subjectivity (Manzini, 2009). "I consider the attempt to force design to be scientific to be ludicrous – for several reasons, including that the whole point of design is that it is design. Design is a way of acting, a way of thinking." (Glanville, 2007, p. 1174). This can be translated into a qualitative approach.

In this research a qualitative approach has been adopted; this is not only related to the difficulties of the design documentation in numeric terms [being design often studded by tacit knowledge and sticky information (Von Hippel, 1994)], but also because of the complex nature of the design practice itself. A practice where multiple factors play together in the complex process of creation, which is often intuition-based, contextual and fuzzy (W. Gaver, 2012), in fact while scientific research can predict action irrespective of context, design theories describe conditions for change (Zimmerman et al., 2007). My personal experience as a teacher gives confirmations of it: even if the same brief and conditions (time, tools, etc.) are given to students, it is impossible to obtain two replications of the exact same solution. For these reasons the design theories are not falsifiable per definition, and their goal is not to demonstrate that a theory (or procedure) is never wrong, but to highlight that it is sometimes right (W. Gaver, 2012) and to define some knowledge *for action*, rather than knowledge *per se* (Glanville, 2007). These considerations inevitably touch the widespread discussion regarding the relation between science and design. This discussion is not going to be addressed here, but it is important to underline as even if a theoretical distinction between the two is reached, the distinction is never normative and in real life scientific research and design practice always come together in the same project (Fallman, 2007), as it has happened in the here presented work. In fact, for specific design aspects quantitative approaches must be adopted while for the process itself and the value of its outcomes, a qualitative approach is here advised.

In conclusion, this research seeks at understanding the phenomenon of change in design, with the goal of finding new opportunities raising directly from the existing state of things: new economic and cultural systems, new technologies, etc., all described in **Chapter 3, Foundations**. A new state of things that considers diversity (and therefore change from the ideal status) as a crucial aspect for design, to be opposed to standardization and that considers change something unavoidable, that can lead to product improvements rather than an aspect to be opposed. These opportunities refer both to the academic world and to the design practice.

2.2. Research structure

The first part of the methodological structure, the Foundations (see **Chapter 3**) served to better focus the topic of the research and its main general question: "What is the role and value of change in industrially designed products?", starting point of this research (see **Chapter 1, Introduction**). It has provided definitions, theories, models and examples fundamental to sketch the general landscape where Open-ended Design is located. This section, also defined as **Foundations**, has never stopped and has been developed in parallel to every study, supporting and providing useful insights.

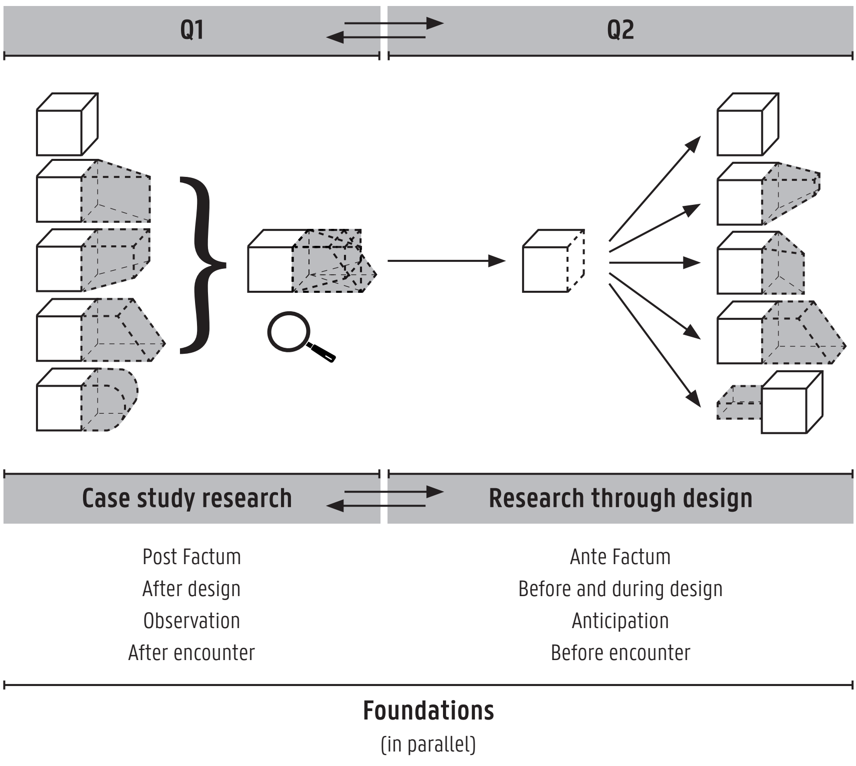


Figure 2.2. In figure the research method and the relation between the two main reserach questions. An iterative process was adopted and the two questions have been explored in parallel

Investigations is divided in three chapters, exploring both Q1 and Q2. **Chapter 4** focuses on "How can the phenomenology of change in industrially designed be described?" which has an analytic nature, while the second section focuses on "How can we intentionally support change in industrially designed producst?" which has a constructive nature. Relation between foundations, the three **Chapters 4, 5** and **6** and the research questions is represented in **Figure 2.2** (in the previous page).

The first section, addressing Q1, **post factum, Study 0**, starts from the observation of existing products and gives order to the previously unorganized phenomenon of change in design. This first investigation builds upon what is already designed, placed in the real environment and used (therefore, observation after design). In other words, it focuses on products for which the encounter between product and real context has already taken place (from production on). The second section, addressing Q2, **ante factum, Studies 1 to 5**, builds upon a set of 5 original studies each one based on materializations, meaning newly developed products. This section has the concrete goal of understanding some of the multiple operative aspects of dealing with Open-ended Design and focuses on industrial designers. All the developed products were designed by keeping in mind the *lessons learned* about Open-ended Design from the first section, which means that they were designed trying to anticipate the phenomenon of change. In this way the two sections have worked in iterative ways, often in parallel, giving insights and supporting one another.

In **Figure 2.3** the timeline and the connections between studies is visible. The black lines represent how the conclusions (or insights) of one study directly influenced another study. The grey lines show how the communication between the Post factum explorations (Q1) and the ante factum ones (Q2) were constantly compared and developed in parallel. Following a brief list of the topics addressed in the specific investigations displayed in **Figure 2.3**.

- **Study 0**. Analysis of more than 100 cases to underpin the dynamics of change. This study resulted on the publication of the website: open-ended-design.com, which is an on-going project.

- **Study 1**. Co-design with small offline communities. This study was published in 2015 in the Rapid Prototyping Journal, with the title "+TUO project: low cost 3D printers as helpful tool for small communities with rheumatic diseases".

- **Study 2**. Online transfer of solutions co-designed with small offline communities. This study was published in 2016 in the International review research in open and

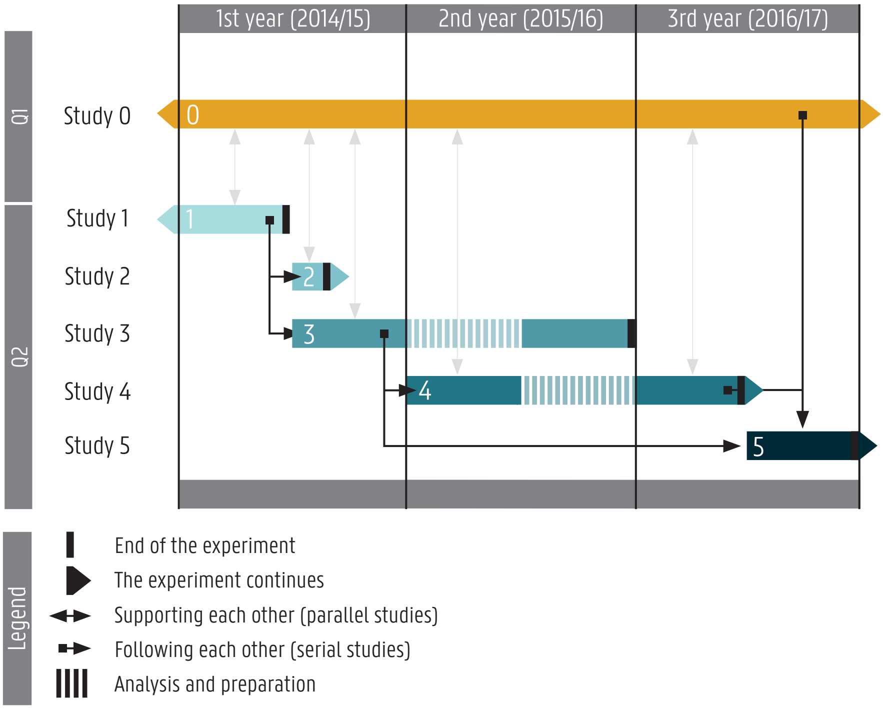


Figure 2.3. Graphical visualization of the developed investigations, their connections and distribution in time

distributed learning, with the title "The Role of Re-Appropriation in Open Design: A Case Study on How Openness in Higher Education for Industrial Design Engineering Can Trigger Global Discussions on the Theme of Urban Gardening".

• **Study 3**. Opening up solutions co-designed for one specific user. This study has been published in 2017 in the Design for Next Conference, with the title "From Design for One to Open-ended Design. Experiments on understanding how to open-up contextual design solutions".

• **Study 4**. Up scaling contextual co-design solutions, meant for one (a glimpse on the How lens: *mechanisms* and *strategies*).

• **Study 5**. Teaching Open-ended Design and testing the workflow. This study is being published and presented in 2017 in the Relate System Thinking and Design Conference, with the title "Open-ended Design as Second-order Design. A case study of teaching Cybernetics and System Thinking to Industrial Design students".

Study	Question	Sub-question
Study 0	Q1	How can the phenomenology of change in industrial design be described?
Study 1	Q2	(a) How can we co-design with small offline communities with diverse needs?
Study 2	Q2	(b) How does the re-apropriation of our co-designed outcomes occur?
Study 3	Q2	(c) How can we understand and anticipate what conserves and what changes in our designed outcome?
Study 4	Q2	(d) How can we bring to the market our co-designed outcomes, without loosing openness?
Study 5	Q2	(e) Can the combined and iterative method of anticipation and observation become a learning process?

Table 2.1. Overview on studies with focus on research questions

In order to facilitate the dialogue between different parts of the thesis and stakeholders a set of ten lenses has been created (see **Chapter 4, Observation**) through which it is possible on one hand to "read" the results of the post factum observations and, on the other hand, to discuss the results obtained with the ante factum explorations. These lenses are also used to show our reformations and possible strategies for embedding open-endedness in our designed outcomes, at the very end of this manuscript.

A limitation of the methodological structure of this thesis, important to be introduced here, is related with time. The initial goal was to close the cycle that goes from the post factum to the ante factum (and post factum again), which means to introduce the developed artifacts into real context and to follow the occurring changes in time. While for some experiments this has been done, for others it has been impossible to really up-scale the products into the market. The reason has to be seen in the high amount of resources needed, finance among others, but more importantly time related. In fact, change always requires a certain time to occur. Sometimes it can be in form of a sudden dynamic, sometimes it is slower and reaches out way further than the time of this research. Future explorations will be needed to track, *in time*, the real effects of certain materializations.

2.3. Research methods

Here following, a detailed description of the methods and setups of the two experimental phases. As anticipated, this research is practice-based, which can also be defined as "design research through practice" (Koskinen et al., 2012). The research also engaged in participatory design and co-design methods (Sanders & Stappers, 2008), seen as fundamental in order to give freedom to all the stakeholders to construct reality by adding something in the design solution, during the design process itself. Particular value was given to the reflection-in-action that the designer exploits while conducting the design process in a *complex*, *unstable*, *uncertain* and often *conflictual* realities (Schön, 1983).

Each investigation is described reporting on these aspects:

1. Research method
2. Specific context and research objects
3. Actors (only for the ante factum part)
4. Methodology
5. Results and evaluation

In **Figure 2.4** the methodological setup has been represented. The work started from the observation of *ultimate particulars*, this can be also called *alpha process*. The learned instances were then grouped and translated into a more abstract level (general and simplified, by taming wicked problems) thanks to the development of the previously mentioned *lenses*, through which a better understanding of change in design can be achieved. These understandings were then re-applied, and further explored, in the process of creating new and original materializations. When possible, in terms of time and other resources, the new materializations where brought into the real environment again. They were then observed and served, through observation of the *x process* (where *x* counts the iteration cycles), to improve the understanding stage itself. The process was highly iterative and not linear. Some experiments proceeded in parallel and only at the end of the thesis itself all the Lenses were defined.

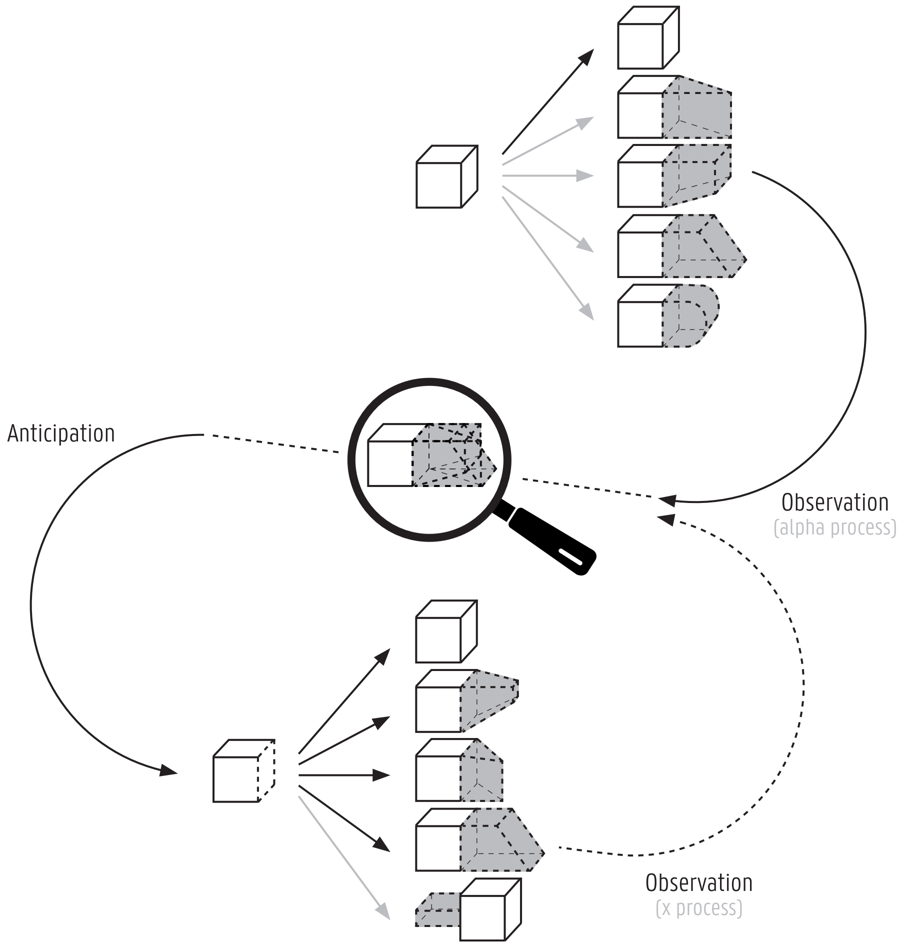


Figure 2.4. The methodological structure of the thesis.
The post factum observation, led to a series of ten lenses useful to support the ante factum anticipation studies.
(the process is highly iterative and the two processes happened often in parallel)

2.3.1. Post factum: observation of reality

2.3.1.1. Annotated portfolios of existing cases

To approach Q1, insights derived from the work of Christopher Alexander on Pattern Language, defined as the study and interpretation of repeated design solutions to similar (but never identical) repetitive problems in order to identify or extract a set of "patterns" of solutions (Alexander, Ishikawa, & Silverstein, 1977). These can be seen as common aspects among objects and can help while trying to give a sort of order to an occurring phenomenon. A case study approach, that is "a research strategy which focuses on understanding the dynamics present within single settings" (Eisenhardt, 1989, p. 534), has been selected for this investigation. Annotatet portfolios, based on case studies, is not a methodological choice, but a choice of what is the center of the study itself (Denzin & Lincoln, 2005), in this case, the *ultimate particulars*. Case studies can be *intrinsic*, *instrumental* or *collective* (Denzin & Lincoln, 2005). In this dissertation, collective case study has been adopted, being the analysis conducted for a broad number of specific cases. In fact, even if the learning points derived from the single case can be fundamental, at this stage of the research, importance has been given to commonalities and differences among different cases, as described afterwards.

The overall structure of the experiment follows what suggested by Eisenhardt (Eisenhardt, 1989) who, starting from the common problem of lack of methodological structure, proposes a road map to be followed while doing case study research. Roughly, the process can be described as follows:

- **Definition of the research question.** In this dissertation the general question (GQ: What is the role and value of change in industrial design products?) and its more articulated formulations have been introduced in **Chapter 1**.
- **Selection of the cases.** The topic of change in design is, out of any doubt, multisided and extensive. The case selection has been based on the simple definition of change, as difference between two statuses (ideal – real, but also real, in time). In this way, every product that presented an ability to change has been collected. Some cases, like the ones in **Figure 1.1, Chapter 1**, change in a way not anticipated by the designer, while others (the majority of the cases) have been intentionally designed to support change.
- **Data collection.** For this work, the main data sources have been online archives (blogs, websites, etc.), daily observations and interviews to the designers who engaged with change in design.
- **Method of analysis of the cases.** The analysis lasted the whole timespan of the thesis itself (see **Figure 2.3**) and has been highly iterative. All the information about the product were gathered and then many different attempts of analysis and coding have been done (i.e. to locate the different cases on the product's life cycle, or to divide them for volume of production), but none alone proved enough interest, as explained later in **Chapter 4, Study 0**. At the end, the most valid analytical way is represented by the combination of ten lenses, all referred to change and formulated in form of questions. The analysis is qualitative in nature, rather than quantitative, because the main focus remains on the phenomenon rather than on occurrence.

2.3.1.2. Research objects

"Designers often turn to existing examples of design to inform the development of their own ideas. Why might this be so? I suggest it is both because of the provisional nature of theory, and the definite nature of designed artifacts" (W. Gaver, 2012, p. 943). The cases used in this exploration are existing design products. The selected objects are meant to represent a population of cases sharing similar attributes, choices or processes with regard to the studied phenomenon. As said, for the first observation, it has been decided not to focus on one specific case, or few, but to adopt the concept of "annotated portfolios" introduced by Gaver (B. Gaver & Bowers, 2012). These collection of multiple artifacts, going beyond the single instance may serve a role in guidance for designers and even in the formulation of theories. In this ways annotated portfolios can be seen as deeply related to the previously mentioned studies on *design patterns* (W. Gaver, 2012). In fact, the cases maintain the particularity of being individual examples, supporting the articulation of the design issues that join or differentiate them. They can help designers and practitioners to quickly cover the gap between the theoretical concepts and their manifestations. Furthermore, they embody the complexity of the design process. As Gaver points out, examples in design play a fundamental role being the embodiment of the myriad of choices made by designers. That would be almost impossible to attain in a written (or diagrammatic) account (B. Gaver & Bowers, 2012).

2.3.1.3. Data collection

How the research objects for this investigation were collected is just briefly explained, and more details are reported afterwards in **Chapters 4, 5** and **6**. Starting from the phenomenon under study, that is the capability of certain products to change in meaningful ways, more than 200 cases were collected. Models and theories, reported in **Chapter 3, Foundations**, have been adopted in order to focus this research. The main contribution can be seen coming from Japan, as is the aesthetic philosophy of *Wabi Sabi* (Juniper, 2011), later described in detail. This helped in focusing the attention on the meaningful imperfections of the collected solutions, which often represents the trigger and facilitator for the change to happen in a sustainable way. Some cases were selected from literature, but mainly from blogs, websites, etc. Even if this observation is still on-going, a closure has been reached, for what concerns this dissertation and its focus. The volume was considered sufficient when new cases were replicating similar patterns, and when the lenses were fully developed. At that point, there was no need to iterate between the models and the data, which can be interpreted as the data saturation limit (Eisenhardt, 1989). At the same time, it is important to notice that the strategies utilized to created Open-ended Design, and here defined as the *sum* of the ten lenses together, give almost infinite combinations, being limited only to the creativity and resourcefulness of the designer. Of those examples, just a few are here introduced, to be used more as inspiration rather than a conclusive list.

2.3.1.4. Evaluation

The analysis of the real products is crucial in order to have a grasp on the broader picture that they represent, but it is also the least codified part of the entire process (Eisenhardt, 1989). During the analysis of the whole amount of cases the author of this manuscript acted as single investigator, but always within a team of researchers and professionals with whom a constant exchange of opinions about the obtained results was conducted. The collected cases were compared by pointing out some instances (first check), by checking their presence in other cases (cross cases link, second check) and by understanding the more technical choices (third check). Sometimes, as described later in **Chapter 4**, during this analytical process a method of triangulation was adopted, specifically in order to avoid misinterpretation. This was done by compiling the same questionnaires of the designers, discussing with colleagues and interviewing the designers who realized the product in the first place.

2.3.2. Ante factum: anticipation of reality

2.3.2.1. Research through design of original cases

Also research through design is a type of research in which artifacts are used as main evidence and center of the study. These designed artifacts, or *materializations*, can transform the world by interacting with the context they are embedded in. They physically embody theory and technical opportunities (Zimmerman et al., 2007). Also, they foster collaboration between all the involved stakeholders, supporting consequently the learning process of the designer. This last dynamic is defined as participation (Ehn, 2008)(Manzini & Rizzo, 2011)(E. Björgvinsson, Ehn, & Hillgren, 2010), which is a specific design method adopted for this research and described in detail in the next section, **Chapter 3**. The exact procedure, methodology and standards for this research method are under discussion. In this dissertation it is shared the opinion that a strict definition of such methodology could imply a risk of limiting it, decreasing its potential value (W. Gaver, 2012). What we have considered more interesting in this work is, at the end of the process, to evaluate the quality of the results by adopting the criteria listed below (see **Paragraph Evaluation methods**).

In this case, the materializations (such as: sketches, pictures, prototypes, functional prototypes, products, etc.) cover a dual role: first of all, they become the evidence of certain design choices, but more importantly they cover possible gaps in communication, typically among different actors when designing in co-generative manners.

2.3.2.2. Research objects

The continuous creation of different materializations has been the guideline of all the five original studies of the ante factum investigations. While in the post factum the cases were already existing and developed by others, here the need to follow each case from the very start of the design process was clear. Every study has certain specific goals (the five sub-parts of Q2), focuses, limitations, actors involved, etc. The common elements among each Study are: to adopt materializations as a mean to communicate and to be in contact with the real context. Also, for every study there was an attempt to *anticipate* future scenario that could be enabled and/or facilitated by the adoption of open-ended solutions. This attempt was at first very intuitive, and in the last studies structured in detail. Because of the needed contact with the final user/context, it can be stated that all the developed artifacts *encountered reality*, even if sometimes the products were in the form of prototypes and not in their *final* version, due to lack of time and resources. On the other hand, especially when dealing with digital production and/or DIY (Do It Yourself) contexts, the difference between final products and working prototypes is hard to define and could be worth some reflections.

This approach responds to the need to integrate design research (and artifacts done for this purpose, such as prototypes) and practice. In fact, the embodied knowledge that designers put into their design outcomes can be, in part, made more explicit with the intention of communicating these results also to other stakeholders (Visser, Stappers, van der Lugt, & Sanders, 2005). Finally, as stated before, these artifacts - even if innovative and original - are never considered as knowledge per se (being ultimate particulars), but as means to show and to help verbalize certain dynamics related with the core phenomenon of Open-ended Design, and to hopefully provide some knowledge for action.

2.3.2.3. Actors

In this research a mixed group of design practitioners, with a higher percentage of students, has been involved. In total more than 100 designers have taken part to the research, which made it a participatory process of (co-)creation. Students of Industrial Design Engineering of University of Ghent, Campus Kortrijk, were systematically engaged in the framework of Design Laboratories, specifically with regard to the following courses.

- Cybernetics and system thinking, given to the 3rd year.
- Integration project, an intensive workshop of two weeks, given to the 3rd year, and including students of other nationalities and professional backgrounds.
- Co-creation, a multi-disciplinary course, given to the 3rd year, in collaboration with occupational therapist of the high school Howest, in Kortrijk.
- Innovation oriented entrepreneurship, given to the 4th year.

More details about the courses and the involvement of the students are provided in the single chapters of the studies. The author of this manuscript also personally covered the two roles of researcher and designer, which implies that the role of observer "standing outside" the design process was never adopted. The second big group are the final users that have been systematically involved being *known*, meaning personally present in the process or not present but part of an offline community which shares a common interest/issue (for example people with rheumatic diseases, urban gardeners, etc.) or *unknown* meaning not personally proximal and not specifically addressed by the developed solutions (in this case the solution was firstly developed for one and then up-scaled and shared in order to find other potential users). Details will be written for each specific study.

2.3.2.4. Data collection

In this case, the investigations were often coupled with the courses and laboratories, as explained in the previous chapter "Actors". Direct input and briefs were given both to professional designers and students in design engineering in order to tackle specific issues. A good documentation was always required, sometimes online in form of blog or websites and sometimes offline, in form of design reports, presentations, etc. For all the cases, functional prototypes were considered mandatory, being - as introduced earlier - the main communication mean and an important object of observation. The data collection covered a period of 3 years, for a total of 5 Studies and 77 originally developed products.

2.3.2.5. Evaluation

To evaluate the overall method adopted and the dynamic of the study, we refer to the following paragraph **2.4.2 Evaluation methods for the quality of the outcome**. The evaluation of the specific design outcomes and their relation with open-ended instances was developed in various ways: first of all, the projects are always co-designed and therefore the actual stakeholders (present both online and offline) were the first judges of the result itself. Secondly, and more importantly according to the goal of this research, the projects were often *made public*, through websites, submission to contests or even, in few cases, brought to the market. In this way, an attempt to verify the interest of other communities towards such solutions was conducted, and evaluated based on the possible capability of such design outcomes to trigger a more global conversation. Finally, the projects done by students always received scores from a team composed by professional designers and teachers. These scores refer to general design issues, and are not specifically related to their open-ended qualities, therefore are not included in this dissertation.

2.4. Intended outcomes

"Design knowledge is of and about the artificial world and how to contribute to the creation and maintenance of that world" (Cross, 2001, p. 5). This knowledge can be gained following different paths, among which exploring the inherent knowledge in the existing artifacts populating the world (Cross, 2001)(Alexander et al., 1977). The knowledge can be seen as part of the material aspects of products [also definable as *embedded knowledge* (B. Gaver & Bowers, 2012)], in the way they are used and adapted, and by reflecting around the design process followed to create such artifacts. In the last case, the practice of making and creating becomes the route to discovery itself (W. Gaver, 2012). These three possible ways to achieve new knowledge and general insights about a certain phenomenon are the ones adopted in this research. In this research through design approach, the identified and/or created artifacts have the potential to become *pre-patterns* from which design patterns can eventually emerge (Zimmerman et al., 2007). Theories, and important understandings, can emerge from the design practice. This emergence can be seen as a bottom-up approach to create knowledge, other than and complementary to the approach that sees how theory should be confirmed by the design practice (W. Gaver, 2012). The knowledge created in this work intents to bridge the ideal design space with the real environment (goal of this research), which can be seen sometimes as the gap between academic research with its application into the design practice and vice versa (to bring concepts from the design practice into academia) (Dix, 2007).

As E. Stolterman writes "Designers can be prepared-for-action but not guided-in-action by detailed prescriptive procedures" (Stolterman, 2008, p. 941), it is really hard to precisely guide the complex, creative and context-dependent design process. Also, it is our belief that knowledge, as tangible products and any other outcome of a creative act, is dynamic and should be adapted by every single reader, according to his/her own needs.

Therefore, the intended outcomes of this work are four, different in nature:

- A theoretical framework (**Foundations**): this outcome is analytic in nature and, even if often represented with the use of practical examples, is abstract in nature. In the previous representation of the tree, these are the *roots*.
- A specific picture, or landscape, about the phenomenon of change in design, here defined as Open-ended Design (**Observation, Study 0**). This landscape is populated by various existing cases where change plays a fundamental role for the designed solution. This is a fundamental benchmark for designers, a place to gather inspirations and useful insights. In the previous representation of the tree, this is the unsightly cluster of *leaves* reorganized through the view on some of the *branches* beneath.
- An open methodology that can be used as analytic and generative tool, to read and set up strategies and mechanisms to obtain Open-ended Design solutions. In the previous representation of the tree, these are the ways to join roots and branches, creating new design outcomes, in form of *leaves* (explored from **Study 1** to **Study 4**, and summarized in **Study 5**).
- A framework for new research trajectories, meant to analyze in depth specific issues related to the Open-ended Design topic. These proposed researches are reported in **Chapter 5, Termination, Future Studies**.

All these outcomes are followed by a critical discussion regarding two main aspects: on the one hand the method adopted to explore this topic, and on the other hand, the implications and limitations of Open-ended Design and its creation.

2.4.1. Quality of the outcomes

This work started with broad questions and no hypothesis. It doesn't aim at quantifying a phenomenon or at proving a specific theory. It is actually concerned with gaining a broad understanding of the phenomenon of change in design, and - by combining analytic and generative approaches together - it can be seen as a broad of State of the Art, being descriptive in nature. In order to evaluate the quality of the developed work different criteria were considered. Some of them have been already proposed previously to evaluate the outcome and quality of a Research Through Design contribution in interaction design (Zimmerman et al., 2007). These criteria, Process, Invention, Relevance and Extensibility have been integrated with other two criteria, Conversation and Scalability (Hermans, 2015).

- **Process.** Even if there is no expectation that by reproducing the process the same result can be achieved, a good documentation of the design process is needed in order to achieve high quality and let readers understand how and why choices have been made.

- **Invention.** The research must represent an original integration of different subjects in order to tackle a specific situation. The work builds upon existing literature review, and still is original and innovative.
- **Relevance**. It is fundamental to always sketch the motivation of the work, why it is relevant now and appropriate to be addressed in this specific moment.
- **Extensibility.** The results and evidences raised by the research should be open for adaptations. The results can be, for example, applied by other designers and the knowledge created can be understood and re-appropriated by other stakeholders.

Other additional criteria considered fundamental are:

- **Conversation**. Open-ended Design deals ultimately with the interaction (in time) between the designed solution and the specific context (Manzini, 2010). Therefore, it is fundamental, in order to judge the quality of the research, to discuss how our materializations triggered interest and discussion in the contexts they were introduced in.
- **Scalability.** In practice based studies, a clear distinction between research artifacts and artifacts made for a final market is made. In the context of Open-ended Design we find valuable, in order to judge the quality of the outcome, to briefly explore the real possibilities of re-appropriations, adoption and up-scaling of such solutions.

These six criteria have been used to shape the conclusive discussion, in **Chapter 7, Termination**. Furthermore, in every chapter, as in the final part, the work has been critically viewed in form of SWOT (Strengths, Weaknesses, Opportunity, Threats) analysis. This kind of view has been always developed on two levels: the method adopted and the kind of results proposed.

2.5. Conclusions

In this section, **Chapter 2**, the main methodological structure of the work has been presented. A mix of different qualitative research methods has been used. Case Study, Research through Design and Research Through Prototyping represent the main focus; all methods that put the artifacts and the making process (Design Practice) at the center of the exploration. This way, we avoided prescriptive processes and were able to choose the most suitable research methods for the specific design problem, as advocated by Zimmerman (Zimmerman et al., 2007)(Koskinen et al., 2012). One potential problem with these qualitative mixed methods, is that some aspect of the method may be lost or weakened in translation. This relates to the subjectivity involved in the design process, which is based on reflection and deliberate choices (Manzini, 2009). These methods and approaches are adopted to ultimately understand how change happens in design, and how designers can intentionally support it. Where, by supporting, we mean both to enhance the value and feasibility of the changes made in order to reach a better status (i.e. reparations and adaptations), and to decrease the possibility of reaching disruptive changes that can lead to users' dissatisfaction and products' short life spans. Furthermore, all the originally developed materializations are documented and available (some to the end user, some to the addressed community, both online and offline). This allows the possibility of different interpretations *in time*, which is the real dimension of Open-ended Design. In fact, as described afterwards in this manuscript, it appeared that products able to change meaningfully are designed intentionally in order to be out-of-control, which is what we tried to emulate with our own design outcomes. In this way, we can let spontaneous processes become manifest, becoming a powerful learning tool.

CHAPTER 3

FOUNDATIONS

Brief summary

Consumption patterns such as hyper-consumerism became dominant, causing drastic environmental repercussion. A new paradigm, that questions the very nature of the design process and outcomes, is advocated. If on the one hand top-down standard solutions often face rejection or early abandonment, on the other hand bottom-up local solutions are hard to spread, because of their very contextual nature. In order for both kind of outcomes to have a positive impact, an engagement in form of *conversation* among all the stakeholders is considered fundamental. This chapter introduces some on-going conversations. For example, the ones between user and products, in form of emotional bond and personalization. The ones between users and technology, result of the disruptive new industrial revolution. Conversations between communities of users, fostered by the appearance of open design and conversations between users and designers, recognized under the big hat of participatory design. Finally, with meta-design, a vision that pursues the creation of unfinished and ever evolving outcomes (*imperfect* by intention), the conversation reaches the design-after-design space, becomes out-of-control, aiming at creating new knowledge, emergent from the real, messy world. Two main challenges open up: how can this *intentional imperfection* become the mean to support a design action for conversation? And, how can designers learn from it? Goal of this research is ultimately to answer these questions, by creating a unified Open-ended Design method that bridges the world of design practice (that develops unstructured strategies and cases) to the world of research (that develops organized visions and methods). A goal supported by action oriented, system thinking and cybernetic approaches aiming at intentionally trigger change.

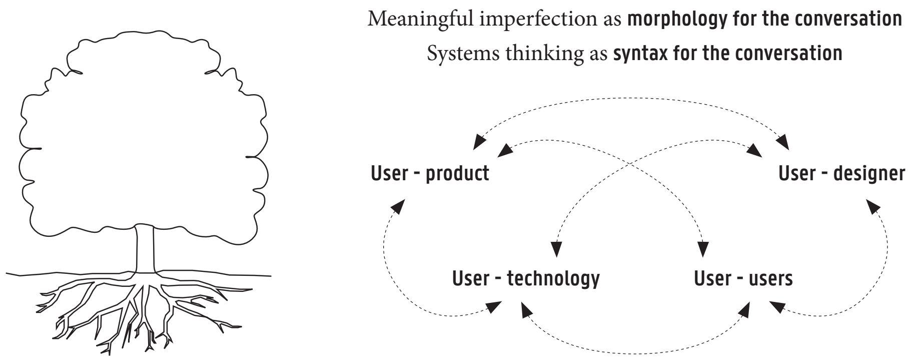


Figure 3.1. Chapter 3 is about the discovery of the roots motivating and supporting change in design. A specific focus is given to the need for active interactions between actors and products-actors, defined as conversation.

In the previous sections, we have sketched the main research questions, goals and methodologies of the here presented research. In **Chapter 3**, the main foundations are introduced. These foundations start from the shared challenge towards more sustainable design paradigms, and extend very broadly. The topics have been summarized in the following paragraphs:

- 3.1. New design paradigms for sustainbility
- 3.2. Current paradigms and their limitations
  - 3.2.1. Standard, top-down solutions
  - 3.2.2. Unique, bottom-up solutions
- 3.3. The need for conversations
  - 3.3.1. Conversation user-product: emotional bond
  - 3.3.2. Conversation user-technology: digital revolution
  - 3.3.3. Conversation user-users: open design
  - 3.3.4. Conversation user-designers: participatory design
- 3.4. Approaches for out-of-control conversations
  - 3.4.1. Time in design for behavioral change
  - 3.4.2. A broader view on imperfect systems
- 3.5. Intentional imperfection as morphology for these conversations
  - 3.5.1. Design action for intentional change
  - 3.5.2. Imperfection for dynamic experiences
- 3.6. Systems thinking as syntax for these conversations
  - 3.6.1. Cybernetics and design
  - 3.6.2. Circularity and its representation
- 3.7. Conclusions

In this section various models and theories will be introduced. This knowledge represents the groundwork (or, foundation) for the construction of the ten lenses, a set of specific questions about change in design. These questions were initially formulated broadly following the typical 5W1H (why, who, what, when, where and how) used to gather information in the first exploratory phases. The here presented research tries to give answers to them. At the same time, and together with the Observation phase, it articulates the questions better in order to reach more specific formulations, as described in the following chapters.

3.1. New design paradigms for sustainability

Consumption patterns across the industrialized world, such as the tendency towards accumulation, hyper-consumerism and throwaway dynamics became dominant, causing drastic environmental repercussions (Cooper, 2010)("Annual Report on Sustainable Development Work in the OECD," 2008). Also, it has been recognized that most of these impacts are defined since the design phase (Thackara, 2005), putting the role of the designer in strong connection with the need for a more sustainable development, defined as a development that "meets the needs of the present without compromising the ability of future generations to meet their own needs" (Brundtland, 1987, p. 13). It is important to focus on two main aspects of this definition: the future perspective and the diversity of needs (*their own needs*).

This led to the elaboration of many tools and methods for eco-efficiency (eco-design, design for the environment, design for sustainability, etc.), which even by reaching the goal of – for example – using less material and energy, didn't improve the overall picture (Strauss & Fuad-luke, 2008)(Manzini, 2009)(Manzini, 2010)(Walker, 2006). Reason for this can be seen in the sometimes reductionist view that lead, one among others, to the occurring phenomenon of *rebound effect* (Berkhout, Muskens, & W. Velthuijsen, 2000). In other words, these eco-efficiency strategies alone cannot guarantee more sustainable scenarios. What is asked to the designers in order to become agents in the transition towards sustainability, is to find ways to achieve new models for sustainable behaviors, focusing on new patterns of both consumption and production (SCP). SCPs have been increasingly studied and supported at international institutional level, for examples by the Organization for Economic Co-operation and Development, OECD (oecd.org, sustainabledevelopment.un.org), and demand a strong multidisciplinary approach (Cooper, 2010)(Manzini & Rizzo, 2011).

In this new paradigm eco-efficiency (technological advancement) meets eco-sufficiency (cultural advancement), aiming at reaching an overall sustainable scenario based on eco-efficacy (Vezzoli & Manzini, 2008)(Cooper, 2010) visible in **Figure 3.2**.

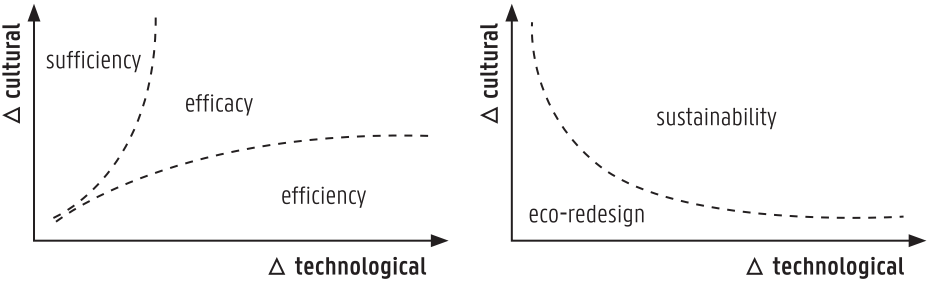


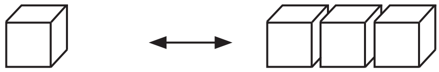
Figure 3.2. Landscape of sustainable solutions. While only technological development leads to higher efficiency, only cultural acceptance leads to sufficiency. Efficacy, seen as the most sustainable solutions, have to be found where both cultural and technological implementations are explored. Figure adapted from Vezzoli and Manzini (Vezzoli & Manzini, 2008) and Cooper (Cooper, 2010)

Design goes then beyond the creation and modification of the artificial aspects of the world, since it ultimately deals with social organizations and patterns of human interactions (Nelson, 1994). This transition can be supported by engaging with i participatory design in combination with an open process where small local activities operate while keeping in mind a more global vision (Manzini & Rizzo, 2011)(Manzini, 2010), as explained in more detail in the next paragraph. This transition can be supported by the current digital revolution, that builds upon networked society with increased trust in sharing dynamics, diffusion of creativity and production capabilities. In other words, radical social and technological innovations where resources (creativity, knowledge, etc.) are shared.

Thanks to the arise of these innovations, which can both foster the conversation between different stakeholders, new qualities already appear diffused: the quality of places, communities, commons and time (Manzini, 2009). A new sense of time, with the rediscovery of slowness as a desirable component, allowing attention to the important things in life. A new idea of well-being itself. This scenario is, to conclude, what E. Manzini defines as the ongoing change towards a network society and knowledge society (Manzini, 2009) and from which designers must learn in order to take an action in trying to re-orient it towards even more sustainable scenarios. “We must also regenerate the physical, social, and cultural quality of places, and the physical, social, and cultural quality of the planet as a whole” (Manzini, 2009, p. 8). Finally, as advised unanimously from the previous studies, sustainability cannot any longer be addressed as a product oriented problem-solving profession, but it should be rather seen as a system thinking approach, able to embrace complexity and intentionality (Nelson, 1994). These latter topics are discussed in **Paragraph 3.6**.

3.2. Current paradigms and their limitations

For the listed reasons, sustainability is increasingly emphasized in courses on design and engineering (Melles, de Vere, & Misic, 2011). In this Section, two diametrically opposed approaches to design and design for sustainability are introduced: the general (or universal, ideal, standard, *for all*) approach and the local (or contextual, idiosyncratic, unique, *for one*) approach, both represented in **Table 3.1**.



Design for one	Design for all
local	global
unique	standard
bottom up	top down
small volume	high volume
proximal	distant

Table 3.1. Design for one as opposed to design for all outcomes

In other words, these design outcomes can be distinguished depending on the relation between the end-use environment, or *real environment* as defined in **Chapter 1**, and the solutions itself, as in **Figure 3.3** (next page):

(a) general solutions for global needs, mainly referring to the *theoretically* best material, best technology, etc. or

(b) specific solutions for local needs, mainly referring to the available material, available technology, also defined as "appropriate" [for a detailed description of "appropriate technology" see appropedia.org/Appropriate_technology].

In the case of general solutions (a), also definable as top down solutions, difficulties can be found while introduced in the end-use environment. Examples include One

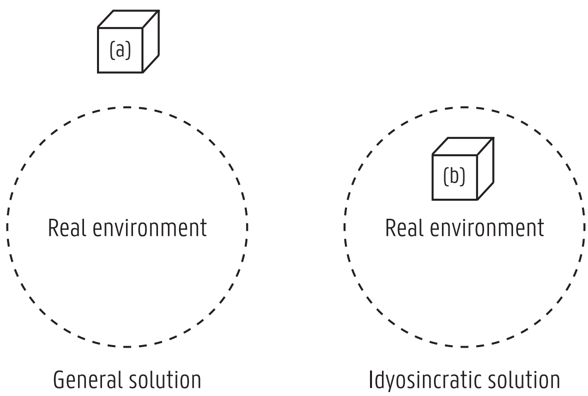


Figure 3.3. Relation between design solutions (general and specific) and end-use environment

Laptop Per Child (wiki.olpc.org), and NeoNurture (designthatmatters.org/neonurture). These solutions can be considered mainly technical and may face problems during adoption and use phases. In fact, the product may face non-acceptance in the real environment because of loss of the "intentional" (from the designers' point of view) initial value: or it may happen that users' behaviors escalate, generating the previously mentioned phenomenon of rebound effect. In the case of specific solutions (b), also definable as bottom up, difficulties can be found while up-scaling them in order to solve global problems. Examples could be provided by very context-dependent and local projects, as Design for Every(one) (designforeveryone.howest.be), and the EyeWriter (eyewriter.org). This dynamic is represented in **Figure 3.4**.

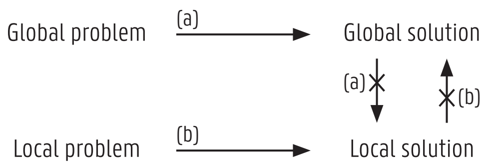


Figure 3.4. Arrows indicate the typical paths used to reach solutions (a) and (b). Crosses indicate where the difficulties can be found. For example: to reach idiosyncratic solutions (b) designers start from local problems and reach unique and "appropriate" solutions. Difficulties can be found in the up-scaling process (from local to global) of these solutions.

These solutions, even if extremely valuable, risk to remain limited to the unique local context, in other words *closed* (because of the technical/cultural/linguistic skills required to acquire, and eventually adapt them in order to let them fit the new environment) and unconnected, as opposite to what stated in Manzini (Manzini, 2010). Typical paths to reach solutions (a) and (b), and related difficulties are synthetized in

Figure 3.4. From our perspective these problems raise both from the design method adopted, as in Wiley and Hilton III (Wiley & Hilton III, 2009), and for the kind of outcome desired. Sometimes, in fact, the design process is seen as solution-oriented and aims at reaching a "perfect" end-result. In our perspective, shared among others researches later introduced, the design process is never ending per definition and sustains the learning process of the designers. Therefore the design outcome must change as well, becoming open-ended, comparable to a prototype used to learn. In fact in this context, the design outcome can be considered a *boundary object* to be shared between all stakeholders becoming the common ground to start and coordinate a conversation (Arias & Fischer, 2000). Next, limitations faced both by standard, top down and global solutions and by unique, bottom up and local solutions are introduced.

3.2.1. Standard, top down solutions

Durability measures how long a product functions within the *intended* use and without big efforts of repurposing and reparation. On the contrary, the *life-span* extension requires some deliberate efforts from the users, such as maintenance, reparations or reuse of functional parts (Cooper, 2010). One of the mayor threats for long lasting products is represented by the *planned obsolescence or built-in obsolescence*, which can be defined as the outcome of a deliberate decision for which a product should no longer be functional or desirable after a predetermined period of time (Slade, 2007)(Papanek, 1984)(Cooper, 2010) and can be seen as divided in some big sub-categories of obsolescence: the *aesthetic* or *psychological* and the *functional* or *technological* one, to which also the *social* and *economic* ones could be added. Thanks to this concept, introduced in literature since 1932 by Bernard London in the work "Ending the Depression through Planned Obsolescence", and to the sometimes too high costs of reparation, the absence of push for maintenance, etc., products almost never reach the end of their physical capacity to function. In other words, because of early abandonment, we don't *consume* enough, highlighting with this the difference between use and consume, where the latter means to use something till the end of its function. This concept will be extended in **Chapter 4**, **Study 0**. Depending on the product category (particularly, wheter or notthe product uses energy during use), it is shared opinion that more durable goods can have potential environmental benefits. Still, in case of standard products, produced in high volumes, there are reasons for companies to believe in the paradigm of selling more and faster, and therefore to engage with planned obsolescence. In this perspective the responsibility for trying to extend the life-span of products is shared between many different stakeholders, among which producers, designers and users. In the next **Paragraph 3.3.1**, **Conversation user-product** we describe main influences on product's durability.

But, while obsolescence is often intentionally created by the producers, there is another threat for sustainable behavior that derives from intrinsic limitations of the design outcome and design process themselves: the problem of rejection. In this case the product is thrown away, or not used, because of lack in functionality derived by its standard, top down nature. Industrial mass production, generally seeks for a high level of standardization, following the model *one size fits all*, and cannot always fulfill everyone's needs. This problem applies in many contexts, and becomes particularly damaging when designing assistive devices (Couvreur, Dejonghe, Detand, & Goossens, 2013), products created to support people facing some disablement while conducting their own daily activities such as eating, writing, walking, doing their hobbies, etc. Assistive devices are meant to facilitate patients' occupation and participation in the society, and try to increase the users' well-being and empowerment (White, Lentin, & Farnworth, 2013)(Schneider, Manabile, & Tikly, 2008) (Hammar Ottenvall & Hakansson, 2013).

This research addresses the topic of assistive devices in many studies presented in **Chapter 5**, **Studies 1** to **4**. It is clear as standard solutions are limiting particularly when dealing with people with specific diseases, characterized by different, individual needs and progressions to the point of transforming the previously mentioned paradigm *one size fits all* to *one size fits none*, or at least the traditional approach to assistive technology has to focus on the average and eliminate the *extremities* in order to reach an economy of scale (Couvreur, 2016). But this is not the only reason for rejection, according to previous studies, psychological factors related to self-confidence and device perception may be the more important factors that cause the non-acceptance, non-use or rejection of assistive devices (Rogers, Holm, & Perkins, 2002), which puts greater pressure on understanding the actual individual needs. In fact, if aesthetics and usability of devices are important, involving the end user in the selection process of the assistive devices is evenly important, in order to decrease the degree of a non-use scenario (Wessels, Dijcks, Soede, Gelderblom, & De Witte, 2003). In other words, to let the user participate to the selection, or even generation, of the product can increase the emotional bond and the feeling of empowerment (Ehn, 2008). For assistive devices this problem can be seen as fundamental, for the other problems it still influences the user/product bond and the acceptance of the solution, leading again to early abandonment. To conclude, a third threat must be highlighted: the early abandonment of products that don't fulfill our needs *anymore*. This can be seen as similar to the planned obsolescence dynamic, but it doesn't necessarily derives from a business model choice, but rather from a lack of dynamism of the designed solution itself. This topic is addressed in **Paragraph 3.3.**, **The need for conversation.**

3.2.2. Unique, bottom-up solutions

In the previous section the main problems of standard and top down solutions were introduced. But we have to acknowledge as nowadays a diametrically opposite phenomenon is also occurring. In fact, for example, online platforms (i.e. Instructables, Thingiverse, etc.) often provide design solutions developed for one specific person, in order to solve her/his specific needs. These solutions are created using different approaches and technologies; from more traditional DIY (Do It Yourself) and hacking solutions to digitally fabricated ones. The developer decides to share the solution with online communities, believing in its potential value for other stakeholders. Some of these projects are picked up by the community, stimulating a conversation and sometimes being reproduced in other contexts. Occasionally, the picked-up solutions are even distributed back to the online community in their often adapted and implemented version. We define this process as *re-appropriation* (Ostuzzi, Couvreur, Detand, & Saldien, 2017)(Ostuzzi, Conradie, Couvreur, Detand, & Saldien, 2016)(Redström, 2008)(Dix, 2007). In this transformative process the user modifies some features of a designed solution in order to make it more fitting to his/her context. The kind of products for which such re-appropriation is important, and even necessary, are here defined as *contextual* to highlight the crucial role played by the context of use (or real environment) and the inappropriateness of transferring them "as they are" to other contexts, as seen for standard solutions. Again, a typical example is the one of assistive devices, and in broader terms, also for environmental sustainability the same concept can be applied, as some activities have a global impact, but lots of them have also important local repercussion. Yet, while solutions may be applicable in a local context, they are not necessarily suited to be re-appropriated and reused on a wider scale (Chiappe & Arias, 2015). This represents our initial challenge of trying to decrease the disconnection existing between the *design space* as defined in **Chapter 1**, and the real environment [defined as "supersystem" in Wiley & Hilton III, 2009 (Wiley & Hilton III, 2009)].

A challenge is then to explore how different methods and outcomes, in the field of Industrial Design Engineering, can stimulate acceptance and re-appropriation of both local and global design solutions, making them longer lasting and of higher value; where re-appropriation can lead to advantages such as described by A. Dix: situatedness, dynamics and ownership (Dix, 2007). This can happen by supporting local solutions in contributing to global discourse on issues related to sustainability, and by allowing global solutions to be re-appropriated locally. In this challenge a new paradigm is needed [represented by (c) in **Figure 3.5**], where local problems can dialogue with globally diffused ones and which starts again from the crucial role of conversation.

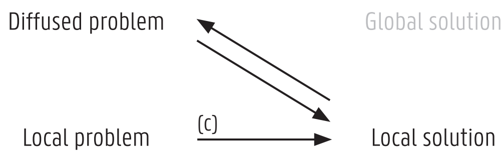


Figure 3.5. From local problem to local solution. Through "global" discussions and re-appropriation cycles there is a chance to disseminate several local solutions

There is need and conversation between local and global, as "[a] decentralized system can only produce genuinely intelligent results if there's a mean of aggregating the information of everyone in the system. Without such a mean, there's no reason to think that decentralization will produce a smart result." (Surowiecki, 2004, p. 170).

3.3. The need for conversations

The capability of design outcomes to last, and even to be used, longer can be therefore seen as deeply connected with the capability of engaging with the real context of use. Engagement is here defined also as participation or *conversation*, referring the continuous exchange of values and meaning, between all the involved stakeholders. Without this dialogue, which starts from the perceived capability of everyone to *take part to it* and *contribute* with his/her own view and means, less sustainable scenarios might become dominant. To start these conversations, to support them in time and more importantly to learn from them, many aspects have to be considered. Previously we have listed the major threats for this conversation not to start, or not to continue in time. Here, on the contrary, we are introducing some on-going conversations, their values and limits, starting from the ones:

- between user and products, in form of emotional bond and personalization;
- between users and technology, as result of the disruptive digital industrial revolution;
- between community of users, fostered by the appearance of open design;
- between users and designers, under the big hat of participatory design.

3.3.1. Conversation user-product: emotional bond

As said, efficient and technically durable products, face the risk of being prematurely discarded, becoming just more durable waste (Cooper, 2010). In other words, one of the reasons why we can find in trash bins or landfills perfectly functional products is the lack of subject/object emotional bond. After all, emotions are profoundly implicated in all aspects of our daily life and consequentially also in our behavior towards products (Blevis & Stolterman, 2007)(Wrigley, 2013). Emotions shape our consumption patterns, in a way that is far more complex than for example, the desire of purchasing new and shinier things (Cooper, 2010). The emotional bond, in fact, is related with love, memories, interaction, passion and, more importantly, it changes in time. In fact, if we correlate the general pleasure towards product with time (Woolley, 2003), we can imagine a curve similar to the one displaced in **Figure 3.6**.

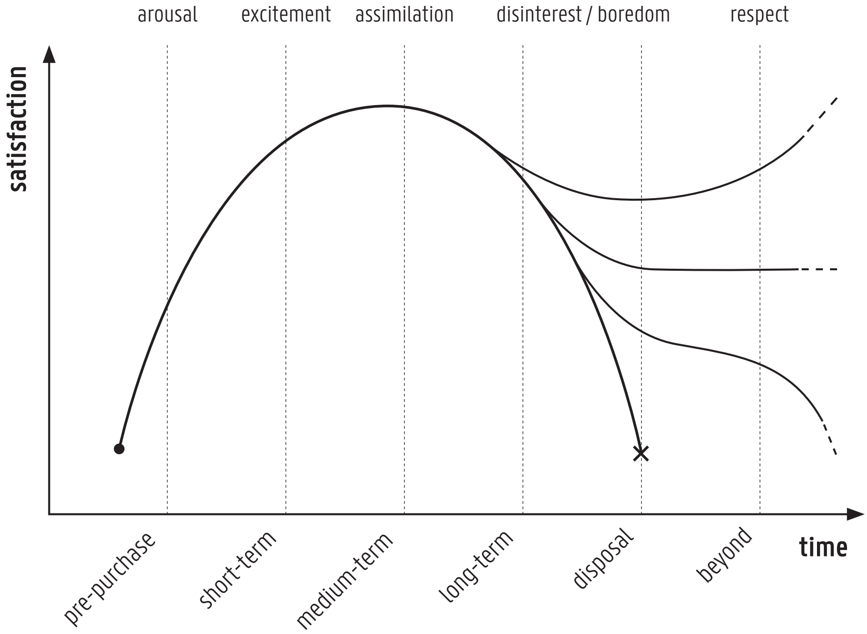


Figure 3.6. Satisfaction cycles, in relation with time. Adapted by Woolley (Woolley, 2003)

In the pre-purchase, we anticipate the product use with a growing pleasure and, in the short-term exploration of it, we reach the optimum pleasure and feel excited about our new acquisition. But, in the medium-term we already start facing a decreasing pleasure due to assimilation, which can be seen as a physiological trend. Finally, in the long-term we might start feeling disinterest or bored by the product, and face therefore the decision of retaining or disposing it. To dispose it means to end its life as product, or to give it to some (un)known users, which means to face emotionally not-durable products (Chapman, 2005).

In case of retention, what we experience is that some products might trigger an increased emotional value, becoming similar to heirlooms, or considered irreplaceable. Other ones, even after an initially increased emotional value, might face disposal after a longer period of time. Because of our daily experience with products, we know very well this dynamic. It is defined as *choreographed obsolescence*, in order to distinguish it from the *built-in* one.

3.3.1.1. Product experience

The problem is, while generally the emotional demand of users evolves, products remain somehow inert. For this reason there is the need to search for a longer lasting emotional conversation between user and product, that can be defined as *Emotional Durability* and relates to the field of SID, Sustainable Interaction Design (Odom, Blevis, & Stolterman, 2008)(Blevis & Stolterman, 2007)(Cooper, 2010). Emotional durable products are very spread: we still keep the ticket of the concert of our favorite band, we have in our shelves our grandmother's heirloom, we would never throw away our pieces of jewelry (Blevis & Stolterman, 2007). As clear from these examples, the emotional bond is not only about the product's functionality or aesthetics, in fact it can be about the perception that these products are irreplaceable (meaning "a possession that a consumer resists replacing, even with an exact replica, because the consumer feels that the replica cannot sustain the same meaning as the original" (Grayson & Shulman, 2000, p. 17) and even sacred especially when related to a specific past event or beloved one (Curasi, Price, & Arnould, 2004)(Chandler & Schwarz, 2010)(Mugge, Schoormans, & Schifferstein, 2009)(Arnould & Wallendorf, 1988). Emotional cognition, as human psychological response to a product that includes both affect and cognition, is in literature articulated in three levels: the *visceral leve*l, which responds to quick sensory perception and is biologically determined, the *behavioral level*, which interprets the sensory data and develops judgments starting from them, and finally the *reflective level*, which relates judgments with emotions and meanings (Wrigley, 2013)(Norman, 2004). The problem for the designer is that these responses are not objective qualities, comparable to parts embedded in the products, on the contrary: they are subjective interpretations of the objective sensorial qualities. This interaction can also be defined as *product experience*, and becomes crucial in order to foster the emotional bond (Schifferstein & Hekkert, 2007). For example, the anthropomorphic beliefs towards products, can lead users to treat objects as living entities, increasing the emotional quality of the experience and, in time, fostering the sense of attachment (Chandler & Schwarz, 2010). Also, sometimes our belongings become symbolic of our own personality, for example of important self-worth domains, as for something we built or earned or when the possession reflects certain values we agree with. This can elicit love feelings and in case of loss of the product, even grief reactions (Russo & Hekkert, 2007)(Coulter & Ligas, 2003)(Ferraro, Escalas, & Bettman, 2011)(Grayson & Shulman, 2000). In general several kind of subject/object attachment have been listed in literature such as the one based on meaningful tools, based on their function and what they do rather than what they are (note the similarity with Functional Unit, used in Life Cycle Assessment), meaningful associations, relating to the symbolic meaning of the product, and the ones based on their qualities of living objects (Battarbee & Mattelmaki, 2003)(Odom, Pierce, Stolterman, & Blevis, 2009)(Russo & Hekkert, 2007). With this respect, a critique towards the current design is that it became only a "packager of technology, housing hardware within intelligible skins that enable thoughtless and effortless subject/object interactions. Both the scope and power of emotional experiences delivered via objects born of this ideology are incredibly limited and offer very little to users. Their ability to both support and mediate evolving narrative experiences are weak" (Cooper, 2010, p. 69). The behavioral aspects towards product acquisition, retention and disposal, which are ultimately the capability and willingness of creating an emotional bond with products is not only a designers' responsibility, but also a personal attitude, that can be described by introducing two extreme profiles the *packrats*, people with a (stronger or softer) product retention tendency (Haws, Naylor, Coulter, & Bearden, 2012), accumulating objects without disposing them and the *purgers*, incline to fast acquisition and as fast disposal (Coulter & Ligas, 2003). While the first one starts from a practical view and a general care for environmental issues, but faces a fear of loss and (Curasi et al., 2004)(Haws et al., 2012) the second ones are not necessarily driven by consumerism or little care for the environment, but more from practical reasons of efficiency.

Design strategies to increase the emotional bond can be found in literature, and focus on the front end and early stage emotional response (Noble & Kumar, 2008)(Desmet & Desmet, 2003) while other focus on the emotional bond functional to longevity. The latter ones are addressed in this work, being related to the time view of the issue. The strategies for emotional longevity focus on the creation of products both dynamic and flexible, capable of supporting the emotional experience of users. Products that can embed means of renewal and reuse, even among different and sequential owners (Blevis & Stolterman, 2007)(Cooper, 2010)(Wrigley, 2013). Other strategies try to achieve longevity of use, and even the heirloom status (Jung, Bardzell, Blevis, Pierce, & Stolterman, 2011). The fact that the product is a gift can relate to the concept of *indexicality* defined as the link between the product and specific memories, for example in time and place (Grayson & Shulman, 2000)(Odom et al., 2008)(Russo & Hekkert, 2007)(Arnould & Wallendorf, 1988). Also, it is advocated a focus on the creation of an aesthetic that is in deep contrast with the uniformity of products aesthetics nowadays, an aesthetic that rather embraces more the dynamic nature of products, capable of ageing and accumulate meaning over time. This shouldn't be misunderstood for the fashionable attitude nowadays that *fakes aging* (a good example are the jeans sold already *aged*) provoking an increased use of resources during production, without adding ensoulment to the product. In these terms, such aesthetic can be considered the one of sustainability and lead to products ensoulment, seen again as an emergent quality from the interaction with the products, and are considered ethical issues (Blevis & Stolterman, 2007)(Walker, 2006)(Odom et al., 2008)(Odom et al., 2009)(Woolley, 2003). More concrete suggestions are, among others, the raise of the specification of 'core' products with extendable, adaptable and open-ended capabilities and appearances that are as future-proofed as possible (Woolley, 2003).

3.3.1.2. Personalization

Another important prerequisite to achieve longer lasting products is the stimulation of the user to action (Wrigley, 2013): for example, to reuse products as they are, to repair them or misuse them, which could be supported by anthropomorphizing the products themselves by adding specific product's features for this purpose (Chandler & Schwarz, 2010). The effort (physical and mental) done to re-appropriate the product, such as for products personalization or control on functionality, is stimulating stronger emotional bonds (Jung et al., 2011). Similar dynamics, of direct actions of the user directed to product personalization, are: DIY, Hacking, Hand-crafting, Non-intentional design, etc. These dynamics, and the motivations that can trigger them, are reported in the next **Chapter 4, Study 0**.

Customization, personalization and niches: a new landscape

The previously listed cases refer to spontaneous processes of personalization, occurring in the *use phase*, often not controlled or anticipated by companies. Still, companies are nowadays giving more and more value to products' variety in order to increase the possible choice for users. This has a close connection with the Long Tail economics, later described. The inclusion of the user in the design phase is a spread phenomenon nowadays and can be seen as mainly divided in two possible procedures: customization and personalization. Where both refer to define the creation of different appearance or functionality of a product, and customization refers to the situation where the user can choose between definite options, and personalization refers to the situation where the user can give inputs not anticipated by the company and designer. In both cases the user can have an impact in terms of qualities of the final outcome. This process of engagement responded to multiple needs and opportunities: to reach a higher fit to individual preferences (both aesthetic and functional), it can increase the symbolic value of the product, as for becoming an extensions of the self or communicating ownership, it can therefore increase the perceived value of the product itself, both because of the higher fit (on soft and hard attributes) but also as reward for the participation during the process itself (Mugge et al., 2009).
But it has some important limitations: in fact, even if choice is essential for the human autonomy and satisfaction of personal needs, we shouldn't forget as, first of all to personalize a product substantial design skills might be needed (Leong, Vetere, &

Howard, 2006), but more importantly, when faced with completely *unconstrained* freedom to choose we can develop feelings of misery and paralysis, defined as the Paradox of Choice (Carr, 2004). Furthermore, the run for higher product variety, if not structurally related to real users' needs can lead to more unsustainable scenarios, visible as the *explosion of choice* (Carr, 2004, pp. 86-104). In these terms, choice and actual participation are still distant and while customization, even if leading to higher functionality, is not enough to stimulate a positive emotional response (Norman, 2004), personalization still refers to the manufacturing of a tailor-made product, and not a real mass produced one (Piller, Schubert, Koch, & Möslein, 2005)(Cruickshank & Atkinson, 2014). Importantly, the attitude to repair and personalize products has been a common practice, disregarded for some decades and only recently again in the design landscape. Examples are represented by the DIY approach that became popular in the '50s (Watson and Shove, 2006), also in its famous *designers' version* from Enzo Mari "Autoprogettazione" (1974). This moves close to the digital revolutions and the concept of "prosumer", that indicates the decreased gap between user and consumer (Toffler, 1980) and that is later described.

In conclusion, to reach more sustainable scenarios an engagement of all the stakeholders is advocated. The subject/object relation, in form of emotional bond, is a complex phenomenon related to: product's function, symbolism, acquisition dynamic, ease of interaction, quality of the interaction, material qualities, etc. Strategies as personalization can be adopted to increase product fit, and emotional bond in the early stages. But we should consider as products attachment is dynamic in time, which brings the attention to the capability of products to change and support the emotional demand of users, as it evolves. A strategy to obtain this would be to design unfinished, in other words intentionally imperfect, products. This concept, will be further analyzed in **Paragraph 3.5**, **Intentional imperfection**.

3.3.2. Conversation user-technology: digital revolution

The new digital revolution is changing the way we *program* the physical world (Gershenfeld, 2012)(Dougherty, 2008) changing drastically the conversation between users and technology. The worldwide spread of digital technologies is powerful, because of its ubiquity, to the point of being defined as a *desktop revolution*. Products can be produced on demand, by using low cost technologies. A growing number of persons have access to production tools, directly or through fabrication labs, and to the knowledge needed to fabricate objects with such technologies. This phenomenon implies big changes in the business models, in the role of the designer and in the users themselves (Anderson, 2006). About the business models, one of the most interesting changes consists in the Long Tail economic model that represents the volume of sales as connected with products variety, see **Figure 3.7**. The main findings are that the variety can now be bigger than before (that is, the length of the tail), it is economically possible to reach those areas of high variety and low volume (thanks to the success of the internet, and the digital production), and furthermore, all the areas with high variety and low volume (defined as *niches*), if summed together, represent a very big portion of the market, comparable to the one of the *hits* (high volume, low variety). In other words, nowadays the small is no longer small and local is no longer local (Manzini, 2010). The Long Tail economics is represented in **Figure 3.7**.

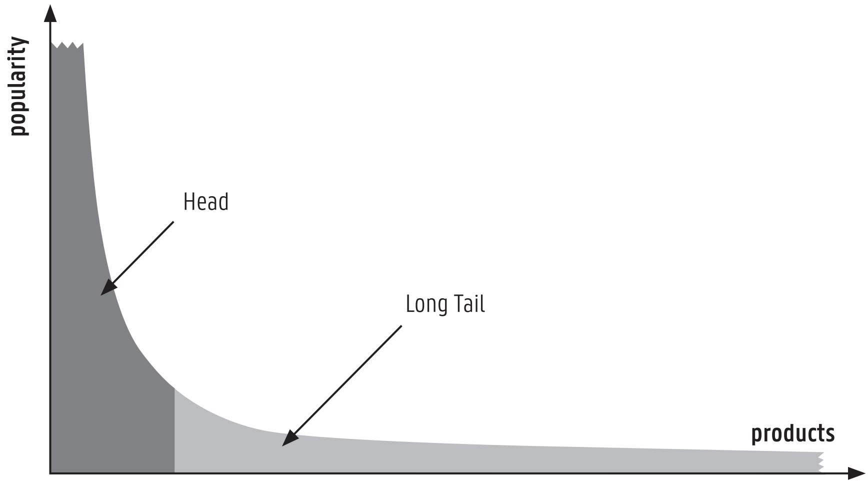


Figure 3.7. The long tail of niches, products with high variety and low volume. Adopted from Anderson (Anderson, 2006)

An alternative vision of users is shaping, they become more like *creative appropriators*, hackers, tinkerers, *prosumers* (Ritzer, Dean, & Jurgenson, 2012), artists and even co-designers or co-engineers (Tanenbaum, Williams, Desjardins, & Tanenbaum, 2013). These are the *makers*, main actors of the maker movement, a movement that shares many aspects with the hacking and DIY (Do It Yourself) approaches (Dougherty, 2008). The makers can also be seen as a community of practice, meaning not a mass of unrelated users, but an actual community that interacts and continuously challenges each other in the design process (Wenger, 1998). Thanks to this revolutionary context, it is possible to work under the motto "think globally, fabricate locally" (Gershenfeld, 2012), which connects to the challenge introduced earlier, related to SLOC (Small Local Open Connected) outcomes, that focus on local problems and aims at having globally diffused impacts (Manzini & Rizzo, 2011). What makes it possible, apart from the success of the internet itself, is the spread of Open Source Design.

3.3.2.1. Open-source hardware and low-cost 3D printers

The term Open Source, in general, refers to the availability of the source files and information of a certain product. It started as a phenomenon mainly involving communities of programmers, remaining in the software domain. More recently the Open Source dynamic hit the hardware sphere, by designing and sharing the sources of physical artifacts, and becoming OSHW, Open Source Hardware. Three main factors are of particular interest for this thesis: (1) the process of creation and re-appropriation of such outcomes (see **Chapter 5, Study 1** and **2**), (2) the communication among the users and communities (see **Paragraph 3.3.3**), (3) the access to advanced manufacturing processes (such as 3D printing, laser cutting, etc.), focus of the next Paragraph. It is interesting to notice as the dominant dynamic of open source has a close relation with the local solutions view, previously introduced. In fact the developers often start from their own problems or problems of people close to them, they then create idiosyncratic solutions for these specific needs. Finally, they distribute the solutions *as they are*, leaving other stakeholders free to reuse and if possible and needed re-appropriate, through adaptations, the shared solutions (Gerhard Fischer & Giaccardi, 2006). It is important to mention that in software design, the concept of "openness" has been thoroughly applied and explored both under the points of view of licensing (i.e., open source) and the possibility of re-appropriations from *laydesigners* (i.e., Wikipedia), through highly iterative and shared processes. While in hardware design many projects often focus mainly on the licensing and technological aspects (some famous cases have been analysed in (Raasch, Herstatt, & Balka, 2009), rather than on the ease of re-appropriations occurring after the design, which implies the real participation of different stakeholders. This last point is a crucial aspect for this work, as introduced in **Chapter 1**.

In fact, the spread of digital production technologies can foster users engagement and the conversation between user and production processes themselves. Previously, this possibility belonged either to factories, and was therefore limited to the operators, or to the craftsmanship, and was limited to the *field experts.* The experts should be seen as opposite to lay designers (Hermans, 2014). The most interesting example we want to focus on are 3D printing technologies that in recent years have spread because of increased accessibility, cost reduction and media hype. A high number of low-cost 3D printing systems, especially FDM (Fused Modeling Deposition), were introduced on the market. These systems target Entry-level Users, mainly for personal use. However, a high impact on industrial design is recognized, especially for enabling rapid prototyping and manufacturing of products previously thought to be impossible to produce. This innovation addresses former industrial design issues typical of traditional mass production techniques such as: geometrical freedom, economical scalability and products variety. Currently also the accessibility is drastically increasing through the creation of low-cost, open-source FDM machines that are implemented and distributed through Fab Labs and other maker-spaces (Campbell, Bourell, & Gibson, 2012). Scholars defined this phenomenon as democratization of technologies (Tanenbaum et al., 2013) or democratization of manufacturing (Igoe & Mota, 2011): a significant cultural shift in how people engage with technology that challenges the dominant paradigm in which the user is perceived and considered only as a consumer, passive receptors of mass industrialized products. While industrial and high-cost AM technologies (Additive Manufacturing) find applications in several fields like automotive, aerospace and medical, the application of low-cost systems, as FDM ones, don't always value the potential of the technology, remaining linked to the production of gadgets, or products driven by aesthetic values rather than functional ones (Cruickshank & Atkinson, 2014). Little by little, tough, low-cost and entry-level 3DPs are finally being applied to more functional and end-use contexts, e.g. for the creation of health-related devices, as design tools in small enterprises or in relation with DIY craftsmanship.

The number of innovations on materials, processes and accessibility related to low cost and entry-level 3DP technologies has been increasing in recent times. We have decided to focus specifically on FDM 3DP, a technology that is based on a polymeric filament extrusion on a building platform. This kind of 3DP is highly diffused in low-cost and entry-level contexts. It is not limited to rapid prototyping, but can also be used to produce functional final products. The main advantages of the low-cost FDM technology and its uses are based on the layer-to-layer building approach (Campbell et al., 2012)(Evans & Campbell, 2003)(Lopez & Wright, 2002)(Tuck, Hague, Ruffo, Ransley, & Adams, 2008)(Gebhardt, 2011) and can be synthetized as:

- **High geometrical complexity** achievable in products and components.
- **Production flexibility** that leads to higher products differentiation. This allows overtaking the mass customization approach, getting closer to a full industrial personalization.
- **Rapidity** referred to design rapidity from idea to production (while on the other hand the production process itself can be highly time consuming).
- **Accessibility** in fact these technologies are already spread around in different places, such as local Fabrication Labs (Fab Labs). These realities grow on the assumption that "giving people the ability to make things for themselves can be the fastest way to solve their problems" [fab.cba.mit.edu, last accessed on June 2017].

Among these advantages we note some design-related values. For example, the possibility to develop *fit to one* products, to personalize each product aesthetically and geometrically, to improve functionality whilst increasing design complexity. The main limits of the technology are: production speed, accuracy, nonlinearity (i.e. different resolutions for XYZ axes), narrow commercial material availability and the possibility to only produce relatively small dimensions (Campbell et al., 2012). When dealing with low volumes (or one-piece-manufacturing) the comparison between rapid manufacturing technologies and workshop-based technologies (Evans & Campbell, 2003) might prove interest. Studies focused on future uses of 3D Printing in private contexts just began (Shewbridge, Hurst, & Kane, 2014); first results show how the adoption of fabrication tools such as 3D Printers may sustain the creation of physical representations of product ideas / concepts. The term "everyday making" was introduced in order to describe the process, related to everyday design, of creating physical representations of ideas using fabrication tools. Other studies focused more on the idea that users might be more engaged with objects they are able to produce themselves thanks to 3D Printing processes (Khot, Hjorth, & Mueller, 2014).

To conclude, if the first industrial revolution *obsolesced* many individual practices related to craftsmanship, creating a machine-culture where almost everything becomes a resource to be consumed and increased the distance of comprehensibility of the machines themselves, this digital revolution is working on the very opposite direction (Tanenbaum et al., 2013). At the same time it is important to keep in mind the limitations of a technology that is suffering from the phenomenon of *hedonization*, for which the pleasure of production overcomes the value or significance of the products themselves, which brings us back to the topic of unsustainable patterns, in this case not only of consumption, but even of production.

3.3.3. Conversation user-users: open design

This same revolution can also support conversations between user and user, that ultimately means to support the creation of communities. As seen, Open design products are related to the open source movement. This movement, sustained by the Internet, facilitates the collaborative creation of products (virtual and physical) by previously dispersed and unrelated users, without the need of physical presence or contact. These realities question the dominant market's peculiarities – standardization, mass-orientation and closure – which are normally in contrast with the idea of "openness" (Maldini, 2014). In fact, as explained previously, thanks to distributed production technologies and new consumption patterns, designers can focus more on local, decentralized, flexible, single-consumer oriented, open design (Igoe

& Mota, 2011). This new landscape is not ruled anymore by economies of scale, and presents real possibilities for innovating in niche markets (Oliveira, Zejnilovic, Canhao, & von Hippel, 2015), creating a long tail of product adaptations (Anderson, 2006). Within this paradigm, a relationship with potential social change is also assumed, sustaining "openness" by the collaboration and interaction of diverse and connected communities (Maldini, 2014).

"Static artifacts" are in contrast with open-designed objects, they are products fully defined by the professional designer, and do not anticipate any modification by the consumer (Hermans, 2014). Similarly to meta-design approaches, open design can be characterized by "the emergent properties of the interacting system rather than the conclusion obtained by one designer or one team of designers" (p. 16). The ecology of open design is highly complex and includes: design specification, fabrication, collaborative action, supply and value chain management, business models, legal aspects, technological infrastructure and normative values (Avital, 2010).

As described in **Chapter 1**, open design outcomes are shared on online platforms, which is the arena for these confrontations to take place. Often this open sharing leads to actual conversations between users. These can be in form of comments and "likes", but also certain solutions are used, and adapted according to specific needs. Many open design interactions can be defined as re-appropriations (meaning: understanding, copying and modifications of the original, core project) and occur among large communities. Basically, "openness" means accessibility to view, modify and use a project (Avital, 2010); thus, transparency is advocated both in forms and contents. From a meta-perspective, these re-appropriation cycles can be sustained by "design spaces" or "solution spaces" (Hermans, 2014) and the resulting design behavior can be considered as the actual users' space of freedom to express their own needs, desires, and possibilities. The freedom to express some situational differences (Avital, n.d.) can be explored both online and offline, in the physically proximal environment. When enough re-appropriations cycles happen, in an incremental way by continuously sharing them back to the system [which, if it doesn't happens it represents a major problem of decentralized systems (Surowiecki, 2004)], the creation of very interesting design solutions might be achieved (see **Figure 3.8**). This solution is not only Open, but tackles a diffused problem, by being every time modified to become a ultimate particular. One example of this dynamic is represented by 'Enabling the Future' (enablingthefuture.org) a 3D printed prosthetic hand that from being the contextual solution for one child, became a parametric design available for all. This started with all the people who shared their variations and implementations of the same product and continued with the effort of translating all the obtained data into information useful for the community, in this case in form of a guide on how to build the prosthetic hand according to specific dimensions of the child's forearm. Such dynamic intrinsically refers to communities that share a common need, but that are too diverse [a sort of *inner diversity* of the community, also defined as *contextual knowledge* (Cruickshank & Atkinson, 2014)] in order to be satisfied by a *standard* solution. In **Figure 3.8** the basic re-appropriation cycle is represented, followed (on the right side of the image) by the iteration of such cycle, that can lead to more structural open design solutions.

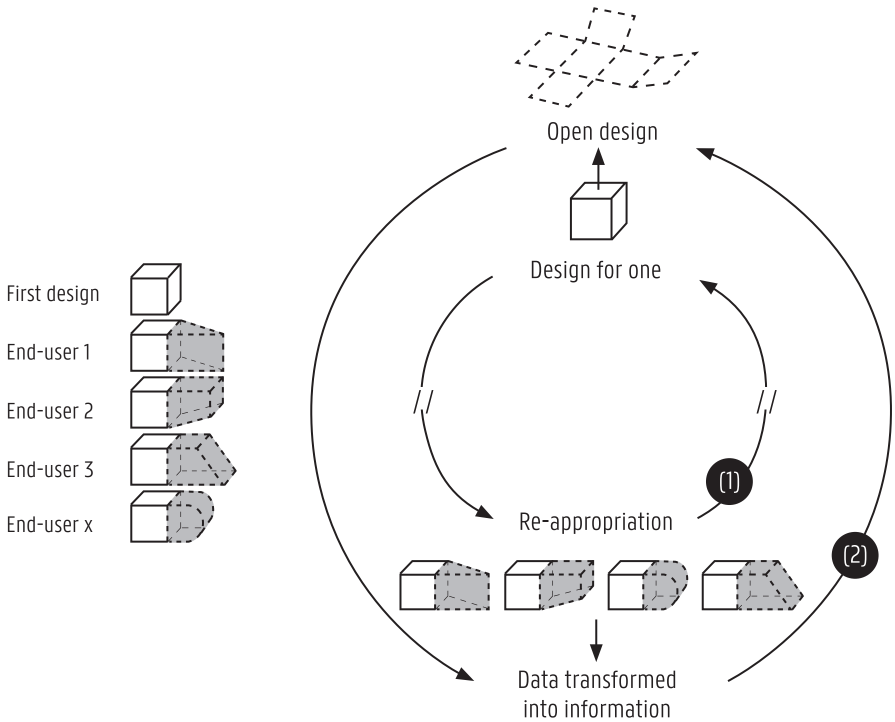


Figure 3.8. Re-appropriation can be seen as the process of products adaptation according to the users' needs. After several re-appropriation cycles of the same product, data can be aggregated to simplify the process itself, reaching a more interesting open solution. As explained afterwards, the symbol "//" refers to a time buffers.

After all, the dynamic process of re-appropriation occurs offline, in the design-after-design sphere and can be defined as "defining use through use" (Redström, 2008). This happens also for products that are not intentionally open and not digital, but while some studies focused on the digital manufacturing field (Hermans, 2014)(Ostuzzi, Rognoli, Saldien, & Levi, 2015), little has been done (Dalton, Desjardins, & Wakkary, 2014) in understanding how to facilitate, by design, the re-appropriation of low tech and highly contextual hardware solutions from different, unknown, unpredictable but yet connected stakeholders. As understandable, the main problems are related to the ability of anticipation (1), during the design and communication phases, of future possible needs of the potential users (Poli, 2009) (Zamenopoulos & Alexiou, 2005) and the translation (2) of this knowledge into actual design features or design instructions (Yen, Flinn, Sommerich, Lavender, & Sanders, 2013). In such collective dynamic one aspect is fundamental: the role of crowds, in comparison to unrelated and dis-connected users. In fact, while the single users are better at coming up with specific solutions the group, or crowds, are better at deciding between possible solutions (Surowiecki, 2004). Also, crowds engage with diversity which is fundamental for good decision making, by expanding the group possible solutions and by bringing new data and problems conceptualization into the conversation.

Decentralization plays a crucial role with regard tacit knowledge, as defined by the economist Friedrich Hayek. Tacit knowledge is the part of our knowledge that can't be easily summarized or conveyed to others, because its profound link to a particular place or job or experience. At the same time, is an tremendously valuable knowledge since it contains all the context-dependant information, also definable as sticky, that can help in traferring the technology or solution to other contexts (Surowiecki, 2004)(Cruickshank & Atkinson, 2014). Certainly, there are many problems related to the re-appropriation of dpen design products, as introduced in **Chapter 1**. First of all the relatively small diversity of people contributing to the discourse, mainly identifiable as design professionals or students in design, and as said for the crowd to become wiser relevant diversity remains fundamental (Surowiecki, 2004). This can be seen as related to the still high level of skills needed to really re-appropriate open design products. Therefore either there is an exclusion from the dialogue, or the risk of becoming passive reproducers of professional designers creative ideas (which, in our definition deeply differs from re-appropriation) occurs. In fact, to just copy and reproduce a design, as it is shared, means to lose the contextuality of it, which is often the main reason for it to be adopted at first place. Finally, but most importantly, there is a problem of responsibility, if some products might not be connected with big risks, others (i.e. medical devices) might imply more dangerous situations, where the direct input from professionals should still be considered as fundamental (Cruickshank & Atkinson, 2014). For these reasons we advocate the creation of something different than open design, which is Open-ended Design, where the imperfection should be meaningfully designed and balanced with closure and definition.

3.3.4. Conversation user-designers: participatory design

Finally, the conversation between user and designer is here reported. The work of the designer cannot be considered as separated from the users, in fact design can be seen as having the goal of enhancing *self-expression* of others (the users), definable as *other-expression* (Nelson, 1994). Co-creation can be seen as any act of collective creativity, while co-design can be seen as the collective creativity applied throughout the whole design process (Sanders & Stappers, 2008). In this scenario the users move from being subjects of the design, as for User Centered Design approaches, to be active partners. Therefore, to accept such approaches, the designer has to believe that all people are creative, and embrace a change that sees a design *for* people becoming a design *with* people (Sanders & Stappers, 2012). The area of this landscape, well described by B. –N. Sanders, where we want to focus our attention is the one of participatory design. With this term, we refer to the design of products, services, or systems based on a collaborative approach, which includes the different stakeholders in the creative process (Erlhoff & Marshall, 2008). This is a strong strategy that tackles two of the main problems of the *fuzzy-front end* of the design process: it ensures an early inclusion of the existing skills during the design process (Ehn, 2008) and gives support anticipating the use phase, an approach also defined as design *use-before-use* (Redström, 2008)(Simonsen & Hertzum, 2012).

Participation implies a mutual learning process, occurring among the designer and the real environment. What we have defined as *real environment* in **Chapter 1**, can be here better defined as the social-material assemblies that create the context of design, and where the design itself is located. In other words, the products' ecologies are composed by several factors: the designed product itself, the *other* products and systems of products; the stakeholders (including their attitudes, disposition, roles, and relationships), the environment, composed both by norms and routines of the place the product is used and the socio/cultural aspects of it (Ehn, 2008)(Forlizzi, 2007). A particular focus should be put in the role of non-human participants, such as visualizations, mock-ups and prototypes (Ehn, 2008), considered as thinking tools to be used through the process in order to trigger reflections, to support conversations, to bind different stakeholder together (Sanders & Stappers, 2012)(E. Björgvinsson, Ehn, & Hillgren, 2010), rather than merely describing the object of design itself. These non-human design devices can be considered as *boundary objects* as introduced previously (Arias & Fischer, 2000).

A constant negotiation of meaning in co-design practices is addressed by E.B. Björgvinsson (E. B. Björgvinsson, 2008), by which he introduces the concept of *prototypical practices*, as a practice oriented, co-design work where particular focus is given to the novelty and exemplarity of the studies practices. In other words, they can be referred to as the practice of doing continuous experiments, in situ, where to remain engaged by paying attention to whatever these experiments evoke. These are fundamentally learning practices. What is interesting to focus here is the fact that open-ended prototypical practices create the favorable conditions for the meaning negotiation between different stakeholders, which, in other words, refers to the fostering of communication within stakeholder and communities. Non-designers (users, communities, but also companies and institutions) and designers are then participating in a conversation, in which a mutual learning process is in place, and therefore knowledge is created (Gerhard Fischer & Giaccardi, 2006)(Simonsen & Hertzum, 2012)(Manzini, 2009)(Ramaprasad, 2009).

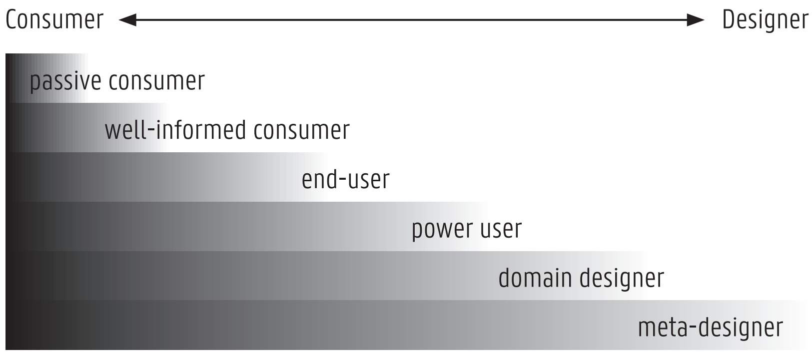


Figure 3.9. The consumer/designer spectrum. Adapted from Fischer (Gerhard Fischer & Giaccardi, 2006)

In **Figure 3.9** represented the consumer/designer spectrum. Furthermore, as often occurred in this dissertation, the human actors of the co-design process cannot be seen as single users, but as communities as described in the previous **Paragraph 3.3.3**, **Conversation user-users**. This bring us to a community-based participatory research (CBPR) an approach that tries to cover the gap between knowledge produced through research and what is practiced in communities (Viswanathan et al., 2004). The term community, is generally referred to "community of practices" defined as groups of "people who share a concern or a passion for something they do and learn how to do it better as they interact regularly. Note that […] learning can be the reason the community comes together or an incidental outcome of member's interactions." (Wenger, 1998, p. 1). Three main aspects become then fundamental: the shared domain, the community nature and the practice-based approach. The dimension of each aspect can be variated, but never blank. Communities of practices are therefore also characterized by an action-oriented attitude, of searching for each other and sustaining a conversation. The web has fostered and extended the possibilities of interactions beyond the geographical limitations, as explained previously.

To conclude, it is important during the design process to always engage in a conversation with multiple stakeholders. The goal of this conversation is to define the clients' *desiderata* (Nelson & Stolterman, 2012) by reaching an *expected unexpected* outcome (what the user asked plus what he/she didn't' ask) that leads to a self-recognition by the user, without pushing solutions (designer as artist) or simply providing them (designer as facilitator) but more in co-designing them with the context.

3.4. Approaches for out-of-control conversations

Participatory design works with identifiable users (Ehn, 2008), or stakeholders, at a precise moment, while the final products will be addressing – of course – to more users, stakeholders, ecologies, at different moments in time (E. B. Björgvinsson, 2008). This way, the unexpected part the *desiderata*, a more honest conversation in time, and potential subversion of non-intentional appropriations might be lost (Dix, 2007). Different methods are then needed to engage with reality in its messy dynamic, in which design becomes "not a matter of getting rid of the *emergent*, but rather of including it and making it an opportunity for more creative and more adequate solutions to problems" (Gerhard Fischer & Giaccardi, 2006). This can be done only by observing reality and anticipating, or *foregrounding*, it. The term anticipation is different from prediction, and it is used to highlight the *conscious not knowing* of the designer (Nelson, 1987).

Many researches aim then at going beyond the user centered design or participatory design (as occurring in the front end of the design process), by reaching the use time, being open for design-after-design, letting the user becoming a co-designer throughout the whole existence of the system (Ehn, 2008)(E. Björgvinsson et al., 2010)(G. Fischer, Giaccardi, Ye, Sutcliffe, & Mehandjiev, 2004). One example is the process of sustained participatory design, introduced by Simonsen (Simonsen & Hertzum, 2012), an iterative process where they propose how to follow the design and implementation process by identifying and measuring the effects of actual use of a system, see **Figure 3.10**. The process consists in: identification of desired changes, specification and implementation, real use that enables unanticipated changes, and evaluation. This process, as stated afterwards, strongly resembles the iterative meta-design process of seeding – evolutionary growth and re-seeding (Gerhard Fischer & Giaccardi, 2006), and starts acknowledging the dynamic nature of product ecology, definable as adaptive, dynamic, in other words subject to change (Forlizzi, 2007). Three different kind of changes have been here identified: the *anticipated changes*, planned ahead, the *emergent ones,* unexpectedly and spontaneously arising from the context, and the *opportunity-based changes*, changes introduced as result and reaction to unexpected changes. All these changes imply a mutual change investing both users and products. This phenomenon, later defined as second order cybernetics, gets also close to the view on design things defined as *ontological* (Ramaprasad, 2009).

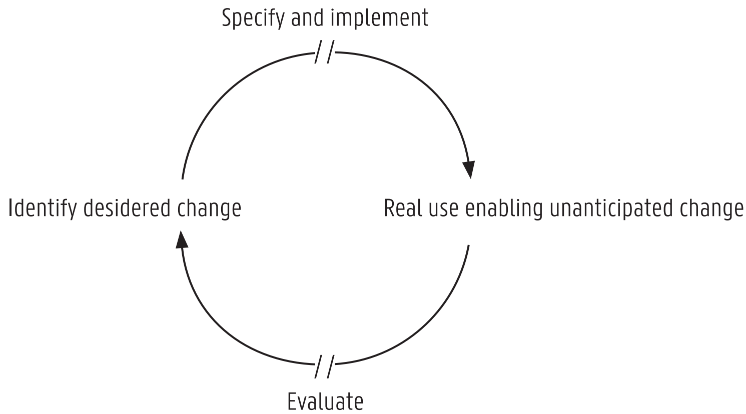


Figure 3.10. The iterative method as proposed by Fischer & Giaccardi (2006)

It is clear that such process, anticipating real use dynamics (after all, “truly successful decision making, of course, demands more than just a picture of the world as it is. It demands in addition a picture of the world as it will (or at least as it may) be.” (Surowiecki, 2004, p. 46), engaging with it and being open to unanticipated changes to happen, requires to design in time, and for time use. Following some approaches to this topic.

3.4.1. Time in design for behavioral change

The relation between time and design can be found in the emergent concept of slowness, also deeply related with sustainability, as *to lose time is good for the planet* (Manzini, 2012)(Thackara et al., 2004). Slow design goes far beyond the simple act of designing, it can be seen as opposed to the high efficiency of fast design, in this view deeply related to hyper consumerism (Erlhoff & Marshall, 2008). Slow design aims at triggering behavioral changes, and builds giving value to six very interesting principles: the narrative revealing the daily experiences connected to them, the temporal dimension capable of showing their dynamic nature, the capability of triggering *reflective use* through the accumulation of traces, the openness that stimulate engagement, the request of participation in a common co-generative process, the evolution that represented in products can finally support behavioral change (Strauss & Fuad-luke, 2008). Clearly, this relates to interaction between user and environment, an interaction that creates mutual changes (Hallnäs & Redström, 2001). This matter can be applied to many aspects, for example to the topic of objects able to evolve (i.e. by accumulating traces) (Strauss & Fuad-luke, 2008). “Time is the essential condition by which equilibrium of fit occurs”, in other words good fit can occur only through adaptations (change) in time, which is what has been recently defined as unselfconscious interaction (Wakkary, Desjardins, & Hauser, 2016)

3.4.2. A broader view on imperfect systems

Error-friendliness, a strategy that highlights the necessity to accept the idea that each material and human factor implies errors, has been proposed by E. Manzini as main strategy to create resilient, reliable and long-lasting socio-technical systems (Manzini, 2012). To design in an error-friendly way means to deal with systems, acknowledging the complexity of the design challenge and therefore relates profoundly both with the designer paradox (introduced in the next section) and the intrinsic need for more sustainable solutions.

The suggested way to realize such systems is to engage with *sub-optimality*, which can mean – for example – to focus on modular, decentralized and diversified solutions [otherwise defined as SLOC, Small Local Open Connected (Manzini, 2010)], capable of embracing the occurrence of unexpected events without leading to the disruption of the system itself. Sub-optimality can be seen as the meaningful imperfection left in the product. The concept of meaningful imperfection has already been introduced by the author as a design strategy that can be related to sustainability (Salvia, Ostuzzi, Rognoli, & Levi, 2010)(Ostuzzi, Salvia, Rognoli, & Levi, 2011), with a special focus on the possibility of increasing the emotional bond thanks to it. In general, the error-friendly approach means that significant parts of the design process and outcome should be handed out to the users (E. B. Björgvinsson, 2008), this is made possible by under-designing the system or by making it flexible enough to let the user interact with, in a design-after-design dynamic, occurring during the use time (Ehn, 2008)(Redström, 2008). Being a sort of participation separated in time and space, this strategy strongly connects to the meta-design approach, sharing with it the aim of creating socio-technical systems that empower and enable users to engage in the continuous development of systems, not only in the *design time* but also in the *use time* (G. Fischer et al., 2004)(Ehn, 2008)(Gerhard Fischer & Giaccardi, 2006)(Dix, 2007). Use time refers to the phase when the users on their own use and adjust the system. The created socio-technical environmental must be flexible, unfinished (not completely designed prior use), open for diversity, being connected with others, being able to communicate to all the stakeholders and designed for evolution (Ehn, 2008). In fact, they should be able to support complex interactions, rather than linear or even iterative design processes.
But, once the unfinished design is released, what is the role of the users? How can they remain participating in this process? To answer these questions *meta-design*, a

term used by Fischer et al. in relation to the End User Development (EUD), advocates that we should find the fine balance between user motivation, effective tools and management support (G. Fischer et al., 2004). The motivation can be sustained by the fact that changes in the outcome must seem possible and should be technically feasible (on the contrary to Open Source design, where sometimes the adaptations require high and specific technical skills). Also, benefits from the engaging in adapting the system should be perceived by the users, and as advocated previously, low barriers to exchange the developed changes must be assured. To conclude, the main difference between traditional design and these error-friendly approaches can be found in the issue of control. In these strategies the dialogue becomes transparent, and gives to the real environment the control on the outcome, in order to observe and learn from the emergent qualities arising from this interaction in time. Finally, "to be out-of-control, with no agendas, outcome expectations and similar scripts of logic aimed towards a predetermined end is essential for the emergence of breakthrough insights" (Nelson, 1994, p. 8).

3.5. Intentional imperfection as morphology for these conversations

As seen, a new design is always too complex to be completely understood during the process of creation, because we cannot fully predict how it will serve the real world and, in turn, how it will change or be changed by it (Nelson & Stolterman, 2012). But, by anticipating the possible changes and by losing control on our outcomes, through the adoption of sub-optimal systems, it is possible to deal with change in design. Change can be both reactive and proactive. While the first represents a more typical problem-solving approach, that moves away from what is undesired, the second works towards what is desired and can be recognized as the design activity itself (Nelson, 1994). In this second case we can refer to intentional change. Intentionality plays therefore a crucial role for designers, and it becomes manifest through design actions.

3.5.1. Design action for intentional change

Design and action have often been put in relation. Design action represents both the process of design and its outcomes (Nelson & Stolterman, 2012). It is seen as a solid strategy to tackle the complex challenges that we are facing nowadays, meaning those challenges belonging to ever-changing contexts, where the designer is facing a constant lack of the resources needed to gather the desired information. Challenges where complexity, chaos and non-linearity are considered as emergent aspects (Nelson, 1994)(Manzini, 2009). In other words, challenges characterized by wicked problems. The view of such scenarios, often leads to a paralyzing feeling or to the desire of taking only small incremental actions. This paralysis depends by the knowledge that in the first phase of the design process not enough information is available, while the influence of the decisions taken is very important. It is often described as the *designer paradox*, and it is visible in **Figure 3.11**.

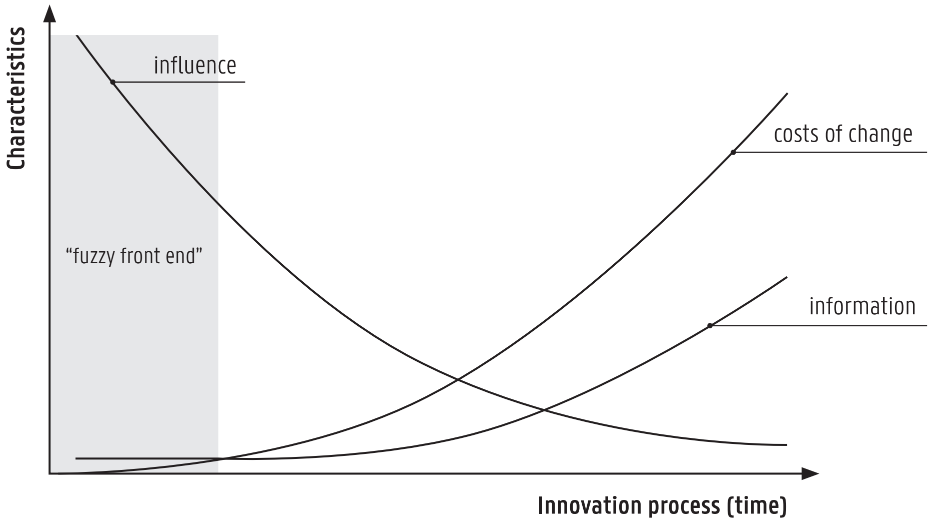


Figure 3.11. The designer paradox. Adapted from Ullman (2010)

The action becomes a possible approach to overcome paralysis, and can be seen as the possibility of contextually *taming* such wicked problems (Dubberly & Pangaro, 2015), a way of momentarily framing the complex situation and put it under observation. After all, when change is reactive, and therefore solution-oriented, the designer (or problem solver, in this case) has *no right to be wrong* (Nelson, 1994) (Gerhard Fischer & Giaccardi, 2006). By taking actions, the designer tries to trigger a conversation with the real environment, to overcome the paralysis, by starting a conversation. This conversation, in form of action, has the double purpose of both understanding and modifying the behavior of the context under observation (Braun, 2002). But, as in every conversation, in order to get a deeper sense of it, the *speaker* (in this case, the designer) needs to be willing to lose control of the conversation itself. This can be done by asking open-ended questions, in form of Open-ended Design, made in order to embrace what defined by Nelson as an undisciplined and out-of-control design approach, and introduced earlier (Nelson, 1994). Imperfection becomes then the basic strategy for designers to engage with sub-optimal, unfinished and open-ended solutions. In the next paragraphs some practical approaches to include meaningful imperfections in the design outcome are reported.

3.5.2. Imperfection for dynamic experiences

As already described in **Chapter 1**, as designers and citizens we experience every day that even the standard products, designed in high volumes, identical and meant to be universal, become ultimate particulars once addressing specific environments. Still, designers sometimes tend to design in terms of *ideal* status, forgetting about the spontaneous processes that imply change in the products. When this happens resources are used to reach a utopian goal which is never fully reached, and surely never fully reached *forever*, with clear consequences in terms of sustainability, as introduced earlier in **Paragraph 3.1**. In reality, the design process should consist in continuously making approximations, the closest as possible, to the idealistic view of the solution (Nelson & Stolterman, 2012). These approximations try to bridge the gap between real and ideal, a gap that can also be defined as imperfection of the design itself. Imperfection is then double-sided, it is the reason why products change, or have changed, but it is also the fundamental reason why "we must design, because we are not perfect" (Nelson & Stolterman, 2012). Imperfection is a constituent part of every outcome ever made. And, as designers, we can decide to embed imperfections in our product, by executing an intentional design action. They are also definable as *meaningful imperfections*, understood as intentional lack of definition of the design outcome (not to be mistaken with a lack of design effort) that the designer creates in order to intentionally support change, as described in the error-friendly, out-of-control, meta-design approaches. To summarize, the introduced difference between unintentional change and intentional change (Nelson & Stolterman, 2012) can be seen as the difference between unintentional and intentional imperfections. In this dissertation, both concepts of imperfections are explored, consequently examples around both unintentional and intentional imperfections are provided. Open-ended Design, as explained in the next **Chapters 4**, **5** and **6**, is anyway a design solution where a meaningful imperfection has been intentionally embedded in the design outcome. Finally, imperfection is not a new topic for design, hence in the next paragraphs a broad overview of the topic is provided.

3.5.2.1. Wabi Sabi: beauty as emergent attribute

An aesthetical philosophy traditionally gave value to the impermanence nature of objects: *wabi sabi*. Wabi sabi can be seen as similar to "ego, gravity and evolution; you may know it well, but have never named it" (Powell, 2004). It is an ancient Japanese philosophy, hard to be precisely defined, because its main characteristics can be easier lived and experienced rather than discussed (Juniper, 2011). Originally the two terms *wabi* and *sabi* were used separately and only in time they merged to create a new meaning, that is still open for discussion (Juniper, 2011). Some definitions can be found in literature, for example L. Koren (Koren, 2008) defines wabi sabi as the beauty of imperfect, impermanent, and incomplete things. The beauty of humble things, and modest things. Also, wabi sabi is seen as the beauty of unusual things. In addition, A. Juniper (Juniper, 2011) defines it as "an intuitive appreciation of a transient beauty in the physical world that reflects the irreversible flow of life in the spiritual world. It is an understated beauty that exists in the modest, rustic, imperfect, or even decayed, an aesthetic sensibility that finds melancholic beauty in the impermanence of all things". As last, C. Sartwell (Sartwell, 2004) describes it as the beauty of rusty, eroded, scratched, ephemeral (…) things. A form of beauty that "overcomes the dichotomy of beauty and ugliness, even as it overcomes the dichotomy of ordinary and extraordinary", adding as "every [wabi sabi] object is its own history". It can be summarized that three aspects are crucial in the wabi sabi approach: (1) the appreciation of visualizing the passage time [often referred as patina (Tanizaki, 1977)], (2) the acceptance of imperfections as trigger for dynamic products and (3) the value given to the use, also definable as interaction. The relation between these aspects can be seen in **Figure 3.12**.

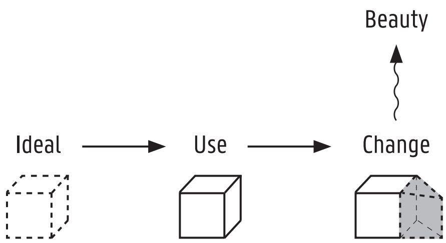


Figure 3.12. Beauty as emergent quality. Beauty is not created with the product, but emerges in time and thanks to the use. Imperfection works as main facilitator of this process.

In this perspective, beauty – seen as the property of being useful, functional, sustainable, proper, etc. – is not created initially with the product. It emerges thanks to the use, and is supported by the imperfection of the product itself. As commented before, the imperfection itself allows the dynamic nature of products.

In Japan, many fields have been influenced by this aesthetic, from the design of gardens that can follow and represent the seasons, to the poetry (especially the *haiku*) that trigger a sense of incompleteness and infinite in the reader; from the famous flower composition called ikebana where void and time are main actors, to the *raku* ceramics famous for the rough, uneven and unpredictable surface finishing. In synthesis, the main precepts of wabi sabi are: natural materials, irregular and rough surfaces, soft colors, organic materials, undefined. Some examples, representing the listed concepts, are reported in **Figure 3.13**.

Figure 3.13. Examples of wabi sabi compositions. The famous Kizaemon bowl (a), an example of flower composition, called ikebana (b), the zen garden Ryōan-ji (c) and raku ceramic pieces (d).

It is clear that this view of the material world seems distant from the western view. Actually, many examples can be found, in the landscape of Western design, that reflect the same concepts both intentionally and more intuitively. For example, as introduced in **Chapter 1**, Wikipedia itself is a product voluntarily created as imperfect and, thanks to the use we make of it, reaches and higher level of *beauty*. The risk, as mentioned by G. Dorfles (Dorfles, 2009) is that when we start learning from this aesthetic, which merges the "artificial with the natural, the ordered with the disordered, the machine-made (in series) and manually-corrected (handcrafted), we might only reach the formal imitation of the original wabi sabi objects, where it seems enough to add "a bit of inaccuracy and a bit of whim"[1]. The challenge, reported in the following paragraphs, is then to understand how these concept could be translated in our

[1]The original extract is "L'incontro dell'artificiale e del natural, dell'ordine e del disordine, del fatto a macchina (in serie) e del correctto a mano (artigianalmente): questo é l'insegnamento d'un'estetica dell'assimmetrico che oggi ci viene soprattutto dall'Est ma che ormai sta penetrando profondamente anche nella nostra sensibilità occidentale. Guai però se, per introdurla noi, crediamo sia sufficiente un po' di inesattezza e un po' di capriccio".

specific context (Salvia et al., 2010), without facing the risk of a mere aesthetic copy.

3.5.2.2. "Western" Wabi Sabi

As said, wabi sabi is concerned with uncertainty, with time, with change. When reading about wabi sabi is common to find references to emotional statuses as well, as if its own nature could serve as trigger for reflective and meditative moods. From literature, some concepts deeply relate with these characteristics, such as: ambiguity, patina, incompleteness, randomness, error-friendliness, etc. In all these approaches, time plays a fundamental role. Objects become part of a temporal story where the use, and other stages of the life cycle, are considered as part of the designed solutions. More importantly, objects become part of an interaction that is considered out-of-control, as suggested by Nelson.

Ambiguity and randomness

Ambiguity could be defined as inconsistency or fuzziness. In the case of product design, it can refer to products being out or with little context, evocative rather than didactic, and mysterious rather than explicit (W. W. Gaver, Beaver, & Benford, 2003). Ambiguity can be seen as an opportunity and a resource for design, because of its capability of stimulating people to interpret situations for themselves. In other words, it influences the *interpretative relationship between users and products*, which is how the user builds the personal meaning of the product itself. Ambiguity is articulated by Gaver as: ambiguity of information, ambiguity of context and ambiguity of relationships. In this way, ambiguity is not seen as a property of the product itself, but more as a contextual emergent characteristic. According to the authors, ambiguity can lead to: bigger space for interpretations, breakage of preconceptions, encouragement of imaginative processes, etc. Especially this last aspect is also reported by Smith et Al., who focuses on the beneficial role of ambiguity and imperfection in stimulating creativity during the design process (Smith, Inoue, Spencer, & Tennant, 2017). Ambiguity can also be linked to incompleteness, seen as the design strategy used to create bigger space of interpretation and freedom for action (Tannfors & Kristensen, 2004). On the other hand, ambiguity might lead to product failure, with specific reference to users engagement (W. Gaver, Bowers, Kerridge, Boucher, & Jarvis, 2009). A possible explanation for this might be that ambiguity has to be well designed, as balance between randomness and accuracy. In fact, if the randomness is too high, the user might have the perception of not being able to grasp the meaning of the product, feeling frustrated or perceiving the product as being erroneous. This balance is clearly a design issue that deals with the importance of consistent feedbacks in the user-product interaction. Thus, ambiguity shouldn't be mistaken as "an excuse for poor design" (W. W. Gaver et al., 2003), but considered a possible strategy to suggest interpretative solutions to the users, without imposing them.

Randomness, well represented by the Apple shuffle listening option, is also considered as valuable resource for design (Leong et al., 2006). Because of the qualities of unpredictability and discontinuity, it can stimulate positive users' emotions such as the perception of renewal of the experience, it might encourage spontaneity and trigger the feeling of surprise. Both ambiguity and randomness are deeply related to the user interaction sphere; but while ambiguity can elicit reflection, randomness is presented as more related to the feeling of 'happy coincidence', which is another way of creating meanings by connecting previously unrelated events. It is clear as this proposed strategy sees the user as more passive, being also beneficial for the desire of saving the effort of choosing (see the paradox of choice, earlier introduced). As for ambiguity, also randomness can be the cause of unsatisfactory and unpleasant experiences. In this context, the reason could be found too in the lack of consistency in the communication between user and product. A careful design is necessary to balance random and constrain, but no further advice is given by the authors. It is interesting to notice that these two strategies don't imply physical changes, rather a change in the interpretation and in the meaning given to products (van Gennip, van den Hoven, & Markopoulos, 2015).

Time in design: patina as strategy for dynamic products

The valorization of imperfection, as traces of time and use, in order to increase the emotional bond with products is also well described in the project Eternally yours, time in design (Thackara et al., 2004). The project started aiming at contrasting the tendency that sees us living in the fear and discomfort of sharing our life with objects that remain forever *distant*. This fear leads to product rejection and early abandonment. Goal of the project is to sketch a possible scenario where products are considered as living entities, able to change and especially to elicit emotions of attachments and trust. In order to reach this, some proposed solutions can be found in the book: for example, to work with modularity, to consider – starting from the design phase – the potential emotional bond by focusing on the *future nostalgia*, to remember how style is irrelevant and to put the maximum design effort on understanding how the product can evolve and age with dignity. Even if this collection of articles opens-up extremely interesting views on the topic of dynamic products and time in design, it still lacks, in our view, of practical examples. These, are in fact needed for the design practice, serving as examples and inspirations (B. Gaver & Bowers, 2012).

In general, a topic that recurs when dealing with time in design is the role of *patina*, that (as introduced in the **Paragraph 3.5.2.1**) can be loosely described as the evidences of the material aging effects in products. Patina can also be seen as a design strategy, for example to foster personalization (Lee, Son, & Nam, 2016). This means to embed in the product unique identities and personal stories. It is therefore related to self-expression and, on the contrary of ambiguity and randomness, it follows the user's behaviors, through accumulation of signs during the actual use phase. The idea of personalization during the use stage proves particularly interesting, as reported previously, because the majority of the strategies aiming at personalization have been focused on the manufacturing phase instead. In this way, to embrace traces seen as all the alterations, that represent the loss of the initial quality of products (the *ideal ones*), happening through aging or use, can become a strategy to personalization as part of the user experience, especially focusing on the inclusion of symbolic meanings, which can stimulate memories and foster the feeling of product attachment. These concepts are related with reflection, memories, with the aesthetic experience of visualizing time, which can be seen as a narrative quality (DeSilvey, 2006).

The objects become process themselves, being dynamic, and perceived as alive. But, while in the reported study the traces come from a digital (in this case: engraving), non spontaneous procedure, many cases report on the value of traces in products seen as a tangible aspect of their dynamic nature (Giaccardi, Karana, Robbins, & D'Olivo, 2014)(Pedgley, 2014)(Candy, Sommerville, Kalviainen, & Oksanen, 2008) (Boniver et al., 2010). Meaning a spontaneously occurring process, deeply related with the entropic processes of aging and decay (DeSilvey, 2006). In literature, the approaches are mainly material-oriented, and refer to surface qualities, belonging to the field of material experience (Robbins, Giaccardi, Karana, & D 'olivo, 2015) (Karana, Pedgley, & Rognoli, 2013, see specifically Chapter 11, T*oward a New Materials Aesthetic Based on Imperfection and Graceful Aging*, pp; 145-154)(Karana et al., 2013). Also the authors contributed to this discussion, with a specific study about the relation between materials (plastics, in the specific), time and emotions (Nobels, Ostuzzi, Levi, Rognoli, & Detand, 2015). This research put itself in continuity with the project Proud Plastics (materia.nl/material/proud-plastics) by M. Sonneveld and L. Bonekamp. In addition, if undoubtedly the passage of time in products can be fascinating, and it is important to mention how this is not necessarily in conflict with the paradigm "newer is better!". In fact, even if the perceived level of novelty can lead to positive impressions about products' quality, it is not necessarily related to the presence of novel technical components or features (Mugge & Schoormans, 2012). In this way, the previously mentioned renewal of the experience, can still be elicited by the change on surface qualities, instead of by the complete substitution of what is old with what is new.

3.5.2.3. Conclusions

To conclude, many different views on imperfection (considered as the design attribute enhancing the capability of the product to change from the ideal status to the real one, and vice versa) have been reported. What is shared among all these studies, and this dissertation among them, is the starting point: the object of study points to an already occurring phenomenon commonly considered as undesirable and to be opposed. As strategies *for* use must also be open for appropriation or appreciation *in* use (Ehn, 2008).

In these studies, there is the common proposition of changing name for these *spontaneous processes*, in order to accept their existence, and embrace it with an intentional design act, by asking: "How can the object of design be made *manipulatable*?", as suggested by Ehn (Ehn, 2008). For this reason, we could talk of *meaningful* and *intentional* ambiguity, randomness, imperfection, sub-optimality, slowness. This doesn't mean that the entire product is imperfect. On the contrary: almost univocally all the studies advise to use these strategies in a carefully balanced way. Another shared point is that all these approaches aim at a full engagement with the user, who becomes a co-designer often just by using the product itself. Therefore, all the suggested strategies are deeply related with the user-product interaction, as well as the broader environment-product one. More importantly, these solutions are learning objects for the designers themselves, helping to understand contextual-related variables and dynamics, and therefore to overcome the designers' paralysis occurring in from of wicked problems (Nelson, 1994)(Rittel, 1972). By creating an object that is imperfect per definition, and by following with a design action, the designers leave the solution open to start a conversation, where they must remain involved in order to learn. This topic, meaning how to learn from the created solutions, which is ultimately related to cybernetics and system thinking, is reported in the next **Paragraph 3.6**. In other words, it is not only the user who should remain engaged with the product, but also the designer.

3.6. Systems thinking as syntax for these conversations

Designing for the real world "is not objective; it's subjective. It's messy." (Dubberly & Pangaro, 2015, p. 4). To manage this complexity, a constant communication with the real world is needed and, in order to learn from it, our communication should be left as open as possible. To do so, we can use intentional imperfections as morphology, but we still need to define our syntax. With syntax we refer to the way we arrange our words and phrases, meaning the way we see connections between parts, in order to create meanings. In design, two domains can help us with this constructivist approach: systems thinking, an approach to "synthesize complex information into congruent patterns" (Dubberly & Pangaro, 2015, p. 4) and cybernetics, the way we learn from this observation and conversation (Dubberly & Pangaro, 2015). Even more importantly, cybernetics, term that comes from Greek with reference to the action of *steering*, can help us in operating in the real world supporting us in achieving certain goals, adopting action oriented design approaches based on intention rather than purely chance (Nelson, 1987)(Dubberly & Pangaro, 2015)(Francis, 2001)(Glanville, 2007).

First-order cybernetics is the observation of an operation and it is conducted by registering the changes in physical symbols and signs, while second-order cybernetics is the *observation of observing* (Erlhoff & Marshall, 2008). In other words, second-order cybernetics can be seen as the cybernetics of cybernetics, where the observer's presence is admitted and included as part of the system (Glanville, 2004). "The boundary of what is being observed is no longer the same. Where there was, in the case of first order cybernetics, a crucial boundary between the observer and the system-and-goal […] in the case of second-order cybernetics there is no such boundary." (Glanville, 2004, p. 1384).

3.6.1. Cybernetics and design

The connection between Cybernetics and Design is not new (Glanville, 2007)(Glanville, 1999)(Dubberly & Pangaro, 2015)(Couvreur, 2016). De Couvreur defines the connections between the two fields, synthesizable as:

- **Situatedness**, which is the way of learning that comes along the environment, here defined also as *context-dependency*. Where, with environment we refer to the product's ecologies, alive and therefore dynamic (Forlizzi, 2007).
- **Constructivism**, which refers to various philosophies that see the constructions of models as result of subjective understandings of reality (Erlhoff & Marshall, 2008). Importantly, "Constructive design researchers routinely build prototypes that are sometimes very elaborate and that work not only as illustrations of an argument, but also as proofs of a concept. In this context prototyping is equated with a conversation, both are mechanisms to contain a constructivist act. No meanings are passed, rather, they are made by the participants." (Couvreur, 2016). We will get back to discuss the role of prototyping in supporting the design action in **Paragraph 3.6.2.1**.
- **Out-of-control**, which was described previously in **Paragraph 3.4.2. Error-friendliness, out-of-control, meta-design systems**, and that can be summarized as "Being in control also restricts the world to what one can imagine. Self-organization

assumes that no interaction is equal." (Couvreur, 2016, p. 81), acknowledging as always something different than imagined will also happen and being our choices always built on particular intentions (Nelson & Stolterman, 2012). Also, the shared acceptance of the out-of-control nature of system deals with the inescapable presence of products ecologies, both non-human and active human, often defined as actors (Glanville, 2007). But importantly "Control is neither in one element nor the other, but between them, shared." (Glanville, 2007, p. 1182).

- **Co-experiences**, this aspect relates to the previous one, seeing the meaning and value of a project as emerging from the process itself followed to designing it. De Couvreur underlines the importance of *diversions* or *disturbances*, meaning events on which the agent has no direct control, but that – once recognized – might trigger the attempt of controlling, or steering, their effects. In this aspect, disturbances are deeply related with the role of spontaneous processes later described.
- **Embodied congnition**, tacit knowledge constitutes a big support to designers during their design process and is represented by that kind of expertise, and information, that we are not able to verbally share with others. This portion of knowledge is often referred to be the biggest one (Sanders & Stappers, 2012). Prototypes help the designer in translating and elicit this kind of knowledge, as embodied knowledge, into tangible interactions.

Finally, design has been related to second-order cybernetics, by acknowledging design as the action and second-order cybernetics the explanation (Glanville, 2007) (Glanville, 2004). Both, circularly, support the need and possibilities for the conversations described in this chapter. With this regard, Dubberly proposed the following syllogism: if design, then systems; if systems, then cybernetics; if cybernetics, then second order cybernetics; if second-order cybernetics, then conversation (Dubberly & Pangaro, 2015). This conversation is oriented at understanding what conserves and what changes in the design outcome, and to take then actions accordingly (Dubberly & Pangaro, 2015).

3.6.2. Circularity and its representation

To learn through cybernetics we observe, we take specific actions and we observe again, this is the circularity of cybernetics also defined as loop (Glanville, 2004). In design this process is often done through materializations, sketches, images, mock-ups and prototypes. "Communication takes place between entities that build understandings (meanings) out of their interpretations of what they sense their conversational partner (or partners) offer them. This understanding is fed back to their partner(s) in new offerings that the partner(s) in turn interprets and compares to their original intention. This dual generation of what might have been called messages constitutes feedback and allows errors to be detected and new offerings/messages to be tendered that attempt to correct such errors. This is a complex model that operates both as communication and as communication about communication, simultaneously; where communication takes place between the communication partners so that meaning, insofar as there is any, is uniquely constructed by each partner individually." (Glanville, 2004, p. 1382).

To better understand this circularity, and the circular causal relations described by it [different from the linear causality typical of science (Glanville, 2007)], we introduce here some terms, concepts and symbols that will be also used to support our original studies, later described. First of all, in system thinking to every action taken a reaction will follow (in time); this reaction is defined as feedback. By reading feedbacks we interpret data and therefore we learn (Dubberly & Pangaro, 2015) (Ramaprasad, 2009). Feedbacks can be of different nature and "there is no feedback that is not communicative in intent" (Glanville, 2004, p. 1381). They communicate information about the behavior of the system, which occurs in time. In this way, when designers input something in the system, they have to remain engaged in order to read the upcoming feedbacks, while the time needed for them to become manifest is defined as *buffer* (and represented with the symbol "//"). Buffer, or delays, can provoke the misinterpretations of certain feedbacks.

For designers, many product-related aspects can work as feedback (remember **Figure 1.1** and **1.2**). For example change in material properties (oxidation, discoloring, stains, etc.), change in shape (deformations, hackings, etc.), change in interpretations (misusages, non-intentional designs, etc.), and other phenomena can give insights on how the product was used, where it was used, for how long, etc. In other terms, these changes become a visible manifestation of a specific context and, important to notice, the material change in the physical world is not the focus of the observation, the real focus stays on the informational level these aspects bring.

It is not surprising that designers might be scared by feedbacks, since they are often created by disturbances that are out of their control. Feedbacks can sometimes represent a shift from what was *predicted*, which could be interpreted as failure, by some. For examples a product that breaks while being used constitutes a feedback from which we, as designers, can learn. On the contrary, the whole point of seeing both design and cybernetics as conversation is that "iteration of the circle of conversation allows, on each cycle, the addition of more functions and requirements to be accommodated into the design outcome. These can lead to failure, or they can lead to development. Their assimilation and accommodation does not always have to be perfect: the requirement is that they fit in well enough." (Glanville, 2007, p. 1191-2), which translates into the title of Glanville's work "Try again. Fail Again. Fail better.". The same approach towards *failure* as learning process for designers is well represented in the work of De Couvreur, where students were asked to iteratively analyze their tests conducted with prototypes and users by noting four aspects: expected positive and negative, and unexpected positive and negative. This gives recognition to the aspects of both negative events and unexpected ones.

Positive feedbacks are loops (+ + or - -) that reinforce (accelerate) the trend of a process (which can be both ascended or descendent), while negative feedbacks (- +) are the ones that balance (decelerate) the trend of the same process. They can be represented as causal loops, as in **Figure 3.14**. Therefore, in a positive feedback loop A produces more B, which produces more A, while in a balancing feedback loop A produce more B, which produces less A.

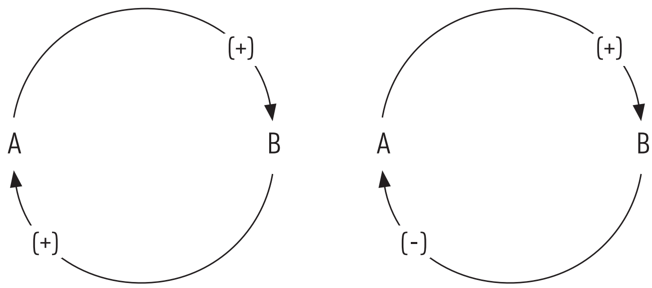


Figure 3.14. Positive (reinforcing) loop and negative (balancing) loop

By representing and analyzing feedbacks, the designer acquires new knowledge, learns, and ultimately changes (Glanville, 2007). By doing so, the designer can start taking controll of the process, meaning with control not a restrictive action, but the guidance towards better performance. From the observation of a specific situation in a systemic perspective, understanding circular causalities, we can observe limitations and opportunities, and try to understand how to decrease their power and consequences, or how to support the realizations of potential opportunities (Dubberly & Pangaro, 2015). At one point of this observation process the designer needs to take action, by trying to influence the system. This should happen not when the perfect solution is achieved, since there is probably none and surely none meant to last *forever*, but one that is perceived as "good enough". This leads to the next step, which is a feedforward, or anticipation, to be distinguished from a prediction. In fact, the design act in this perspective becomes a way to explore an hypothesis, and not a way to confirm a solution. “This is a recognition and accommodation of the presence of error – that core aspect of cybernetics.” (Glanville, 2007, p. 1193).

As we will see later on in this manuscript, to design open-ended products means to acknowledge these out-of-control interactions. In fact, all products are subject to disturbances and are therefore open-ended per definition, so when we say to intentionally design open-ended devices we refer to the possibility of learning from these interactions and, by intentionally embedding imperfections in the product, learn from it because of the amplified readability of certain feedbacks, which is to design traces to be left on the objects. This amplification is supported by imperfection, which is designed as the hypothesis that can be formulated by the designer after a period of observation and understanding of reality. Traces on objects constitutes feedbacks, but sometimes they are hard to read, either because of low intensity or because of the time needed to let them emerge. Anyhow, the powerful aspect of these traces is their capability of embedding information and knowledge that are tacit. Traces can therefore tell us more than what could be known by directly asking or observing the user (Sanders & Stappers, 2012). In these terms, Open-ended products become similar to prototypes, becoming a design outcome focused on gathering information from the real world.

3.6.2.1. Prototypes to communicate and learn

Prototypes are typical design tools used before the artifact exists (Coughlan, Suri, & Canales, 2007). They can play a fundamental role to help designers while facing their paralysis, which is to support action and to tame complex problems. Taming complex problems in fact doesn’t mean to over-simplify them, but rather to acknowledge their complexity and to look at them taking one perspective seen as one possibility among many others (Dubberly & Pangaro, 2015). Prototypes are therefore used to take actions without having in mind a solution oriented approach, but rather a need for a better problem framing (E. B. Björgvinsson, 2008). Prototypes ground communication between different actors, since they become the mean through which every actor shares values. Because of this, in the design phase, they should be iteratively done in order not to over focus one one, which might lead again back to a solution oriented approach which is what can be defined as adaptive prototyping (Ehn, 2008)(Dow, Fortuna, Schwartz, Altringer, & Klemmer, 2011)(Dubberly & Pangaro, 2015)(Lim, Stolterman, & Tenenberg, 2008). One again, through the observation of process of adaptations we start “conversations which explicitly and implicitly, whether to oneself alone or with others, embody what we value and what we seek to conserve.” (Dubberly & Pangaro, 2015, p. 5).

3.7. Conclusions

Thanks to the continuous study of the presented foundations it is possible to summarize how design could be seen as the process of creation of what is *not there*, and what is *ought to be* (Nelson & Stolterman, 2012). One of the main problems of this complex process is the gap is created between the ideal design space and the real context of use (Hermans, 2015). This gap often leads to the creation of products that face early abandonment or rejection, with clear repercussion on the environment. To cover this gap, a constant conversation is needed, between all possible stakeholders of the design process itself. Thanks to this conversation, which can be seen as Second-order Cybernetics, the actors learn about what conserves and what changes in the designed solution thanks to the context/environment (Dubberly & Pangaro, 2015), which can also be defined as re-appropriation (Ostuzzi et al., 2016). This conversation can occur only in time and in the real context of use. To facilitate the conditions for this conversation to happen, which is ultimately a design act done *by others*, a second-order design is advocated (Dubberly & Pangaro, 2015)(Krippendorff, 2007). The definition by Dubberly et al. of second-order design as "[The signage system] is never completely finished, never completely specified, never completely imagined. It is forever open." closely resembles the definition of Open-ended Design as outcome of the design process that is "able to change, according to the changing context. Open-ended Design, can also be defined as suboptimal, error-friendly (Manzini, 2012), unfinished, Wabi Sabi, contextual, context-dependent and is characterized by its inner flexibility, due to the voluntary incomplete definition of its features, also defined as its Imperfection." (Ostuzzi et al., 2017). Open-ended Design locates itself in the design-by-doing landscape, being itself an open-ended activity that takes place in the design-after-design space (E. B. Björgvinsson, 2008). In this terms, Open-ended Design becomes, thanks to its open-endedness and flexibility, a product-prototype (or proto-design) that can be jointly explored and defined by all stakeholders (E. B. Björgvinsson, 2008). In other words, open ended-design is a proposal, based on the opportunities we meet (Manzini, 2009), in continuous balance between realism and optimism.

Main limitation of the here presented studies is an overall lack of practical examples. In fact, the studies advocate the creation of sub-optimal outcomes to be delivered to the user(s) in order to be easily re-appropriated. The only few examples reported in the mentioned studies often belong to the digital word where the intelligence is embedded in the *soft* component of the products, which doesn't always foster the emotional bond. Also, the proposed strategies and methods remain somehow abstract, which might lead to a failure in applying them in the design practice. The next step of this research, reported in **Chapter 4**, has started from such observations: the need for reporting on specific ways of fostering the designers' capability of triggering conversations (Manzini & Rizzo, 2011) by using design *informed intuition* (Nelson, 1994)(Nelson & Stolterman, 2012) in order to support change. The need for specific ways to understand for which aspects of the outcome is possible, and beneficial, to lose control. The need for examples, in form of benchmarks, able to explain the need for the designer to remain engaged in the design process, even when after-design.

INTRODUCTION TO THE INVESTIGATIONS

This section describes the different original investigations (also defined as empirical studies, observations, explorations, or just as studies), originally designed and developed in order to answer the research questions presented in **Chapter 1, Introduction**. As mentioned, the investigations can be distinguished in two main categories: post factum and ante factum. The first refers to the observation of already existing outcomes that support change, while the second refers to the anticipation of possible dynamics of change, through the development of original design outcomes. Both investigations build upon existing cases, following a research-though-design method (for details see Part II). The observation, post factum, is reported as one main study that covered the time frame of the entire thesis. The anticipation, ante factum, is divided in 5 studies each one focusing on one specific part of the overall dynamic of creating Open-ended Design outcomes. For more details, see **Figure 2.3** in **Chapter 2**. Next to that, several other studies have been developed, in order to test and explore different aspects of the phenomenon of change in design. Not all the studies are reported extensively, only listed at the end of the manuscript, in **Chapter 7**, **Termination**, the entire list has been reported.

Every study builds upon the **foundations**, presented in **Chapter 3**, and is here presented following the same overall structure, composed by:

- Brief introduction to the specific context of the study
- Method adopted to conduct the study*
- Main results of the study*
- Discussion, conclusions and relation with other future studies

Four of the six presented studies ara published, two in form of Journal Article (A1) and two as conference papers. In the previous list, highlighted with (*), the paragraphs that in case of an already published study, remained almost unchanged with respect to the public article. All the other paragraphs were (from partially to completely) modified in order to stress the link between the specific study, the research questions and the other presented studies.

To summarize:

- **Chapter 4** describes **Study 0**, post factum, observation, that addresses **Q1**.
- **Chapter 5** describes **Studies 1**, **2**, **3** and **4**, ante factum, anticipation, that address respectively **Q2-a**, **-b**, -**c**, and -**d**.
- **Chapter 6** describes **Study 5**, the conclusive inverstigation, developed in order to explore **Q2-e**.

CHAPTER 4, Study 0

POST FACTUM, OBSERVATION

4.1. Annotated portfolios

In the previous section, **Chapter 3**, Foundations, we introduced several theories that could help designers in determining certain qualities of the design outcome (error-friendly, imperfect, unfinished, out-of-control), but these give little guidance in the practice about what specifically should be made (Gaver & Bowers, 2012). At the same time, strict procedures and methodological frameworks might decrease designers' creativity and not be efficiently applicable in every context. "Theory promises generality and guidance but it seems inadequate to capture the situated, multidimensional, and configurational nature of design." (Gaver & Bowers, 2012)(Gaver & Bowers, 2012)(Gaver & Bowers, 2012). At the same time, a single artifact cannot lead to the development of theories, being a situational expression, result of convergence between tacit and explicit considerations (Löwgren, 2013)(Bowers, 2012). Nevertheless, methods that combine the practice based nature of design – and its outcomes – with theoretical models, exist and provide valuable contributions to research. Generally, these methods belong to the research-through-design arena (see **Chapter 2**, **Research method**). In this part of the presented research a case study method, formalized as annotated portfolios, has been adopted. Annotated portfolios are collections of specific design outcomes, analyzed and commented on the base of concerns fundamental for the conducted research. In other words, these portfolios respect the particularity of the design outcome (definable as *ultimate particular*, see **Figure 2.1**, **Chapter 2**), pointing out specific features capable of opening up discussion in more abstract manners (Bowers, 2012). The considerations, or annotations, don't aim at describing the presented devices but at creating new meanings by a systematic comparison between them (Gaver & Bowers, 2012)(Löwgren, 2013). Ultimately, annotated portfolios aim at communicating results considerable as intermediate knowledge, between the ultimate particular and the ideal theory and exemplified by methods for design, guidelines, patterns, etc. (Löwgren, 2013). Annotated portfolios can also be seen as open-ended and perspectival tools, allowing re-appropriations by other researchers (Bowers, 2012).

4.1.1. Procedure

As introduced in **Chapter 1**, Introduction there are many examples of change in the products we use every day (see **Figure 1.1** and **1.2**). In this study we have collected several examples of design products (more than 100) that share these certain qualities, synthesizable as their capability to change meaningfully. To be noted again, in this thesis there is a specific focus on the material – hardware – aspects of the products, rather than the software or service components, leading to a selection of hardware, low tech design outcomes. These artifacts were collected from different sources: design blogs, fairs, companies' websites and visits. At first, the collection was followed by general observations and reflections about the role and dynamic of change in such products. Soon enough we felt the need of re-organizing them, finding similarities and dissonances, and trying to create new meanings thanks to this comparison. The first attempt led to the reorganization of the cases (present at the time) following one criterion: the moment *when* the change (referred as the gap between ideal and real statuses) occurred. In other words, we distributed them along the Product life cycle (Francesca Ostuzzi, Salvia, Rognoli, & Levi, 2011). This is a typical approach utilized in design for sustainability, because of its strong connection with Life Cycle Design and Cradle to Cradle approaches (Vezzoli & Manzini, 2008)(Braungart, McDonough, & Bollinger, 2007). In this way, four main strategies to support change through a specific design choice were identified. Namely:

Standard/Unique, focusing on changes during the production phase and referring to a product produced with an open-ended and out-of-control industrial process.
Signs of time and use, focusing on changes during the use phase, and referring to products designed to accumulate traces during their lives.
Breakage followed by reparation, also referring to the use phase.
Breakage followed by a second life, occurring after the end of life.

This classification implied several publications (Salvia, Ostuzzi, Rognoli, & Levi, 2010)(Francesca Ostuzzi et al., 2011)(Pacelli, Ostuzzi, & Levi, 2015)(F Ostuzzi, Salvia, Rognoli, & Levi, 2011). Nevertheless, it appears clear today as this kind of reorganization is too limiting. Many newly collected cases were *falling out* of these categories, or were not comprehensively represented. At this point an highly iterative process started (see **Figure 4.1**), where to the first main question "when?" we started adding up other relevant questions, with the typical 5W and 1H (When?, What?, Why?, Where?, Who?, How?). These questions already provided a more wide-ranging description of the cases, but still some aspects of the phenomenon of change where not addressed. Finally, after few more iterations, a set of twelve questions was phrased and considered final to cover this complex matter, within the framework of this dissertation.

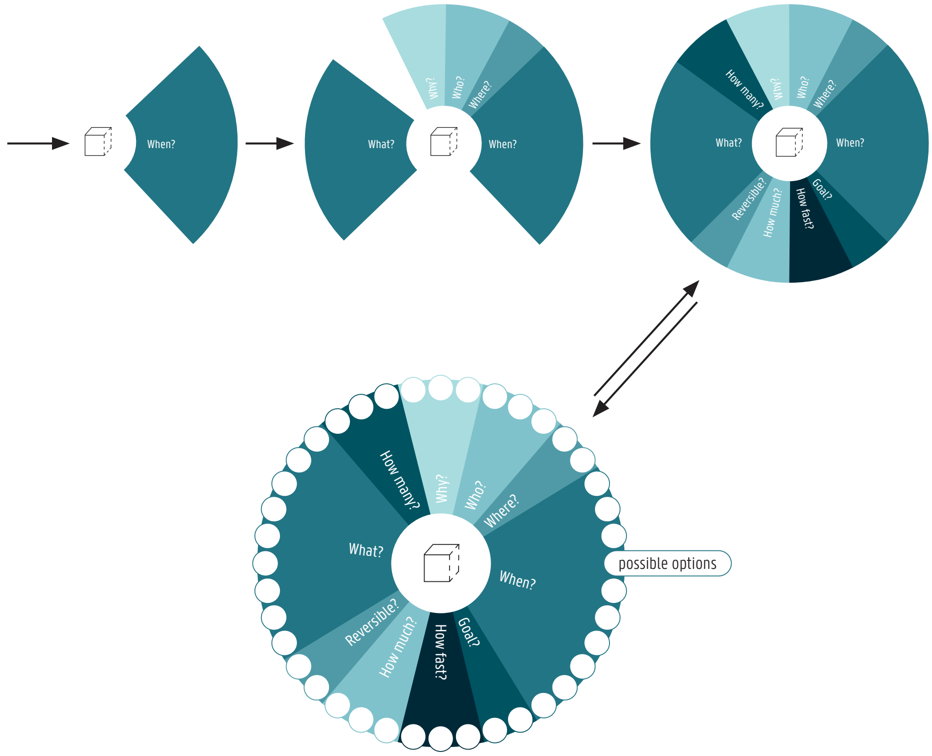


Figure 4.1. Process of identification of the ten lenses and the possible options for each lens

Systems become again the mean of inquiry and the goal of it. A good way to communicate complexity is to visualize it with forms, structures, etc. In this case we adopt many different questions, as viewpoints, in order to acknowledge the complexity and sometimes paradoxical nature of certain cases that might be virtuous under one perspective and irrelevant under the others.

The questions, referrezd as ten lenses, are:

1. Why is the product changing?

2. Who is making the change?

3. (goal-orientedness) Is the change result of a deliberate act?

4. When is the change happening?

5. How fast is the product changing?

6. Where is the change happening?

7. How many products can be made?

8. What is changing?

9. How much is the product changing?

10. (reversibility) Is the change reversible?

→ **How 1.** How is the product designed to support change (**mechanism**)?

→ **How 2.** How is the product realized to support change (**strategy**)?

We use the term lenses to highlight as, by answering these questions (or even just by asking them), the designer/researcher has to see the specific artifact or situation from a different perspective. "Lenses are different from filters in that they make things clearer. […] Of course, lenses are also tuned to certain frequencies, which select and pass information within restricted bandwidths." (Nelson & Stolterman, 2012, p. 67) Important to notice is how, if all these lenses are profoundly inter-related, they have different roles. In fact, while the first 10 questions can be considered one by one, or coupled (i.e. How much? – How many?) in analytic manner, the last two lenses generate from a specific mix of different variables, corresponding to the contextual conditions were the Open-ended Design has to be created. In other terms, the last two lenses *emerge* from the conversation between specific combinations of the other ten lenses and the creative process of the designer. The How? lenses are divided in *mechanisms*, referring to the specific design and engineering knowledge, and *strategies*, referring to the business model needed to put them in contact with the real world (see **Figure 4.2**).

The first ten lenses have been linked with a set of possible answers that raised from literature (from which we borrowed models and frameworks), case studies analysis and from original experiments (see Study 3). These possible answers where listed once a saturation of the collected information was reached (Hancock & Algozzine, 2006)(Eisenhardt, 1989). For the latter two lenses this process of answer definition was not possible. In fact, too many combinations exist. This has to be justified by the very nature of the design outcome: a unique representation of various specific conditions ranging from emotional values, to market dimensions, from technologies available, to business model, from products' function, to target users, etc. This mutual relation among the different lenses will be later expanded (see **Paragraph 4.3.2**).

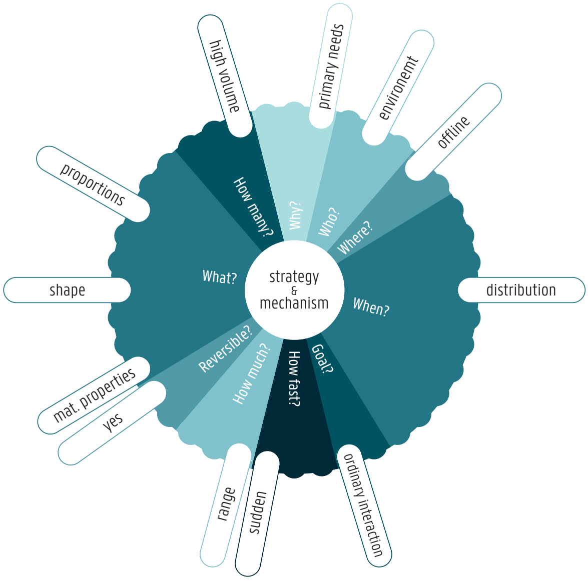


Figure 4.2. Strategies and mechanisms, as emergent possibilities of the combination of the 10 lenses (in figure, one example)

4.1.2. Supporting examples

To report this analysis several examples of product are used, constituting a pragmatic way to visualize more complex concepts. These, as introduced before, are hardware products, where the intelligence is emerging from the material aspects. This choice has been done because of two interrelated reasons: first, open-endedness in digital product exists and is diffused allowing easy access and re-appropriations to anyone connected to the web (i.e. Wikipedia); second, we believe that the smartness of our devices should also be followed and supported by their materiality. In fact, it is shared opinion that nowadays designers tend to undervalue the role of tangible interactions in, for example, increasing the emotional durability of interactive electronic devices (Blevis & Stolterman, 2007)(Jung, Bardzell, Blevis, Pierce, & Stolterman, 2011). To be also noted is that some reported examples might be less sustainable than others, some more trivial, less function oriented, etc. The reason has to be seen in the fact that the cases have been selected because of the message they (un)intentionally bring, which is their capability to evolve and embrace change without reaching disruptive scenarios. In other words, they have been selected upon their communicative capabilities, rather than overall value as design outcomes.

Also, while in this daily observation we collected all the possible mutations occurring in objects, in this section only *intentional* Open-ended designed products are introduced (see **Figure 4.3**), meaning products that are intentionally created to be changed by the environment, in a way that is out-of-control of the designer. The term intentional Open-ended Design stresses the fact that, in our view, every product is open-ended being subject to dynamics of change. At the same time, it also means that change, even if intentional and anticipated, will always be potential (not certain) and the result unpredictable. These are the main reasons why the designer, while engaging in Open-ended Design, should always engage in an iterative process of observation and anticipation. These topics are expanded in **Study 5**.

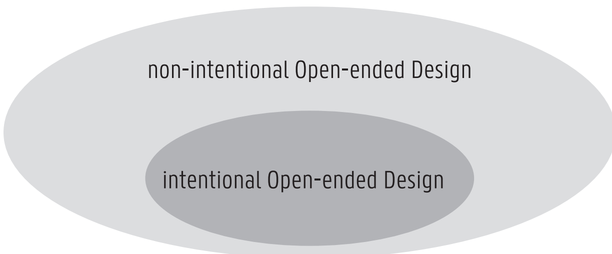


Figure 4.3. Every product is non-intentionally (from the designer perspective) able to change. Some instances can be Intentionally design in an open-ended, imperfect, suboptimal way, in order to support meaningful changes. This thesis mainly focuses on how to Intentionally create Open-ended Design outcomes.

Finally, we are introducing here 20 case serving our narrative description of the lenses, by providing more tangible examples. Important to notice is that these cases have been selected for their inegnious way to deal with change, and not for their relation with sustainability.

1. **Adaptive Eye care**, by Joshua Silver, 1996 (adaptive-eyecare.org). In the Adaptive Eye care glasses the lenses are built as flexible membranes filled with liquid that can change shape easily. The change in the shape, that implies a change in the power of the lenses themselves, is controlled by a small pump so that the user has complete control on it and can adjust his / her own glasses according to the need. These glasses can correct myopia, presbyopia but not astigmatism. These glasses represent an easy way to increase accessibility by distributing glasses without prescription (initially thought for developing countries), or for example, to keep

them even when the need is changing over a period of time.

2. **Ariante 30 Arlecchino**, by Francesco Trabucco for Vortice (vortices.it). In Ariante 30 Arlecchino every component is produced in 5 different colours (yellow, grey, pink, light blue and light green). The assembly of these pieces occurs randomly so that every Ariante 30 Arlecchino presents different combinations of colours. in total 78.125 possibilities are possible, among which also monochromatic ones. In this simple way the producer can give aesthetic uniqueness to an industrial piece without using digital technologies or increasing drastically the time of production.
3. **Custom sneaker kit**, by Jgoods (jgoodsonline.com). This kit provides you with everything needed to personalize your sneakers (colors, brushes, etc.). Starting from a standard shoe every user can have a unique version of it, representing his/her own personal aesthetic values.
4. **Stain**, by Bethan Laura Wood, 2006 (bethanlaurawood.com). Stain is a set of tea cups that change through use. As known, tea tends to stain cups over time, which for somebody can lead to a decrease in the perceived aesthetic value of the product. In this case, the shape of the stain is designed beforehand and the pattern (colored by the tea) appears in time, at a speed that is proportional to the use we do of this product.
5. **Verderame**, by Paolo Giacomazzi and Tommaso Caldera for Fioravanti, 2009 (fioravanti.eu). "Verderame is a copper tile based on the idea of mutation. When it is set on the floor it looks just like a normal copper tile, but in a couple of months the oxidation process starts to change the color of the tile. Some parts of the tile are protected with a transparent film. The oxidation will make appear an hidden texture, showing the typical things that we can find on a floor: a pen, a shoelace, a running bug." (from fioravanti.eu/project/verderame, last accessed on June 2017).
6. **Do break**, by Frank Tjepkema and Pieter Van der Jagt for Droog Design, 2000 (tjep.com and droog.com). This vase comes with no decoration and with a rubber layer in its inner wall. In case of accidental breakage (or more intentional, for example during a lover's quarrel) the surface breaks showing a craquelé structure, while the vase doesn't lose its function. "Not only can the vase still be used but it also gains in beauty as the cracks multiply to form a unique pattern. From now on, any lover's quarrel is an improvement." (from tjep.com, last accessed on June 2017).
7. **Objects of necessity**, by Ernesto Oroza, 1994 – present (ernestooroza.com). Objects of Necessity deals with re-appropriation of existing products. It shows how creativity can raise from actual needs and how, by using a simple re-assembly and

modification of previously un-related and often discarded objects, new functions can be achieved.

8. **Do scratch**, by Martí Guixé for Droog Design, 2002 (guixe.com and droog.com). This lamp comes covered with black paint, so that the light cannot pass, making the lamp useless. In order to make it function the user has to take an action, to be creative and to scratch the surface so that the light passes. Every lamp becomes unique, in its aesthetic and in the quantity of light allowed to pass.
9. **Freitag**, by Markus and Daniel Freitag, 1993 (freitag.ch). Every Freitag bag is unique. The strong textile used in these bags was in fact a trucks tarp once. The material is collected at the end of life, washed and finished. While colors and decorations of the bags are random, coming directly from the graphics of the trucks, the good properties of the material (mechanical properties, but also waterproof quality, etc.) are maintained for every product.
10. **Incremental houses**, by Elemental, 2012 (elementalchile.cl). Incremental Houses is a project or people who lost their own house during an earthquake in Chile. This house is not finished, while the entire structure is visible and half of the volume is completely built, the second half is still empty. To finish the house, the occupant has to take an action, to re-appropriate the void. In this way every house becomes personal and different from the other surrounding ones. The house, that started as identical to many others, becomes personal and addresses the aesthetic and functional needs of the occupant.
11. **Cell cycle**, by E. Rosenkrantz and J. Louis-Rosenberg for Nervous System, 2009 (n-e-r-v-o-u-s.com/cellCycle). Using this physical-based tool you can easily personalize your own jewel by choosing variables such as size, shape, material, color, etc. The jewels are then produced using 3D printing and shipped to you. "Instead of designing objects, we craft computational systems that result in a myriad of distinct creations. [...] The design systems we encode are generative; they have no fixed outcome. Rather than thinking of them as mere tools, we consider them our medium." (from n-e-r-v-o-u-s.com/cellCycle, last accessed on June 2017).
12. **Grow card**, by Niko Niko (nikoniko.nl). These postcards are made of handmade paper including seeds of flowers. After receiving the card is possible to plant it. In this way the product disappears at the end of life, or better it transforms into a small plant or flowers.
13. **Sugru**, by Jane for formformform, 2008 (sugru.com). Sugru sticks permanently to many materials like ceramics, glass, metal, wood, plastics (not all of them) and fabrics. It is a material thought to repair things, to hack them adding new functions and creative repurposing. Not only the material is great, but also the Sugru blog (sugru.com/blog) is worth checking to find very good inspirations.

"Repaired things bear the scars of a life of use and abuse: they can remind us that they've served us well." (from sugru.com, last accessed on June 2017).

14. **Post post**, by Skrekkøgle, 2015 (skrekkogle.com). Post Post is an aluminum canvas "to be sculpted by the mail service". As we know, products might be hit and deformed during the handling of the box, and this is something we cannot always avoid. The ides of Skrekkøgle is to embrace this unavoidable event, allowing it to take part of the creation process. In this way every received Post Post is different and the designer is finally allowed to lose control on the final shape. "As every sheet is handled differently in the mail, each Post Post is unique. We don't have any control over how roughly the package is treated, so it might come out really crumbled or just slightly dented." (from skrekkogle.com, last accessed on June 2017).
15. **Una seconda vita**, by Paolo Ulian, 2006 (paoloulian.it). The decoration of this ceramic centerpiece is designed to give a Seconda vita (literally a *Second life*) to the product in case of accidental breakage. In this way, from a big centerpiece we can obtain a set of small bowls. "I like to think that this object can become a sort of admonition of not getting rid of products too easily", writes the Italian designer Paolo Ulian.
16. **Moka express**, by Alfonso Bialetti for Bialetti, 1933 (bialettigroup.it). The Moka, famous coffee machine created by Alfonso Bialetti in 1933, revolutionised the way coffee was made. This product is special not only for the simple way of use and for the daily ritual it creates, but also because its function improves with use. The taste of the coffee improves thanks the contant use of the Moka, and that is related to the patina that is formed on its inner wall.
17. **Lego brick**, by Lego, 1960 (lego.com). LEGO brick was nominated "Toy of the century" twice, and shouldn.t be described. What makes this toy so interesting is its highly adaptable nature, thanks to which by starting from small standard components the users can achieve very complex and unique architectures.
18. **Bat-tagliere**, by Paolo Ulian, 1999 (paoloulian.it). This marble cutting board is fully realized with semi-processed waste. These marble pieces come in fact as production scrap of another product, a wash basins tops. If you see the shape of the cutting board, you can recognize the "void" of the sink.
19. **Saving/space/vase**, by Joe Velluto for Plust, 2009 (plust.it). Saving/Space/Vase is big vase for outdoor use. Each piece of the collection is unique, thanks to the industrial production process used to create it. Mainly, the vase is first rotational moulded and then – while still lukewarm – deformed with a vertical pressure. This second process is more open, and leads to unpredictable (within certain limits) results and therefore unique products.

20. Mycelium, by Maurizio Montalti for Officina Corpuscoli (corpuscoli.com). Mycelium is the fast growing vegetative part of the fungi, structured by interconnected filaments. Mycelia can be combined to agricultural waste in order to create a material that has both aesthetic and structural properties. This material, being the result of a growing process, presents always a unique appearance.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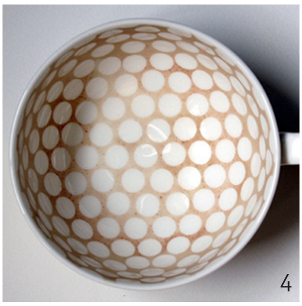
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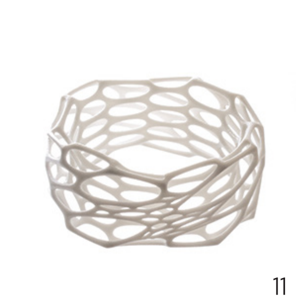
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Figure 4.4. The described cases, used to support and exemplify the description of the lenses. All pictures belong to the authors and have been retrieved from the websites listed in the text

4.2. Ten lenses to focus on change in design

The lenses previously listed are here described also thanks to the list of possible configurations (or *answers*) they can have. In order to support the reader through this analysis, we have decided to represent the possible variations in the design outcome (mainly the possible identified answers to the listed questions) via an archetypical product design: the chair (see **Figure 4.5**). We have found this graphical expedient of use to simplify and make concrete some otherwise complex aspects. Also, the chair is a product subject daily to human interactions, something to which we can relate easily. We have created an icon for every answer of each lens. Finally, to accompany every description the specific introduced cases are used, in order to exemplify the concepts with real examples.

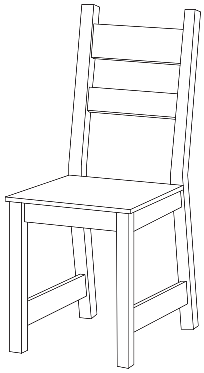


Figure 4.5. A chair, in its "ideal" status

4.2.1. 1st lens: why is the product changing?

This question is, in our opinion, the most fundamental one. As introduced in **Chapter 1** we started with one main postulate, which is "if the product is put in interaction with the real environment, then it changes". This process can be motivated by many factors, for example the passage of time can generate changes in the product such as rusting, or dusting, or variations in the properties of materials (discoloring, higher brittleness, etc.). We define these as *spontaneous processes* occurring because of the interaction of the product with non-human components of the products ecologies. This types of changes are unavoidable, since everything ages. If, on the contrary, changes occur because of human interaction we can have several distinctions. To achieve the following definitions, and deeply understand the reasons why products change, we conducted a dedicated study, **Study 3** (Francesca Ostuzzi, Couvreur, Detand, & Saldien, 2017). We concluded that some changes must be done for the product in order to function (i.e. to fit a prosthetic arm to the patient), we defined these changes as *contextual*, being deeply related with the context and impossible to anticipate by designers, in other words these changes support primary needs of the users. These are normally function related ones, that are the ones that – if not encountered – can imply early abandonment or rejection (see **Chapter 3**). On the other hand, we have changes that can happen, but should not necessarily occur for the product to function. We defined them as *undefined*, or secondary needs, being needs related to self-expression and self-actualization and becoming manifest when the primary needs are satisfied (Maslow, 1943). Also, the cited study helped us in understanding the fundamental role of the closed instanced (defined as *defined-fixed*) which can be seen as similar to the core infrastructure of a product, as considered in mass personalization (M. M. M. Tseng, Jiao, & Wang, 2010). This question could be also re-formulated as "what triggers the change?" in order to highlight as is not the product itself that triggers the change, but its interaction with the environment. Important is to highlight that the reason why the changes happens is not referring to the intentionality of making the specific change happen (i.e. the chair might get cratched because of primary need of sitting, but without me scratching it *on purpose*). It is clear as products are very often subjects to interaction both with human and non-human actors at the same time. For example, in case of the **Adaptive Eye care (1)**, the adaptation in the product is necessary, allowing the user to see. It corresponds therefore to a primary need. In the case of **Custom sneakers kit (3)** the adaptation is clearly for aesthetic reasons, listed here as secondary needs. In these two cases, as explained in **Chapter 3**, the change can lead to higher emotional values and possibly longer life-spans. In **Verderame (5)** the copper ages and oxidize, which makes it going from the shiny orange appearance to the matte green one. This is a process linked to the chemical reactions occurring in time. Following, in **Figure 4.6** the representations of the three possible reasons why products change.

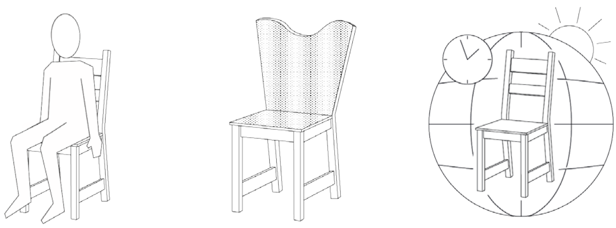


Figure 4.6. Why is the product changing? From left to right, because of primary needs, secondary needs and/or because of the interaction with the non-human components

4.2.2. 2nd lens: who is changing the product?

This lens is related to the previous one. As mentioned, every product is put in interaction with a complex ecology (Forlizzi, 2007), which intentionally or unintentionally, consciously or unconsciously, modifies it. The contact with the real environment, as we will see in the lens *when*, occurs earlier than the contact with the end user. For this reason, for example, a change can be obtained already during the production process, as in the case of **Saving/Space/Vase (19)**, where the designer is engaging with Open-ended and out-of-control production processes, that reach an outcome characterized by unique features. In the case of the **Lego (17)**, as in the majority of cases introduced, is anyhow the user to do the actions needed to change the product. Finally, especially in the case of changes occurring because of non-human components (see **Figure 4.6**), the change can have as agent processes such as: the passage of time, the weather conditions, the location of the product (i.e. outdoor or indoor), etc. Part of the products' ecologies are also other actors, for example, in **Post post (14)** the product is modified by the postman who delivers the sculpture to the end user. In many cases different agents modify the product, at the same time (i.e. **Verderame (5)**, where both time and use have impacts on the aesthetic of the floor). Following, in **Figure 4.7**, the representations of the three possible agents changing the product.

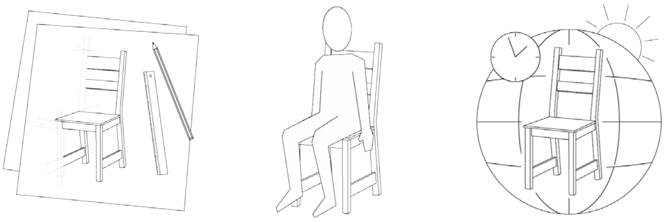


Figure 4.7. Who is changing the product? From left to right, the designer, the user and/or the product's ecologies including both human and non-human components

4.2.3. 3rd lens: is the change itself the goal? (goal-directedness)

Another important aspect is to understand how much is the agent of the change in desire of making the change itself (what we also define as goal-directedness or intentionality). In fact, in some cases the change is done on purpose, which is what we define as re-appropriation, underlying its intentional nature. For example, when someone repairs or hacks something with **Sugru (13)** is taking a deliberate action, with the goal – in this case – of extending the life span of the product or increasing its value. The reasons behind the possibilities to take similar actions can be seen in the user motivation and intention (Fogg, 2009). Furthermore very interesting works have been done to facilitate the capability of users to start this object/subject conversation in the digital era (Hermans, 2015), especially focusing on layperson or non-experts. At the same time, products are subjects to changes that occur while we are using them for their daily function, for example in the case of **Stain (4)** while drinking the tea daily the user is creating the graphic of it, which is an emergent quality of this interaction as the *traces* described in **Chapter 3**.

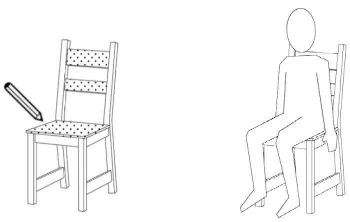


Figure 4.8. Is the change the goal? From left to right, the change is the main goal of the action taken by the agent, or action mode and/or the change occurs because of ordinary interactions (defined also as goal mode)

“All people are creative but not all people become designers” (Sanders & Stappers, 2008, p. 12)(Sanders & Stappers, 2012). Four levels of creativity can be defined: productivity (doing level), appropriation (adapting level), asserting skills (making level) and inspiration (creating level). In other terms the user can decide to actively change the product to the extent of appropriating it by modifying some features or to actually co-designing new ones. These levels depends on the skills, passion, desire… in other word, in the specific attitudes of the users, and are therefore hard to foreseen. Still the designer should not forget as, next to the overall personal motivation (out of the control of the designer), to stimulate users into creative actions also the ability plays a fundamental role (Fogg, 2009). The ability of change in a product can be supported by specific design act, as explained afterwards. In this view, the improved ability of the user to take part of the design process, can lead to higher personalization or personification, and can be recognized as consequence of the post-industrial era (Hermans, 2015). We should not forget as anyhow the designer should take certain design decision to intentionally support potential change, since to predict the cognitive and emotional reactions in usage situations still represent a serious problem (Hassenzahl, 2003). Hassenzahl proposed, in order to support the design in this complex process, to distinguish the usage modes between: goal mode, were goal fulfilment is fundamental (i.e. to sit on the chair to rest, were rest is the goal), and action mode, were the action is the goal itself, so the product can be the goal, instead of – as seen before – the goal for something else (i.e. to sit on the chair to try out its comfort, of to repaint it for aesthetic pleasure). Using terminology developed by Forlizzi, the first kind of experience, or mode, is fluent, while the second one can be either cognitive or expressive (Forlizzi & Battarbee, 2004). Every product can be experienced in all these states (Hassenzahl, 2003).

4.2.4. 4th lens: what is changing?

This question is one of the most fundamental for industrial designers, because of its deep relation with the designed outcome. A big problem with openness, as for with ambiguity, randomness, imperfection (see **Chapter 3**) is the balance between these instances and their contrary. In fact, and Open-ended Design is defined by some meaningful open, undefined, out-of-control, aspects, while all the others are completely defined. In other words, not the complete outcome should be open, on the contrary only certain aspects need this quality. This aspect is particularly controversial and needed further studies. Specifically, **Study 3** focused on the process needed to understand which aspects should be open, which could be open and which should not (Francesca Ostuzzi et al., 2017). The same study addressed the extension of the openness, reported in the next lens “how much?”. Here we report the results of that study, in which two main families of products’ attributes were defined: the hard and the soft ones (Hermans, 2014). By manipulating them, the designer creates an intended product character, which will be or not confirmed by the user perspective on it (once in the real environment) (Hassenzahl, 2003). With hard attributes we refer to material attributes such as: shape, architecture, dimensions, proportions, etc. while with soft attributes we refer to functions, values and meanings. It is evident as, also in this case, many different attributes can change at the same time and, as well, as some changes in one attribute might imply changes in another attribute (i.e. if the shape of a product has been changed to reach higher functionality it is possible to think that also the value of the product will change accordingly, as explained in the section **Personalization**, in **Chapter 3**).

For example, with **Sugru (13)** it is possible for the user to change very easily the material properties, the superficial qualities, the kind of connections and also the function of the product itself (i.e. in hacking approaches). In **Adaptive eye care (1)** by a slight change in the shape of the lens (more or less convex), the functionality can be reached. About the soft attributes, a good example is provided by **Objects of necessity (7)** a typical non-intentional design (Brandes, Stich, & Wender, 2009). In this case, thanks to the creativity of the user, a product can deliver different functions than the ones previously anticipated by the designers. Often, in non-intentional design, don't require any change in the hard attributes of the product. In **Figure 4.9** the various identified options.

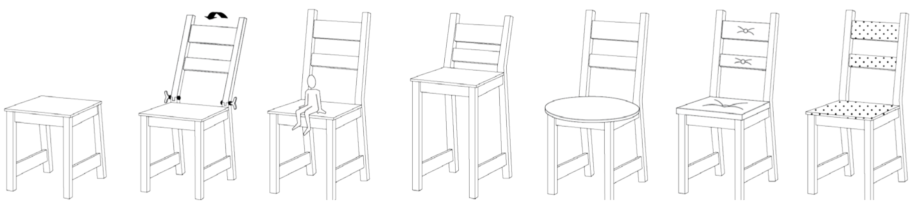


Figure 4.9. What is changing in the product? From left to right, hard attributes are architecture, connections, dimensions, proportions, shape, material properties and/or surface qualities

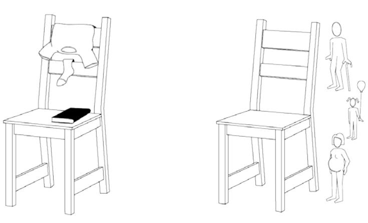


Figure 4.10. What is changing in the product? From left to right, soft attributes are users' needs, product function and value, or product interpretation

4.2.5. 5th lens: how much is the product changing?

This is another very crucial aspect to be considered by the designer. In fact, it has relation with many design aspects as well as many other lenses. Especially, it deals with the willingness, possibility and capability for the designer of leaving some aspects of the design solution completely out-of-control. Which, under another perspective deals with the capability, or not, of the designer of anticipating possible configurations. For example, with **Sugru (13)** the openness is total, in a way that the designer is not capable (and doesn't need) to give constrains to the possibility in terms of shapes and functions of the products. In the case of **Cell Cycle (11)** we have a (mainly) continuous set of options within certain limits, which in this case can be seen as min and max dimensions of the 3D printer itself. In this case we refer to personalization strategies, where the company or designer cannot precisely foresee all the possible options because of the enormous number, which is still anyway limited and definable. This can also be defined as interval (Couvreur, 2016). With steps, we refer on the contrary to a very precise and limited (even if big) amount of non-continuous options. For example, the choice between several shapes or colors, or combinations of the two. In this way the choices are pre-defined and we enter in the area of customization (Kumar, 2007)(M. M. Tseng, 1996). Some after encounters (meaning when the product meets the user, see **Figure 4.13**) products for customization, for example the Sneaker custom kit, are in this perspective an example of open product, since the combinations are created by the user in an out-of-control setting. On the other hands, customizations approaches done by the industry cannot be considered, under this aspect, Open-ended Design.

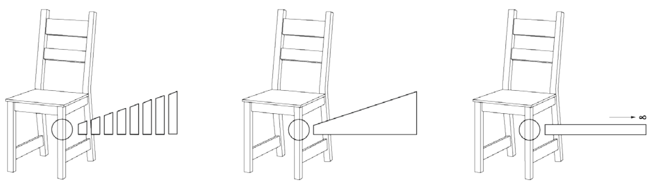


Figure 4.11. How much is the product changing? From left to right, steps, range or open

4.2.6. 6th lens: how many products can be produced?

This lens deeply relates with the previous one. In fact, if the need for a certain range of options can be technologically driven, the same happens for the volume of production. The economy of scale traditionally followed the paradigm of high volume and standard solutions, in order to reach financial sustainability. Nowadays a Long Tail economics has been recognized in its value, following an opposite paradigm of low volumes and high variety. But the mass personalization remains, in our opinion, limited to an after encounter field ad cannot be yet technologically supported (Kumar, 2007), what is possible to achieve is unique products through the adoption of randomness in the assembly phase. For examples **Ariante 30 Arlecchino (2)** is produced with a typical standard technology, that is injection molding. The pieces are printed in different colors and randomly assembled, creating the possibilities for 78.125 unique combinations. Some technologies, especially the digital ones as 3D printing and laser cut, are characterized by relatively long times of production, pertaining normally to the low volume category, as for example the product **Cell Cycle (11)**. Products based on production waste [as different from the scraps (Pacelli et al., 2015)] are of unforeseeable volume.

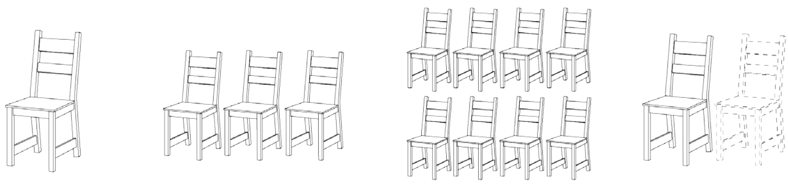


Figure 4.12. How many products can be produced? From left to right, one or few pieces, low volume, high volume or an unpredictable number

4.2.7. 7th lens: when is the change happening?

As introduced earlier, this was the only perspective adopted at the beginning of this research. Typically, when we deal with sustainability in design we have to adopt a Life Cycle approach. This can be defined as the design approach that considers the product (since the design phase) under all the sequential stages that will follow in its life (Vezzoli & Manzini, 2008)(Braungart et al., 2007). Main phases of the products life cycle are: extraction of raw materials, (pre-)production, distribution, use, end of life. Thanks to the conducted research some life cycle stages have been expanded, reaching the following list: extraction of raw materials, (industrial) production, (industrial) assembly, distribution, (home) production, (home) assembly, use, breakage (of, in more general terms, end of the main anticipated function) and end of life. Important factor for the designer to be considered is that these stages can also be divided in: pre-encounter or post-encounter, meaning the moment of contact with the end-use environment. Thanks to this distinction it is easier to define who are the agents possibly involved in the change. For example, some products like **Bat-tagliere (18)** can face a change in the function already during the production phase and being then transformed from scraps to be discarded to useful materials or products. In other cases, the change can happen during the distribution phase, as for **Post post (14)** shaped by the careless handling of postman. Mane examples focus on changes after encounter, as for example **Do Scratch (8)** which needs a sudden active re-appropriation, without which the product cannot function. **Una seconda vita (15)** anticipate the breakage stage, and is therefore designed to have already a second "embedded" function, that becomes manifest only in case of fall of the vase. Finally, some products or materials that have already been discarded, as in the example of **Freitag (9)**, can find a new value after their first end of life, which goes under the broad name of reuse.

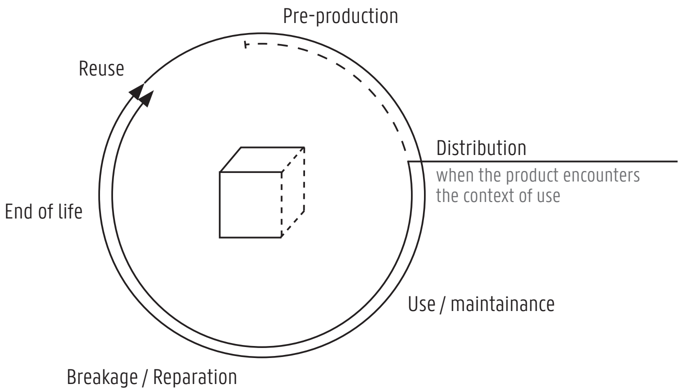


Figure 4.13. Representation of a typical Life Cycle. Highlighted, the moment when the "encounter" with the context of use happens. This moment is moving backwards in time, thanks to the co-design and co-production possibilities given by the industrial revolution

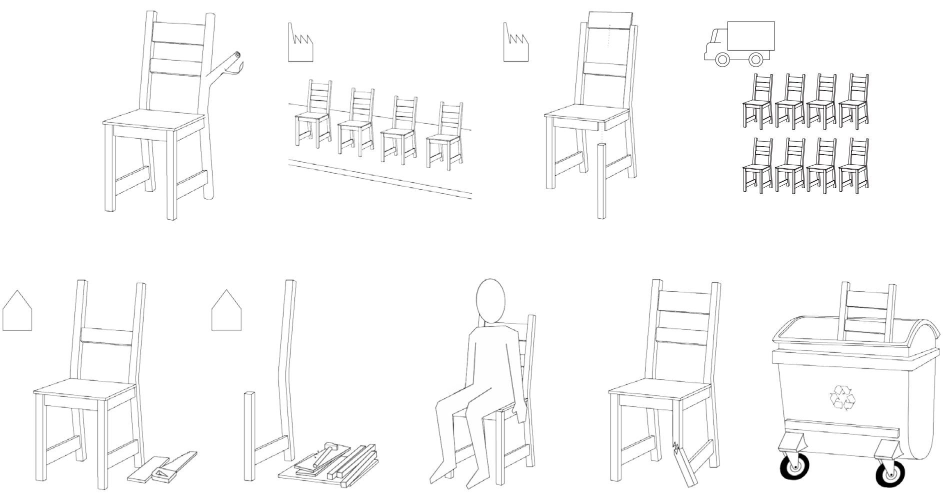


Figure 4.14. When is the product changing? From left to right, extraction of raw materials, (industrial) production, (industrial) assembly, distribution, (home) production, (home) assembly, use, breakage and end of life

4.2.8. 8th lens: how fast is the change happening?

Through this lens we try to understand how fast is the occurring change visible at the eyes of the involved stakeholder. Important to notice, here we refer to the speed of the process of change once this has started, since the starting of this process is not predictable by the designer and might never occur [see examples as **Incremental Houses (10)**, **Seconda Vita (15)**, **Do break (6)**], this helps us to underline again why the change is potential, not always sure. If the user adapts the lenses how the **Adaptive eye care glasses (1)** the feedback of this change will be sudden. While the designed patterns in **Stain (4)** will need some months to appear, because they accumulate over time, and are proportional to the use of the product. Finally, every product changes in terms that are hard to read, because of the continuous interaction with the complex surrounding environment.

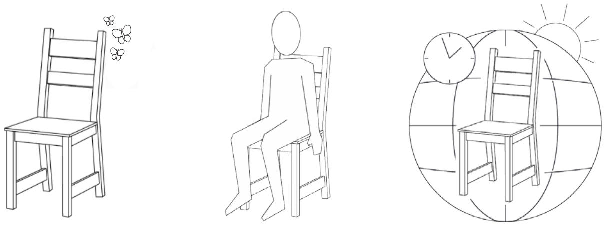


Figure 4.15. How fast is the change happening? From left to right, suddenly (seconds, minutes, hours), human time, easy to read (days, weeks, months, years), slow, hard to read (decades, centuries)

4.2.9. 9th lens: is the change reversible?

Some processes of change are unidirectional while others can be taken back, in the second case a new input of energy is anyhow required, as defined by the laws of thermodynamics.

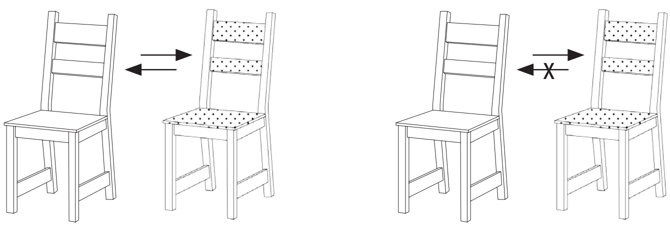


Figure 4.16. Is the change reversible? From left to right, yes or no

4.2.10. 10th lens: where is the change happening?

In **Chapter 3** we have provided an extensive description of the current digital industrial revolution and its implications. In this new landscape previously unrelated actors can communicate, and co-design in the online space. For this reason, it is important to understand if the change occurs with a physical contact with the real environment, as for example with **Grow Cards (12)**, that to become plants need to touch the ground, or if the change can occur through a virtual, online, encounter similarly to what happens with **Cell Cycle (11)**.

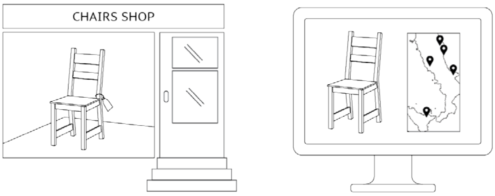


Figure 4.17. Where is the change happening? From left to right, offline and/or online

Every lens asks to the designer to acquire a different point of view to analyse the same phenomenon. In this way, the designer can adopt multi-perspetives views and learn more about the complexity of the analysed case. It is hard, if not impossible, to imagine the lens as “stand-alone” views, since very strong or weak correlations between two or more lenses already exist. For example, digital production relates -nowadays- to small or low volumes or it is hard to imagine a change done by the user in the raw material selection. This has been seen as a temporary limit where the cause can be referred to, for example, a lack of specific technological developments or designers creativity. In this way, these specific combinations (or missing ones) could serve as trigger for designers to innovate.

4.3. Results

4.3.1. Online inspirational tool

The cases are being collected in the website open-ended-design.com (work in progress). The website is designed to serve as inspirational tool for designers, willing to engage with open-ended outcomes. Every case has been categorized according to the ten lenses, furthermore a brief description and all the information (designer, brand, year, materials, technologies, etc.) have been included. There are two ways to explore the website's contents: the user can decide to navigate through the entire collection (**Figure 4.18**, next page) or to follow a specific lens. If a specific lens is selected all the cases are re-distributed according to the possible options (**Figure 4.19**, next page). Thus, if the user is interest in understanding how material properties can change (lens "What?"), by using this function it becomes easy to find benchmarks of products where the same change occurs. A first drafts of the website has been briefly tested during an international course hosting 50 students from 7 different countries, the test is now anyhow here reported.

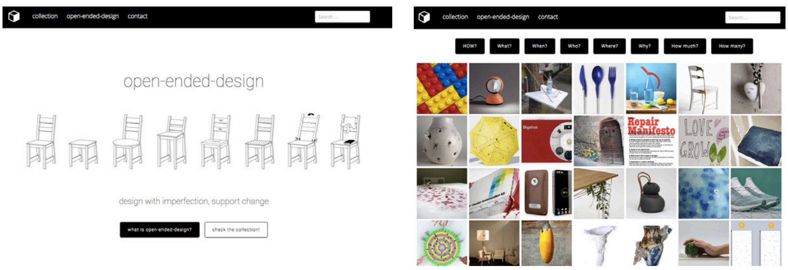


Figure 4.18. Website homepage (on the left) and cases collection (on the right)

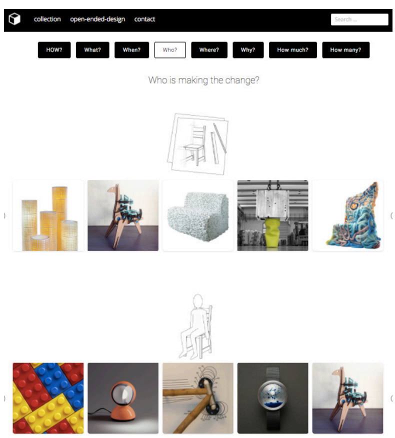


Figure 4.19. All the cases can be re-organized according to the specific lens of interest

4.3.2. Combining lenses

It has been mentioned many times that many lenses are connected with each other. For example: if the change is happening during the use phase, then it is likely the user or the general environment to change it, and not the designer. This often depends on some practical limitations, that represent the very nature of the design practice. Two lenses in the specific (How much? and How many?), once merged, can give interesting insights about what we defined as landscape of design solutions. By putting in the two axes the volume of production and products variety variables we achieve the landscape in **Figure 4.20**. The volume of production goes from high volume to small series or unique pieces, while the variety goes from standard products to products with unique features.

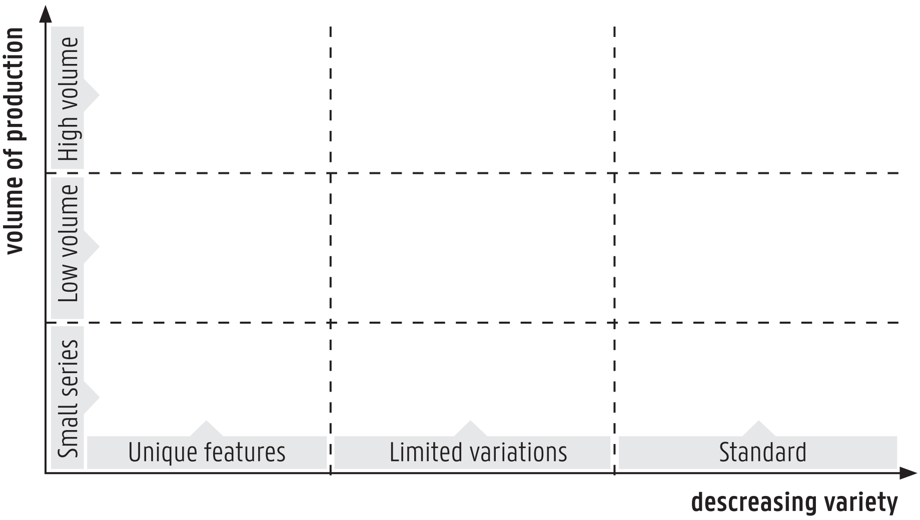


Figure 4.20. By merging products variety (lens: how much?) with volume of production (lens: how many?) we can identify a landscape composed by 9 areas

In this landscape six areas are well known by designers. Here following a brief description.

1. **(Traditional) mass production** (high volume, standard features)
2. **Mass customization** (high volume, limited variations)
3. **Mass personalization** (high volume, unique features)
4. **Low volume manufacturing** (low volume, standard features)
5. **Limited editions** (small series, standard features)
6. **Craftsmanship or design for one** (small series, unique features)

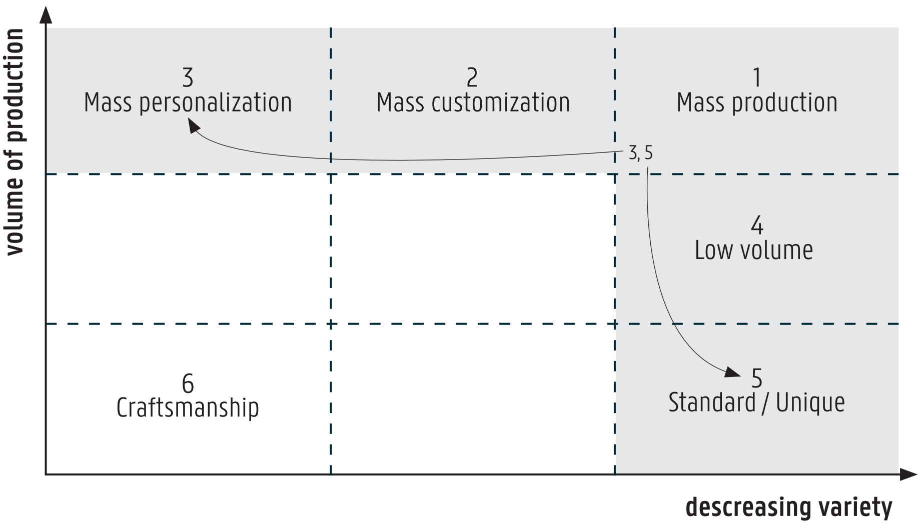


Figure 4.21. Landscape of design solutions, with more traditional areas highlighted

We attempt now at describing it using one simple product as example: shoes. Normal shoes, for example, All Star from Converse (converse.com) are mass produced. The variability introduced, sizes and colors, is completely foreseen by the company and therefore we can define this product as standard. In the case of Nike iD (nike.com/NIKEiD) the user can design his/her own shoe, by choosing among several different options for different attributes (model, color, material, soles, etc.). In this case, the design can have a unique outcome (if, for example, nobody selected the same combination) but the freedom of the user is still limited to the available options. Moving a bit further in the direction of higher variety, we reach the area of mass personalization. This area is often mentioned in literature, personalization is different from customization under mainly these aspects: the design space is bigger, there is a strong value given to intangible customer experience and goes beyond a configuration-to-order. In fact, while customization builds upon products' family and defined parameters, personalization aims at allowing possible changes in the design itself, at least in part of its features (M. M. M. Tseng et al., 2010)(Risdiyono & Koomsap, 2011). Still, mass personalization has a controversial nature, since it still or resembles mass customization approaches (offering very limited participation to the user) or personalization of products in lower volumes. This has to be seen in the need for economy of scales, for traditional manufacturing processes (injection molding, extrusion, casting, etc.) and in the absence of such economies for digital and more flexible production technologies (CNC, 3D printing, laser cut, etc.). For these reasons, this area can be defined a technologically paradoxical area. Decreasing the volume, on the area of products with standard features we find the region of Low volume manufacturing, for example limited editions of a shoe, or the semi-industrial production of high end products. Other typical examples for this area are digital technologies applied for the construction of production tool, defined as rapid tooling, or short-run tooling (Campbell, Bourell, & Gibson, 2012). Moving further in the same direction, we approach another paradoxical area of the matrix, the paradox in terms area. In fact, here we should find products identical, but in very small pieces or even unique.

Finally, on the extreme of the landscape we find another well-known area: the one of small series, or single products, with very unique features. This is traditionally the area of craftsmanship, which creates tailor made products, normally engaging in costly processes (in terms of time and skills required). This area can also be seen as the one of design for one, introduced in **Chapter 3**. The entire region surrounding the Design for One is fairly new, and unexplored, and is inhabited by low volumes (to small series) of highly diversified products. In other words, this area corresponds to the Long Tail of products niches (see **Chapter 3**, **Figure 3.7**) (Anderson, 2006).

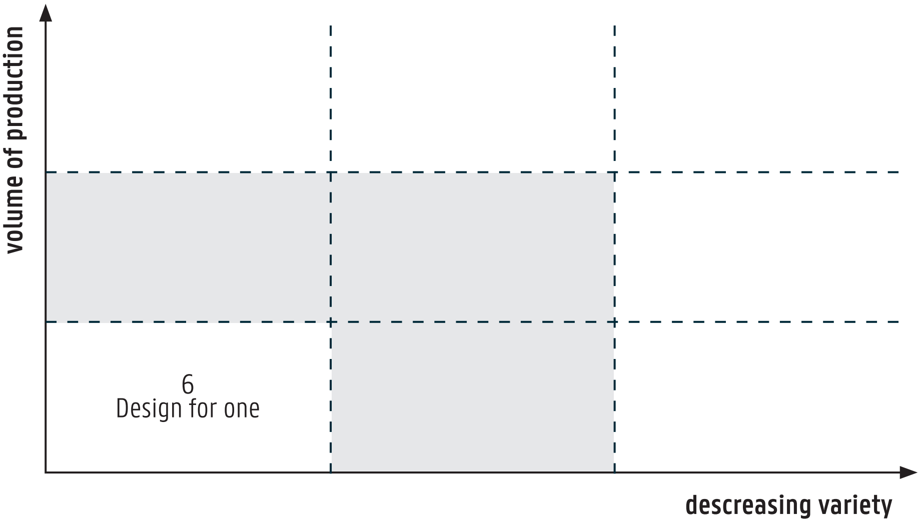


Figure 4.22. Landscape of design solutions, with the long tail of niches highlighted

It emerged from the analysis of the case studies that thanks to solutions able to embrace dynamics of change (open-ended intentionally or not), it is possible to overcome the economic and technological limitations, and ultimately reach the two paradoxical areas. These possibilities lay in the after encounter time span [also defined as use time, or after-design (Redström, 2008)] and need an active role of the user, in term of re-appropriation of standard mass produced solutions. For example, with designed DIY kits (i.e. the Sneakers custom kit, Xeroshoes kit, Earthing shoe, etc.) the producer creates a very standard product (area 1), that works as a white canvas to be re-appropriated by the end user. The final outcome of this process is out-of-control, since it is impossible to predict the personal choice of every user (from area 1 to area 3). At the same time, some standard produced products (area 1) can be re-appropriated by the user in their soft attributed, such as the function, acquiring a completely new, contextual and unique meaning (from area 1 to area 5). This dynamic is defined as Non-intentional design (Erlhoff & Marshall, 2008)(Brandes et al., 2009)(Brandes & Erlhoff, 2006) and, if not predictable by the designer, can be certainly used as a learning tool to learn about extraordinary uses of the designed products. One example can be seen by the re-use of shoes with other functions, as for example pots, as visible in **Figure 4.23 (b)**.

Figure 4.23. Examples of design-after-design ways to reach two paradoxical areas of the design solutions landscape (images from (a) sisuguard.com and (b) crocsitalia.it and homedecorgiftandmore.com)

Finally, the Long Tail region can also be addressed, as described in **Chapter 3**, by the online sharing of products originally meant for one, and can reach also relatively high volumes or diversified products, created through *desk factories*. Or by hacking or DIY solutions, with a unique bottom up dynamic, which are also shared online. This is, to conclude, the landscape that a designer can consider nowadays while designing, where open-ended outcomes can help to overcome the technical limitations, and support the reach of those areas not yet accessible otherwise.

4.3.3. “How lenses” as sum of all the other lenses

Last result of this study is represented by the emerging possibilities in terms of “How can we design Open-ended Design?”. With answering the 10 lenses we follow a deconstructive process useful to understand details, but only by unifying the ten answers we can re-construct and merge all the different analyzed aspects, sketching the bigger picture where each case lays. The How question, also phrased as “How is the change supported by a design decision or design aspect?” can be divided in two different categories: mechanisms and strategies.

Mechanism are technical (as physical/material, technological, etc.) choices made by the designer by which the change is allowed or supported. Mechanisms have the specific goal of increasing the intensity (and therefore the readability) of the change that would naturally occur (spontaneous process). Also, the mechanisms are thought to let the change not become disruptive of the product main function, in other words good mechanisms for Open-ended Design solutions increase the resilience of the product, by celebrating diversity (de Pauw, 2015). With resilience we refer to attitude of a system to repair itself when damaged, as introduced in **Chapter 3**. Mechanisms are the engineering part of product development, and to be wisely developed good knowledge of technical aspects is needed. For example, materials' properties, technological capabilities, etc. The main lenses: when?, how fast?, where?, how many?, what?, how much? and reversibility? In other words, the mechanisms have generally little connections with the lenses: why?, who?, goal? Being related to more *soft* attributes of value and meanings.

Strategies are, instead, and even more comprehensive description of the entire set of combinations among the 10 different questions. Strategies are profoundly related with the value of the product (why?, who?, goal?), its target user (who?), the dimension of the market (how many?), the strategies to reach the market (when?), etc. In other words, strategies correspond to the overall design strategy as deeply related to the business model, meaning the overall plan of a company to successfully reaching the market. Finally, there is univocal correspondence between mechanisms and strategy, as showed later. Both mechanisms and strategies are the real field of the applied creativity of the designer, whom expresses him/herself both in technical and entrepreneurial terms. Here following some combinations, with the corresponding mechanisms and strategies, are displaced. The goal of this section is purely inspirational, serving possibly both practice and education, and no full coverage will be reached. We are positive in the continue development both technological and of the creativity of the design community. In fact, if some strategies/mechanisms have been explored to the point of being very common, we believe there is a great space of improving them by creating new combinations of the ten lenses and by bringing in contact new methods and technologies.

4.3.4. Example of strategies and mechanisms

The following examples are general strategies, obtained through the adoption of specific mechanisms. These strategies can be read via the 10 proposed lenses. By looking at the details of every case the reader can understand, even if here presented inside a general overall strategy, each case has its own peculiar characteristics. This is due to the high variety of option possible, and the dependency – in their definition – from the specific context. Important to notice is that some aspects (answers to specific lenses) are shared among cases of the same broad strategy, while others are not. This is to show how also strategies are unique and within one broad definition (i.e. unfinished products) we can actually encounter many different variations. We will highlight anyhow the USP (Unique Selling Proposition) for each strategy.

4.3.4.1. Design solutions for reparing existing objects

Sugru (13) represents a strategy that consists on creating new products meant to repair other existing products, that commonly face abandonment due to breakage (typically: home furniture, ceramics products, clothes, etc.). The main mechanism supporting this strategy is the design of smart connections, in fact, all the collected examples use or chemical, or mechanical way to connect their solution with the existing products, which is out of the designers' control, requiring therefore extreme flexibility. These solutions can also be defined as "repairing solutions" since they goal is to help the user extending the life span of his/her own products (Salvia, 2013). A big difference between these solutions and a normal glue, can be recognized on two main aspects: these repairing solutions give an aesthetical value (i.e. using bright colors) to the reparation, which improves the narrative aspects of the product and its ensoulment; also they make it easier for everyone to approach a reparation procedure, motivating the user to take action. As business strategy to design open-ended outcomes to repair other objects is also becoming a new trend, since it can have bigger target audiences, being produced in standard format and re-appropriated in the use time. Apart from Sugru, already introduced, other examples of these strategy/mechanism are:

- **Réanim**, by 5.5 Designers, 2004 (5-5designstudio.com). This set of products is meant to repair (or as 5.5 Designers claim to "rehabilitate") other, very traditional and very common, broken products. Mechanisms adopted for these products are: flexible materials for the connections, use of standard pieces, use telescopic connections. By doing so, these simple products can fit very different models of chair.
- **Kintsughi rapair kit**, by Humade, 2016 (humade.nl). Kintsugi* repair kit is a DIY kit that helps the end user repairing objects, by simulating the ancient Japanese technique, named Kinsugi, that consists in repairing (mainly ceramic) objects

with gold. This technique, and the kit itself, underlines the aesthetic value of cracks and repair interventions done in our daily objects, as occurring in the wabi sabi aesthetic. Mechanism for such product is a chemical connection, created with glue and highlighted with golden color.

- **Woolfiller**, by Heleen Klopper (woolfiller.com). Woolfiller is a kit created to repair holes (or to cover stains) in woolen products. The mechanism to support this solution is, once again, a smart connection. In fact, the woolen fibers contained minuscule scales which open up when they are pricked with a needle (provided with the kit).

Figure 4.24. Three examples of repairing solutions. (a) Reanim (5-5designstudio.com), (b) Kintsighi repair kit (humade.nl), (c) Woolfiller (woolfiller.com). Images are taken from the listed websites

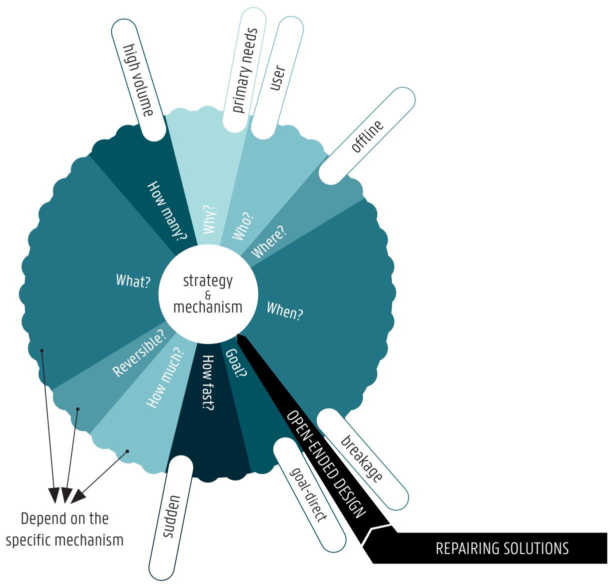


Figure 4.25. Visualization of the lenses composition while dealing with the strategy of repairing solutions. Some lenses remain open, since they differ according to the specific designed mechanism

4.3.4.2. Out-of-control or open-ended production processes

Saving/Space/Vase is a unique product produced with very traditionally standard transforming techniques (in this case rotomoulding). The strategy defined as Open-ended process or Standard/unique (Salvia et al., 2010)(Pacelli et al., 2015). This strategy consists of using standard technologies in extra-ordinary ways to bring to the market unique products, still produced in high volume, that don't require high additional costs to be created.

Typical mechanisms to support such strategy are: combine different processes in un-conventional ways, leave and intentional space of freedom to during the production process to create randomness, use the assembly stage and flexible technologies, strategies to re-use scraps (predictable, systematic waste) or production waste (unpredictable), modular architecture combine with very flexible technologies, or by adopting materials that already embed (or create while shaped) certain imperfections. This last mechanisms opens up to the approach of growing materials (i.e. corpuscoli.com) and even growing products (i.e. fullgrown.co.uk or thomaslibertiny.com). Important to notice as to reuse scraps of production (as in **Bat-tagliere (18)**, as to engage with uncontrolled production system mean that the change will happen during the production process, and therefore before encounter. We consider fundamental to underline as Open-ended in fact can be achieved throughout the whole life span, and not only one in contact with the user. This strategy focus therefore on the change occurring between the ideal product and the reality of production, which always implies error and mistakes. Limitation of this strategy is the fact that the uniqueness of the product, even if potentially linked with higher user satisfaction, doesn't require (or better, doesn't allow for structural reasons) an active user engagement (Pacelli et al., 2015). Examples are:

- **Pompon sofa**, by E. Belforte and G. Rivoira, for Con3studio, 2009 (con3studio.it). PomPon sofa is realized starting from a scrap material from the textile industry. Industrial scraps are different from industrial waste because of their predictable occurrence, becoming easier to be used as input material for new processes. In this case the uniqueness of every selvedge (in the images) allows the creation of unique chairs, different in terms of colors and type of textiles. Mechanisms to support such strategy is of logistic and automation nature and consists in automatically collect the scraps in order to facilitate reuse.
- **Standard/unique chair**, by Maarten Baas, 2009 (designboom.com). This series of wooden chairs is realized by combining two steps: a flexible but highly productive CNC process for cutting the wood in very diversified pieces that share a modular nature and a random assembly phase. In this way every chair is slightly

different from the other, without high additional costs.

Figure 4.26. Two examples of open-ended production. (a) Pompon chair (con3studio.it), (b) Standard unique (designboom.com). Images are taken from the listed websites

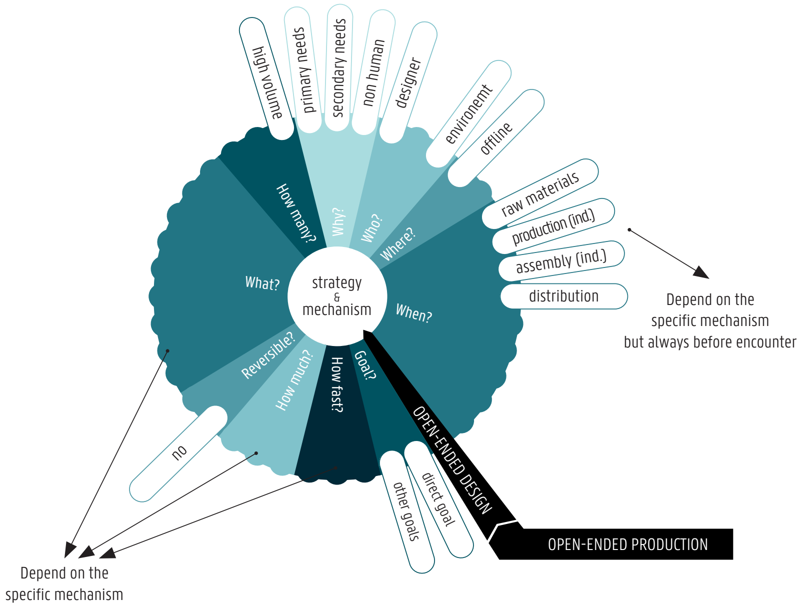


Figure 4.27. Visualization of the lenses composition while dealing with the strategy of open-ended industrial production. Some lenses remain open, since they differ according to the specific designed mechanism

4.3.4.3. Design for accumulation of traces

Verderame (5) and **Stain (4)** are products that evolve in time. They mainly change in their aesthetic aspects, especially with regard of the surface qualities or small geometrical variations. This strategy, already explained in **Chapter 3**, can be defined as Design of Traces and refers to the accumulation of sings and traces on the object, occurring in time and thanks to the use. In this way, a very product can be realized in a standard way and, thanks to the continuous contact with the real environment, can become unique, dynamic and enriching its own ensoulment. In other words this is an approach that sees the value on the evolutionary nature of products. Typical mechanisms to support such changes are: to anticipate and eventually manipulate material weathering dynamics and effects (rusting, dusting, dis-coloring), consider material hardness, porosity, friability, etc. (Nobels, Ostuzzi, Levi, Rognoli, & Detand, 2015), (Giaccardi, Karana, Robbins, & D'Olivo, 2014), (Karana, Pedgley, & Rognoli, 2013). Examples are:

- **Makeup fossils**, by Skrekkøgle, 2015 (skrekkogle.com). Makeup Fossils is meant to trigger the curiosity of the user. In fact, little-by-little the user discovers the fossils hidden beneath the makeup powder. This idea can trigger the users' curiosity, and maybe let them finish entirely the product before throwing it away. The nature of the product itself is to vanish (see strategy 7. Vanishing act), in this project the designers decided to make this process more beautiful and engaging.
- **Underskog**, by Kristine Bjaadal, 2009 (kristinebjaadal.no). In this chair the wearing process of the tissue is designed in a similar way to the previous product. By using the product a new aesthetic, previously hidden, emerge.
- **Slastic**, by A. Mir and E. Padros, for Moustache, 2009 (moustache.fr). Slastic is a coat rack that, while used, leaves a traces on the wall where is located. In particular, the structure embeds some colourful pencils that move once the coat is put on / taken off from the rack, sketching random lines on the wall. In this way the use is made visible, thanks to a dynamic result, obtain without an active act of re-appropriation.

Figure 4.28. Three examples of accumulation of traces. (a) Make-up fossils (skrekkogle.com), (b) Underskog (kristinebjaal.no), (c) Slastic (moustache.fr). Images are taken from the listed websites

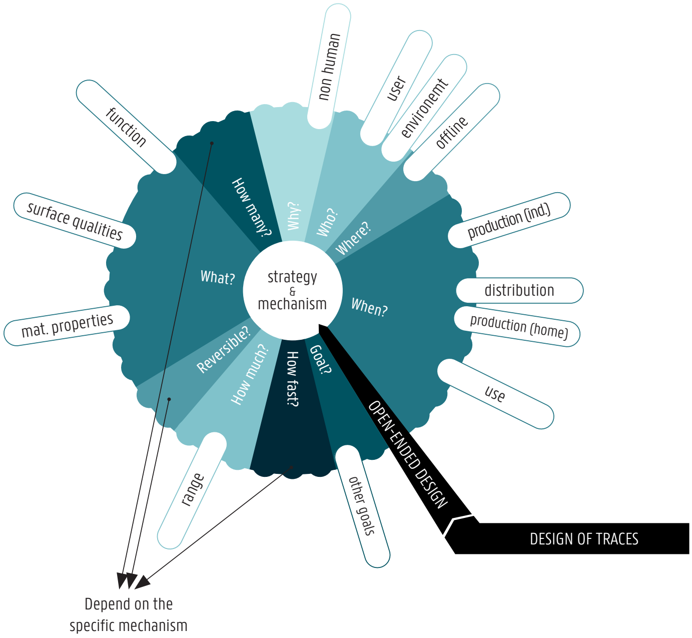


Figure 4.29. Visualization of the lenses composition while dealing with the strategy of design for accumulation of traces. Some lenses remain open, since they differ according to the specific designed mechanism

4.3.4.4. Unfinished products

Incremental house (10) is a very good example of a strategy that we have defined here as unfinished products. Also in this case, a standard product can become unique, in the *after encounter space*, thanks to the active re-appropriation done by the user. This strategy can be divided into: unfinished but still functional and un-functional. While in the first case the re-appropriation is optional, in the second case without re-appropriation the main function of the product cannot be delivered. In both cases the act of re-appropriation can lead to higher emotional bond with the product, thanks to the effort (mental and physical) that the user invested in conducting the adaptations (see **Chapter 3**). Typical mechanisms to support the re-appropriation of unfinished products are: the use of white/neutral colors, use of materials easy to shape, ductile materials, distribution of weights in the product to make them unbalanced, etc. Researches focusing on this are: (Smith, Inoue, Spencer, & Tennant, 2017), (Inoue, Rodgers, Tennant, & Spencer, 2016), (Fischer & Giaccardi, 2006) and others. Examples are:

- **Do scratch lamp**, by Martí Guixé for Droog Design, 2002 (droog.com, guuixe.com). This lamp comes covered with black paint, so that the light cannot pass, making the lamp useless. In order to make it function the user has to take an action, to be creative and to scratch the surface in order to let the light pass. Every lamp becomes unique, in its aesthetic and in the quantity of light allowed to pass. This products needs to be re-appropriated before being used.

- **Terra!**, by A. Sanna and B. Robino, for Nucleo, 2000 (nucleo.to). TERRA! is an unfinished product. It comes as a cardboard frame to be put in your garden and filled with ground. In time, the frame becomes part of the landscape and an actual armchair, completely covered with grass. In this way the product starts as imperfect and unfinished, and only thanks to the passage of time and the work of nature it becomes functional. This can also be defined as natural re-appropriation and has strong connections with the topic of growing products. This product needs to be re-appropriated before being used.
- **Parasitz**, S. E. Wilhelmsen, 2008 (sirenelisewilhelmsen.com). Parasitz is a mobile seat, developed to offer personal seating outside the home. The seat should be unrolled and temporarily attached to an external structure (it can be a tree, a stone or a column, for example), only by this additional element the seat becomes balanced, and therefore can be used. This can be seen as an unfinished, unbalanced product that, without re-appropriation cannot be used.

Figure 4.30. Three examples of unfinished products. (a) Do Scratch (droog.com), (b) Terra! (nucleo.to), (c) Parasitz (sirenewilhelmsen.com). Images are taken from the listed websites

4.3.4.5. Adaptable products

Lego (17) and **Adaptive eye care (1)** are very good example of easily adaptable products. This is a very spread strategy to let the user adapt the product to his/her own contextual needs. Typical mechanisms are: flexible materials, flexible structures, modular components, smart connections (standard, telescopic, rotating, interchangeable, …), etc. In this case we can have more open adaptations, as in the case of the Lego Block, and range ones, as in the case of Adaptive eye care. Of these products we can have a very broad set of examples. We report the ones where we found a particular interesting interaction with the system (i.e. the adaptation is both functional and aes-

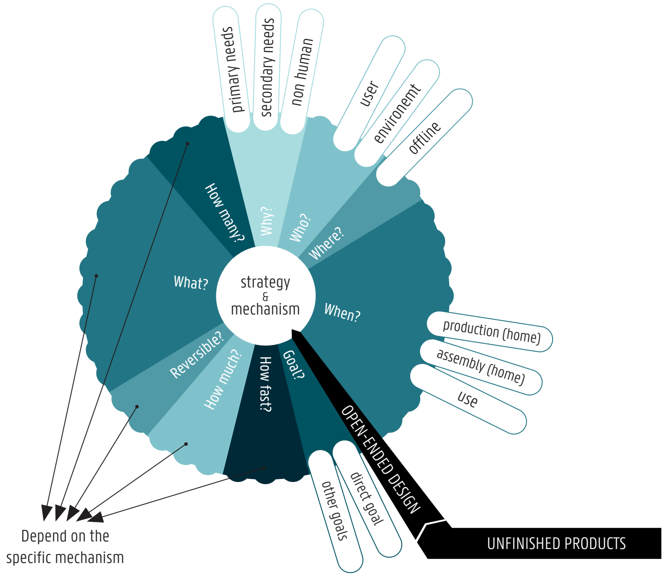


Figure 4.31. Visualization of the lenses composition while dealing with the strategy of design unfinished products. Some lenses remain open, since they differ according to the specific designed mechanism

thetically pleasurable) or wise material/architectural choices to improve adaptability. Example are:

- **Eclisse**, by Vico Magistretti, for Artemide, 1967 (artemide.com). The Eclisse lamp allows its users to adapt the quantity of light according to his/hers own needs. In fact, the inner spherical element can rotate on its axis, (dis)covering the bulb and reproducing the visual effect of eclipses.
- **Mizu**, by A. Prossakowska, 2015 (alicjaprussakowska.com). Mizu is a shelves-system that can adapts its shape according to what you place on it. Its fluid shape, and capability to adapt, is created by the use of smart connections (see images) and thin wooden layers, able to be strong and flexible at the same time.
- **Clouds**, by R. and E. Bouroullec, for Kvadrat, 2008 (bouroullec.com, kvadrat-clouds.com). Clouds is a famous modular wall system made in fabric. Thanks to the rubber band used to connect the tiles, this system is characterized by extreme flexibility. After buying the product, the user can design his/her own configuration by choosing different colours and different disposition of the tiles. The system can also be easily changed in time, and completely disassembled.

Figure 4.32. The examples of adaptable products. (a) Eclisse (add), (b) Mizu (alicjaprussakowska.com), (c) Clouds (bouroullec.com). Images are taken from the listed websites

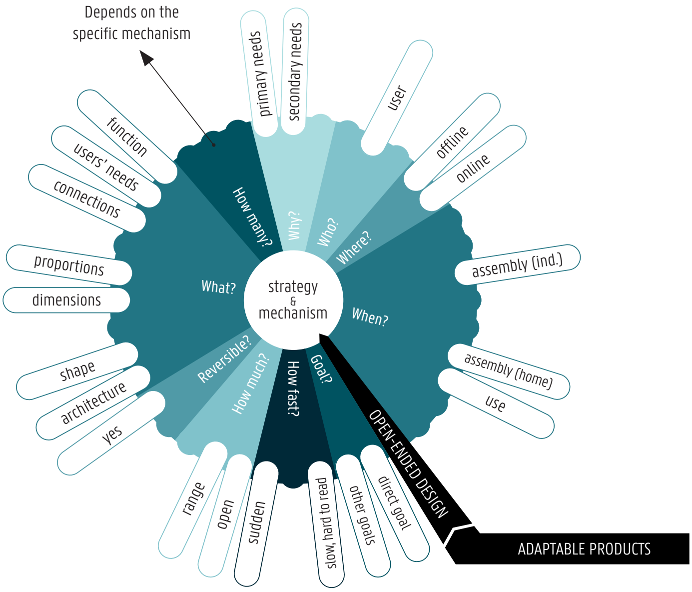


Figure 4.33. Visualization of the lenses composition while dealing with the strategy of adaptable products. Some lenses remain open, since they differ according to the specific designed mechanism

4.3.4.6. Designed breakage

Una seconda vita (15) is a product that follow the strategy defined as designed breakage, or second life. This strategy consists of designing the product already thinking about what could happen after his breakage. Some mechanisms are: wisely connect geometrical variations with materials properties, foreseen other function for the same materials' properties, choose materials and structures easily manipulability by users, etc. Some examples of this strategy are reported in the next page.

- **Ombrello the reusable**, by A. Bertola and B. Civilini, 2009. This umbrella is designed with a graphic that shows instructions on how to eventually reuse it once before throwing it aways completely. The waterzproof material is used in products were the same function is respected.

Do break, by F. Tjepkema and P. van der Jagt, for Droog Design, 2000 (droog.com, tjep.com) This vase comes with no decoration and with a rubber layer in its inner wall. In case of accidental breakage (or more intentional, for example during a lover's quarrel) the surface breaks showing a craquelé structure, while the vase doesn't lose its function. "Not only can the vase still be used but it also gains in beauty as the cracks multiply to form a unique pattern. From now on, any lover's quarrel is an improvement." (from tjep.com, last accessed on June 2017).

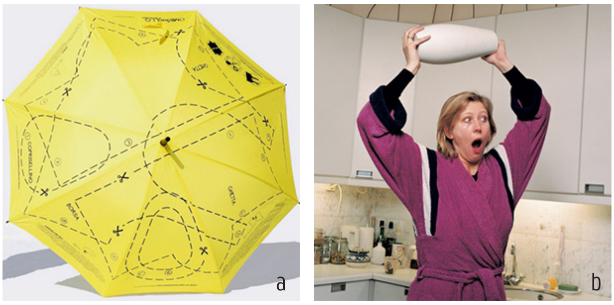


Figure 4.34. Two examples of designed breakage. (a) Ombrello the reuslable (reedo.it), (b) Do break (droog.com) Images are taken from the listed websites

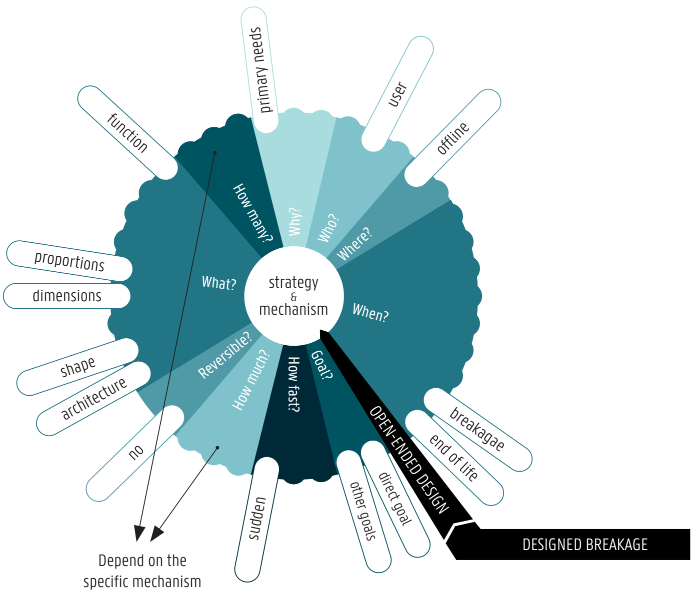


Figure 4.35. Visualization of the lenses composition while dealing with the strategy of designed breakage. Some lenses remain open, since they differ according to the specific designed mechanism

4.3.4.7. Vanishing products

Grow card (12) is a product that follows the strategy defined as Vanishing act (Guixé,, 2008). This strategy consists of using a product that, at the end of its life, vanishes. Of course, in reality the product transforms into something, changing all his properties and functions, in this way different from a reuse approach. Typical mechanisms for vanishing acts are: edible materials, water soluble materials, inflammable materials, biodegradable materials. These materials should always be accompanied by good products architecture, which allow easy disassembly or consider mono-material solutions. By following this strategy, we are sure that the product is consumed at the end of the use, and not thrown away. In these terms, the Vanishing act strategy might induce products to be of single use, which can decrease the overall efficiency because of the productions/transportation costs which will remain invariable, if compared with reusable products. Therefore, the designer engaging with such strategies must consider carefully the impacts in the overall life cycle. Apart from Grow card, example of such strategy are:

- **Plant me Pet**, by Martí Guixé, 2008 (guixe.com). “The Plant-me Pet, with vegetable plant seeds for eyes, is useless until you make it disappear, burying it so that it might grow into an edible food plant. It is a pet that forces you to decide between emotion and function.” (from guixe.com, last access June 2017). Mechanisms of such creation is to use all biodegradable materials, including seeds for the growing phase.
- **Terra stool**, by Adital Ela (aditalela.com). This stool is created with earth and natural fibers gathered from agricultural waste. The product is biodegradable. Also in this case the mechanism is in the adoption of only biodegradable materials.
- **Edible cutlery**, Savoury & plain spoons, (bakeys.com). These mono-material cutleries are created with edible materials, to be consumed at the end of the meal. This project clearly challenges the thrown-away competitors. The mechanisms here consist on creating a mono – and edible – material product.

Figure 4.36. Three examples of vanishing products. (a) Plant me pets (guixe.com), (b) Terra stool (aditalela.com), (c) Edible cutlery (bakeys.com). Images are taken from the listed websites

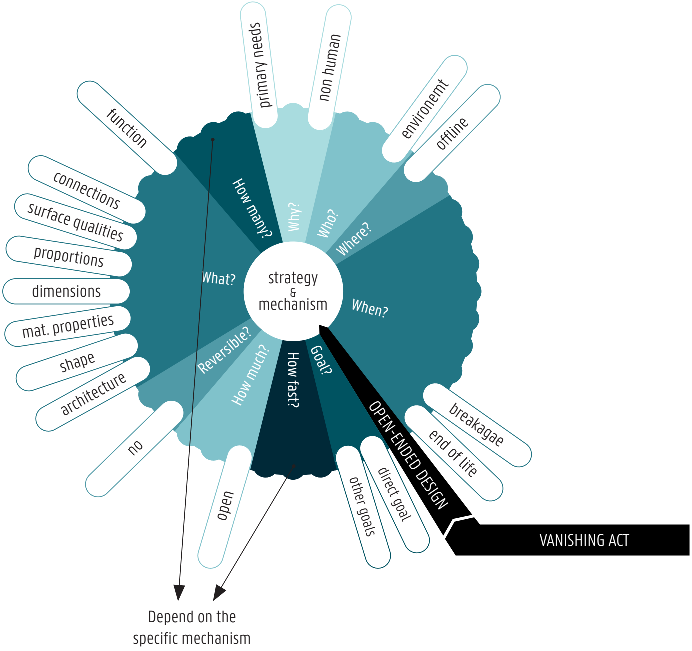


Figure 4.37. Visualization of the lenses composition while dealing with the strategy of vanishing products. Some lenses remain open, since they differ according to the specific designed mechanism

This approach can also be seen as "natural re-appropriation" and has connection with "growing materials.

4.4. Discussion

In the period when this research was conducted, more and more cases where collected. Almost daily a new interesting example raised. At a certain moment we saw as the cases where not expanding anymore the set of possible questions/answers, representing the reach of the data saturation. In this way some of the more recent examples might not have been included, and will need to be collected afterwards because, in reality, as we know very well, the technological development and the unlimited creativity of designers can lead to unexpected and extraordinary combinations. Also, if the lenses seem to be overall collected, the number of strategies is always raising. This acknowledgment underlines once more our choice of not listing all the possible strategies obtainable. In other terms, we suggest to approach these lenses as Lego blocks, that can be re-organized freely by whoever uses them, in almost unlimited combinations.

None of the provided lenses is prescriptive, or aims to be, as change are always of potential nature and can be anticipated rather than predicted. By leaving the outcome undefined, but still giving some examples we aim at triggering the creativity of the designer (Dahl & Moreau, 2007). This underlines the open-ended character of the model itself, which can describe reality under certain aspects (the lenses), but cannot describe the multitude of creative ways to put them together (mechanisms and strategies). Also, in this study the ten lenses were developed and used as observation tool, of existing realities (post factum). In our intention, explored in the last Study 5, the overall Open-ended Design method suggests the use of the lenses both as observation of reality in its ultimate particulars manifestation, and as anticipation of what is *ought to be*, in the designer's intention. This is an iterative process that can start at any time, and needs continuous follow ups to grow in time the insights gained by the designer. In this perspective, the main question "How can we intentionally design Open-ended Design to support potential change?" has not been fully answered yet, since the here presented analysis can be compared to a picture of what already exists.

4.5. Conclusions

In this study several case studies (100+) were collected and analyzed in order to better understand the phenomenon of change in product design. The cases are here reported in form of annotated portfolio, which is a tool that helps the communication of research through design, by merging contextual and general in the same narration. Thanks to this study we have better understood the phenomenology of change in design, its attributes and influence and have tried to highlight many unrelated designers are already intentionally design with this perspective. The outcome of the analysis is a set of 12 questions, defined as Lenses, that help the designers in understanding existing change. Still the limitation lies on the fact that this observation is post factum, and little is known about the design process while developing such cases. This can be seen as product-centered model for user experience (Forlizzi & Battarbee, 2004), meaning a model thought to support designers while understanding existing designs, but also while developing new ones.

The here presented study lasted few years, and was conducted in parallel with all the other experiments. Some of the knowledge introduced here is, in fact, coming from other studies later described. Next studies will focus on the way a designer can reach the creation of an Open-ended Design, also by actively engaging with these lenses, located inside a more general method. All the created outcomes have been, in the single chapters, analyzed through these lenses. Goal of our next studies is to understand how use Open-ended Design outcomes to move in the introduced Landscape of design solutions. We have seen, in fact, how from the region of standard and high volume product we can reach some paradoxical areas thanks to the openness of some products which were here introduced. We believe the same can be done starting from the opposite site of the landscape, the highly contextual and for one solutions. These solutions, as explained in **Chapter 3**, are of bottom up nature and tend to be spread by the internet. The can be created by co-design processes, or using hacking approach developed by laypersons. The problem we identified is how these solutions tend to lose, once shared to the community due to the difficulties in re-appropriating them.

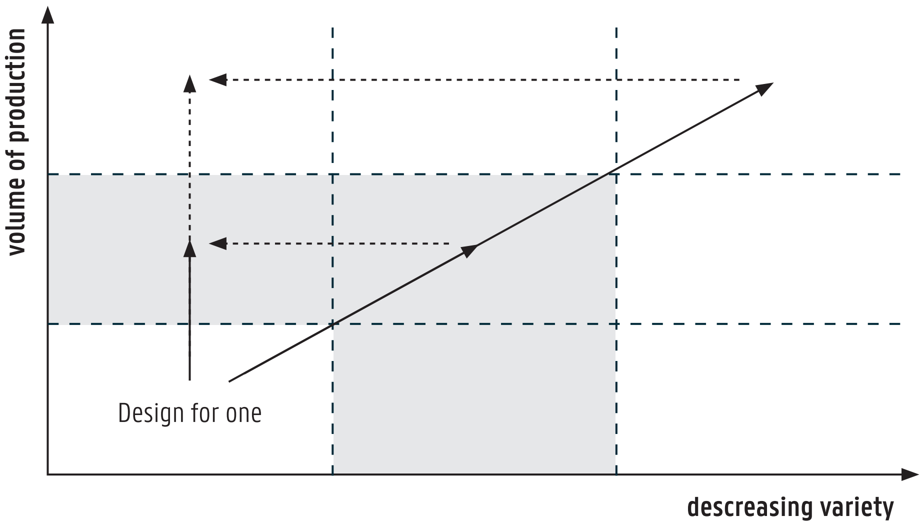


Figure 4.38. Goal of the next studies, understand how can we start from solutions for one (intentionally done or as ultimate particulars) and upscale them without losing their openness to contextual information

CHAPTER 5, Study 1

CO-DESIGN WITH SMALL OFFLINE COMMUNITIES

After the Observations presented in the previous chapter, we would like to introduce the experiments specifically designed in order to better understand Open-ended Design. These studies, defined as Anticipations, have proceeded in parallel with the Observations, supporting each other, as highlighted in **Figure 2.3** in **Chapter 2**. **Study 1** focuses on the very first steps of the Open-ended Design realization: the co-creation of highly context-dependent solutions. In this study our goal is to understand the approach needed to tackle such a user demand and, furthermore, to understand how to bring these solutions meant to be for one, to other stakeholders (that we define here as a community) sharing the same needs, but that can only be satisfied by the adoption of different outcomes. These stakeholders are encountered in the offline space, proximal and directly observable from the designer since the goal is to understand how this change *from one to (known) few*, is happening. What aspects of the design solution conserve? What aspects change? What are the main problems of transforming one specific solution into few specific designs? This study builds upon the theoretical framework of **Chapter 3** and has been published in 2015 in the *Rapid Prototyping Journal*, Vol. 21, Issue 5, with the title "+TUO project: low cost 3D printers as helpful tool for small communities with rheumatic diseases" (Ostuzzi, Rognoli, Saldien, & Levi, 2015) and the following chapter contains extracts from it and is enlarged with some unpublished contents. +TUO is the Italian title given to the project and refers to processes of personalization and empowerment. +TUO is a project design and thought by the authors of the published article and Dr. Silvia Ostuzzi, project manager for Alomar, the Italian regional associations of people with Rheumatic diseases RDs (alomar.it) which also participated together with the 3D

Printing Lab (piulab.it), both in Milano, Italy. Here following the structure of the chapter:

5.1. Assistive devices for chronic conditions

As introduced in **Chapter 3**, **Foundations**, early abandonment and products rejection can be motivated by many different reasons. One of the most common is the lack of product fit (both functional and aesthetic). This often occurs with standard products made focusing only one the most representative users, through a *one size fits all* paradigm, which unintentionally leaves out entire niches of "out of average" users (Anderson, 2006). This problem is even more fundamental for assistive devices created for people with disabilities, since non-acceptance might imply the impossibility of conducting certain actions. In the here presented design case we focus on users with Rheumatic Diseases (RDs), a condition that limits certain movements and actions, because of pain and stiffness in patients' articulations. RDs affect daily occupations, jeopardizing the well-being, independence and empowerment (Hammar Ottenvall & Hakansson, 2013)(Schneider, Manabile, & Tikly, 2008)(White, Lentin, & Farnworth, 2013), reason why various assistive devices have been created, aiming at supporting users' occupation. Our research involves people facing a hindrance on some specific daily activities and focuses the attention on the design and production phase of these devices, outlying here the main problematic areas. Apart from low fit levels, it has been shown as psychological aspects related to self-confidence and device perception may be even more important factors that cause non-acceptance, non-use or rejection (Rogers, Holm, & Perkins, 2002)(Wessels, Dijcks, Soede, Gelderblom, & De Witte, 2003). This puts great pressure on understanding how to actively involve individual users in the selection, or even creation, process of the assistive devices in order to reach a deeper understanding of their needs. Additionally, this study investigates the willingness of participants to use new technologies (3DP in this case), taking part to the Digital Industrial Revolution by interacting with desktop technologies and communicating with other actors sharing similar needs.

5.1.1. Rheumatic diseases

In Europe one fourth of the population suffers from one rheumatic disease (eular.org, last accessed in June 2017). In general, RDs are chronic inflammatory joint diseases and are characterized by pain, stiffness and fatigue that limits activities of daily living (ADLs). Some consequences (Bury, 1982)(Schneider et al., 2008)(White et al., 2013) of such conditions are:

1. Abandonment of work and social life;
2. Decrease in life quality and health perception;
3. Feeling of premature ageing and loss of self-confidence;
4. Increased dependency on others (with consequent sorrow and distress).

Previous studies revealed that occupation could empower people with on-going health conditions through four main dynamics: revealing, explaining, managing and overcoming health conditions (White et al., 2013). In fact, while the experience of on-going illness and its treatment has caused profound disruption to patients' lives and self-confidence, new occupations can help them to overcome their conditions by introducing a new meaning in their lives and providing a renewed sense of purpose (White et al., 2013)(Wilcock, 1999)(Hammar Ottenvall & Hakansson, 2013)(Steultjens, Dekker, Bouter, & Schaardenburg, 2002). The importance of ADLs and involvement linked to a disability is also the main feature of the theoretical model of the International Classification of Functioning, Disability and Health (ICF), created by The World Health Organization (WHO).

The use of assistive devices is often crucial to support daily occupations. These devices are frequently prescribed to patients with RDs in order to compensate physical limitations, limit their pain and protect their joints. Previous studies were developed in order to better understand how to design assistive devices for people with RDs (Rogers et al., 2002)(Yen, Flinn, Sommerich, Lavender, & Sanders, 2013), still the problem of non-use is diffused and can be related, as anticipated, to functional and aesthetic non-fit, lack of active participation in the selection of the devices and length of the delivery period: the sooner the end user receives the assistive devices the less likely he will abandon it (Wessels et al., 2003). Our own direct experience, supported also by previous studies, confirms that existing devices are often adapted by end users to create new products that fit his/her specific needs. "Objectively, these self-made and humble artifacts cannot compete with the standards of mass production, but from the perspective of all engaging stakeholders they deliver profound happiness" (Couvreur, Dejonghe, Detand, & Goossens, 2013, p. 58)(Hammar Ottenvall &

Hakansson, 2013)(de Boer et al., 2009)(Couvreur, 2016).

5.1.2. User involvement

As previous studies have shown, involving end users in the creation process of assistive devices to support ADLs can be extremely valuable. This co-creation improves identification and understanding of specific user's needs and wishes, and actively engages all the stakeholders in a more social community based process (Couvreur et al., 2013)(Couvreur & Goossens, 2011)(Couvreur, 2016). But it is complicated for a person with RDs to be actively hacking and building products, because of pain which often implies loss of handcrafting abilities, confidence, discretion, etc. For these reasons we focus with the use of 3DP technologies, since they don't imply any specific physical effort or manual skill, they can be easily accessed by citizens (through, for example, FabLabs) and are a mean to connect previously unrelated stakeholders, fostering the community feeling. Importantly, in our opinion, thanks to the spread of digital technologies and in particular of entry-level and low-cost FDM printers we can start expanding participation from the front end to the actual product generation (what we call *co-production*) and manufacturing itself: making together is a powerful method that provides pleasure and meets meaningful goals. To some extent, this technology covers here a role that goes from a proper production tool to a toolkit, useful to stimulate creativity and participation.

Some studies explored similar processes (Hermans, 2014)(Hermans, 2015)(enablingthefuture.org, digitalforming.com, last accessed on June 2017) and prove as, generally, this hands-on approach allows end users to "adapt their assumptions through the engagement with design activities within their own local environment" (Couvreur et al., 2013, p. 67)(Mugge, Schoormans, & Schifferstein, 2009). In co-design traditional roles get mixed up and the creation of a multidisciplinary team is fundamental: in this study we defined a cross-functional development team by following the same team definition described in the project D4E1 (designforeveryone.howest.be, last accessed on June 2017) to which we added the figure of a researcher.

- **End user**: expert in his/her experience;
- **Designer**: generates tools and settings, supporting the End Users' needs and following the making process;
- **Occupational Therapist (OT)**: validates ideas and final products, with a particular focus on damages limitation.
- **Researcher**: facilitates communication between actors and observe the dynamic of the co-design sessions.

5.2. Research method

+TUO project uses a mixed methods approach, of qualitative nature, in order to explore the possibility to satisfy single user's needs in terms of assistive devices, by using low-cost 3DP technologies. The project's overall structure is as follows (see **Table 5.1**).

1. Questionnaire
   a. Questionnaire analysis
   b. Participants recruitment
2. Design of Reference Products
3. Activation stage
4. Generative session
   a. Co-design stage (eventually reiterated)
   b. Co-production stage (eventually reiterated)

Num.	Stage	Sub-stage	Physical output
1	Questionnaire	Insights from 137 participants Recruitment of 10 participants	/
2	Design of Reference Products	/	2 Reference Products (**Figure 5.1**)
3	Activation	- Introduction of participants - Introduction to 3DP and OT - Co-Design, excercise	Iterations on the reference product "zip aid" **(Fig. 5.2 and Table 5.5)**
4	Generative session	(a) Co-design stage (ideation-prototype-test, iterate) (b) Co-production	Unique products **(Table 5.4)** Iterations (10 in total) on the reference product "bottle opener" **(Table 5.5)**

Table 5.1. +TUO process. Overview on stages, sub stages and physical outputs

A brief premise on specific terms here adopted is important. When we use the term "assistive device" we mainly refer to small, non-medical devices, that help end users during the execution of small daily activities such as eating, writing, cooking, etc. The terms "actor" and "co-designer" refer to whoever actively participated to one or more +TUO stages, while the "team" refers to the specific operational unit of each stage. Terms such as: "end user", "user" or "participant" always refer to selected persons affected by RDs: they are the ones who will use the assistive device on their daily routine. They are expert of their own condition and novice users (in this case study) of the technology. Similarly, when we use the term "designer" we specifically refer to design professionals, seen as experts in the use of the technology and in the design process, but with minimal knowledge (again, in this case study) of the specific RDs implications. With "OT" we refer to the third group of actors: Occupational Therapists. They are expert with respect to the problem understanding, materials and solutions creation and/or selections, but novice users of the technology. Finally, "researchers" also participate to the process: their main role is to facilitate the communication and to observe the co-design dynamics taking place at each stage. Important to be noticed is that everybody can be an expert and a novice user, depending on the point of view (Sanders & Stappers, 2012). This is why we define these *cross-functional teams*, referring to the combination of different expertise focusing on a shared goal. A summary of +TUO participants and their roles at each stage can be found in **Table 5.2** (next page).

5.2.1. Questionnaire and participants' recruitment

Through a questionnaire with 136 respondents we obtained a first overview on patients' daily activities, needs and desires with particular focus on specific assistive devices. A first discovery is that 85% of the respondents limit their daily activities since the RDs uprising. Participants listed all the used assistive devices already, underlying pros and cons for each one, and listed also all the assistive devices they needed but did not adopt yet, explaining motivations for this non-use. Reasons are generally related with high prices, low availability and low fit, both functional and aesthetical. As last, participants were asked to express their willingness to participate further to +TUO and 81 responded affirmatively. For this pilot study only 10 participants were recruited – eight women and two men. This selection is consistent with previous studies, since the disease affects women with a percentage four times higher than men (Bury, 1982) (alomar.it, last accessed on June 2017). In **Table 5.3** (next page) some additional details are reported.

5.2.2. Design of reference products

Among the activities (and related devices) listed as problematic, we see: walk upstairs, dress up, open bottles or jars, tie shoes, conduct general sport activity, make up, gardening, maintain social activities, cook and work. Two activities recur more often: to open bottles and to close dresses or bags. Designers of +Lab (piulab.it, last accessed on July 2017), an additive manufacturing laboratory of Politecnico di Milano, designed then two reference products: bottle opener and zip-aid, as depicted in **Figure 5.1**. The design was developed with 3D CAD software that helps designers to make quick changes in their virtual prototype, if and when needed. In general, this process was developed by designers not actively involving with the end users

Num.	Stage	Actors*	Role
1	Questionnaire	E, R	E: 126 potential users answered to the quetionnaire E: 10 of them were selected as participants of +TUO R: Analysed the results, grouping them and obtaining the first highlights
2	Design of Reference Products	D, R	R: Transferred important highlights to Designers D: Created the Reference Products, based on the questionnaire highlights
3	Activation	D, E, OT, R	3 teams each one couting: three E, one OT, one D, one R R: Facilitates communication and observes dynamics E: Describes his/her daily relation with products D: Introduces design and 3DP OT: Introduces assistive devices and Occupational Therapy
4 (a)	Generative session Co-production	D, E, OT, R	9 teams each one couting: three E, one OT, one D, one R R: Facilitates communication and observes dynamics E: Gives continuosly inputs on his/her wishes and needs in terms of functionality, tests prototypes, determines the moment when a prototype can become a final product D: Sustains the idea generation with brainstorming, sketches and 3D prototypes OT: Focuses on technical aspects of assistive devices related with RDs, evaluates the product during the test
4 (b)	Generative session Co-production	D, E, R	The previous team composition, without OT R: Facilitates communication and observes dynamics E: Gives inputs on his/her wishes and needs D: Finalizes the detailed design and optimizes the printing process

Table 5.2. +TUO Process. Overview on stages, actors, and their role in each stage. *E: End user, D: Designer, OT: Occupational Therapist, R: Researcher

or the Occupational Therapists. Designers tried to imagine and address the Users' needs developing benchmarks, using their own personal experience and conducting online researches. The reason why we developed these reference products are two: to use them as example during the Activation stage, and to check after the Generative session differences raised because of the processes of adaptations done for each user.

Name	Age group (years)	Gender	Rheumatic disease	Onset of the disease (years)	Limitations on Daily Activities	Limitations linked with specific objects
s.	30-50	f	rheumatoid artritis	10-20	yes	yes
v.	30-50	f	rheumatoid artritis	10-20	**no**	**no**
mg.	50-70	f	lupus erythematosus	>30	yes	yes
n.	50-70	f	rheumatoid artritis	2-5	**no**	**no**
a.	50-70	m	rheumatoid artritis	2-5	yes	yes
l.	30-50	f	fibromyalgia, with Sjogren's disease	2-5	yes	yes
f.	50-70	m	rheumatoid artritis	20-30	yes	**no**
r.	30-50	f	rheumatoid artritis	20-30	yes	yes
mp.	50-70	f	rheumatoid artritis	20-30	yes	yes
m.	30-50	f	rheumatoid artritis	>30	yes	yes

Table 5.3. Participants demographics and information linked to the disease and the relation with objects

5.2.3. Activation stage

The Activation stage is the first collective workshop, where main focus is to introduce 3DP low-cost FDM technology and motivated on the belief that occupation-based practice are both a therapeutic medium and a goal of the therapy (Sundarrao, Dekker, & White, n.d.)(White et al., 2013). The activation stage aims at creating a sense of community, engaging end users in social activities, raising their awareness about the illness through comparison with other patients and explaining functionalities, advantages and disadvantages of low-cost 3DP.

Three groups were formed, each one with three end users (one absence), one occupational therapist, one designer and one researcher. This team composition allows

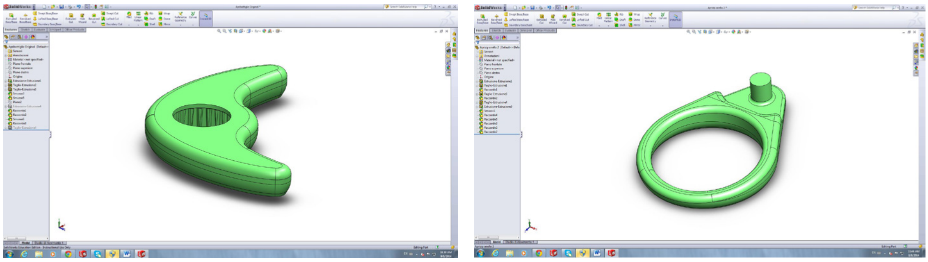


Figure 5.1. Reference products, bottle opener and zip-aid, design by +Lab

and stimulates the communication between novice and expert users, referring to the different domains previously listed. Conversations between actors was then facilitated, as well as conversations users-technology since 3DP can be seen as toolkit stimulating creativity, helping to engage laypersons in the design process (i.e. in this context: End Users and OTs) and can be therefore compared to a digital-physical toolkits (Hermans, 2015). After obtaining an informed-consent agreement, a practical co-design exercise with 3D Printers took place, and was conducted by the designers. This introduced the technology to all participants showing them a simple case study. We've chosen the zip-aid (see above) as a reference product (see **Figure 5.1**), simple and quick to be realized. Each participant changed this reference product, in order to make it more *fitting* with his/her own needs. Together, users, OTs and designers uniquely modified geometrical, dimensional and aesthetical aspects of the product. At this point them designer virtually modelled the personalized zip-aid, sharing the process with all the other actors, and printed soon after with a printed in the middle of the meeting table, as in **Figure 5.2**.

Figure 5.2. Settings and results of the activation stage

5.2.4. Generative session

During the Generative sessions, the core of +TUO, several assistive devices were realized from concept to production, following two main stages (see **Figure 5.3**): co-design and co-production. The co-design is an iterative process of ideation-prototype-test that has to be repeated as many times as needed to obtain a satisfactory product for the end user. In general, during the co-design stage the main goal is to define the functional aspects of the device such as: geometry, dimensions, proportions, weight, etc. The second phase of the generative session is the co-production stage. During this stage, after the tested prototypes are ready to be produced, the focus is on defining aesthetical variables like: color, texture, small decorations while considering also all the variables related with the printing process (printing speed, object orientation, etc.). The whole dynamic of the generative session is represented in **Figure 5.3** and further details are reported in the next paragraphs.

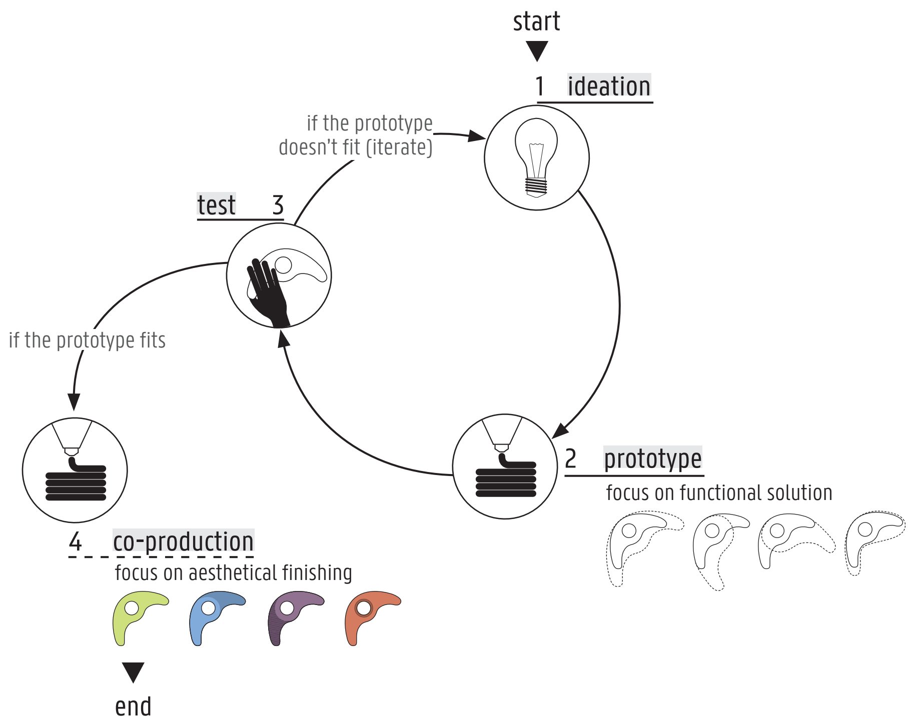


Figure 5.3. Generative stage overview: from the iterative co-design process "ideation –prototype –test" to the co-production stage

5.2.4.1. Co-design stage

This stage, developed in +Lab, when the product is designed, has a particular focus on its functional requirements. This stage took place two weeks after the Activation stage. In this bridging period, as a preparation, end users had to focus carefully on their personal struggles with specific products while conducting their usual ADLs (Activities of Daily Living), and in this phase they were supported by diaries designed ad-hoc. They arrived to the co-design stage with lists of potentially needed products (i.e. a mouse aid for computer, a toothpaste squeezer, a key holder, etc.) from which one was chosen together with the specific help and advice of OTs. At this point the process was mainly to identify possible designs together with the other team members, following the iterative process of ideation – prototyping – test.

- **Ideation**. First we identified wishes and demands and highlighted limits linked to the pathology, as well as technical / technological limitations linked to 3DP. Each team naturally adopted the tools/techniques considered more suitable and well-known by the designer. In general, a brainstorms followed by rapid idea visualization using sketches on paper or tablet. This way each team generated concepts, validated some ideas and then outlined potential solutions.
- **Prototyping**. these solutions were rapid-prototyped by the designers using low-cost 3DP see **Figure 5.5** and/or more traditional workshop prototyping materials, as clay, wood, paper, etc.
- **Test**. All the prototypes were tested by the users, under the guidance of the OTs to avoid dynamics potentially harmful for end users' articulations, see **Figure 5.4**.

The approach is similar to the one adopted in D4E1 project where all the stakeholders communicate using tangible, physical prototypes, keeping an open mind to observe unexpected interactions, creating a social setting (with groups rather than one on one meetings), using a research method as spontaneous as possible. This way we aim also to reach and share a wellness feeling among the participants, a purpose of the research that goes beyond the product itself. "By sequentially asking why one prototype is better than another triggers the participants to examine their responses. Non-designers often have problems with the notion of creativity. We invite them to suggest new ideas through the process of copying, transforming and combining elements from the several user-prototype interactions" (Couvreur, p. 67). This Co-design process (ideation – prototype – test) lasted a maximum of four hours each time and was iterated up to three times; sometimes only small details were changed in order to reach a fit-to-one, then followed by the co-production stage. Apart from the personal device, we developed with every user the same co-design process also on the second reference product, the bottle opener. Without creating a completely new design each time it was possible to focus on what changes and what conserves in the reference product, which can give insights on some variables more related to the person than to the overall solution. Specific outputs of this stage are listed in the **Paragraph 5.3.2.**, **Results of the generative session**.

Figure 5.4. Test with prototypes during the co-design sessions

5.2.4.2. Co-production stage

When the test reveals that a prototype is good enough, the team can start with the production of the final product (see **Figure 5.3**). It is important to highlight that the production and the prototyping processes have been developed by the exact same machine and the only difference between the "prototype" and the "final product" is that for the latter the printing process and aesthetic are optimized, while technical and functional aspects (as geometry, dimensions, weight, etc.) are identical. Therefore during the co-production the designer pays attention to small geometrical, material and technical variables in order to reach a high printing quality (i.e. printing speed, layer thickness, product orientation, etc.), while the user is invited to focus on aesthetical aspects, such as color choice, small decorations, texture, etc. Occupational therapists are not present at this stage, as long as the product is already defined in its functional features.

Basically, to print an object with 3DP technology a virtual 3D model in STL file format is needed. This file is produced by designers with 3D CAD software e.g. SolidWorks. The STL file is then processed by a software to make it suitable for print, modeling the product layer by layer. The prototyping process from concept to final product can be very fast (in our context in less than one day a new product design could be realized from scratch). All the products manufactured during +TUO were produced using WASP 3Dprinter (wasproject.it, last accessed on June 2017) an Italian made FDM (Fused Deposition Modelling) machine, **Figure 5.5**. Users were present and involved, but more as spectators and rarely they were able to actively participate in the technical steps (for example using SolidWorks or activating the 3DPrinter). The software is in fact quite complex and a medium-high level of expertise is required to use it. These are limitations reported in **Paragraph 5.4**, **Discussion**.

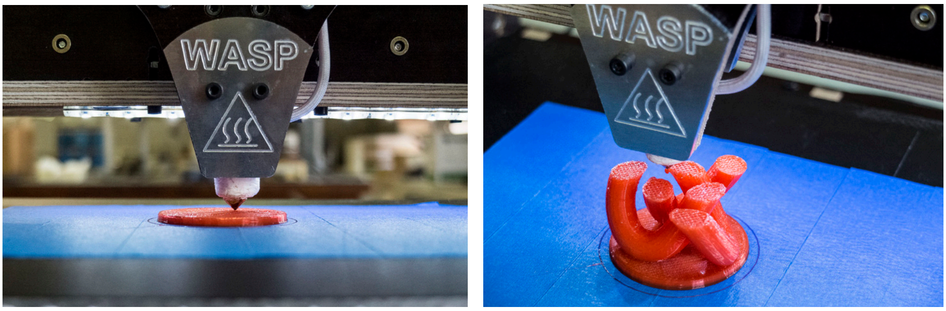


Figure 5.5. WASP Project, printing a sample product

5.3. Results

The following results, divided into the sequential stages of +TUO, summarize all the achieved physical outputs and the insights we collected from this first step of the Open-ended Design research.

5.3.1. Results of the activation stage

In order to explain the functioning of the FDM technology we used a comparison with normal desk printers. This appeared to be clear also to participants without any specific technological knowledge in informatics or materials. The designers' vocabulary was pre-discussed and some rules were applied, i.e. using the word "plastic" instead of "polymer, PLA, ABS, etc."; "virtual drawing" instead of "3D model"; "heated head" instead of "extruder", "horizontal width (and depth) and vertical height" instead of referring to "x, y, z axis". Such details were fundamental changes in our everyday lexicon and proved right not to lose attention simply because the technology was not understood. None of the participants ever had seen a 3D printer before, making clear as the desktop revolution is not indeed really for everyone, but still focused on highly skilled persons, mainly with technical background (Von Hippel & Paradiso, 2008). Anyhow 7 out of 9 participants showed high interest, asking questions and staying longer than planned to see the machine actually printing. It appears clear that this approach could be done just because of the low-cost machine itself; other industrial machines of the same technology could be not so accessible, light and transportable. In fact, it was crucial to put the 3D printer on the table, as it appeared simple and not too "technological".

At this stage we started a brief co-generative exercise focusing on the reference product zip-aid. From the overall outputs some recurring variables are highlighted. For example, while the product architecture remained the same for every user (when compared with the reference product), other variables like color, dimensions, geometry, proportions and connections are different for every user. Some examples are visible in **Figure 5.6**. Here following some conclusions. The material choice is too small; some end users reported the need of a softer and more flexible material in comparison with PLA. We tried with TPU (Thermoplastic Polyurethane) but the result was still too rigid. We solved the problem using the 3DP in order to build a mould for casting silicon [in **Figure 5.6 (c)**]; the need raised from the user's perspective, was confirmed by the OTs and the suggested technique was determined by the designers' experience. In our opinion the activation stage was a first meaningful moment of teamwork and community creation thanks to the technology and the cross-disciplinary team. It helped from the very beginning to show the role of each actor and to identify each specific expertise.

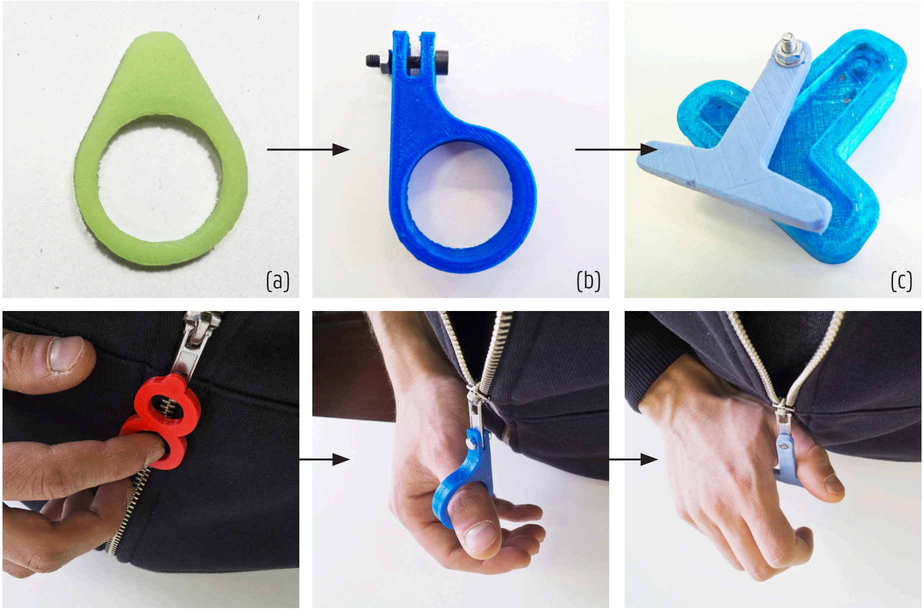


Figure 5.6. Results of the first co-design session on the zip aid. (a) Zips in PLA. (b) Zips in silicon, with mould in PLA. (C) Gestures. Modifications are obtained thanks to a collective design process and, while some aspects are useful for every user, some are different for each participant

5.3.2. Results of the generative session

During these sessions, as anticipated, we developed one product for each participant. In detail: toothpaste squeezer, vegetable holder, various zip aids, assistive devices for using a mouse, cutting board aid, medicine bottle opener; all products are visible in **Table 5.4** (next page). These ideas of products rose thanks to the participants' self-observation that took place between the activation stage and the generative session, and thanks to the communication between different stakeholders during the first phase of the co-design process: the ideation phase. Here following the results from the co-design and co-production stages. Particular attention is given to the obtained artefacts.

Final products were eight instead of nine since one participant had a need specifically linked with flexible materials such as textiles, making 3DP unsuitable. Many more ideas were raised, and were rapidly prototyped and tested, but here we decided to focus just on the ones that from prototypes became final products. Problems occurred when objects needed were too big, too small or too detailed. It was difficult at the beginning to explain to the actors all limitations and advantages of the technology, especially when linked with technical solutions. Another limit that raised concerned the material: often this polymeric material (PLA, Polylactic Acid) was perceived as poor, cheap and not resistant enough; on the other hand, the availability, grand amount of bright colors and its light weight were appreciated.

The iterative co-design stage was mainly focused on the functional aspects and helped all the involved actors to discover or better understand real needs in terms of shapes, dimensions, gestures, etc. After the ideation phase, when main ideas coming from the end user were listed and the first design was collectively developed, there was the prototyping phase finally followed by the test phase on the 3D printed prototypes. In each phase of the iterative process (ideation – prototyping – test) each actor played a different and fundamental role. For example, during the ideation a central role was given to end users, because of their deep knowledge on their own daily condition. During the same phase designers were sustaining the process using tools and methods such as brainstorming, sketching and rapid materializations of small mock-ups; while occupational therapists shared more technical insights pointing out clearly pros and cons of different solutions in terms of safety for articulations.
The prototyping phase was led by designers, because of their prototyping skills, particularly related in this case with 3DP and virtual modelling; as mentioned also OT and users participated during this phase, and demonstrated enthusiasm and curiosity but adopted a mainly observing role due to lack of technical knowledge on 3DP. A central role was adopted by OTs during the test phase together with end users: in

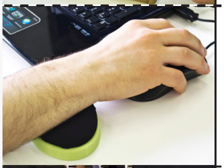
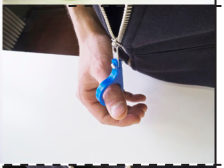
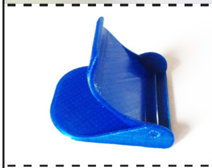
Names initial	Product		Description
V.			Bottle and other jar opener
S.			Bottle opener
m.			Add on for cutlery
l.			Cutting board aid
mp			Mouse aid
r.			Zip opener
a.			Flexible zip opener (mold)
v.			Toothpaste squeezer

Table 5.4. Output products: specific devices designed by and for each end user, together with the whole team

fact, some users sometimes expressed appreciation for specific prototypes that were not suitable according to OTs who were able to provide a solid vision of possible articulation damages at a later stage. Thanks to this interaction between actors some prototypes apparently good were discarded, in order to limit damages in time. This brings us to the reflection of how important is to share the device selection process with professionals or to receive all the needed support in order to understand on what to base the selection with a longer time-span view.

5.3.3. Adaptations of the reference products

Particular attention should be given to the personalized re-design of the two Reference Products. In fact, while products in **Table 5.4** are unique expressions made for one, the work made on the Reference Products has been iterated by each team in sequential way. This iteration has led to the creation of a small series of unique representations of the same input products. As shown in **Table 5.5** both bottle openers and zip aids have been developed in nine unique ways thanks to different combinations of shape, color, dimension, geometry, architecture, etc.

By analyzing what conserves and what changes in every artefact, we can understand as some modifications are specifically related to the participant (for example: choice of favorite color, the handle dimension is related to the hand, the orientation of the handle to strength and shoulder pain, etc.) while other modifications made by one user suddenly improved the product in a way that helped everybody and thus sequentially was adopted in all variations. For example, the first user (S.) found the bottle opener already good enough, and no changes were made on the reference design. The second participant (MG.) couldn't open any bottle with the reference product, because the action required too much strength and the grip between device and lid was not sufficient. As shown in **Figure 5.7 (a)** the grip part in the reference product was only geometrically different (a small corrugation in the surface), obtained directly with the 3DP process. Thanks to the test made by MG. it was clear the design needed some improvements. The occupational therapist proposed to use an "anti-slippery" material and the designer explored coherent options obtainable with 3D Printers. The solution was to print an inner ring, see **Figure 5.7 (b)**, with the same corrugated surface, in TPU (Thermoplastic Polyurethane). This ring is printed separately from the main body and then inserted without the need of glue or other connections. A similar example can also be seen in **Figure 5.6** concerning the other reference zip-aid. These collective experiments have allowed us to:

1. Underline the importance of a cross-functional team thanks to which not obvious solutions are found, in other words underline the importance of conversa-

tions among community members.

2. Highlight the importance of a collective and iterative co-design experience in order to achieve modifications on two levels: personalized features and modifications that represent incremental innovations (meaning with this that some modification become the new reference item).
3. Importance of constant materializations to be tested and modified, supported by the technology adopted. Especially since technical properties of prototypes and final products are identical.

Names initial	Bottle opener	Zip aid	Description
V.			(Bottle opener) New shape in order to use it also for other jars (Zip aid) New softer material, obtaine with 3DP mould (1)
s.			(Bottle opener) No change (Zip aid) New shape in order to grasp it with two fingers (2)
m.			(Bottle opener)New shape in order to use only one hand (3) (Zip aid) New shape, to be pinched with two fingers
l.			(Bottle opener) Thinner/longer handles in order to improve the grasp (4) (Zip aid) No change
mg.			(Bottle opener) See (3) (Zip aid) Bigger dimensions (5)
r.			(Bottle opener) See (4) (Zip aid) 90° rotation of the axis in order to use the thumb

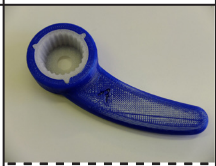
a.			(Bottle opener) See (3) + longer handle to decrease forces needed (6) (Zip aid) New shape
mp			(Bottle opener) See (3) + (6) (Zip aid) New shape
n.			(Bottle opener) See (3) + (6) (Zip aid) See (1) + (5)

Table 5.5. Overview of all outputs built upon reference products. Highlighted what changes and what conserves

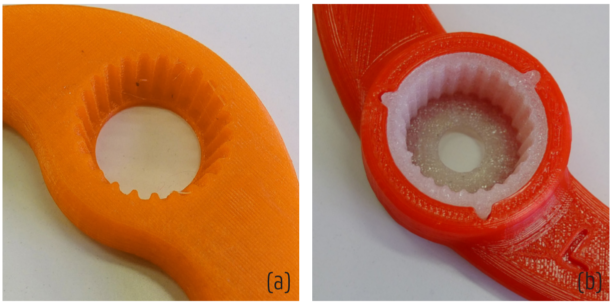


Figure 5.7. Detail of the bottle opener. (a) Grip design in the reference roduct, (b) grip design (in TPU) made thanks to the co-design stage

5.4. Discussion

+TUO pilot study has provided to participants with RDs, designers, occupational therapists and researchers a real opportunity for social interaction and communication. Furthermore, the study has showed the potential of co-design and co-production for personalized assistive devices using an AM technology in its low-cost, entry-level user version. +TUO pilot study has proved that the adoption of low-cost 3DP FDM technologies in such a context is feasible and greatly advantageous, though some limitations have been identified. Interesting conclusions of the Study can be grouped under the two main categories that follow.

- The first side focuses on technological issues, such as the role of 3D printing technology in +TUO contexts and the main pros and cons linked to differences between the low-cost version and the industrial ones.
- The second side focuses on social and user interaction dynamics, mainly represented by the +TUO process, with core in the Generative session.

Firstly, under the technology-oriented point of view we can state as in addition to already validated advantages of low-cost 3DP (as described in the State of the Art) we have found other main values that are mainly related with low-cost 3DP usability and accessibility. This new low-cost and open-course version of AM technologies encourages the process of "making together" thanks to its simplicity, small dimensions and low costs. Other identified aspects are:

1. Participation of users with RDs to the process.
2. Sensorial and mechanical qualities of the outcomes.
3. Fast delivery period of the assistive device.
4. New aesthetics and functions linked with material and geometrical possibilities.
5. Transition from design for one to design for each.

1. Patients with RDs cannot conduct activities that require high manual skills. In general, we have found that the use of 3DP doesn't enhance the distance or deepen a sense of exclusion, being rather simple, cheap and fast. We have to acknowledge as, on the contrary, participants have never actively engaged with it, showing as the conversation with the technology in a real democratic and bottom up manner is not yet there (Cruickshank & Atkinson, 2014).

2. In traditional product developments prototypes are different (in shape, colors, materials, but also geometry, weight, etc.) from final products. In +TUO the difference between the final product and the prototype is limited to small aesthetical details: in this study dirty mock ups, prototypes and final products are mainly the same in terms of production technology and materials. This has implied that when the test phase has been developed uncertainties related with the success of the end result under technical aspects have been very limited. At the same time, some materials, like textiles, or dimensions cannot be obtained, which brings a big limitation on possible outcomes.

3. In +TUO, thanks to the use of Rapid Manufacturing 3DP it has been possible

to deliver a final product within a few hours after defining the product's features.

4. Products created with such a technology have a strong aesthetical character and appearance. The material choice is limited to a small selection, in this project mainly PLA has been used (it is easier to control during the printing, it is cheaper and easier to be found in different colors). Though from the participants' feedback we have found that this polymeric material can be perceived as cheap and not durable enough. On the other hand, it is a very light material and thanks to a careful design of the filling geometry and density, a good relation between weight and resistance was reached. The lightweight is of great value in the scenario of RDs and it is linked to the technology itself, which allows producing geometries previously impossible (i.e. filling patterns were before impossible to be made).

5. Finally, most importantly we have moved from a design for one approach to a design for each. By iterating, within a co-generative process, on the same product we are now able to highlight certain aspects of the starting solution that needed to be changed. In this way we can see as some aspects are function related, while other are aesthetic related and, at the same time, some aspects are specifically related to one participant, while other can represent an improvement also for others. This has been easily done also because of the proximity of the team members and we wonder how this could occur with distant users.

Strenghts	› Community based approach › Fast iterations due to technology and proximity of team members › No sensorial and technical gap between prototype and product › Easy product personalization on aesthetic and functional aspects	› No real engagement of the participants with the technolgy › Limitations on materials and shapes › High time required due to the co-design stage › Narrow view on only one technology	**Weaknesses**
Opportunities	› Transfer the solutions to the same community in other regions › If transferred, broader understanding on what changes and what conserves › If broader understanding is reached, possibility of up-scaling parametric or flexible solutions adaptable for each user	› If transferred, the design outcome might not be adapted to specific user needs › Non-critical use of 3DP technology also when other technologies might be more suitable	**Threats**

Table 5.6. Synthetic SWOT of Study 1 and relation with future studies

5.5. Conclusions and future studies

Various disadvantages have been described in the paper, especially linked with the material perception and the medium-high level of technical skills required to actively take part during the printing process. In addition to these, another important fact needs to be underlined: in the +TUO pilot project we decided arbitrarily to focus just on the 3DP technology. For future works we are foreseeing the possibility of printing just those parts or components subject to contextual modifications (for example in the Reference Product bottle opener the handle) while other parts, more predictable, will be produced with more traditional technologies (for example the rubber insert can be an extruded profile suitable for different kind of bottles).

Under the user-oriented point of view we can observe, as in +TUO pilot study, that a small community composed by all our actors has been created thanks to the active participation of everyone involved (end users, designers, occupational therapists and researchers). This community-based approach is in our perception one of the variables that made +TUO feasible and repeatable in the future in other places and with other unknown actors. The possibility of adopting a "making together" approach, that was rapid and local, has been sustained by the choice for low-cost, entry-level, open-source FDM 3D printers, in comparison with more industrial or high costs versions. With this approach the presence of each actor has been meaningful and everybody found his/her role during different stages in a spontaneous and natural way. Furthermore, as shown some specific choices (functional, aesthetical, technical, etc.) were difficult – if not impossible – without the presence of a cross-functional team. With focus on the End User, it is important to note that +TUO and particularly the Generative process represents a meaningful activity both under the occupational point of view (+TUO is already an occupation, social and creative) and under the assistive devices design point of view. To personalize a product provokes on users a higher emotional link with it, adding value and even opening chances for innovative applications (Mugge et al., 2009). In fact, as seen in **Chapter 3, Foundations**, we've shown that if end users' opinions are considered during the selection of the device (or in this case its creation) a reduced degree of non-use can be achieved (Wessels et al., 2003). End users were then asked about the option of sharing the emerged ideas in the future, within the community of people with RDs: none of them showed uncertainties and all of them offered their personal help on engaging and explaining to other new actors the work done till that point.

Future studies will investigate the possibility for sharing the products with communities based in other regions and other contexts. Explorations will focus on how to communicate the project to different contexts and users easily (e.g. with different machines/technologies to people with different needs/pathologies). These explorations will be based on the same insights from Maker, Open-Source communities and DIY (Do It Yourself)(Dalton, Desjardins, & Wakkary, 2014), but also open to other fields, since we acknowledged the threat of focusing only on one technology. Studies will try to answer questions as: How could we transfer the knowledge gained from this experience to other contexts and users? How could we design devices that are easy to change thanks to the context of realization and to the specific users' needs?

Furthermore, we've highlighted some aspects that will need a deeper investigation, but will not be addressed within this manuscript. For example: what is the new material experience related with 3D printed products? Could we design processes able to realize different finishing on 3DP parts (in order to change mechanical and aesthetical aspects)? Could we enable every user to interact with this technology, by – for example – simplifying the interfaces?

CHAPTER 5, Study 2

CO-DESIGN WITH ONLINE COMMUNITIES: THE ROLE OF RE-APPROPRIATION

Study 2 starts with the open sharing of the bottle opener (reference product of **Study 1**) in an online platform, in order to follow potential re-appropriation processes. This small experiment proved the complexity of adapting solutions created in one specific context, rather than just copying them. We decided then to start again from the very first steps of the Open-ended Design realization: the co-creation of highly context dependent solutions, and then move one step forward by sharing the obtained results with the online community.

Goal is to better understand the dynamics related with re-appropriation processes, that get projects for one copied and adapted in other contexts. In this way, the context-dependent needs of one person get in touch with previously unrelated stakeholders, in the attempt of starting a more global conversation. This study has been published in 2016 in the International review research in open and distributed learning, Vol. 17, Issue 4, with the title "The Role of Re-Appropriation in Open Design: A Case Study on How Openness in Higher Education for Industrial Design Engineering Can Trigger Global Discussions on the Theme of Urban Gardening" (Ostuzzi, Conradie, Couvreur, Detand, & Saldien, 2016) and the following chapter contains extracts of it. The literature review on these topics has been already included in **Chapter 3**, **Foundations**. Briefly, the following study reports on a co-creation project developed by 47 students during two weeks. The end results of this project were shared online and the dynamic of commenting, and copying was followed. In the following page the structure of the chapter.

5.6. Online sharing of Study 1 outcomes

+Lab (the Italian laboratory mentioned in the previous study) decided to share online the results of the +TUO Study. In this case another platform has been used, Thingiverse (thingiverse.com). This is the most commonly used while sharing objects created with 3D Printers. The bottle opener has been shared, in its reference product version (see **Figure 5.1**, **Study 1**), as visible at the link (thingiverse.com/thing:403031, last accessed in July 2017) and in **Figure 5.8**. In Thingiverse the product is normally accompanied by a short description and, more importantly, by the source files needed to produce it (in .STL extension). In this case no specific effort was done in order to simplify the process of adaptation from other previously unrelated users.

Figure 5.8. The bottle opener (pictures from thingiverse.com/thing:403031)

After three years, the product received 943 likes and has been downloaded (or collected, meaning saved by other users in their personal libraries) 1163 times. More interestingly, the bottle opener has been produced (made as it was firstly proposed, no modifications, definable as *copied version*) 18 times by different stakeholders and produced in a *re-mixed version* 3 times. The copied versions are visible in **Figure 5.9**; it appears clear as the majority of the users, who decided to produce this product, made it *as it is* (the only difference is the color, not function related in this product). This, is in contradiction to what learned in the previous study. In fact, thanks to the end user and occupational therapist involvement, we understood as this product cannot perfectly fit each user without being slightly modified. These adaptations emerged as necessary not only in order to reach the goal of opening bottles, but also for the longer term view on joint protection (i.e. the device works and fits the user, who is not realizing how the burden is transferred to another joint, which might become, in time, problematic). Furthermore, we also noticed as some misunderstandings occurred while copying the product; for example, the inner component meant to be printed in different materials in order to reach a higher grip and therefore implying less force needed, has been printed by some users in the same material of the main body. In this way, the only advantage of dividing the two functions in two pieces was lost. In this case, we imagined at least two different scenarios: (1) users printed the bottle opener as an exercise, without being in real need for it; (2) the users printed the product and found it sufficiently matching their needs.

Figure 5.9. Examples of the copied versions of the bottle opener (not all have been here included)

In order to explore our two hypothetical scenarios, users' comments have been analyzed and reported. Some users only reported technical considerations about the printing techniques.

- "Good print, pretty tight fit. Would recommend giving the grip (the small part) a chamfer at the bottom to make the insertion more easy." (from thingiverse.

com/make:145499).

- "First long term print on my Robox. :-)" (from thingiverse.com/make:115906).
- "Thank you for this nice Thing!! Works great." (from thingiverse.com/make:112431).

Only three comments dealt with the actual use of the product, two of which report on making the product for somebody else (specifically wives).

- "Awesome bottle opener for my wife! I made it with dual extrusion. I had a little trouble putting the 2 pieces together, but that was only because they fit so well!" (from thingiverse.com/make:10547).
- "My wife has a tough time twisting small plastic bottle caps open. This thing works perfect! Used ABS for extra strength, I also increased resolution to make it look really nice." (from thingiverse.com/make:206992)

Finally, the last comment creates a mix of the two aspects (technical and functional). Thanks to a phrase ("With much force applied it will grip.") it appears clear as there is not chronic condition of pain involved, since the need to the bottle opener is based up-on the shared need to use less force.

- "Just printed the opener. Two toned. Candy on sweet orange slice. It matches the widely used if not THE european standard 1l soda bottle cap (2.5mm diameter on the top edge) so lala. Missed the Cola cap tragically. With much force applied it will grip. But this will ruin the openers teethes." (from thingiverse.com/make:96590).

As mentioned, we can also see three *re-mixed versions*. In these cases, the output creatively merge two or more sources, becoming a real adaptation of the product, developed according to specific contextual needs, as specified in the projects descriptions reported below.

(a) "In this remix I just made the handle smaller. And since I had problems with the fit I unified the two pieces. It's Perfect." (from thingiverse.com/thing:822397, last accessed on June 2017).

(b) There is no comment or description (thingiverse.com/thing:542610).

(c) "This thing is a bottle opener. The thing 403031 I have printed was too small to grip the caps we are using. But the additional insert used with the single arm lever was ok. I wanted a finger-friendly handle so I put two things together and added a cap." (from thingiverse.com/thing:529737, last accessed on June 2017).

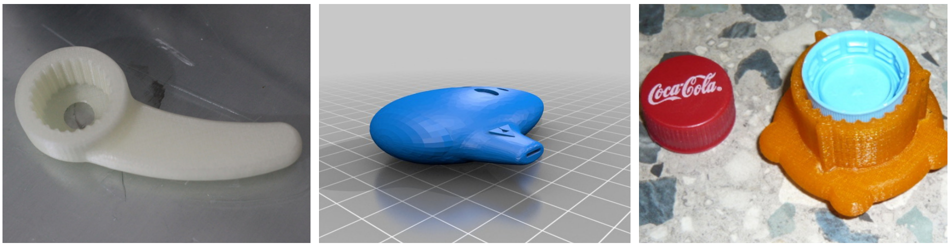


Figure 5.10. Re-appropriations based on functional aspects (in the section remix)

In conclusion, we find that to openly share solutions meant to be contextual, without giving support on how to adapt the product can represent a risk (Cruickshank & Atkinson, 2014). Important information gets lost, as well as the real value of the product (project + technology), which its capability of being personal. At the same time we acknowledge as this solution, meant to be for *small communities*, can prove interest also for a bigger panel of users, not necessarily dealing with chronic conditions. Reflections on these aspects are expanded in the section, Discussion.

Next to this small experiment, we decided to retrace the whole process (from co-design for one user, to online sharing and feedback reading), as described in the rest of the chapter.

5.7. Project based courses for sustainability

Project based courses (or design laboratories) (Dymm, Agogino, Eris, Frey, & Leifer, 2006) are a core activity for Industrial Design Engineering students. In such courses students are challenged to solve problems in valuable ways (functional, user-oriented, economic, environmental, etc.). This opportunity driven approach (trial and error) is the core of the design process and can be tackled in many different ways. In traditional design courses, the end results are shared with teachers and with a limited groups of experts (i.e., industries, design studios, potential final users, etc.), with the purpose of bringing the specific results closer to the actual stakeholders. This, leads often to the creation of design outcomes where the gap between idea environment of design and real use environment is unexplored (for more details see **Chapter 3, Foundations**). To try to decrease such gap from the very front end of the design process we adopted an iterative co-design approach where, as occurred for Study 1, iterative cycles ideation-materialization-test are conducted with tangible prototypes in order to achieve valuable solutions (Roozenburg & Eekels, 1995). This process becomes a collaborative learning medium drawing on the learning approaches known as learning through doing or through experience, formalized by John Dewey (Dewey, 1997), experiential learning (Kolb, 1984) and reflective practice, by Donald Schön (Schön, 1983) which, independently from the achieved solution, sustains students' increasing their knowledge and skills. The accumulated expertise improves students' ability to understand and solve similar problems (Weber & von Hippel, 2000). This expertise, in the form of embedded information, is defined as "sticky" (Von Hippel, 1994) -meaning information is expensive to generate, acquire and transfer.

5.7.1. Openness in industrial design

Sustainability is increasingly emphasized in courses on design and engineering (Melles, de Vere, & Misic, 2011). Yet, while solutions may be applicable in a local context, they are not necessarily suited to be re-appropriated and reused on a wider scale, under both design and educational points of view (Chiappe & Arias, 2015). The result is that sustainability focused projects are not always reused in other contexts, and it is also not clear how effective they might be. This represents a challenge to test our assumptions while trying to decrease the disconnect that exists between education systems and human society [defined as "supersystem" in Wiley & Hilton III (Wiley & Hilton III, 2009)], which has been described in detail in **Chapter 3, Foundations**.

As Manzini and Rizzo (Manzini & Rizzo, 2011) note, to achieve new models for sustainable behavior through participatory design, social innovation is necessary, in combination with an open process where small local activities interacts with different types of opportunities to achieve a large vision. Moreover, systemic problems such as those related to sustainability cannot be solved using the same reductionist techniques that caused them in the first place. Several projects emphasize the role of urban gardening as a community-based project that allows sustainable consumption, and acts as a facilitator of social cohesion. Often in these kinds of projects we face a change from well-defined products or services with well-defined participants to a process for the realization of a "socio-material assembly." In this process, the designer's role becomes that of a facilitator in the construction of a meaningful potentially controversial assembly, for and with the participants in the projects (Björgvinsson, Ehn, & Hillgren, 2010). In this conceptual framework, the knowledge that rises from the designers' activities is captured thanks to the implementation of "boundary objects" (Arias & Fischer, 2000). This knowledge is embedded in the "non-human participants," such as prototypes, mock-ups, models, sketches, notes, and blogs that Björgvinsson et al. (Björgvinsson et al., 2010) call "design devices".
One of the basic assumptions of this whole research is that industrial designers "learn

through doing," for example through project-based learning (Dymm et al., 2006) and by "prototyping," meaning that pieces of hardware become the learning objects for these contexts (Tripp & Bichelmeyer, 1990). A main goal for us, therefore, will be to explore how to "open up the design process." Open design products are related to the open source movement. The open source movement, sustained by the Internet, allows collaborative creation of products (virtual and physical) by previously unrelated users. These realities question the dominant market's peculiarities—standardization, mass-orientation and closure—which are in contrast with the idea of "openness" (Maldini, 2014). In past years a systematic distance from the real user, and proximity with the "average" user for which "one size fits all," was often present. Nowadays, thanks to distributed production technologies and new consumption patterns, designers can focus more on local, decentralized, flexible, single-consumer oriented, open design (Igoe & Mota, 2011). This new landscape is not ruled anymore by economies of scale, and presents real possibilities for innovating in niche markets (Oliveira, Zejnilovic, Canhao, & von Hippel, 2015), creating a long tail of product adaptations (Anderson, 2006). Within this paradigm, a relationship with potential social change is also assumed, sustaining "openness" by the collaboration and interaction of diverse and connected communities (Maldini, 2014). It is important to mention that in software design the concept "openness" has been thoroughly applied and explored both under the points of view of licensing (i.e., open source) and the possibility of re-appropriations (i.e., Wikipedia), through highly iterative and shared processes. Also, in hardware design many projects and research projects focus around the topic of openness, but often focus mainly on the licensing and technological aspects [some famous cases have been analyzed in (Raasch, Herstatt, & Balka, 2009)], rather than on the ease of re-appropriations occurring after the design, which implies the real participation of different stakeholders. This last point is a crucial aspect of the present **Study 2** and can be defined also as the open-endedness of the product itself.

"Static artefacts" are in fact in contrast with open-designed objects, and are products fully defined by the professional designer, and do not anticipate any modification by the consumer (Hermans, 2014). Similarly to meta-design approaches, open design can be characterized by "the emergent properties of the interacting system rather than the conclusion obtained by one designer or one team of designers" (Hermans, 2014, p. 16). Many open design interactions can be advocated as re-appropriations (meaning: understanding, copying and modifications on the original, core project) and facilitated by large communities.

Basically, "openness" means accessibility to view, modify and use a project (Avital, 2008); thus, transparency is advocated both in forms and contents. From a meta-perspective, these re-appropriation cycles can be sustained by “design spaces” or “solution spaces” (Hermans, 2015) and the resulting design behavior can be considered as the actual users’ space of freedom to express their own needs, desires, and possibilities. The freedom to express some situational differences (Avital, 2010) can be explored both online and offline, in the physically proximate environment. The ecology of open design is highly complex and includes: design specification, fabrication, collaborative action, supply and value chain management, business models, legal aspects, technological infrastructure and normative values (Avital, 2010).

In **Study 2** the advocated openness in design is on two levels: on the design (open design) level and on the educational (open learning and education) level. Open Educational Resources (D’Antoni, 2009)(Friesen, 2009), in this case consisting of the project descriptions and step-by-step building instructions, were adopted to let the contents of the course reside in the public domain or have been released under an intellectual property license that permits their free use or re-purposing by others. Furthermore, this project draws upon open technologies and collaboration. Born out of the idea to provide access to education to people who cannot obtain traditional forms of education (Dalsgaard, Halskov, Bardzell, Bardzell, & Lucero, 2016), Open Education (OE) existed well before the internet (Caswell, Henson, Jensen, & Wiley, 2008). However, recent years have seen the convergence of factors that are resulting in advances in OE. These include the availability of online tools and increased community engagement (Iiyoshi & Kumar, 2008). We view these trends as significant in also facilitating the shift from closed to open design.

In this way we adopted the Web 2.0 as a participatory medium, where the students were put in contact with other potential consumers, designers, and general stakeholders, using platforms based on concepts of communication and participation (Gourley & Lane, 2009)(Seely Brown & Adler, 2008). How, in practice, to create an open design is not yet completely defined. We argue that to “open” the design two main steps are needed: (a) “physical” accessibility through online delivery (sharing the project, giving instructions, images, etc.); and (b) the “content creation,” which means to restructure the content in order to facilitate reusability, also defined as re-appropriations (trying to simplify the understanding of the project and identifying the “solution spaces” mentioned before) (Chiappe & Arias, 2015). To explore spontaneous open design behaviour we create a community-based practice within the context of urban gardening. Both steps have been explored during this case study, and represent crucial and complex dynamics.

5.8. Research method

Study 2 aims at transferring local co-designed solutions to global audiences in order to (a) trigger discussions, (b) improve the learning process of students, and (c) facilitate re-appropriation of projects. The course stimulated an active collaboration between students and stakeholders (both offline and online) by being structured as an open process, where new actors can always enter, bringing new ideas, starting new dynamics and finding new solutions—what is defined as “social conversation” (Manzini & Rizzo, 2011). Because the process was open, the final product also had to become open. This approach was chosen for its inner link with social innovation and sustainability. Unlike proprietary or branded products, open design solutions tend to be easy to maintain, repair locally (Thackara & John, 2011) and re- appropriate. Furthermore, the design process that emerges is dynamic and the support of non-designers may lead to conception and implementation of new solutions (Manzini, 2014). The aim was to show to students how to reach what Piller, Schubert, Koch, and Möslein (Piller, Schubert, Koch, & Möslein, 2005) define as “communities for co-design”: online communities that are able to interact with features of products online. In such communities, solving technical problems, sharing practical experiences or adding/modifying some product features are real possibilities.

While Piller et al. (Piller et al., 2005) focus on the customization of industrialized products, this case study deals with Do It Yourself (DIY) projects. This choice was made in order to facilitate dynamics of re- appropriation of the provided solutions. In this research qualitative methods have been adopted. The main findings are presented in a narrative and descriptive way and were collected by researchers through continuous observation and communication between them and the students and between the students and different stakeholders.

5.8.1. Course and participants’ description

Study 2 was conducted within the Intensive Program (IP), a two-week intensive design course. The setting was a small FabLab where the main equipment consisted of: laser cutter, 3D printer (mainly Fused Deposition Modelling technology), CNC milling machine and other hand tools. Twelve teams were randomly created (eleven with four students, one with three) for a total of 47 students, all from the Bachelor of Science (BSc) program in Industrial Design Engineering Technology at the university where this study took place. On the first day of the program a document with the design brief was delivered to each team. Each team was matched with a stakeholder (also defined as “client”) belonging to a local community. Contact details were given to students in order to allow direct communication. During the first week, while students were starting the co-design process, some lectures were given on permaculture, urban gardening and how to build instructions for Instructable.com. During the second week teams were mainly involved in prototyping their solutions, testing them and finally translating them into open design projects.

5.8.1.1. Design process

The IP was divided into three main stages as shown below, in **Figure 5.11.**

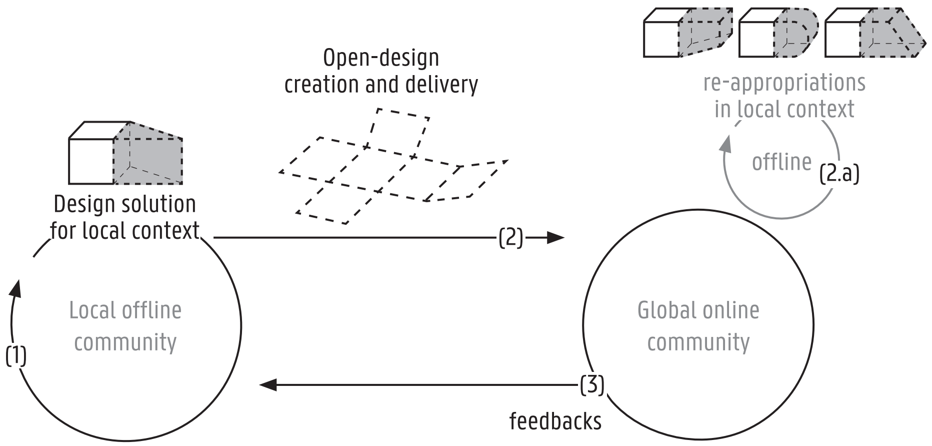


Figure 5.11. The design process adopted for Study 2

- **Stage (1)**. Co-design process: from the design brief to the realization of one-piece functional prototype, made for local stakeholders (offline, or analog).
- **Stage (2)**. Realization of the open design: from the contents definition to the final delivery on Instructables.com (offline and online, or analog and digital).
- **Stage (3)**. Feedback from the online community: collecting insights and improving the project and/or instructions (online, or digital).

These three stages will also be used to structure the description of the results (see **Results 5.9**). In Stage 1 and between Stage 2 and 3 a re-appropriation of the projects occurred. "Re- appropriation" can be interpreted, for the sake of this research, as any action of understanding and/or copying and/or modifying locally developed solutions in a new context. This implies "untethering" the achieved solutions from their context, creating more "mobile" results, and following the trend of developing more "spatially accommodating" solutions [as in (Wiley & Hilton III, 2009)]. While in Stage 1 the students re-appropriate existing offline resources and online projects, the second re- appropriation is vice versa made by other stakeholders and happens in other unknown contexts and focuses on the newly developed projects. This last stage (**2.a in Figure 5.11**) is here only partially reported. Potential future studies could explore this aspect in more detail.

As stated by Chiappe and Arias (Chiappe & Arias, 2015) the LO (Learning Objects, in our case the end results of a design process) available online are not always structured in a way that facilitates reuse, re- appropriation and adaptation. For this specific reason we selected Instructables.com as the sharing medium. Instructables.com is a collection of projects developed by different stakeholders. It represents for product designers what Connexions, Open Learn or other educational resources [for a selection see (Friesen, 2009)] can represent for other kinds of disciplines. The contents delivered should be accessible, low cost, and DIY, while the communication is in the form of step by step instructions, simple and supported by visuals (photos, sketches, etc.). Our goal is to explore possible ways to improve discussion and reuse of solutions developed in Industrial Design Engineering by adopting and developing an approach towards openness in higher education practical laboratories. We also acknowledged the concept of social learning, based on the premise that our understanding of content is constructed through conversations and through grounded interactions, especially with others (Seely Brown & Adler, 2008).

5.8.1.2. Deliverables

To better address the research purposes (see section Research Context) some deliverables of the design process/project were suggested to the students, mainly related to: (a) Functional prototype, (b) documentation, (c) open design and (d) stakeholders' involvement (see **Table 5.7**). The objective was, using transparent and "real world" tools, to facilitate the re-appropriation of the solutions and sustain their validity.

All these physical and virtual outputs have been used as a field to gather data for this research. With regard of data collection methods, every day the teachers gave consultations to each team (focused on both Stages 1 and 2) and in parallel, every two days, students were consulted with the purpose of understanding their learning process during the whole IP. To build up the presented figures all the students' blogs were constantly monitored, as well as the Instructables.com pages. A qualitative analysis of the feedback was conducted personally by the researchers. Finally, the use of public tools (in this case definable as OER), allows other researchers to consult and review the original data we used.

Deliverable	Format	Purpose
(a) Functional prototype	The final outcome should be a working prototype, not just aesthetic or conceptual	Allow iterative testing cycles with real users in the environment of use (as done in Study 1)
(b) Documentation	Every team has to document their design process, on a daily basis, on a public online blog.	Deliver relevant information about their choices and show how they relate with the local context.
(c) Open-design	Each team has to share the final outcome on the online platform Instructables.com. How to structure the information is their choice.	Enable, and possibly facilitate, re-appropriations from other previously unrelated stakeholders.
(d) Stakeholders involvement	Trigger and support conversations about the proposed solutions with both offline and online stakeholders.	Reach deep understanding of users' needs and learn what conserves and what changes, thanks to different contexts.

Table 5.7. Required deliverables of the whole design process

5.9. Results

The results description follows the structure of **Figure 5.11**, while the summary of the functional prototypes, blogs and Instructables.com pages can be found in **Figure 5.8** (next page). Further information can be found at: sites.google.com/site/intensive-program2014/results.

5.9.1. Stage 1: Realization of functional prototypes

Results of this stage derive from students' blogs, consultations, and functional prototypes. The realization of this last output corresponds with the end of Stage 1. This phase was characterized by a constant interfacing with the (offline) stakeholders, following a co-generation process as described in De Couvreur and Goossens (Couvreur & Goossens, 2011) where all the actors involved communicate via prototypes, and tests are done in the physical, final environment of use. In addition, students were invited, but not obliged, to report the results of their tests in a simple matrix: expected/unexpected, positive/negative (Couvreur, Dejonghe, Detand, & Goossens, 2013)(Couvreur, 2016). Specific results can be observed on the blogs. The purpose of this stage was to finalize a "highly contextual" functional prototype, which means without putting any effort into finding the "one size" that fits all. Results were ap-

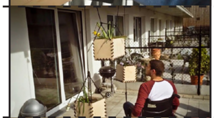
Project	Image	Blog and Instructables links
Growing potato tower with turning bins		• aardappelplantbak.blogspot.be • instructables.com/id/DIY- Growing-potato-tow- er-with-turning-bins
Standalone rainwater collector		• regenopvang.blogspot.be • instructables.com/id/Stand- alone-rain-collector
Space efficient gardening rack		• terrastuinieren.blogspot.be • instructables.com/id/Space- Efficient-Garden- ing-Rack
Liftable hanging planters		• plantbakrolstoelip.blogspot.be • instructables.com/id/Hangin g-planters
Seed house (one-way sharing system)		• berghok.blogspot.be • instructables.com/id/One- Way-Sharing-System
Modular triangle event planter		• budadak.blogspot.be • instructables.com/id/Modula r-triangle-event-planter
Modular vegetable protection cage		• duiven.blogspot.be • instructables.com/id/Protect- your-vegeta- bles-against-birds
Transportable kitchen		• mobielekeuken.blogspot.be • instructables.com/id/Mobile- Kitchen-a-bike-trailer- kitchen-on-gas
Modular greenhouse		• mobieleserre.blogspot.be • instructables.com/id/Casa- Verde-A-modular-green- house
Coffee cycle reusing coffee ground		• koffiegruis.blogspot.be • instructables.com/id/Coffee- Cycle-reusing-cof- fee-ground
Worm composter		• wormcomposteerbak.blogspot.be • instructables.com/id/LARGE-EASY-TO-BUILD-WORM- COMPOSTER
Self-watering bin		• bewatering.blogspot.be • instructables.com/id/How-to-make-a-self-watering-bin

Table 5.8. Overview of the outcomes

proved by both teachers and stakeholders during a "go/no-go" presentation: all the prototypes were judged to be coherent with the brief, functional, and suitable to be translated into open designs.

This iterative co-design approach is well established (Dow & Klemmer, 2010)(Mao, Vredenburg, Smith, & Carey, 2005). The added value in this case is in raising the students' awareness of the "contextual" design elements. Already, in this stage, re-appropriation cycles can be found: some students used already existing online open source solutions as a starting point for their own local design process (i.e., aardappelplantbakip2014.blogspot.be). In doing that they had mainly developed Stage 2.a in **Figure 5.11**, which means that they had to understand what aspects of the existing projects were for them useful, repeatable and feasible in their own context.

5.9.2. Stage 2: Creation and upload of open designs

Results of this stage are derived from personal consultations and Instructables.com pages. These results show the value of connecting people and contents via the web. They are divided into the creation of the open design (content) and its delivery.

Creation. Students were first asked to reflect on what contents (design elements, final output image, instructions, etc.) should be delivered. They also had the possibility of slightly changing the design specifications in order to make it easier to be re-appropriated. Their choices were supported by literature (Dahl & Moreau, 2007) and by constant consultations with teachers. Other concepts applicable to the stimulation of reusability through open education were applied to the content creation (our Learning Objects) in order to create less contextualized content, improve use granularity (i.e., solutions were divided into independent sub-solutions to be applied to different contexts) and stimulate adaptation as described below (Chiappe & Arias, 2015).

Consultations were focused on the exploration of the design elements, trying to divide them into "contextual" (highly context-linked) variables, and "fixed" variables, as listed in Ostuzzi, Rognoli, Saldien, and Levi (Ostuzzi, Rognoli, Saldien, & Levi, 2015), see Study 1. This process was developed in order to avoid any information overload (Dahl & Moreau, 2007) or other hindrances. For students both the understanding of the concept and the identification of these elements was extremely easy: the iterative co-design process probably helped them distinguish, for example, between a choice made because "laser cutter is the only available machine" or because "laser cutter is probably the best technology for such a geometry/material/etc." (i.e., berghok.blogspot.be). Furthermore, these consultations helped teachers' understanding of students' level of knowledge about aspects of technical design.

Delivery. To deliver the open designs, the students were asked to create online instructions. Various supports related to this topic are available (Dalton, Desjardins, & Wakkary, 2014). End results can then be seen as "open" not only because freely available online, but also because of the effort of "openness" while designing them (defined as open design). Examples include, but are not limited to:

- Use of modularity;
- Use of standard pieces (screws, bolts, profiles, etc.);
- No defined dimensions (instructables.com/id/Space-Efficient-Gardening-Rack/?ALLSTEPS), but rather guidelines to suit the context of use;
- Written or visual proposal of alternatives (see **Figure 5.12**, below).

Figure 5.12. Alternative ways to create the same 90° joint, as reported in the Modular vegetable protection cage project

It is interesting to note that the majority of these solutions—freely defined by students and primarily meant to enable and facilitate the (also conceptual) re-appropriation of their projects from different stakeholders—are basically LCD (Life Cycle Design) strategies that also confirm previous assumptions about the relationship between open design and sustainability (Cooper, 2010)(Vezzoli & Manzini, 2008).

5.9.3. Stage 3: Online community

Results of this stage derive mainly from the observation of online interaction. The "opening" of the process and end results had the goal of stimulating a global and social conversation with unknown and unrelated stakeholders in order both to get useful insights and to verify the ease of the re- appropriation dynamics. This brought to students very practical answers regarding the perception and application of their solutions and gave them interesting and not generic “off the shelf” information [as defined by Wiley & Hilton III, (Wiley & Hilton III, 2009)]. Furthermore, the conversation stimulated students to improve some solutions, representing a real completion of the assignment outside the class and academia itself. A constant online monitoring by researchers occurred during the 18 months after the online publication (from February, 2014 to August, 2015) and were last accessed while writing this manuscript, on June 2017. The number of views and comments decreased after a few weeks. The projects able to start this conversation are highlighted in **Table 5.9**. below (to read the actual comments, we suggest to check instructables.com pages). Comments were grouped as:

- Questions
- Related works
- Suggestions
- Critiques
- “I’ve made it”
- (Not-) supportive

It was decided to report, in a narrative way, only comments pertaining to the first five categories. The (not-) supportive comments are generally not meant to start any discussion (i.e. “Good idea!”).

Questions. These comments are questions (around functions, costs, maintenance, etc.) submitted in order to better understand the project (i.e. “How do you address the issue of over- filling?”; “Can you explain the purpose of turning the bin.. ?”, etc.). To ask a question can be considered the most direct way to explore new items, and the fact that these questions were online, in a public medium, and asked for “black and white” answers, often pushed students to rethink and restructure their projects and instructions. One example, (instructables.com/id/One-Way-Sharing- System) where, thanks to some comments, the students understood how to improve their video and the way they deliver information to unknown audiences.

Previous works. Some comments referred to existing related projects trying, for example, to argue why one solution was better than the other. Some internal or personal references were also used (i.e. “Reminds me of my experience at instructables.com/id/…”). Because the IP took place within a very brief time frame these comments

Project	Questions	Related works	Suggestions	Critiques	I've made it
Growing potato tower with turning bins	X	X	X	X	X
Standalone rainwater collector	X	X	X	X	X
Space efficient gardening rack					
Liftable hanging planters			X		
Seed house (one-way sharing system)			X	X	X
Modular triangle event planter					
Modular vegetable protection cage			X		X
Transportable kitchen					
Modular greenhouse			X		X
Coffee cycle reusing coffee ground		X	X		X
Worm composter					
Self-watering bin					

Table 5.9. Combinations projects and specific reactions from online stakeholders

provided the students with some inspiration and challenges, inspiring them to further effort if a proper "state of the art" had not yet been developed or even bringing insights not reachable otherwise.

Suggestions. Students received suggestions, in the form of tips, practical ideas, and possible improvements on the project instructions. Sometimes the suggestions were visual - see **Figure 5.13** ("Green tarp would have been a better option."; "Actually - you can redesign it so that you have an entire string of them... One perhaps as a dead weight / counter balance at the end? and a whole string of them in a row."). These comments helped students to improve their solutions, and represent useful tips, especially for other users wanting to copy the project. Some suggestions drew attention to contextual aspects not previously recognized by students or teachers ("If you're in the US, be careful that you aren't violating (dumb) rainwater collection laws. I know where I live, you need a permit to collect any rainwater").

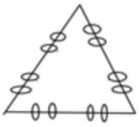


Figure 5.13. "Is there any reason you could not skip the rectangles and just use cable/zip ties to form a loop through each hole? Then they would act as the hinge too. I hope my sketch will help explain."

Critiques. Comments also expressed doubt about the functioning or value of projects (i.e., "This is just a nicer looking alternative to a tower made from a stack of old tires"), and are often followed by suggestions and/or related works. These comments pushed students to explain the motivations for the existing solutions (when in disagreement with the critique), or to find new solutions (when in agreement with the critique). In specific cases safety issues were pointed out (i.e., "An intelligent person minimizes risks to him/herself. A teacher helps others to minimize risks to all of us (in part)"). Apart from the specific case this last comment refers to, it raises a very interesting issue related to open design and education: to what extent is it the responsibility of the creator?

"I've made it." This feedback is probably the most interesting in terms of identification of contextual and fixed design elements; in fact, it again pulls the project into the offline and local dimension (i.e., "I will have to try this. I live in North Idaho were the growing season is very short so this seems like an excellent cost effective solution to jump start the growing season"). Some examples developed this re-appropriation process from the understanding of the project to its (modified) realization; these comments were often accompanied by visuals ["I made mine out of steel tubing and used chicken wire on them too. I used mine as mulch cubes", in **Figure 5.14 (a)** and "I used tie raps to secure the basket to my bike. It's very secure and I love

Figure 5.14. Examples of re-appropriations re-posted on instructables.com

it!", in **Figure 5.14 (b)**. In these examples changes are made: materials and dimensions are, for example, different. Users declared that they used what was available to them, or what suited their environment best. In this sense a sort of "design after design" was shown to students: a dimension where their idea has taken different shapes and, again offline, helped to solve someone's practical problems.

5.10. Discussion

In this case study we stimulated students' engagement in a process of opening education and its end results. The university acted as mediator of a new approach towards openness (Wiley & Hilton III, 2009) trying to orientate and sustain students while interfacing with different (unknown) stakeholders. In two weeks it was already possible to understand the value of this approach, specifically when adopted in Industrial Design Engineering courses. First of all, design students' solutions were taken outside the academic environment to reach an online platform (Instructables.com). This approach allowed students to increase their number of peers (with an average of 19,900 views for each upload, and a peak of more than 62,000 views for the Seed-house project) and see their own solutions evaluated, developed, criticized, re-appropriated, etc. by unknown stakeholders. In particular, it was thanks to the comments—the real medium of this global conversation—that students could collect some "lessons learned," which led to real changes in their projects and/or online instructions.

For example, comments in the form of questions showed to students how certain information, originally well understood or at least understandable by offline peers, was completely unclear for on- line communities. As seen, some suggestions and/or "I've made it" comments confronted students directly with a re-appropriation process where they had to "lose control" over their own solution in order to make it suitable in different contexts. This approach, with its Open-ended Design elements (e.g. material, shape, production techniques) is theorized in different studies [e.g., van Hinte (Thackara et al., 2004)] but is sometimes hard to be visualized and explored by students in their practice. It is a known fact that the personalization and realization of products can add value to the user-product relation in terms of retaining time and satisfaction (Dahl & Moreau, 2007), but it is still hard to teach students how to achieve this in practice.

Furthermore, given that Industrial Design Engineering is a very broad discipline, there is always the need (for the academic staff) to involve experts of specific fields during the design process and the assessment of the end results. In this case study this need was automatically satisfied by the sharing of the end results, thank to which stu-

dents managed to find experts in real and different application fields also unknown to their teachers. It's important to underline that the research problem (as defined in the "research context" section of this chapter) is difficult (Rittel & Webber, 1973). Many limitations emerged, mainly linked to low student engagement, to the choice of the online medium (which, for example, gives visibility for just few weeks), or to the difficulty in tracking all communication and connecting causes and consequences in a linear way. For these reasons this study adopted a mere observational point of view, with the purpose of testing the dynamic and identifying some aspects that can be more deeply explored in future studies (see **Paragraph 5.11**). A big limitation was also the language barrier. Students were asked to write their blogs in English, but some of them naturally switched to their native Dutch to make communication easier and less stressful, especially with the local stakeholders.
In general, the goal of joining a global conversation and visualizing re-appropriation processes was achieved. Users, both online and offline, had unique solutions, based on what was more available and/or more suitable to their contexts. These concepts are linked to sustainability, appropriate technologies and education. Also, the goal of a first exploration of OER delivery practices for industrial design engineers was achieved, giving a first understanding of the kind of media and content useful for such a field, creating extended connections with shared and distributed practicums to develop new experiences from new and unknown contexts, as advocated in (Seely Brown & Adler, 2008).

Strenghts	› In short time the conversation went from being local to global, moving from known to unknown stakeholders › Fast feedback loops useful to understand what changes and what conserves	› Many "re-appropriations" are in fact uncritical copies of the provided design outcomes › Access limited to skilled users, often already engaging with digital and DIY production techniques	**Weaknesses**
Opportunities	› Reach a deeper understanding on how diffused user needs still require unique solutions › If many re-appropriations occur, the data can be transformed into knowledge to reach more adaptable design outcomes	› Uncritical diffusion can lead to the production of unuseful devices or, worse, of unsuitable ones › Exclusion of a big portion of the real end users from this conversation (because unskilled, not digital, etc.)	**Threats**

Table 5.10. Synthetic SWOT of Study 2 and relation with future studies

5.11. Conclusions and future studies

Study 2 focuses on how to deal with the "opening" process of design solutions created in a local context, in order to trigger a global conversation, reuse (re-appropriation of the solutions) and potential improvement of the designed solution itself. The magnitude of the study is quite limited in time, while its role can be considered crucial. In fact, it highlighted the occurrence of uncritical diffusion of digital solutions, provoking a pivotal change in the research path that can be described as a *double loop learning* (Argyris, 1977), triggering a change in the direction that was taken by the experiments, as visible in the next presented work, Study 3. For now, the findings support the idea that working with open design, while teaching sustainability to designers, represents an effective reality-based way of learning and confronting students with unknown contexts and potential peers. As advocated by Wiley and Hilton III (Wiley & Hilton III, 2009) the openness of the education, and in this case of the products of design processes, can trigger fast connections with unknown stakeholders, personalization of the shared material and the creation of new solutions, improving the initially proposed ones. In conclusion, this study proves as students could reach feedbacks from very diverse contexts of use, with regard of their solution. The few practical examples of adaptations here reported highlighted as some design aspects are more subjects to change than others but, even if some team attempted to intuitively create more open instructions, we still witness a majority of copies without modifications. The goal remains to facilitate reuse and learning experience, rather than just publish the end results as they were in their analogical version (that is, **Figure 5.11**, **Stage 1**). Next steps in the research will focus on how to let designers better understand how to anticipate what can change and what conserves, and how to learn from the feedbacks received. In fact, after all every comment, like, modification or just copy of the product constitutes a readable feedback for the design, from which he/she can learn. In broader terms, we believe that the educational system should stimulate the ability of Industrial Design Engineering students to create more open design while engaging in the co-design of local solutions but with a potential global impact. This will support a constant reflection about the achieved solutions, involving different stakeholders rather than just the academic ones, and improve the solutions' sufficiency (Vezzoli & Manzini, 2008). Open design can be a powerful engine able to help students while solving difficult problems. Thanks to the opening of the design process, implemented by the universities, this innovative teaching can keep students relevant and connected with the current scene; furthermore, the fact that open designs are meant to change with changed requirements stimulates students (and, in general, designers) to look at the world through the eyes of their stakeholders, engaging in new offline/online co-experiences. We will not focus on such topics in this manuscript, and also not only engage with the use of online platform, but also other media suitable to let users re-appropriate the design solutions according to their own needs.

CHAPTER 5, Study 3

OPENING UP DESIGN OUTCOMES "FOR ONE"

Study 1 and **2** focused on the creation and sharing of design solutions initially meant to be *for one* specific user or context. We highlighted that a co-design process is fundamental in order to firstly better understand the users' needs. Also that it is possible to trigger re-appropriations, if supporting the communication to unrelated stakeholders with specific information about what can change and what can conserve (according to the designer's anticipation) in the proposed outcome. On the one hand these experiments helped the designer in exploring which design aspects of the solution can and/or should change, on the other hand they resulted in:

- high time and resources consumption needed for this identification (see **Study 1**),
- re-appropriation occurring without a change on the fundamental design aspects considered as context-dependent,
- re-appropriation occurring mainly by already skilled users, that don't always match with the final user in need for a specific solution.

Study 3 aims at better understanding if designers are capable, and if so how, to anticipate which design aspects (or *attributes*) need to change and which conserve, once in contact with different and unknown end users. This study has been presented in 2017 in the Design for Next Conference, in Roma, with the title "From Design for One to Open-ended Design. Experiments on understanding how to open-up contextual design solutions" (Ostuzzi, Couvreur, Detand, & Saldien, 2017), and is in press in *The Design Journal* (RFDJ) with Taylor and Francis. Extracts of this paper are used in the following chapter, which has been also implemented with additional information, figures and details. Here following the structure of the chapter:

5.12. Dynamics of re-appropriation

Nowadays online platforms (i.e. Instructables, Thingiverse, etc.) often provide design solutions developed for one specific person, in order to solve her/his specific needs. These solutions are created using different approaches and technologies; from more traditional DIY (Do It Yourself) and hacking solutions to digitally fabricated ones. The developer decides to share the solution with online communities, believing in its potential value for other stakeholders. Some of these projects are picked-up by the community, stimulating a conversation and sometimes being reproduced in other contexts. Occasionally, the picked-up solutions are even distributed back to the online community in their often adapted and implemented version. We define this process as *re-appropriation* (Ostuzzi, Conradie, Couvreur, Detand, & Saldien, 2016) (Redström, 2008). In this transformative process the user modifies some features of designed solution in order to make it more fitting to his/her context. The kind of products where such re-appropriation is important, and even necessary, are here defined as *contextual.* This to highlight the crucial role played by the context of use and the inappropriateness of transferring them "as they are" to other contexts. When enough re-appropriations cycles happen the creation of very interesting open design solutions might be achieved [see **Figure 5.15 (1)** and **5.15 (2)**]. One example of this dynamic is represented by 'Enabling the Future' (enablingthefuture.org) a 3D printed prosthetic hand that from being the contextual solution for one child, became a parametric design available for all. This started with all the people who shared their variations and implementations of the same product and continued with the effort of translating all the obtained data into information useful for the community, in this case in form of a guide on how to build the prosthetic hand according to specific dimensions of the child's forearm. Such a dynamic intrinsically refers to communities that share a common need, but that are too much diverse (a sort of *inner diversity* of the community) in order to be satisfied by a *standard* solution.

This dynamic process occurs also offline, in the design-after-design sphere, and can be defined as "defining use through use" (Redström, 2008) happening for products that are not open and not digital. What is important to notice is that in both cases (online and offline) the re-appropriation cycles occur more easily with certain solutions than others, as we know thanks to observative experience in the field.

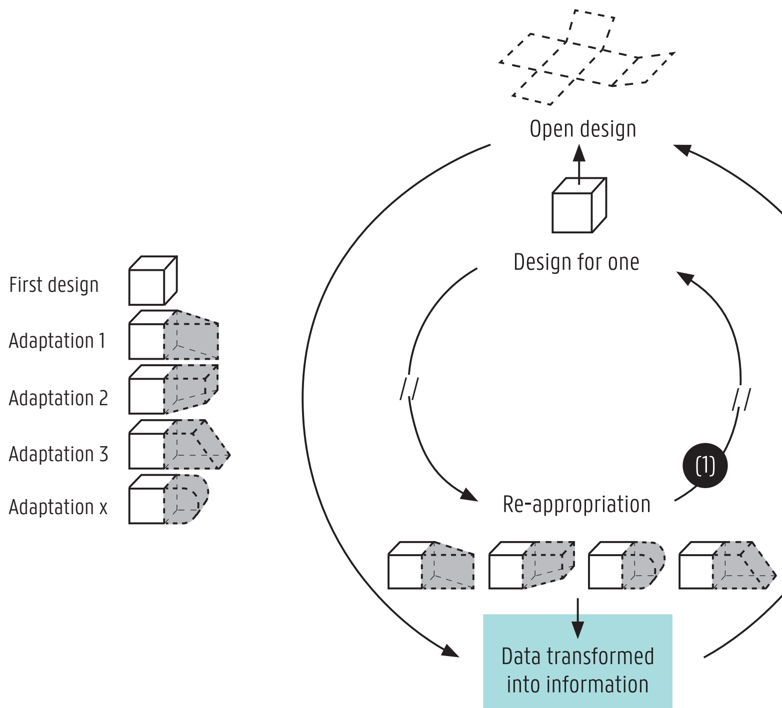


Figure 5.15. Re-appropriation can be seen as the process of products adaptation according to the users' needs. After several re-appropriation cycles of the same product, data can be aggregated to simplify the process itself, reaching a more interesting open solution. To note: this Figure is reported also in Chapter 3, Figure 3.8, for clearity reasons we decided to report it again with slight changes to better address the focus of Study 3. Also, as reminder, the symbol "/ /" symbolizes the buffer between the two actions.

While some studies focused on the digital manufacturing field (Hermans, 2014) (Ostuzzi, Rognoli, Saldien, & Levi, 2015), little has been done (Dalton, Desjardins, & Wakkary, 2014) in understanding how to facilitate, by design, the re-appropriation of low tech and highly contextual hardware solutions from different, unknown, unpredictable but yet connected stakeholders. As understandable, the main problems are related to the ability of anticipation, during the design and communication phases, of future possible needs of the potential users (Poli, 2009) (Zamenopoulos & Alexiou, 2005) and the translation of this knowledge into actual design features or design instructions (Yen, Flinn, Sommerich, Lavender, & Sanders, 2013).

The goal of the presented study is to understand how to understand the dynamic of translating existing projects, created to be for one person, into open design solutions with the relevant design information meaningfully reorganized. By bridging the existing gap between the context of design and the context of use (Hermans, 2014), we aim at facilitating stakeholders to transform useful existing solutions in the most fitting configuration for them. Herein, we will present only the step in **Figure 5.15** of the whole process, highlighted in light blue. This means that we will not discuss the first design process adopted to achieve the solution for one and the translation of these information into actual design strategies (industrial and post-industrial). The communication of the obtained information into the real context of use will be just briefly introduced.

5.13. Imperfect instructions

In this section we overview some important aspects related to the presented dynamic of opening-up contextual solutions. Specifically, we briefly add some information about the role instructions and imperfection in supporting re-appropriations. Our attention is focused on how to understand which are the essential variables of the system, and which are the aspects that can remain the same and be useful for the addressed community. In this sense a well-designed set of information and solutions can become a tool to empower the end user to achieve the optimal solution for his/her specific context, through products adaptations (Redström, 2008).

Studies explored the relation between the presentation of tutorials/instructions (i.e. DIY ones) and the ease of making the products themselves. They imply changes in the amount of information, structuring of the information, the overall formatting of the communication and in the authorship (Dalton et al., 2014) (Wakkary et al., 2015) (Dahl & Moreau, 2007). Often, it is highlighted that some instructions (i.e. the material listing) are incomplete and some relevant information is missing. Furthermore, it is always a basic assumption that the end result should be a copy of the proposed one. In this line, the study of Dahl & Moreau (2007) gives interesting insights about to which extend should the outcome of a creative task be dictated. The study shows, that it is not the definition of the goal of the task in terms of "make this exact result" or "make any result" that drove the participants' enjoyment of the task. More important is the experience of a balanced relation between autonomy and competence. With the end-users being experts of their own experience (Sanders & Stappers, 2008), they switch from *copying* something, to fully *co-designing* it (again, following a re-appropriation cycle), using it as a starting point of existing examples and/or guidelines.

In this case, it appears clear that some of the design instances shared with a broader public should be under-designed in order to leave flexibility and openness to the user to re-appropriate them as needed. The concept is not new to literature, and can be related with concepts like ambiguity and imperfection (Gaver, Beaver, & Benford, 2003)(Smith, Inoue, Spencer, & Tennant, 2017)(Inoue, Rodgers, Tennant, & Spencer, 2016). Both, ambiguity and imperfection can become a resource for creativity that deals with the loss of control from the designers' side. Furthermore, both try to "make a virtue out of technical limitations" (Gaver et al., 2003). According to this view, the configuration and meaning of the product raise (and reaches its complete development) from the context and not before. These imperfections are not meant with a prescriptive purpose, but work in suggesting and facilitating possible scenarios.

At this stage of the research we explored the role of the main building blocks of the products: the attributes. Product's attributes can be hard or soft, depending on their physical or more of meaning role. The relation between the products' attributes, the openness in design and the models to support designers can be seen in Hermans (2015)(Blijlevens, Creusen, & Schoormans, 2009)(Johnson, Lenau, & Ashby, 2003). These attributes can change in order to obtain high customization, or personalization of products with different levels of contribution from the user (Sinclair, 2006). They can change in a discreet or continuous way, they can change in a reversible way, they can change in different moment (be defined during production, or after-design), intentionally or not, etc. What is important is that by identifying and changing meaningfully products' attributes we can reach unique and more fitting version of the same family of products.

Furthermore, other researches supported this study, by suggesting approaches to modify the design outcome thanks to users' involvement (Sinclair, 2006)(Hermans, 2015). In these studies, lists of typical products attributes and approaches to include the user have been explored and, in the case of Hermans, with specific focus on digital technologies and open design. What proved particular interest is the definition provided by Sinclair of opened design, as different from open design, defined as "opened design products are therefore those whose original specification and/or design may be changed with direct consumer input." (Sinclair, 2006, p. 6), which mainly refers to software. Important to notice in this definition is how users are not necessarily involved in the conception phase and manufacture. In this way, opened design, mainly refers to top-down products being re-appropriated *after encounter* with the end user. With all this in mind we started our exploration about how to identify the relevant aspects of contextual solutions and how to organize them.

5.14. Research method

For two academic years (A/A 2013/14 and 2014/15) we observed and interviewed 36 teams of design students of Design for Ever(one) (see: designforeveryone.howest.be; Couvreur & Goossens, 2011), a university course where a co-creation process of unique and personal assistive devices takes place. This course can be seen as meaningful example of co-creation of highly *contextual* and *for one* design solutions. Here, multidisciplinary teams (designers, occupation therapists and users) work together, communicating with prototypes, in order to find a solution for a specific problem encountered while developing a daily activity. The solution is meant for the only user involved in the process, and has to be in form of a functioning one-piece product. Also, this course can be considered of “relevant design” referring to product design outcomes that focus on enhancing the quality of life of the engaged stakeholders (McDonagh & Thomas, 2010).

In this study, at the end of the course, we challenged students with the question of opening-up their solutions, imagining the need of transferring the projects to other (in this case unknown) users and contexts of use. We asked them: What would happen to your project, if used by somebody else? What design attributes should remain the same? What could or should change? For all the analyzed case studies the interest was focused on the fact that the resulting design attributes always started from un-conventional users or way of use, for which no standard solution could fit the approached scenario. Errors and imperfections led to new understanding of possible solutions, often obtained following a re-appropriation cycle in form of hacking strategy. Once all the possible design elements were identified and classified, the way to communicate them and how to structure them were the next fundamental steps in trying to find balance between Open and undefined and Over-design (Dahl & Moreau, 2007). In this framework of experimentation, errors and defects worked as meaningful elements, and unpredictable events were always highlighted (Couvreur, Dejonghe, Detand, & Goossens, 2013) as trigger for achieving meaningful changes in the design solution.

The research method adopted was practice based, qualitative and highly iterative, with the constant goal of understanding the students' choices in terms of design attributes (colours, dimensions, materials, etc.) and their relation with the context from where they emerged.

5.14.1. Interviews

Both years (A/A 2014/15 and 2015/16) we followed the students during their entire design process of 1 semester. At the end of the semester the physical product is delivered to the user, and we asked each team to bring an exploded view of their final result (on A3 paper format). These papers, and the recorded interview, represent our data. Firstly, the goal was to better understand the value of each solution and the reasons behind particular choices in terms of design attributes. Secondly the interview was focused on questions as "What would happen if another user uses this exact product? What attribute can remain exactly the same? What can or should change?".

This exercise was sometimes, especially at the beginning of this research, difficult both for students and researchers. For researchers it was hard to find the correct words "what can change, but should not change?" is deeply different from "what can change, and should change?". This effort on finding the right words was iterative, and helped to facilitate the communication and to formalize different declinations of the design attributes with respect to the opening-up process. In fact, while at the beginning the focus was just on "what can change?" it appeared clear that this was not enough. On the other hand, the exercise was difficult for the students because sometimes it was clearly questioning the relevance of their choices, and therefore their role as designer and the crucial matter of losing control on your own creation: "if everything can change, where does my idea and contribution lay?", "if something should change, who is going to define that?", etc. For example, thanks to these evidences, we understood the importance of asking them to define the core idea of the project, meaning the aspect without which the project would not be *their project* anymore. During the first year a basic model for the interview was created and then implemented during the second year and tested again.

5.15. Results

In this section we present the developed model (see **Figure 5.17**) and 3 cases of application.

5.15.1. Selected cases

Only 3 of the 36 final design outcome will be reported here, these cases were selected

Figure 5.16. The selected cases. (a) assistive device to play the recorder; (b) seating assistive device and (c) aid to build puzzles. (a) and (b) have been created in A/A 2014/15, while (c) in A/A 2015/16

in order to better illustrate the model, the contained definitions and its function. Here following a brief description of the selected cases. All projects were needed because of absence of suitable alternatives in the market.

- **Assistive device to play the recorder** (design by: Kobejoren, C. Geldof, E. Quartier, S. Vanneste and J. Caes). This device is designed for a man passionate of playing the recorder, but who lost his left index finger. This tool gives also the possibility to play different recorders (alto- tenor- and bass- recorder).
- **Seating assistive device** (design by: Jan, J. Leirman, S. Vernimmen, L. Verhaeghe and L. Vanbiervliet). This chair is meant for a 3 years old child with cerebral palsy, and it is helping to keep him in the correct position. The chair is meant to be foldable, light and easy to be transported by his parents.
- **Aid to build puzzles** (design by: H. Bartsoen, T. Gruwez, M. Di Az and S. Roose). This aid tis designed to help people with fine motoric movements limitations, while handling the small pieces of a puzzle. The product has a ring to be put around a finger, and is attached to a pomp and small suction device, capable of lifting the small pieces.

5.15.2. Resulting model

The model in **Figure 5.17** addresses both hard and soft design attributes and its goal is to help designers rearranging the relevant information of their design, when sharing it with unknown contexts. This model was created through an iterative process and the here presented version is the final one. To notice: the first year projects were analysed only with the first part of the module, since the second part was finalized only at the end of the second year, allowing the analysis of only the cases developed at that moment.

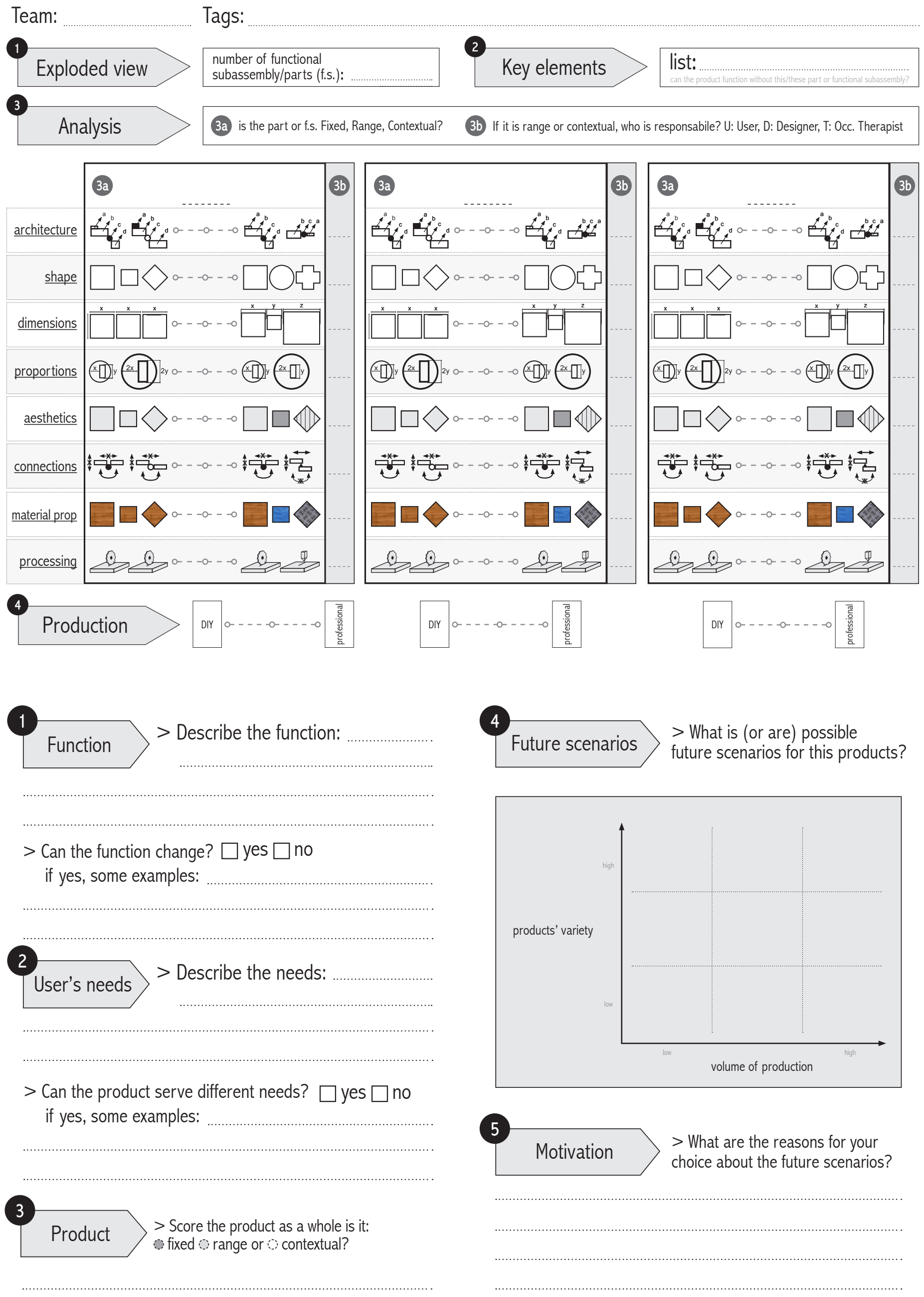


Figure 5.17. Resulting model for analysing both hard attributes and soft attributes. On the left column of the top form, the design attribute is defined as identical, while on the right is defined as changeable. In point 4 of the bottom form, specific focus is given to the possible location of the project in the landscape introduced in Chapter 3, Foundations, referring to a potential up-scaling of the obtained design outcome

The demands contained in the model are here presented.

1. List all the components of your solution (the use of visual or physical representations is highly suggested, i.e. a physical/virtual prototype or an exploded view can be used, **Figure 5.18**).
2. List all the components (or sub-assemblies) considered crucial to deliver the function. These *key elements* (or *core* ones) are the first to be analysed, sometimes the analysis can be considered concluded just analysing them.

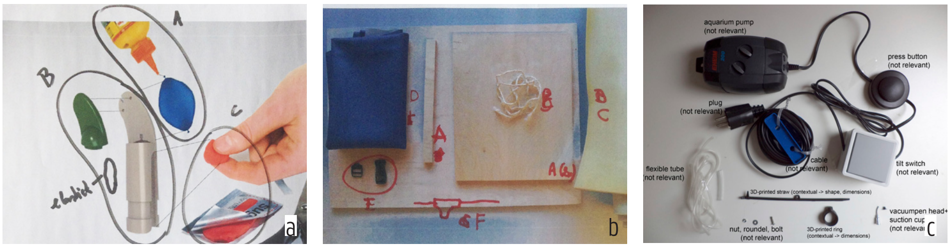


Figure 5.18. Students decided to use a graphical solution where the three main sub-assemblies have been highlighted

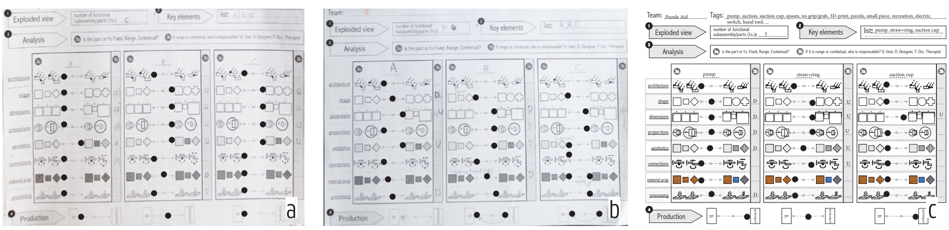


Figure 5.19. Compiled modules for the three projects (students answers have been highlighted with black dots)

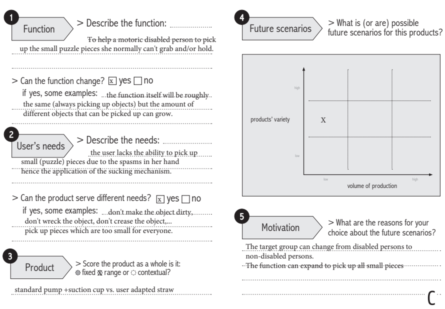


Figure 5.20. Second part of the module, compiled by the project aid to build puzzles

3. Describe the hard attributes (architecture, shape, dimensions, proportions, aesthetics, connections, material properties and processing) in terms of *undefined*, *defined-fixed* and *contextual* definition.
    - With **undefined** elements we refer to design choices that are not important for the solution itself, these elements should not be communicated in order to avoid an information overload. This is the first aspect of open solutions: a possible under-load of the communicated project. For example, in the seating assistive device the back support is square-shaped just because that was easy to be made, this is then an undefined attribute. These undefined elements can be changed or not, with no implications on the functioning of the product.
    - The **defined-fixed** elements are the ones considered fundamental for the functioning of the product itself. According to the interviewed students, any change in these elements can lead to malfunctioning or loss of the initial project identity. For example in the assistive device to play the recorder the main idea of the solution is in the material used to cover the hole [red in **Figure 5.18 (a)**]. Its precise properties allow the function, by changing it a completely the core knowledge of the project would be somehow lost, with a potential malfunctioning of the solution. Therefore, in this case the material properties are defined-fixed. These designed-fixed elements should not be changed in the new context and it is important to communicate them in a precise and exhaustive way.
    - The **contextual** elements are the real field where open solutions find their expression. We refer in this case to elements that need to change, in order to fit in the new context of use. For example, in the assistive device to play the recorder the shape, dimensions and proportions of the B component are based on the shape of the user's hand, thizs are therefore contextual variables. In this case the listed Attributes should change according to the user, in order to function properly. These contextual elements should also be communicated precisely, but in an open manner, for example not communicating any final dimensions, but the procedure needed to obtain them.
4. Define the soft design attributes, starting from the function of the existing solution. Can the function change? Which means, if the solution can be used by the same person to solve other problems. For example: the Seating device is meant to be a transportable one, for short periods, but can be used at home or at school in the same way.
5. Define the users' need. Can the need change? For example: if the solution is meant for paralyzed persons, but also weak ones can find it useful, then the need

can change. Again referring to the seating assistive device, being a light and easily foldable seat, the product can be used by other children, even without cerebral palsy.

6. Define if the overall product is more contextual or fixed, and sketch future up-scaling scenarios according to this aspect and to a potential volume of users (mainly: how big is the panel and how diverse?). Motivate your ideas. For example: the device to play the recorder for a person with an amputation potentially addresses low volumes of users (highly specific need) and mainly contextual (inner diversity of the potential users).

Once all the possible design attributes are identified and classified, there are many steps that can be taken, depending on the situation. In this study we don't present any up-scaling process, but in the next **Study 4** we communicate all the projects to other stakeholders using the form obtained as result of this study.

5.16. Discussion

This study focuses the attention on design solutions made for one person and the possibility of opening them up in order to facilitate re-appropriations cycles, meaning with this changes in their Attributes. These changes are important in situations where high variability between users can lead to malfunctioning or product failure. This need, which is clear for assistive technology, can have implications in terms of sustainability, personalization, emotional bond, value proposition, etc. also for other products categories.

The process of categorization of the design attributes (*contextual*, *undefined* or *defined-fixed*) sees the importance of a first iterative design cycle where a co-generative process is undertaken by all the relevant actors. Such a co-design process is similar to the one needed to approach customization/personalization solutions, but some fundamental differences should be highlighted. Here there is no intention of defining beforehand the possible configurations (as, for example, a set of options) because their definition should raise from the context of use.

Finally, even if we recognize how these solutions can find their realization thanks to the adoption of digital technologies typical of open design, we do believe that their openness should not be limited to that. In certain cases, for example the Seating Assistive device, the need is spread to the point of justifying high volume of production. We see possibilities of leaving *spaces of freedom* for the re-appropriation of the products (by changing the contextual attributes) even when adopting standard non-digital and high volume production techniques. This implies that the proposed solutions should be up-scaled by adopting design strategies where meaningful imperfections in the design allow and even sustain design-after-design dynamics.

5.16.1. Open-ended Design, a new definition

For these reasons, a new definition is introduced which shifts from *open design solutions* to *Open-ended Design outcomes*. An Open-ended Design (OeD) is seen as a project able to change, according to the changing context. Open-ended Design can also be defined as suboptimal, error-friendly (Manzini, 2010), unfinished, Wabi Sabi (Juniper, 2011) contextual, context-dependent and is characterized by its inner flexibility due to the voluntary incomplete definition of its features, also defined as its Imperfection.

Whilst this concept is grounded in software development (i.e. Wikipedia programming system is explicitly inspired by the Wabi Sabi approach), it is still harder to transfer it into hardware and low-tech solutions. In these solutions, the sub-optimality of the design itself might serve as trigger and facilitator for re-appropriation cycles. We use the term "voluntary" in this definition, which might be substituted also by conscious or intentional, to highlight how this research focuses on intentionally made Open-ended Design solutions. At the same time, we acknowledge as every object is, once put in the *real world* (from its own production to the end of life, and second life) open-ended per definition (becoming a *ultimate particulars*) (Nelson & Stolterman, 2012)(Stolterman, 2008). But this happens in a non-intentional way, at least from the designer perspective. Another important term that should be highlighted is the "ability" to change, which underline the knowledge of how we can intentionally support potential and unpredictable changes, without forcing them. This definition gets close to the definition of opened design (Sinclair, 2006) "those whose original specification and/or design may be changed with direct consumer input". But while this refers to the NPD (New Product Development), we believe that Open-ended Design can only become manifest in time and in the final context of use. Furthermore, it can be applied as a learning method of non-intentional dynamics happened after-design. A final important clarification is that the whole research here presented is focused on how to create and support intentionally made open-ended solutions, but acknowledges the possibility of Non Intentional Design (NID) re-appropriations cycles (Brandes & Erlhoff, 2006)(Wakkary & Maestri, 2008)(i.e. ernestooroza.com).

To achieve our results, we engaged into a research through design, based on constant co-generative processes. Many designers and users were involved into this explorative process. We started with no hypothesis and we tried to learn from our observations and interviews, using a highly iterative approach that led to the presented model. We don't consider the model final. This participative aspect is a strength of our research, but also led to weaknesses related to complexity, non-replicability and difficulties of analysing all the data in univocal way. Another limitation of this study, which is intrinsic to it, is the limited presence of follow-ups and tests of our model. This is due to two main factors: the consistent need of resources in order to up-scale and replicate products and the need of time, in order for some changes to happen.

Strenghts	› After a co-generative process it is possible to anticipate on what changes and what conserves in the design outcome › A better understanding leading to the new definition of Open-ended Design › New categorization of the design attributes (fixed, contextual, etc.)	› It is not always meaningful to focus the analysis of sub-components, since every sub-component can deliver multiple functions › Quite rigid structure and nonintuitive steps of the modules used	**Weaknesses**
Opportunities	› Communicate this information to others in order to support re-appropriation processes › Introduce the modules as learning tool during the design course to trigger active reflections on the role of certain design choices	› It might be perceived as a problem solving procedure rather than an open learning and reflective tool › It might lead to uncritical upscaling, since a critical view on the obtained information is always needed	**Threats**

Table 5.11. Synthetic SWOT of Study 3 and relation with future studies

5.17. Conclusions and future studies

This study reports the first step of a bigger project that sees the creation of Open-ended Design solutions as crucial for satisfying communities with shared, but yet diverse needs. Here, only the translation from contextual design (for one) into Open-ended Design was explored. First, thanks to an observational phase on another independent project (D4E1), different kind of design attributes were identified and defined as products' attributes, both hard and soft. Secondly, these attributes were listed and characterized according to the need to remain open-ended, which means intentionally undefined. This excercise has been applied only at the end of the design process, on the products resulting from the course previously described.

Thanks to this, the result of this experiment is a model to support designers while opening-up their designed solution has been developed. The proposed model, which has not prescriptive nature, helps in identifying the relevant contextual design attributes. This means that these attributes will potentially need to be changed in the context of use, in order for the product to function properly. The designer should therefore leave these attributes open and a reasonable balance, between undefined and defined, contextual and fixed elements, should be found. In other words, in this study we mainly answer the question "What could or should change, with the changing context?" by iteratively analysing 36 design outcomes (the completed modules can be made available on demand).

With this research we attempt to identify a space of freedom for the product in order to change thanks to the context of use. This freedom can be seen as an imperfection of the project but, as stated for Ambiguity (Gaver et al., 2003), this should not be considered as an excuse for poor design. We suggest designing with meaningful imperfections, which means to achieve a deep understanding by adopting co-creation processes and by engaging in attempts of anticipating where the Open-endedness should lay. The model can also give inspirations with regard of possible business model and up-scaling strategies, remaining within the Open-ended scenario.

Next studies will follow the up-scaling of the previously analysed projects. They will refer to possible *mechanisms* and *strategies* to transfer such open-endedness into commercial products, and not instructions. In this way future studies should focus on "How could these attributes change, with the changing context?".

CHAPTER 5, Study 4

UP-SCALING CONTEXT-DEPENDANT OUTCOMES

Study 4 is reporting on a series of different original design cases developed between the years 2015-2016. In the previously introduced studies we explored how to create unique products using a bottom up and inclusive approach, and how to openly share the end result with different communities. Afterwards we explored how to identify and anticipate possible design attributes that need to change, in order for the product to remain fitting for the specific contextual needs (lenses Why, What, How Much and How Many). Thanks to these studies it was highlighted as one of the main remaining challenge consists on the up-scale of such solutions into the market. Goal is to understand how can designers re-appropriate and up-scale projects, firstly created by other designers for a specific context and a specific user, to industrial products able to change in a way that is anticipated and supported by precise design decisions. In other words, in this study we explore with more detail the **How lenses**, both in terms of mechanisms and strategies. This study has been never previously published and its main structure is as follows:

5.18. New products development
- 5.18.1. End users' innovations
- 5.18.2. Problems in distributing end users' innovations
- 5.18.3. Goal of Study 4

5.19. Research method

5.20. Results
- 5.20.1. Test 1
- 5.20.2. Test 2

5.18. New products development

The material world created by industrial designers is meant to empower users, enabling new possibilities sometimes previously impossible. As written by Nelson "we must design, because we are not perfect" (Nelson & Stolterman, 2012, p. 13). In reality, sometimes products surrounding us don't empower us, they rather "erode our sense of independence" (McDonagh & Thomas, 2010) while transforming simple actions of our daily activities into hard if not impossible ones. For example, to open water bottles constitutes a struggle for many users (also without specific physical impairments) since the plastic caps are hard to grasp and require a certain force in order to be opened. Many assistive devices have been created to solve this design problem but, sometimes, they are not efficient enough. This leads to escalating frustration, use of resources and also potential danger for the users. Despite the fact that the overall performance of today's Assistive Technologies keeps getting better, it is still difficult to embrace the diversity of end users' individual needs, situations and contexts.

Often, the industry attempts at solving the problems of such heterogeneous group of people, unified only by the common need for a certain product, with one-size-fits-all approach materialized in mass-produced universally designed aids. Universal Design "is not a specialized field of design practice but an approach to design, an attitude, a mindset conducive to the idea that designed objects, systems, environments, and services should be equally accessible and simultaneously experienced by the largest number of people possible." (Erlhoff & Marshall, 2008, p. 419). The larger the group the higher the inner diversity, but also the higher the pieces needed to be produced. This puts pressure on companies which often result in an erosion of the primary goal of product *fit to one*, choosing instead to align to the average *fit to all*, which doesn't necessarily fit perfectly anyone (Nelson & Stolterman, 2012)(Braun, 2002). Furthermore, due to the progression and natural change of the users' conditions also fitting devices might, at one point in time, become less fitting (note that with fitting we refer to both tangible and intangible aspects of the device).

5.18.1. End users' innovations

Under this perspective, we could identify two different dynamics aiming at solving the same frustration caused by unfitting products (which we can define as problem symptom): bottom-up realizations and top-down standard commercial products. These two approaches are deeply connected by a constant dialogue, as represented in **Figure 5.21**.

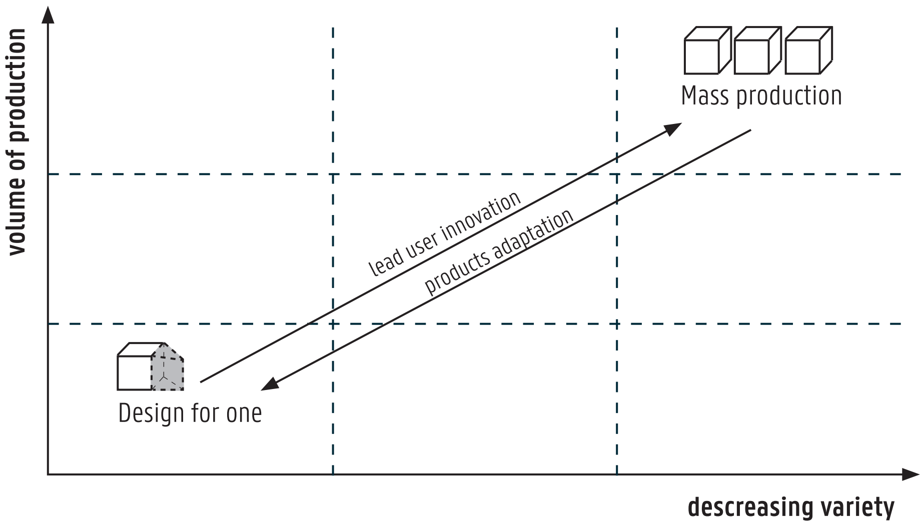


Figure 5.21. Dynamics of up-scaling personal innovations and adapting mass produced solutions

In fact, we could recognize the emergence of design for one projects (i.e. DIY, hackings, etc.) as a reaction or to lacking or to unfitting commercial solutions (Couvreur, 2016)(Couvreur & Goossens, 2011). This phenomenon can be defined as *products' adaptation*, *end-user development*, *design-after-design* or *community-driven development* (Binswanger & Aiyar, 2003)(Ostuzzi, Couvreur, Detand, & Saldien, 2017)(Fischer & Giaccardi, 2006)(Lieberman, Paternò, Klann, & Wulf, 2006). Sometimes the actors of this dynamic get systematically involved during the design process conducted by companies, and/or their inventions become a trigger for products' innovation.

This effect, the innovation paradigm represented in **Figure 5.22**, is defined as consumer, user-developed or lead users innovations (Von Hippel, 2005)(Von Hippel, Ogawa, & de Jong, 2011). Some studies focus on disabled users as potential lead users (Conradie, Herregodts, Marez, & Saldien, 2016)(McDonagh & Thomas, 2010), as they face challenges in the material world that might not be evident to others. Anyhow, the design for one projects undergo an up-scaling process, meaning "the practice of introducing proven interventions into new settings with the goal of producing similarly positive effects in larger, more diverse populations." (McDonald, Keesler, Kauffman, & Schneider, 2006, p.15). Both solutions can be seen as symptomatic ones, since they mainly focus on the problem symptom before mentioned. The dialogue represented in **Figure 5.21** can therefore foster innovation, but can also create a tension that, by continuing in time, might divert the focus from more fundamental and radical solutions (Braun, 2002).

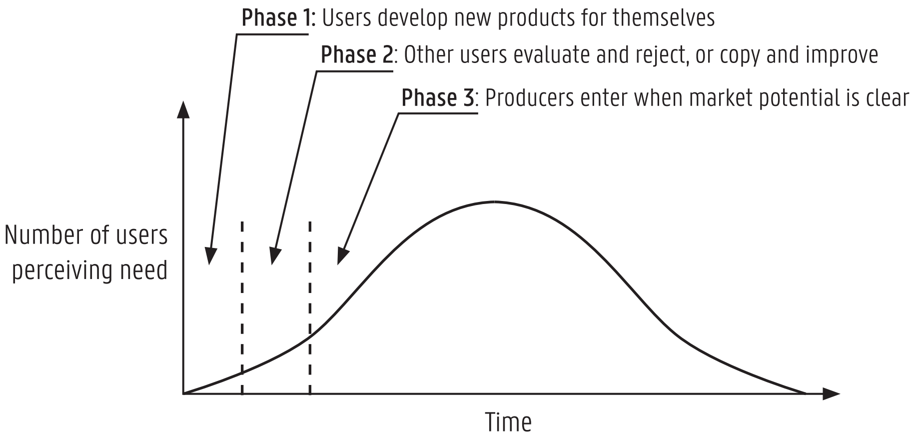


Figure 5.22. A new innovation paradigm, adopted from von Hippel (Von Hippel et al., 2011)

This dynamic can be better understood, in a simplified version, by adopting two system archetypes as reference model. Specifically, we decided to use models that represent the tension between a symptomatic solution and a fundamental one: *shifting the burden* and *fixes that fail*. In synthesis, the model shows that a problem symptom can be either solved by using a symptomatic solution or a more fundamental one.

If a symptomatic solution has been adopted this can lead to a reduced pressure to find more fundamental ones, and at the same time can be seen as a *fix*, which might have unintended consequences that ultimately increase the problem symptom again (but, in time, which is expressed with the symbol //). In this specific case, the rejection and abandonment of devices (*problem symptom*) increases the need for both bottom-up and top-down solutions, which momentarily decreases the problem symptoms itself.

At the same time, these symptomatic solutions divert attention from more fundamental and long lasting ones and even create certain side effects, for example the diffusion of these solutions in a way that makes them hard to re-appropriate, increasing again frustration, rejection and abandonment. In time, by not focusing on more fundamental solutions we are, after all, increasing the problem symptoms.
With *fundamental solutions* we refer to diffused solutions able to be fitting for each user, and not only for one or for all (referring to the ideal and average users). Of course, there is no definitive answer on how these solutions should be designed and sold, but it is clear as -once again- one crucial aspect lies in the ease of re-appropriation of such solutions, in order to make them fit the specific context of use. These dynamics are represented in **Figure 5.23** and **Figure 5.24**.

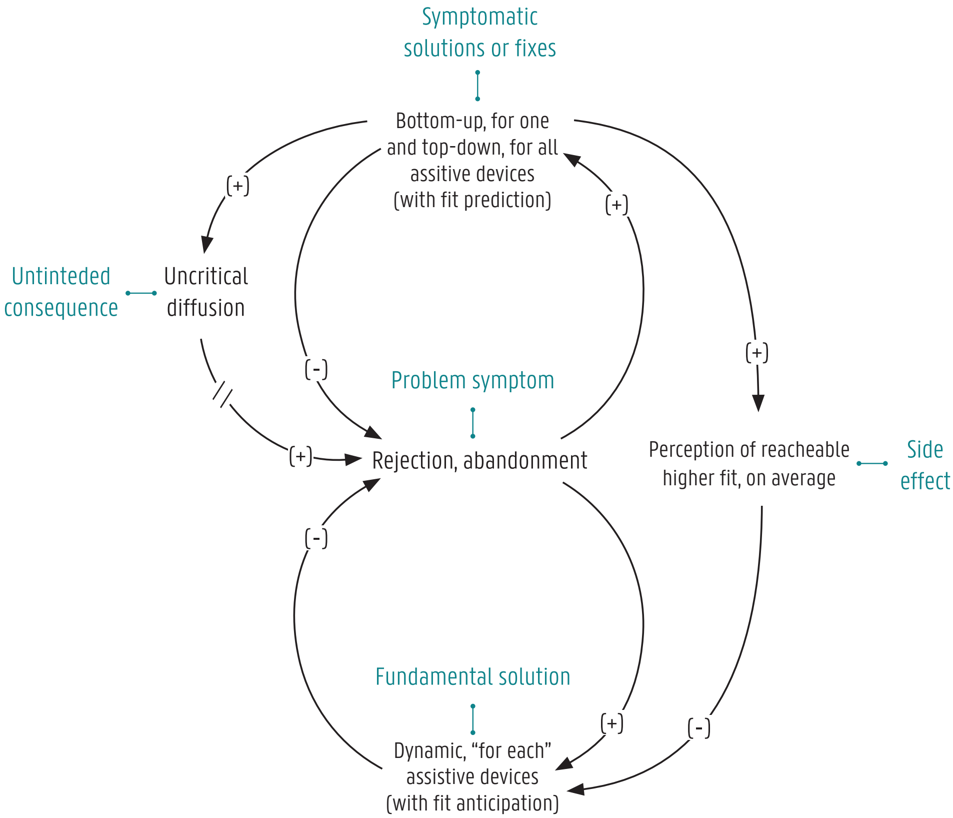


Figure 5.23. Representation of some dynamics occurring with regard of assistive devices

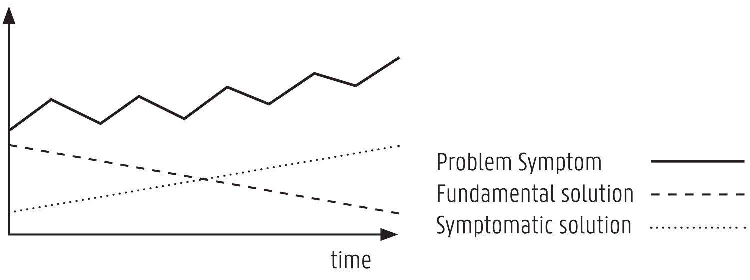


Figure 5.24. Behavior over time. Adopted from (Braun, 2012)

5.18.2. Problems in distributing end users' innovations

Good design solutions meant for one can be either re-appropriated in horizontal manner, as peer-to-peer diffusion, or in a vertical one, through up-scaling. Focusing first on the peer-to-peer diffusion we can highlight several problems: first of all the typical consumer-innovator is male, highly educated and with technical background

(Von Hippel et al., 2011). This shows as to innovate on product level specific conditions are needed, which are not commonly diffused among the average population (i.e. even if digital production triggered the so-called *desktop revolution*, this doesn't imply that everyone has a 3D printed in his/her own desk or knows how to use it). Secondly, even if user-innovators normally don't protect their ideation, still only a fraction of the available solutions face actual diffusion (De Jong, Von Hippel, Gault, Kuusisto, & Raasch, 2015)(Von Hippel et al., 2011). This underlines as "free revealing does not imply that others will adopt what has been freely revealed." (De Jong et al., 2015, p. 1857). These two limitations confirm the view reported in the article *Closing in on open design*, "while there is some evidence for the willingness of people to contribute high-level thinking for little or no return, the evidence for a more egalitarian, vernacular approach is just not there." (Cruickshank & Atkinson, 2014, p. 368). For these reasons these innovations can represent a market failure, according to J. De Jong (De Jong et al., 2015). "When innovation diffusion involves free revealing rather than market transactions, innovators can be expected to invest less than might be socially desirable to inform or assist others to adopt, even when their innovations would be highly valuable to others – a market failure." (De Jong et al., 2015, p. 1856). And "only a minority of innovations deemed to be of value to others did in fact diffuse, and diffusion effort was seldom exerted by innovating individuals. In the case of peer-to-peer diffusion, we find that there is no significant relationship between the likelihood of diffusion and the general value of the innovation." (De Jong et al., 2015, p. 1861).

About up-scaling diffusion, we can list some limitations highlighted by Binswanger (Binswanger & Aiyar, 2003): high costs, hostility of settings and potential partners (as stated by von Hippel hostility can come in form of intellectual protection by the companies themselves against their own consumers innovators) and lack of scale up logistics, for example in identification the community of reference, to check the value of the solution in terms of potential empowerment (Binswanger & Aiyar, 2003) (McDonagh & Thomas, 2010). Finally, a common problem can be highlighted: adaptation to local context might be missing. Not surprisingly *consumer innovators* start by focusing on their own needs, or on the ones of close and known stakeholders, and rarely on others' needs. These *for one* solutions are often shared or even up-scaled as they were design in the context of development, which can be defined as uncritical diffusion.

5.18.2.1. Uncritical diffusion

"What appears to be best practice in one setting may be poor practice in another. While it is useful to draw lessons from successful experiments within a country and from global experience, project design must be adapted to the local context." (Binswanger & Aiyar, 2003, p. 33). The bigger volume of users to which the new up-scaled design solution is proposed leads automatically to an increased variations in the complex products' ecologies (Forlizzi, 2007). The importance of considering the new context while scaling-up certain interventions is considered fundamental (McDonald et al., 2006). Among these considerations we find the ones regarding the meaning and value of the solution for the new context, which is often not in the engineering itself, but on the novel function that the prototype developed by consumer-developers, and that other stakeholder already demonstrated that they want (Von Hippel et al., 2011). To conclude, the upscaling process cannot focus only on increasing the volumes, or on perfecting the engineering, but it should be a multidimensional approach (McDonald et al., 2006). "When the heuristic does not hold in every dimension, the simple, linear "uncritical diffusion" model that many intuitively associate with scale-up clearly no longer applies." (McDonald et al., 2006, p. 16).

5.18.3. Goal of Study 4

With this in mind, **Study 4** triggers and observes up-scaling dynamics of design solutions, previously meant to be for one. It should be seen as continuation of **Study 3**, since part of the analyzed case studies in **Study 3** serves here as starting point to be scaled-up. Aiming at a more broad design for diversity (Cappelen & Andersson, 2013). Its goal is to try to keep these solutions meaningful for new different contexts, open for diversity of users and contexts, which in other words means to decrease the uncritical diffusion. Many questions support the present experiment: is it possible to recognize certain values in these *for one* solutions, that are interesting and deliverable also to other users? How does this re-appropriation from others and for others occur? What are the skills needed and the contextual aspects playing a role in this process? In fact, as suggested by De Couvreur (Couvreur, 2016) and De Jong (De Jong et al., 2015), by giving more attention to the dissemination and reuse of open innovations, it might be possible to better understand what are the disturbances occurring when upscaling these contextual solutions. Finally, which are the best mechanisms and strategies (see: relation with the ten lenses) spontaneously adopted by designers in order to keep the solutions as open as possible, in order to respect and protect the inclusion of the (out-of-control) contexts targeted by their final solutions?

5.19. Research method

To explore the previously mentioned questions we conducted two experiments, consequent to one another. The experiments focus on further developing cases meant to be for one, considered relevant meaning "product design outcomes that focus on enhancing quality of life by improving the user experience of everyday activities in tangible ways (such as, reduce/remove stigma, build in delight factors, use design and materials innovatively).” (McDonagh & Thomas, 2010, p. 186). To conduct the tests a research through design research method was adopted, mainly based on data collection (outcomes of the tests, in form of original projects), data analysis and critical discussion. The analysis was developed mainly by clustering the different outcomes, especially looking at them through the use of the ten lenses. The approach is therefore qualitative and explorative in nature, and is here reported in a narrative way supported by the adoption of many images and tables. During both tests students were weekly coached by different teachers, with various expertise. Every student previously participated to the project “Design for Every(one)” learning therefore the co-design method there adopted (Couvreur, 2016). In general, students were suggested to adopt empathic research strategies, starting from building synergies with the final users and learning from them, by interviewing potential stakeholders, testing with prototypes, and gathering all the possible visual data to support their conclusions (McDonagh & Thomas, 2010).

5.19.1. Test 1

Test 1 was developed within the framework of the design course *Entrepreneurship and Innovation management*, attended by 4th year students in Industrial Design Engineering. The course focuses the attention on the creation of Small Business Projects (SBP) that, starting from a given creative solution and by defining and designing various aspects needed, aim at reaching the market. Main design aspects get summarized in form of business plan and are: technical development, production plan design, brand identity and marketing plan development, market analysis, financial calculations, etc. The course has a duration of 12 weeks and 7 teams of three to maximum four students participated.

The first week students got assigned to a specific case study, seven in total, deriving from the project Design for Every(one) [designforeveryone.howest.be], all originally created to solve the specific problem of one user. The cases have been selected by a three-members commission, covering expertise on production techniques, design and economic aspects. Also the author of the manuscript participated to the selection process. Selection criteria were: overall value and quality of the project, technical and economic feasibility, originality and potential value also for broader markets. The selected cases were first developed by certain students, and in this course assigned to other students in order to up-scale them. We refer to the projects creators as “creating team” and to the projects developers as “entrepreneurial team”. The entrepreneurial team received, apart from the projects’ general description, links to the blog where the creating team described the whole design process followed to achieve the specific design solution, for one (one example of blog: puzzelhulp2015.blogspot.be). In **Table 5.12**, the list of input projects.

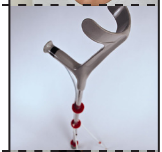
Name	Image	Description	Link + Students' name
Aid to open/close zips		The aid is designed to help a person half paralyzed, while opening and closing the sweater in shops or restaurants.	ritshulp2014.blogspot.be Fabien, Pieter Decabooter, Steffi Mussly, Steffi Eeckhout
Aid to open/close jars		The aid is designed to help operators of one nearby factory to securely close the produced jars.	bokaalhulp2015.blogspot.com Carine, Robbe Terryn, Lennart De Meulemeester, Jill Gremonprez
Aid to build puzzles (fine motoric moves)		This device is created to help people with fine movements limitations, while handling the small pieces of a puzzle.	puzzelhulp2015.blogspot.be Heleen Bartsoen, Thomas Gru-wez, Miguel Di Az, Sien Roose
Aid to keep glasses in position		The aid is designed to keep the glasses in their position in case of seizures, also limiting possible injuries occurring in this occasion.	brilhulp2015.blogspot.com Yoeri, Charles Degeyter, Guillau-me Segaert, Charlotte Deman
Self-standing crutches		The aid aims at improving the stability of the cruthces (stability needed once the crutches are not in use).	handsfreekrukken2009.blogspot.com Sharon, Karen De Potter, Michaël Colson, Esther Declercq, Tille Vanrobaeys
Bag for helping dogs		This project employs bicycle bags to allow helping dogs in the transportation of small goods.	honddraagtas2010.blogspot.com Hilde, Veerle, Basil Vereecke, Levi Algoet, Hilde Ramboer
Rain protector for wheelchair users		This device is already mounted on the wheelchair and, when needed, can be moved in the best position to protect the user from rain.	regenkap2010.blogspot.com Greet, Ben Ebben, Tine De Pauw, Jorrit Sevenants, Griet Castelain

Table 5.12. Overview on selected cases as input for Test 1

Furthermore, every entrepreneurial team received as additional input to their design project the module, result of **Study 3**, filled in by the creating team. In this way, some potentially relevant information emerged from the first co-design process were already highlighted (specifically: the what, why, how much, how many, lenses were already addressed). In **Figure 5.25** the summary of inputs received.

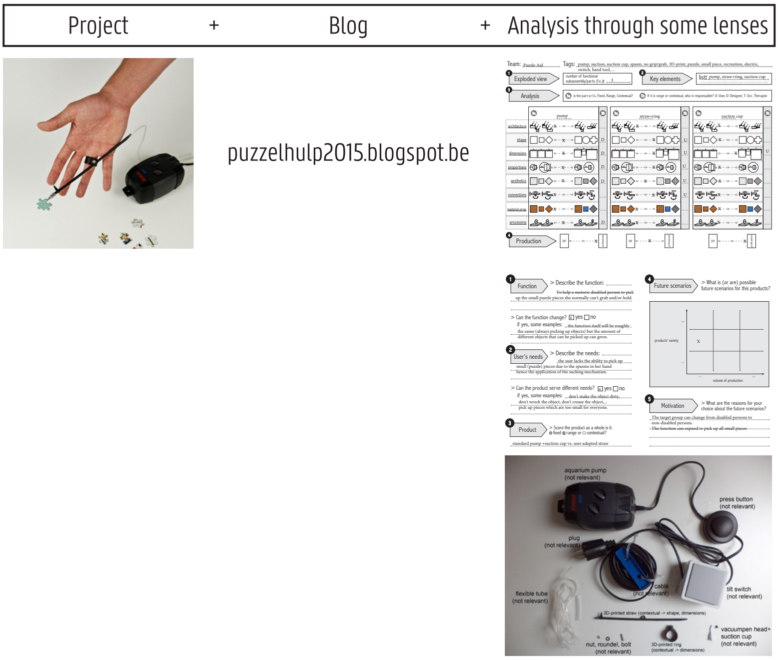


Figure 5.25. Visual example of inputs given to the entrepreneurial team (in figure, the example is referring to the aid to build puzzles)

Students had to developed small-scale specific interventions in order to highlight the most suitable up-scaling procedure. In order to do so, students were coached weekly by a team of teachers (focusing on design, technical, financial aspects), but no specific focus was given to Open-ended Design, apart from the module filled in by the creating team and where all contextual design aspects have been highlighted. Required deliverables are: working prototype, marketing items (logo, business cards, etc.) and business plan. Finally, students compiled again the module developed in **Study 3**, in order for us to highlight what conserved and what changed thanks to this scale-up procedure.

5.19.2. Test 2

Test 2 comes as consequence of Test 1. In fact, if the upscaling process followed in

Test 1 showed that it is indeed possible to find different values on the proposed, for one, solutions, it also proved that the tendency of some designers is to upscale these solutions by closing them up, following a more traditional path. Also, some contextual information gets lost or on the contrary they get interpreted as of universal value, leading to more closed end results. Only some cases reached a more open scenario, as explained afterwards.

To better understand this dynamic, we developed Test 2. Also in this test the two involved students worked on the process of scaling-up context-dependent design solutions but in this case they were free to choose the solutions that they preferred (from the website of D4E1 project), resulting in the selection visible in **Table 5.13**. In this case, the students developed the project as their Master Thesis, implying that they worked alone, but personally supported by external companies (listed afterwards) and could work for an extended period of almost a year. These students were specifically coached also in terms of Open-ended Design, of which they adopted the overall method of observation, analysis and anticipation described in the next chapter reporting on Study 5.

Name	Image	Description	Link + Students' name
Seat device		This seat device is meant for kids with cerebral palsy, who need to sit in certain positions defined together with the therapists.	plooibaarzithulp2014.blogspot.be Kobejoren, Carolle Geldof, Emily Quartier, Sahin Vanneste, Jaana Caes
Trombone aid		This aid is designed in order to help the user while playing the trombone, since his forearm prostesis results not suitable for this activity.	trombonehulp2013.blogspot.com Simeon Arne Malfait, Jonas Maertens, Elien Vanhee, Suzan debuysere

Table 5.13. Overview on selected cases as input for Test 2

5.20. Results

In this section we introduce the obtained results, first describing briefly the achieved outcomes for each test, and then we cluster the same outputs according to different parameters, or lenses, in order to gather some insights useful under different perspectives.

5.20.1. Test 1

Outputs of Test 1 can be seen in **Table 5.14**.

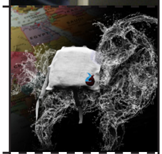
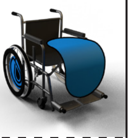
Brand	Image	Description	Students names
ZIPon IZI like child's play		ZIPon is a zipper aid for children between 2 and 6. ZIPon consist of a zipper and a magnetic strip. Thanks to ZIPon children can close their jackets by them self.	Dries Caelen Maarten Van Gestel
Enable Ensure Entrust Enable		ENABLE is a jar opener for people with Arthritis. The user places the jar on the rubber pad and pulls the lever down. The system doesn't require strong grip, northe use of two hands.	Guillaume Segaert Andreas Legiest Loes Verheyen
AMFI BOARDGAMES UNLIMITED JOY!		This game is created to support the possibilities of playing together. It decrease the stigma of people with fine movements limitations, by a design meant for all.	Thomas Gruwez Dries De Kersgieter Charles Degeyter
Odin Patch like a hero		Odin offers a solution for children suffering from Amblyopia, or "lazy eye". Our eyepatch is reusable and personalized while still cost effective.	Sanne Cools Francis Van Poucke Zino Vansummeren
MyAddOn Simply standing		MyAddOn is a small add-on, that focuses on the ergonomics of the hand and has a soft-touch material in order to avoid pain. and on the crutches stability.	Marie Van de Broek Stefan Flamand Jonas Gheysens
GH2OAT TAKING THE WEIGHT OFF THEIR SHOULDERS		The GH2OAT is a backpack designed in the first place for use with goats. It allows them to carry basic necessities such as water over long distances and rough terrain.	Robbe De Clerck Senne Van den Broeck Jeremi Vanderstichele
VOCHTECH BLIJF DROOG, KOOP VOCHTECH		Vochtech is a foldable rain protection, focusing on the fact that the legs of wheelchair users get extremely wet when driving in rainy weather.	Robbe Terryn Joeri Boi Niki Verbrugghe Enzo Martin

Table 5.14. Outcomes of Test 1

A first clear result is that every team managed to up-scale the given project, by identifying a suitable combination of all the business model parameters (value proposition, target users, key partners, etc.). All teams recognized certain values of the given product that were considered worth to be put in the market. The kind of values identified and the translations of the starting projects into marketable ones are extremely different in nature. Three main different dynamics were identified.

1. Some teams *incrementally innovated* [meaning a more trajectory-based thinking which improved existing innovations (D. a Norman & Verganti, 2012)(Erlhoff & Marshall, 2008)] the given projects mainly under technological aspects, by adding or improving some features while maintaining the overall idea and structure of the given project. This is the case, for example, of ENABLE for which the function, user and architecture of the given project was maintained (in detail: the *slot machine* kind of interaction, as students have defined it, which implies less power needed and the use of just one hand). ENABLE improved the solution in terms of openness, if compared with the input. In fact, the outcome can be used with jars of every possible different geometry (in horizontal section: circular, squared, octagonal, etc.) and of a big range of different heights. In comparison, the starting project works only on specific geometries (utilizing dedicated bottom plates to fix the jar) and couldn't close/open circular jars. A similar dynamic of incremental innovation can be recognized for the project Vochtech. In fact, the new project maintains similar choices of the starting project (i.e. function, users, materials, attachments to the wheelchair, etc.), but innovates on one important aspect: this new solution covers the legs instead of the head [innovation that, under certain extend, can be considered radical (D. a Norman & Verganti, 2012), putting this project in between dynamics 1 and 3)].
2. Some teams, after analyzing the input project and the potential market for it as it was conceived, ended-up adopting only certain mechanisms created in the first design, but aiming at completely different target users, with the same or different functions. This can be seen as a change in *meaning*, similar to a market-pull innovation (D. A. Norman, Verganti, Group, & Bio, 2012) also justified by the target users need and market dimension. This is the case for the projects ZIPon, Gh2oat and Odin. ZIPon adopts the ideas of using magnets to simplify the action of closing zips (function and mechanisms are therefore maintained), but proposes it for children instead of half paralyzed uses, as in the input case. Odin team followed a similar path: the function and the idea of shaping some product's components on the unique personal features were conserved and implemented (they adopt a malleable material that the user has to shape on his/her own face to get the right fit), but propose the solution for children having a *lazy eye* condition, instead of users having seizures. In both cases the teams recognized and improved the value of the input idea, in terms of function and mechanisms, and were able to expand the market size by addressing other users were the diversity is after all more limited. This dynamic can be seen as a typical lead *user innovation* (Von Hippel, 2005). Slightly different is the case of Gh2oat, were also the target market was completely changed. The team shifted the focus from visually impaired users to the transportation of water with the use of Ghoat in the Afri-

can region next to Sahara. The transportation done by using a backpack similar as the one given as input project, so in this case the difference is that they didn't change the context in order to enlarge the market, but following the belief that a similar same technical solution could serve important purposes also elsewhere.

3. Eventually some teams recognized the problem highlighted by the input idea, and used it as a trigger to achieve radically different solutions for it, still addressing the same target user. In the example of AMFI the starting problem was to enable persons with fine motoric problems to build a puzzle independently. The team managed to highlight two additional problems, recognized by them as more fundamental: the stigma deriving by specific solution for impaired users, and the social isolation occurring during this otherwise very social activity. For these reasons, they decided to design from scratch a board game were the design could be slightly different for every user, improving accessibility (specifically the handles of the game, produced with laser cut, could be personalized in sizes and color to address specific needs of every user). Similarly, MyAddon expanded the input problem of instability of crutches (occurring when the crutches are not used) by solving the problems of sore hands, due to the handle design, and again of stigma. They reached a completely different solution were the three problems are addressed by one project. Both can be seen as radically innovating technical idea by recognizing the main value in different meanings delivered by the input products, and not by their technical aspects (D. a Norman & Verganti, 2012). Finally, as mentioned previously, the change of focus occurred in Vochtech could be also interpreted as radically changing the outcome.

Dynamic	**Meaning change**		**Technology change**
	in user	in function	in mechanism and/or strategy
1	unchanged	unchanged	unchanged but **improved**
2	**changed**	unchanged*	unchanged but **improved**
3	unchanged	unchanged but **expanded**	**changed**

* i.e. in Gh_2oat the function is to tranport things, as it is in the input project. The change of what gets transported (from common goods to water) is not considered here as a change in the overall function. The same applies to Odin and ZIPon.

Table 5.15. Synthesis of the three highlighted dynamics, terms used for the columns are defined starting from Verganti, Norman (2012) (D. A. Norman et al., 2012)

To understand more in detail what changed and what conserved after the up-scaling process, the two modules filled in by both creating and entrepreneurial team were put in comparison. In general, in the products following dynamic 1 the contextual variables were diminished, while in dynamics 2 and 3 were mainly respected. One example can be seen in **Figure 5.26**.

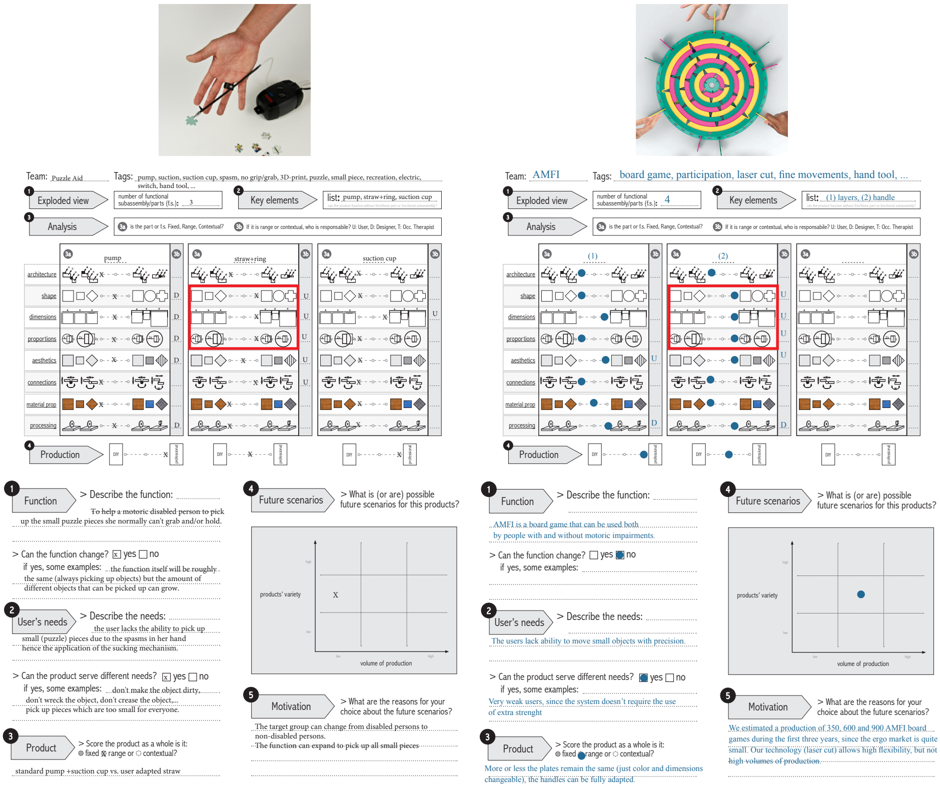


Figure 5.26. On the left side the input analyzed product, on the right side the output analyzed one. Some points conserved after up-scaling

5.20.2. Test 2

In Test 2 we can see some different results. The two students were in fact asked to personally undergo the whole process of understanding the contextual variables (they didn't receive any filled form). In this way, and thanks to the longer time available, both engaged in extensive observations of the current scenario and in detailed users test on the produced functional prototype. This resulted, quite interestingly, in a radical switch of the main focus. In fact, if the input products were examples of contextual solutions (or symptomatic solutions, as defined before) designed for one, both students decided to move their focus to one earlier steps of the design process. Instead of proposing a solution that could serve specific users, they proposed flexible systems able to support the professionals or the users themselves in finding the perfect fit. In **Table 5.16** the description of the two end results developed, the one of Robbe Terryn, in collaboration with Yannick Christiaens (University of Gent) Ann Dejager and Lieven de Couvreur (Howest), Lode Sabbe (University of Gent) and the one of Niel Liesmons, in collaboration with Enrico Bassi (opendotlab.it) and TOG Milano (togethertogo.org).

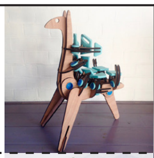
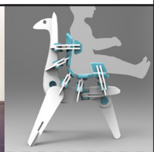
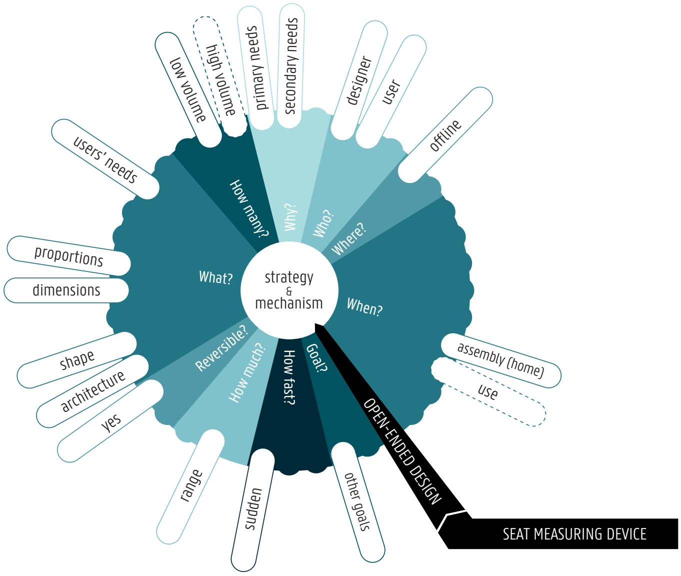
Images	Description	Students names
 	This tool enables occupational therapists to dynamically measure and quantify the 3D geometry of a child's pelvis area as well as how it should be supported. This data can then be used to produce high quality custom assistive seats using rapid manufacturing techniques.	Niel Liesmons
 	This toolkit faciliates users and professionals while designing a new prosthetic forearm for specific uses (in figure: use of a wrench). Its modular structures allows constant adapations during the testing phase, and facilitates the reading of the data needed for the production of the final device.	Robbe Terryn

Table 5.16. Outcomes of Test 2

Both projects aimed at simplifying the process of creation of unique products. In fact, in both cases the real problem occurred when the device had to be created: since the measuring was occurring in a laboratory environment and only on the spot, the device often resulted as inefficient once brought home from, or to other contexts, the user. This normally resulted in the need for many iterations, with increased time and money use. Dynamic measuring systems appear to be, according to the students, a more fundamental solution to overcome the tense dialogue occurring between DIY solutions and standard ones. In fact, also thanks to user tests developed during their studies, we could notice a higher product fit and a shorted time needed for the measurement phase. The two systems have been analyzed by the researcher through the ten lenses, as shown in **Figure 5.27 (a)** and **(b)**. In figure the "High volume" answer is highlighted with a dashed line with the meaning that, even if these two solutions adopted digital production techniques, the openness laid on the way they were designed rather than produced, allowing a further upscaling process to high volume and standard production. Even if similar as strategy, meaning the idea of proposing a more flexible and especially dynamic measuring tools to support the creation of the final device, we can still find some differences, for example: the measurement of the seating occurs when the users uses the chair, which mean that the measurement is done in parallel to this other action. On the contrary, for the forearm device the user has to actively adjust piece by piece the product, in order to find the best fit. Secondly, while the seating measuring device embraces different users' needs while always serving the same function the forearm device can allow the same user to deliver different function (i.e. using a wrench, a comb, a fork, …).

(a)



(b)

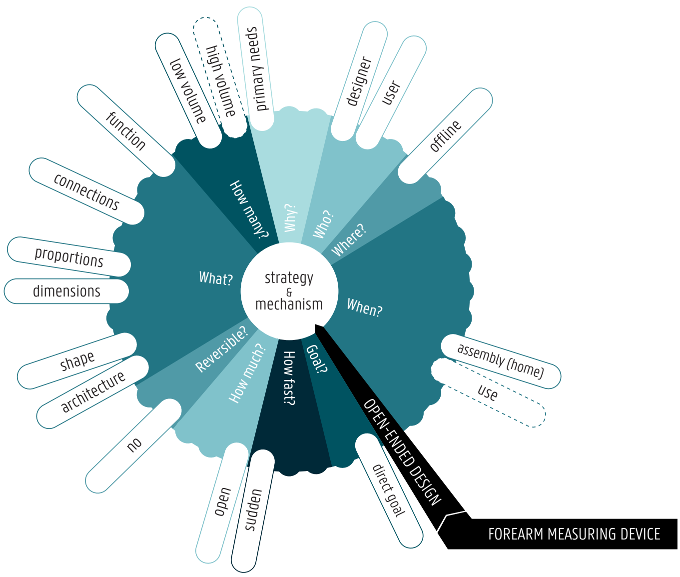
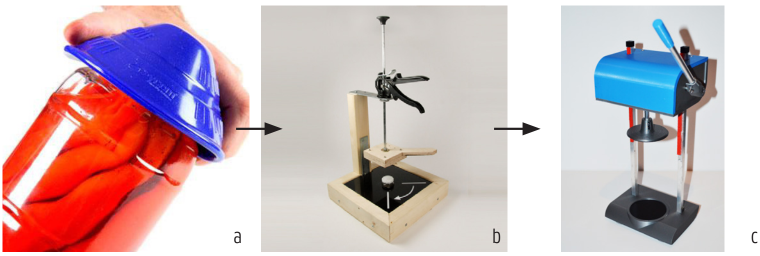


Figure 5.27. Ten lenses combination for (a) seat measuring device and (b) forearm measuring device

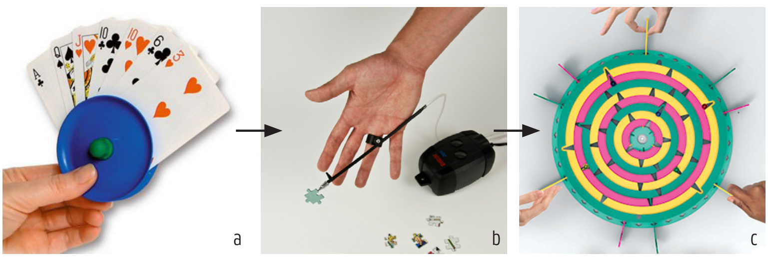
5.20.3. Combined results

Finally, we would like to introduce here some combined results (Test 1 and 2) about the upscaling path and its relation with particular set of mechanisms and strategies adopted by each team. In **Figure 5.28** we see a visual sequence of three steps: (a) an example of commercial benchmark for all, (b) the input projects output of D4E1 and (c) outcomes of Test 1 and 2.

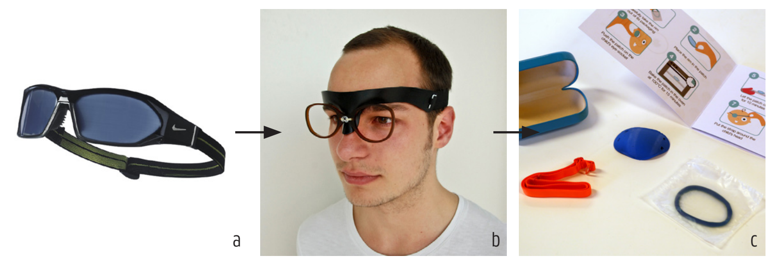
(a) Normal zip (image from pickupmyrepair.co.uk); (b) design for (every)one solution; (c) up-scaled solution



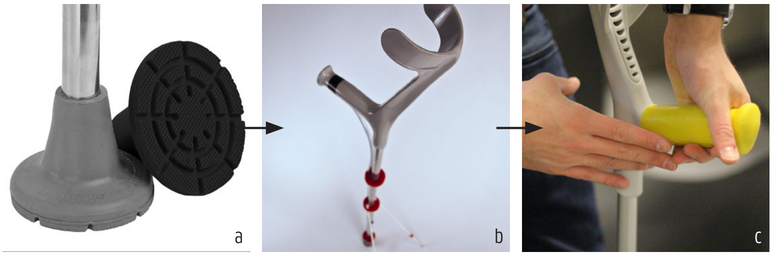
(a) Commercial Dycem© Jar Opener; (b) design for (every)one solution; (c) up-scaled solution



(a) Commercial Peta Easy-grip card holder; (b) design for (every)one solution; (c) up-scaled solution

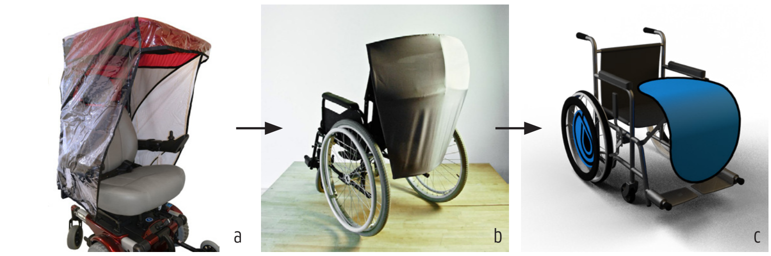


(a) Commercial Nike SPARQ Eyewear; (b) design for (every)one solution; (c) up-scaled solution

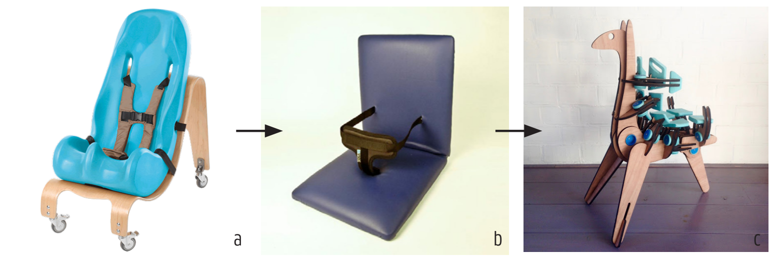


(a) Esenium Conteras Xavi-tac support; (b) design for (every)one solution; (c) up-scaled solution

(a) Commercial product (from: topdogsupply.com); (b) design for (every)one solution; (c) up-scaled solution



(a) Commercial rain protection (from: easymedonline.com); (b) design for (every)one solution; (c) up-scaled solution



(a) Commercial Soft-Touch® Sitters (from: specialtomato.com); (b) design for (every)one solution; (c) up-scaled solution

(a) Commercial i-Limb Ultra (from: touchbionics.com); (b) design for (every)one solution; (c) up-scaled solution

Figure 5.28. Overview of all cases: from commercial benchmark, to design for one, to up-scaled solutions

The examples of benchmarks are mass produced and represent often a Universally Designed aid. Nevertheless, according to some specific users and co-designers of the Design for every(one) solution, their design resulted in various problematic aspects. In this way, we can read the second column as reaction to a specific item, *for all,* resulting in a new design, *for one*. This dialogue was previously described and is represented in **Figure 5.21**. The third column, outputs of this study, tries to distill the value (whatever it is, according to the students) from the first column and the strategy used for reaching different up-scaling landscapes: sometimes getting back to a design for all approach, sometimes dealing with personal manufacturing, and sometimes getting spontaneously closer to more Open-ended Solutions. This different up-scaling strategy, and Open-ended solutions are visualized in **Figure 5.29**.

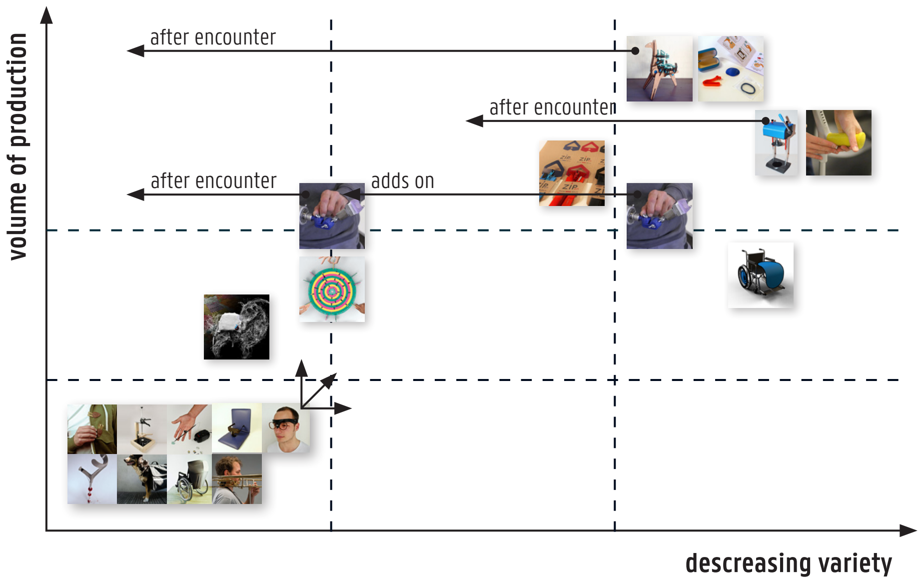


Figure 5.29. Up-scaling strategies, and movements inside the landscape of possible design solutions

As visible, two of the projects, ZIPon and Vochtech, don't show any anticipated change occurring because of the change of context (they in fact propose a more traditional customization). For all the others, after or during production, it was possible to reach more change in a (more or less) out-of-control way. To summarize, the most open-ended products followed the two paths represented in **Figure 5.30**. This shows as the majority of solutions up-scaled the product to higher volumes by adopting more standard design which, meaningfully thought, still enabled re-appropriations after encounter. This can represent a good strategy to cover the paradoxical area of high variety and high volume of production.

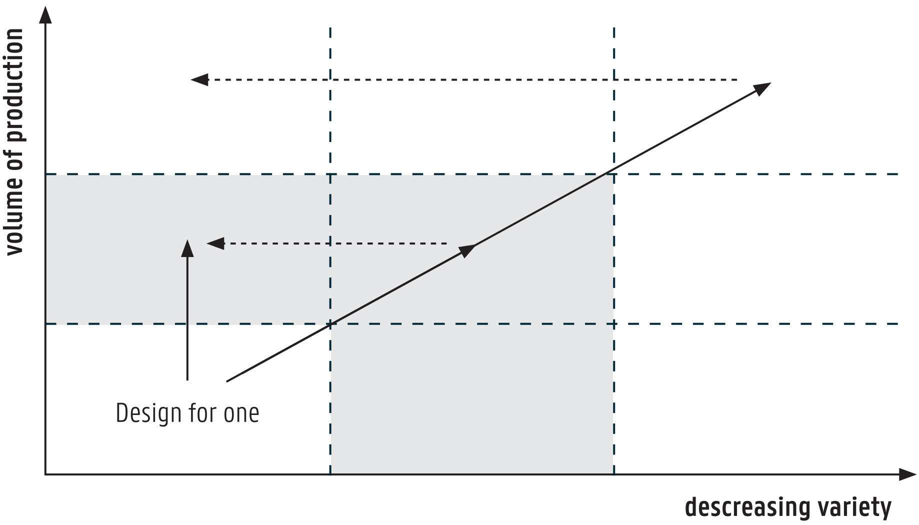


Figure 5.30. In order to achieve openness student flowed the paths sketched in figure. Highlighted in grey the Long Tail area of the landscape

All the 5 projects "moving" in the matrix, can be then considered Open-ended, being able to anticipate possible changes occurring thanks to the changing context of use. For this reason, it is possible to better understand how they embrace change, by applying the whole set of lenses, with the purpose of highlighting the different strategies and mechanism adopted. On the other hand, the two products Vochtech and ZIPon, don't foresee any possible change occurring to their product after designing and producing it. In the following pages, in the sum of all the results, both under the ten lenses in **Figure 5.31** and strategies and mechanisms, in **Table 5.17**.

5.21. Discussion

This Study has a qualitative nature. The here described up-scaling process is, in fact, very complex and requires time and resources, not fully available at the time of conduction of the two tests. Our conclusions are therefore of general nature, and will need further investigations. We can anyhow state that results show that every design for one can be valuable, under very different perspectives. Sometimes the proposed input could be up-scaled almost as they were initially proposed, increasing their product variety after production with very simple strategies. This depends on the fact that the variable design attribute belongs to the non-human domain, and appears easier to be anticipated (in form of customized products, for example) and to the creation of stable and more unstable configurations (Heylighen, 1992). But important to notice is that diversity can be seen in the products of the different contexts (i.e. jars for Enable) or in the human-related aspects (i.e. hands and motoric skills for Amfi), but this is always a choice of the students, since both were always possible.

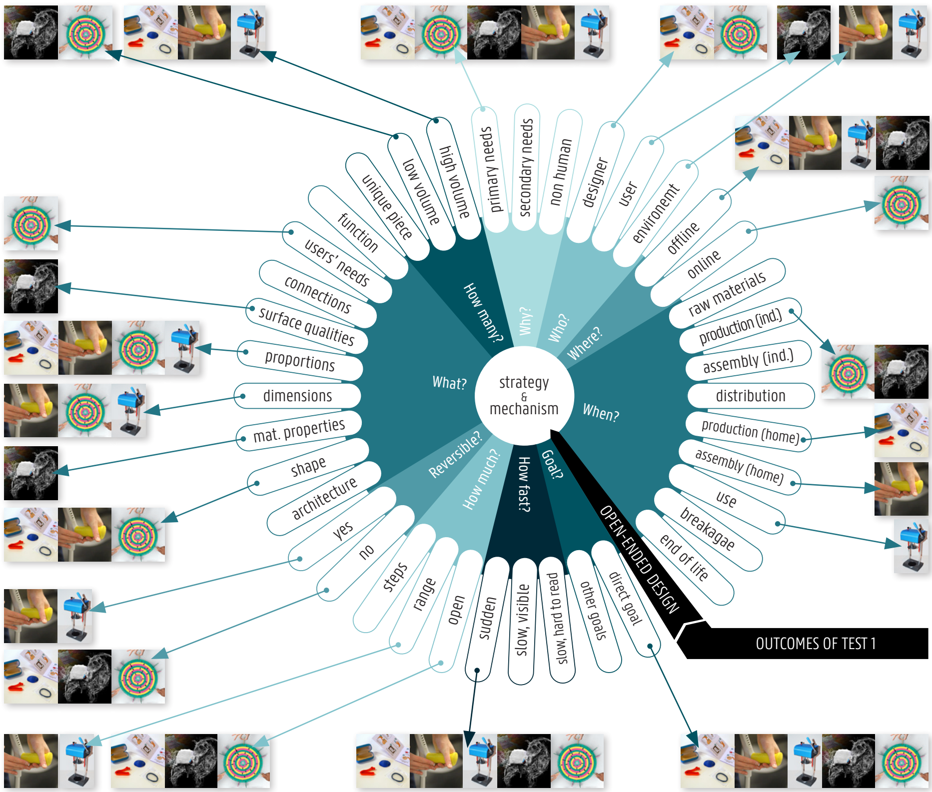


Figure 5.31. Ten lenses combination for outcomes of Test 1

Some input solutions proved to become potentially useful for other users as well (i.e. ZIPon, Odin) which matches with the results by Conradie (Conradie et al., 2016) where ideas generated by persons with disabilities can be valuable to non-disabled ones. Furthermore, even if the implications for entrepreneurs and already existing companies are clear, while for the first it is a fact that the market is ready to enable and support the commercialization of such solutions, for the second it is important to recognize this phenomenon of design which starts without their participation, companies must start gathering more feedbacks from these lead users for example by participating to their online forum or engaging them more actively (Von Hippel et al., 2011).

What was noticed is that the students who could personally chose and observe the starting context and, by using also empathic methods, independentely conducted the starting analysis obtained a deeper understanding of the contextual information (Ostuzzi et al., 2017). An explanation could be that, even by delivering a filled form, we still cannot deliver any sticky information, being the part of our knowledge con-

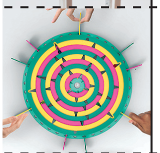
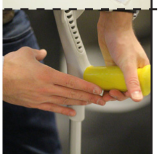
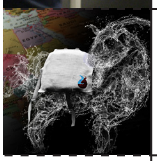
Project	Mechanism	Strategy *refers to not open-ended ones
	The device is connected to the jacket using standard zip. The jacket is the closed by using magnets instead of zip.	• *Product customization (variations in: color, lenght and zip model) • Add-on to already commercial products
	The rotating mechanisms improves the product adapatabiliy. Anti-slippery material to keep the jar from rotating with the system.	• Product mass produced with no variations • The product is adaptable for very different jars
	The whole product (connections included) is produced with laser cutting. The team uses this technology to create some personalized features.	• Low volume and digital production • Some features are tailor-made on specific demand of the user (possible logo, handles, dimensions)
	The ring behind the patch is created with a moldable material, that the user shapes around his/her own eye in order to obtain perfect fit.	• The whole product is mass produced with no variations • One component is sold in form of DIY kit
	The product uses flexible materials, that can stretch enough to fit all the commercial available handles. The patch is sold separately, so the user can position it in the best spot for his/her own needs.	• Mass produced with no variations • Adaptable product • Sold in form of kit (variations are possible during assembly at home)
	The product is designed in a modular way, with simple technologies.	• Clear instructions are delivered to the local producers, where flexibility in envisioned in terms of utilized materials.
	/	• *Mass produced with no variations • Add-on to already commercial products
	The product is designed by dividing all the different points that need to be measured. In this was with one gesture all the pieces find the right positioning.	• The product can be mass produced, identical with no variations • Adaptive product • Measuring device
	The products is designed in highly modular way, in order to let the user decide (together with the therapists) which and how many modules are needed.	• The product can be produced in high or low volume • Only certain modules should be 3D printed • Measuring device

Table 5.17. Outcomes of Test 1 and 2

sidered as tacit (Von Hippel, 1994). In fact, even if this information were given to the design teams of Test 1, they were still sometimes ignored or misunderstood. This shows in our opinion the complexity of re-appropriating projects done by others, which is in line with the idea introduced in Cruickshank & Atkinson (2014) for which Open Design (meaning the free distribution of projects) might not be as positive or as easy as thought. Students of Test 2 managed to highlight several spontaneous processes, occurring to the symptomatic solutions and, by doing so, they both obtained a more radical solution which shifted the focus from a solution-oriented approach to a process oriented method.

General mechanisms and strategies to support Open-ended solutions are: the use of local production, possibly combined with digital technologies, modular architectures possibly reorganized in form of toolkits, DIY components (the ones highly contextual), flexible materials, etc. This shows that it is possible for students to embrace diversity of users and contexts, and to take specific design choices to leave "open" the more contextual design choices. By designing for other stakeholders in mind, some technical and social thresholds can be overtaken with an anticipation attitude, and designer recognize to be no longer responsible for the design of the parts themselves. Almost no team combined the two, having therefore a broader view on the product ecology. This invites us to think that more structural method might be needed, where designers are invited to put the attention on certain aspects while designing for diverse needs and contexts. Another limitation of this study is that the involved students showed the tendency of overlapping prototyping techniques with production ones, implying a tendency of using such technologies as final ones in their project even when there are not utilized for their potential flexibility. This implies that certain projects, not high volume in the intention of the students, could be on the contrary mass produced, if of relevant market value.

Interestingly, none of the designers' teams reached some configurations of certain lenses, for example:

- Used strategies to create diversity after use (lens When? breakage or end of life). This choice could have increased the *circular economy model* upon which they could have created their business model. This might be a specific focus of future studies.
- No team addressed changes occurring in a longer time-span (lens How fast? Slow, visible and hard to read). This choice could have potentially improved the objects' ensoulment, important for fostering the emotional bond (see **Chapter 3**).
- Similarly, no team embraced changes occurring because of non-human inter-

actions in time, only reaching product-product or human-product modifying dialogues.

- Finally, the lens How much? In its *steps* configuration proved to be a possibly controversial answer, since steps corresponds with a solution to be customized (and not personalized) and might never occur. This is again an aspect to be explored with further studies and reflections.

These design decisions can be read under different perspectives, such as the time limit or the main focus of this course on user-centered design and less non-human stakeholders (i.e. out-of-control industrial processes, time, other environmental conditions). Important to notice is also that the moment of strategy creation, which is the moment when different lenses get summed up, is the very creative step of the design process and is steered by different factors and, in this course, specifically by financial soundness. The need for more innovative benchmarks is to support this creative business model creation.

To conclude, Von Hippel suggests to companies dealing with users' innovation to "create documented, open interfaces to support modifications to your products; create "developers' toolkits" to assist further; and create websites so that users with common interests can more easily share information and innovate together." (Von Hippel et al., 2011, p. 34), and connects it with the innovation path as described in **Figure 5.22**. With this specific study we recognize the value of such perspective, underlying especially the possibility of linear upscaling. With this we refer to up-scale a users' innovation solution into a solution for all, even sometimes addressing other target users. But for this research other dynamics prove more interest. In fact we have also highlighted as this "more traditional" or "un-critical" up-scaling dynamic might not be enough to keep the real value of certain solutions, being this value the capability of remaining suitable for every single user and context. This occurrs by triggering users into a conversation of constant adaptations that are out-of-control of the designer.

In other terms, if we want to reach the paradoxical areas of the design outcomes landscape (see **Chapter 3, Foundations**), we need firstly to really understand the value of the solutions for one, and then support this value by taking specific design decisions and not only by, for example, adopting more flexible technologies. To do so, more time and observations will be needed. These are conducted in order to better understand the actual value of the solution, its validity and also its evolution in time. This is, again, the main weak point of this study since to really further prove the student achievement through proven interventions more observations in time are needed (McDonald et al., 2006).

Strenghts	› For every design input, first meant to be "for one", it was possible to identify some potential markets › Several outcomes managed to obtain a design outcome open for contextual adaptations	› The module provided (Study 3) supports the understanding of the problem, but a co-design should still be needed, increasing time consumption › The up-scaling didn't always reach solutions adaptable to user needs (but more to product-related diversity)	**Weaknesses**
Opportunities	› Discovery of potential market strategies for Open-ended Design outcomes › Creation of specific mechanisms in order to support the desired strategy › Possibility of reaching high fit, even by producing standard products in high volumes (thanks to ingenious mechanisms)	› Linear up-scaling, or uncritical upscaling, that transforms products "for one" to products "for all", closing up all the open and context-dependant variables › Potential market failures if the identified open-ended attributes prove to be unsuitable	**Threats**

Table 5.18. Synthetic SWOT of Study 4 and relation with future studies

5.22. Conclusions and future studies

This study confirms as the value and innovation coming from end-user's design, can be applicable to other contexts, new users and even users with different needs. The design for one actual value can be very differently interpreted and, if in certain cases the very structure of the solution can be taken as it is, in other cases it can serve as inspiration to search for other related solutions. In some cases, we noticed in fact as the input design was radically changed in its hard attributes by the new entrepreneurial team, but maintaining high fidelity towards the user and the function highlighted at first place (Binswanger & Aiyar, 2003). The study also highlighted the difficulties on designing in more open-ended ways, meaning in ways that are more respectful of the differences composing the products' ecologies. In fact, certain outcomes decreased the openness of the starting point, reaching more traditional customizable or design for all solutions. What was also noticed is how the designers up-scaled differently the solution according to their focus on where diversity was lying. For example, in the cases of Enable and Myaddon, the diversity comes from products (different jar, different crutches) and, even if complex, resulted easier to be anticipated. Other projects instead focused on human diversity, for example Odin and Amfi (the shape of the face and of the hand, plus the personal skills), which lead to very different mechanisms and strategies, such as the adoption of DIY kits or digital production. Both cases in Test 1 focus on the human diversity (both on shapes and dimensions, and on interests and activities). An important conclusion is that it appears clear that, for designers, to personally get involved in the first stage, the observation and realization of first idea, can be beneficial in terms of insights regarding the contextual variables and their role. This implies the need to test further the overall method, of observation, understanding through lenses and observation of certain assumptions made. This will be the focus of the next and final chapter.

Finally, this work couldn't focus on the finalization of the up-scaling dynamics due to time and general resources constrains. Only the initiation phase of the project and the first part of the scaling up phase (writing of the business plan, with all that this involves) were here addressed. These steps should be followed by the finalization of the up-scaling and by a consolidation phase in order to observe the beneficial aspects of some solutions (Binswanger & Aiyar, 2003). As seen in the Valorization paragraph some solutions might face the market in the upcoming years, which could represent the starting point for further studies. Some of the created projects received recognitions from the design and business Belgian communities, underlying their value in terms of feasibility, originality and good design. For this, we suggest the reading of the **Paragraph Valorization** in **Chapter 7**.

CHAPTER 6, Study 5

OPEN-ENDED DESIGN METHODOLOGY

In this chapter the last study of the manuscript is introduced. After studying the main foundations, and after a constant dialogue between observation and anticipation, focused on understanding how to deal with Open-ended Design solutions, comes **Study 5**. Here, we attempt at merging all the collected knowledge, by reshaping it into one methodology. We define this as the Open-ended Design methodology, meaning a set of reflections, examples and tools meant to help the designers while dealing with change in design. The presented methodology has no prescriptive nature, nor should be perceived as rigid in structure. As described afterwards, it aims at supporting the designer in adopting a different view on design, or better, in extending the traditional view by adding the dimension that aims at recognizing and embracing unexpected, or undesired but still potentially present since spontaneous, events occurring throughout the entire lifespan of a product. This, in other words, is a method that aims at giving a new value to what we could define as the unavoidable imperfection, or gap, that divides the worlds of ideal and real. This chapter will be presented at the *Conference RSD6 - Relate Systems Thinking and Design*, in Oslo, October 2017 with the title "Open-ended Design as Second-order Design. A case study of teaching Cybernetics and Systems Thinking to Industrial Design students.". The following chapter contains extracts from the paper and is enhanced by the addition of extensive original sections. The chapter is structured as follows:

6.1. Introduction
6.2. Open-ended Design methodology, an overview
    6.2.1 to .5 Observation of reality, systems thinking for the broader picture,

6.1. Introduction

Design can be seen as the process of creation of what is *not there*, and what is *ought to be* (Nelson & Stolterman, 2012). One of the main problems of this complex process is the gap that is created between the design ideal space and the real contexts (of production, of use, of end-life, etc.) (Hermans, 2015). To cover this gap, a constant conversation is needed, between all possible stakeholders of the design process itself. Thanks to this conversation, which can be seen as Second-order Cybernetics, the actors learn about what conserves and what changes in the designed solution thanks to the context/environment (Dubberly & Pangaro, 2015), which can also be seen as the manifestation of what we defined as re-appropriation process (Ostuzzi, Conradie, Couvreur, Detand, & Saldien, 2016), a process of change and adaptation of the product which is driven by highly context-dependent and often tacit knowledge (Von Hippel, 1994)(Sanders & Stappers, 2012). Because of its context-dependency the conversation can occur only in time and in the real contexts of production, of use, etc. To facilitate the conditions for this conversation to happen, which is ultimately a design act done *by others*, meant as non-designers including non-human actors, a second-order design is advocated (Dubberly & Pangaro, 2015)(Krippendorff, 2007), as introduced in **Chapter 3**, **Foundations**. The definition by Dubberly et al. of second-order design as "[The signage system] is never completely finished, never completely specified, never completely imagined. It is forever open." (Dubberly & Pangaro, 2015, p. 7) closely resembles the definition of Open-ended Design (OeD) defined as the outcome of the design process that is "able to change, according to the changing context. Open-ended Design, can also be defined as suboptimal, error-friendly (Manzini, 2012), unfinished, Wabi Sabi, contextual, context-dependent and is characterized by its inner flexibility due to the voluntary incomplete definition of its features, also defined as its Imperfection." (Ostuzzi, Couvreur, Detand, & Saldien, 2017), as defined in **Study 3**, thanks to several explorations aiming at discovering how to possibly support re-appropriations of design solutions. Open-ended Design becomes therefore an illustration of second-order design, being a learning process about what conserves and what changes in the designed solution. It starts from reality and it aims at reality, creating a loop of information (feedbacks and feedforwards) that can reinforce or balance each other, helping the designer in overcoming the possible paralysis occurring when facing complexity. In other words, it supports the designer in understanding what can be left open, being never completely imagined, or *unimaginable*, but yet possible and probable. For this reason to think in order of Open-ended Design, or second-order design, means to anticipate what, of the proposed design object, changes (can potentially change or should possibly change) once put in contact with reality. These design attributes, that we define as *context-dependent*, in an Open-ended Design outcome are deliberately and meaningfully left open, giving space to the context to take part of the design process, fostering conversation and letting these information emerge from reality instead of imposing them. All the other design attributes should be, on the contrary, defined and imagined as stable, since Open-ended Design is created only through balancing controlled and out-of-control, and should not drift to completely open and un-organized design outcomes (as shown in **Chapter 3** and **Chapter 5**, **Study 2**, **3** and **4**). The function of Open-ended Design materializations could be compared to the one of prototypes, with the difference of triggering a learning process throughout the whole life span and not only in the front end or pilot productions phases (Björgvinsson, 2008). This implies the importance of the engagement of the designer with his/her own creations, during their lives in order to learn about the interactions with the world. This engagement can be facilitated, also after encounter (see **Figure 4.13**, **Chapter 4**), by the use of the internet which can trigger conservations between different stakeholders, and by intensifying the feedbacks readability (which is done through meaningful imperfections).

After the first two original experiments (**Study 1** and **2**) it emerged as the core of the research doesn't lie only in the way we share the design outcomes, or only in the way we communicate them, but it also lies on the way we conceive our design outcomes themselves. In other words, it also lies in the way we embrace change in design, by making specific design choices. In **Study 3** and **4** we attempted at actively recreating OeD outcomes, learning the importance of the initial co-generative processes and that the potential value of the first co-designed creations can be respected by adopting some strategies to bring them to the market without closing them up. In **Study 5**, we want to finally suggest a method to be used as inspiration while trying to tackle such complex dynamics. The method is firstly presented, with the support of existing open-ended case studies, and then tested with students trained in systems thinking approach. This aims at gathering some starting insights on the clarity of the method itself, its perceived meaningfulness and the capability, of different users, to re-appropriate it.

6.2. Open-ended Design methodology, an overview

The Open-ended Design methodology strongly resembles the overall approach adopted for this thesis, as it is represented in **Figure 2.4**, **Chapter 2**. In fact, it is mainly rooted on iterative dynamic processes of observation and anticipation, where observation is based on feedbacks, and anticipation on feedforwards, as defined in **Chapter 3**, **Foundations**. This iterative process aims at implementing the observed systems in terms of resilience and should be actualized through a design action. In order to support the designer while facing complexity, possibly reaching the *paralysis* that slows him/her down from taking actions, the method has been proposed and ten lenses created, as described in **Chapter 4**, **post factum**, **observation**, **Study 0**. These ten lenses can support the designer by offering new perspectives on complex situations and, looking at them one by one, by giving some partial answers. Merging the ten lenses back together, which is a profound creative act (by nature driven by tacit and contextual knowledge), the designer can anticipate possible futures, undergoing a design action in Open-ended form. This action, according to the presented method, is not a solution and is not fully finished, as it is – on the contrary – a mean to learn and explore further realities. In other words, Open-ended Design is a mean to better define the question, and start a conversation, rather than to give a definite answer. For these reasons, once the Open-ended outcome is realized, it is fundamental to keep observing it, in order to learn and continuously improve. These topics are already addressed in software development, but little has been done with special focus on the material aspects of the designed products. Also, what in theory has been described, gives little support on how to take specific actions in practice. Therefore, this whole dissertation aims at supporting designers while designing hardware products, by merging both practice and theory in one framework.

To summarize, the here proposed method is structured as follows:

1. Observation of reality (supported by feedbacks), in order to identify traces showing the occurrence of spontaneous processes that bring products from ideal to real statuses. This can be supported by the ten lenses, in order to highlight specific aspects related to change.
2. Anticipation of reality (supported by feedforward, in form of Open-ended outcome).
    a. Definition of the main hypothesis that embraces the spontaneous process, attempting at making it less disruptive or more beneficial (see **Figure 6.1**).
    b. Materialization of the outcome needed to explore the hypothesis. This outcome has an Open-ended nature and is based on specific, contextual and

creative mechanisms and strategies (or new compositions of the ten lenses).

3. Observation of reality (supported by feedbacks), in order to verify the previously identified spontaneous processes and the (non-)confirmation of the main hypothesis.

Note as point 3 becomes ultimately point 1 again, starting a new process. The overall method is graphically represented in **Figure 6.1**.

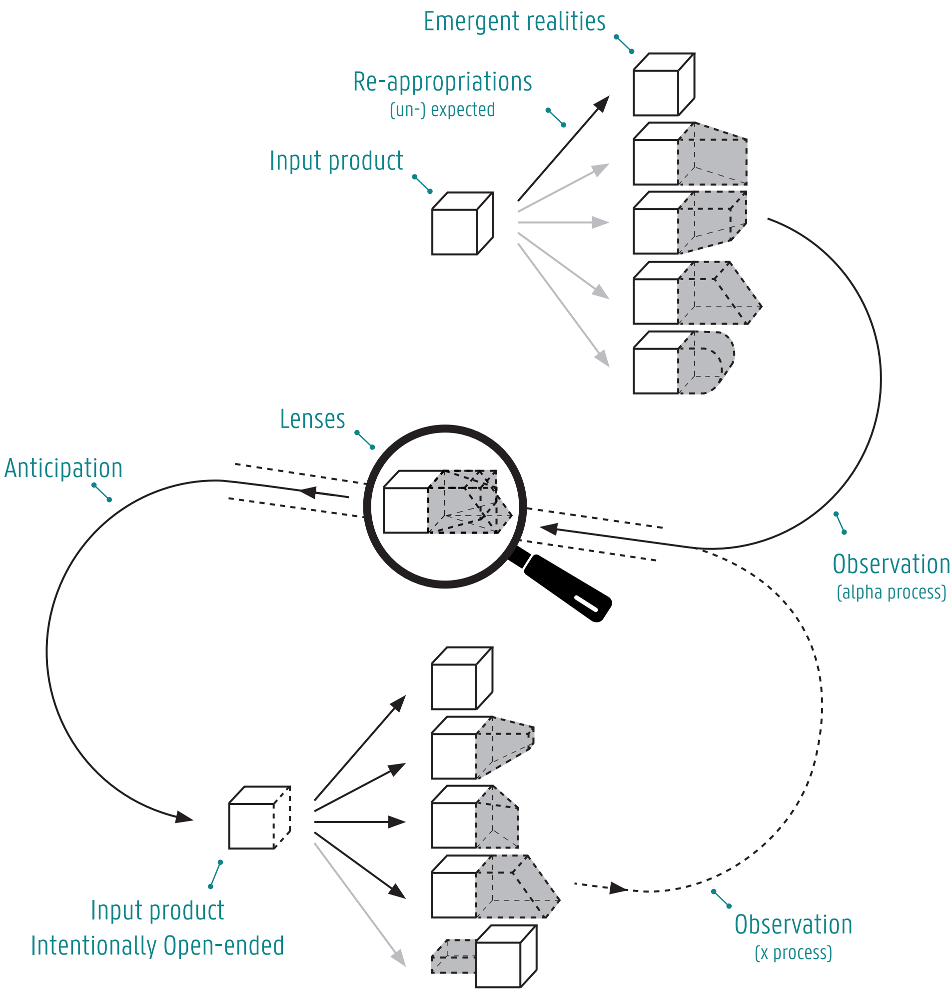


Figure 6.1. Open-ended Design, dynamic and learning process

In the next pages we describe the method, step by step, explaining more in detail its theoretical and practical aspects. This narration is accompanied by three *post-factum* examples (already introduced in **Chapter 4, Study 0**), selected up-on the clarity and completeness they can provide.

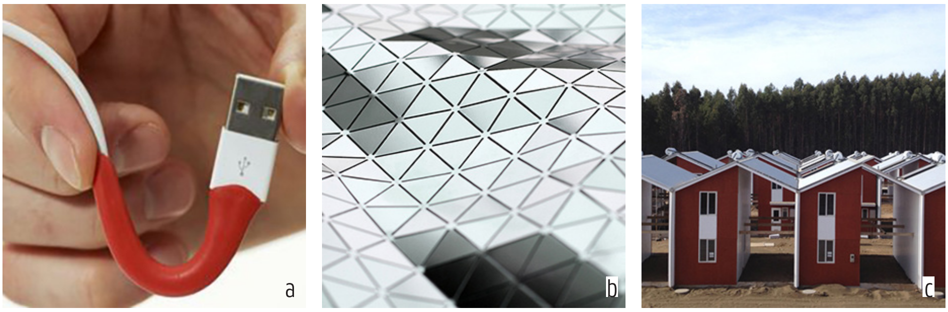


Figure 6.2. The three selected cases. (a) Sugru, (b) Post Post and (c) Incremental houses. All images have been collected from the websites reported in Chapter 3

6.2.1. Observation of reality

6.2.1.1. Systems thinking for the broader picture

In some ways, Open-ended Design is always a re-design, since it starts from reality – and aims at changing it. When we say to observe reality we mean to try to find traces, emergent evidences, of certain phenomena and, more importantly, to try to connect them with circular causality, otherwise defined as loops. This implies that the designer, in this phase, is asked to adopt a systems thinking approach, highlighting links and interactions occurring between different parts in time. It is suggested to support this observation by keeping in mind the systems thinking attitude and specifically examples of System Archetypes (Braun, 2002)(Nelson, 1994). These Archetypes describe common patterns of systems behavior and can be used both ante-factum (prospectively, in anticipation) or post-factum (diagnostically, from feedbacks) (Braun, 2002). Being general representations, and simplified models, they should be applied always acknowledging possible differences arising from the context and purpose they are used for. Some of those archetypes are already clearly connected with phenomena of change, as described in the previous sections. For example, Limits to growth and its behavior in time, can be used to describe the emotional bond with products as represented by Woolley (Woolley, 2003), reported in **Figure 3.6**, **Chapter 3**, and synthetized with the observation as "there is no such thing as unrestricted positive reinforcing behavior" (Braun, 2002, p. 2) meaning that these reinforcing processes, in time, encounters a balancing process. The archetype Shifting the burden and

Fixes that fails can be suitable to represent a common reaction of designers in front of possible threats, or undesired spontaneous processes of change. This reaction is what we will later define as controlling solution (which could be also suitably named denying solution). In fact, it explains the attraction that we might have to focus on more symptomatic solutions (in order to cure the problems' symptoms), rather than on fundamental solutions. Eroding goals, could explain how industry tends to tackle the fundamental problem of products fit, when because of pressure (on time, costs needed for higher flexibility) there is the search for more standard solutions, eroding the initial goal of performance. And finally, the archetype about success to the successful can gives us insights about the role of imperfection, suggesting a needed "unlearning" process, where things firstly perceived as negative, get recognized as potentially valuable and therefore supported. These are just few examples and many more complex connections could actually be represented.

Once some interrelations have been represented in their circular causality, they support learning processes as "The experience, the passage around this circle, is a spiral. That is, the passage acquires history, and, at least for the cognizant observer, there is a process of learning, of change. On each iteration we act, collecting the history of the iterations in an ever enrichening spiral. We do not experience the same spot (twice), for although the spot may appear the same at least in terms of location, we are not." (Glanville, 2007, p. 1184). This learning process can help the designers in simplifying, or taming, complex solutions, which should not be confused with over-simplification (Glanville, 2007). Finally, as clearly highlighted in Study 1, 2 and 3, with observation we also refer to the active engagement with the user and real contexts, in co-design and co-generative practice. When we mention relations and interactions, we refer to the ones with actual materializations, often in form of functional prototypes. In this way, with observation we mean a truly observation from inside, acknowledging the active role of the observe in the observed system (Glanville, 2004)(Dubberly & Pangaro, 2015).

6.2.1.2. Identification of spontaneous processes

While observing reality as described, we can always observe some spontaneous processes, as defined in **Chapter 3**, **Foundations**. By observing them the designer can learn what changes and what conserves in the designed outcome (Dubberly & Pangaro, 2015). Such processes are triggered by many (non-)human actors of the products' ecologies and by their interactions in time (Forlizzi & Battarbee, 2004), examples can be: gravity, chemical processes, hackings, weathering processes, social interactions, personalization, ageing, etc. These processes are necessary but not sufficient, meaning that their observation cannot lead to any exact prediction of certain consequences (non-repeatability), but only to anticipation of potential effects. Through these spontaneous and autonomous (out-of-control) processes realities emerge and transform our environments (Fischer & Giaccardi, 2006)(Nelson, 1994). Examples of such spontaneous processes have been highlighted in the three selected cases, as described in **Table 6.1**.

Project	**Spontaneous process(es)** When products are produced/used/delivered/discarded they eventually...
Sugru	(1) ...break down, and might be i.e. repaired or thrown away. (2) ...don't fit the users' needs (physical and physichological), and might be i.e. hacked to reach better fit or be rejected. (x) ...
Post Post	(1) ...get deformed during delivery, and might or not i.e. lose their function. (2) ...get ruined during delivery, and might be i.e. still accepted or rejected by the user. (x) ...
Incremental house	(1) ...don't fit the users' needs (physical and physichological), and might be i.e. personalized to reach better fit or reach abandonment. (2) ...change in time, thanks to the i.e the daily use or active personalizations. (x) ...

Table 6.1. Examples of possible spontaneous processes occurring for the three selected examples

6.2.1.3. Controlling solutions

Often designers won't focus on spontaneous processes, since their visualization requires a vision in time and the creation of connections between previously unrelated elements. More importantly, even when faced to certain spontaneous processes, some designers might have the desire of generating what we defined as *controlling (or denying) solution*: this kind of solutions tries to fix the problem symptoms by denying the spontaneous process existence or by trying to control it, meaning the restrictive meaning of the term. In this way, resources (time, money, creativity, etc.) are input to *fight* against something, definable as diversion (Heylighen, 1992), that being spontaneous is also unavoidable, unexpected, out-of-control and coming from an initially unknown origin. Of course, to certain extend this is reasonable and suggested snice it aims at reaching for optimization and efficiency. In other terms, this aims at good design practices, which should be the base of out creative process, but it becomes unsustainable when the effort overcomes our possibility of controlling, which can be seen as the area of "controlling at any costs". This definition refers to a parallelism with the paradoxes of recycling area "at any costs", where the energy input is higher than the energy output of the system. This dynamic can be represented as in **Figure 6.3**.

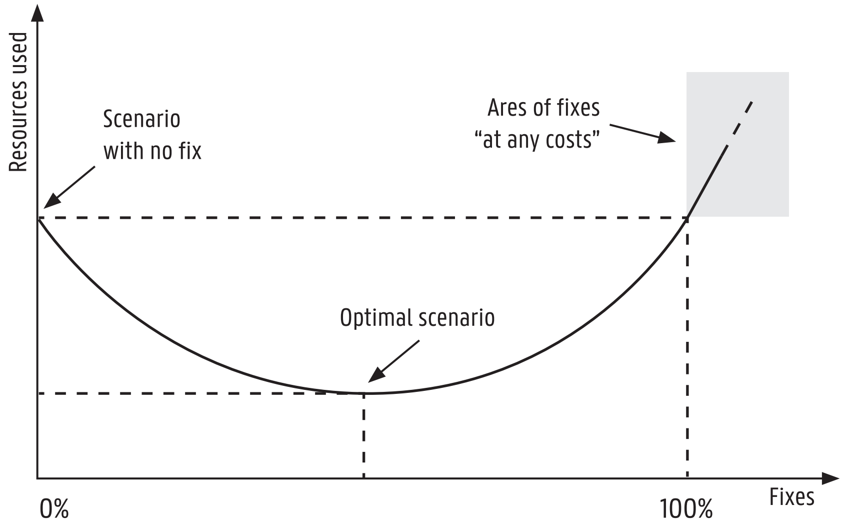


Figure 6.3. A lesson from plastic recycling, in every context there is an optimal scenario above which we might use more resources to obtain less benefits

This area should be tackled with more creative and diverse ways, where the unavoidable is recognized and embraced as part of the product's potential life. One example could be represented by the approach to defects in production as described in the paper published within this manuscript that proposed a methodology for reusing scraps (unavoidable waste) of production (Pacelli, Ostuzzi, & Levi, 2015). One example can be briefly reported on the case Post Post: if during the transportation process our product gets broken, then it could be insightful to re-design the distribution process or the packaging. In both cases we would probably go for more expensive (also environmental resources-wise) solutions that aim at decreasing the possibility of damages, without completely avoiding the problem occurrence at first place. To better understand this, few lines on the controversial nature of change might be needed.

6.2.1.4. Reinforcing and/or balancing change

From the observation of a specific situation and the occurring spontaneous processes, we can observe limitations and opportunities, and try to understand how to decrease their power (of limitations) and consequences, or how to support the realizations of potential opportunities (Dubberly & Pangaro, 2015). In other terms, we could either choose to balance the phenomenon (balancing loops, + -) or to reinforce it (reinforcing loops, + + and - -). This is motivated by the controversial nature of change, or better of its consequences on the system itself. This dual nature is perfectly synthetized by two Bertolt Brecht's poem verses in 1931 "because things are the way they are, things will not stay the way they are.", where we witness the recognition of the spontaneous process of change, and "I love nothing more than the dissatisfaction with the changeable and I also hate nothing more than the deep dissatisfaction with the immutable." (original text *Ich, der ich nichts mehr liebe / Als die Unzufriedenheit mit dem Änderbaren / Hasse auch nichts mehr als / Die tiefe Unzufriedenheit mit dem Unveränderlichen*).

In fact, change can be perceived (and therefore invest a role) either of positive or negative effect (beneficial or disruptive), but can also be too slow (things perceived as that they cannot change) or too fast (things that change too much). These opposite views represent ultimately the same phenomenon: the under value we give to designing for change. In this way to design Open-ended solutions can mean either to facilitate potentially beneficial change or to make disruptive ones less influential or both, as visible in **Figure 6.4**. Important to notice is how beneficial and disruptive might change thanks to the context and thanks to the perception of the different actors. In other words, by dealing with material and tangible changes, we aim at changing perspectives and behaviors of the involved stakeholders. In the same terms, we shift from first-order cybernetics to second-order one (Glanville, 2004)(Dubberly & Pangaro, 2015). Therefore, in this perspective were observer and observable influence each other, the beneficial or disruptive implications of certain changes are subjective to change as well, and are aimed as intentionality of the designer him/herself.

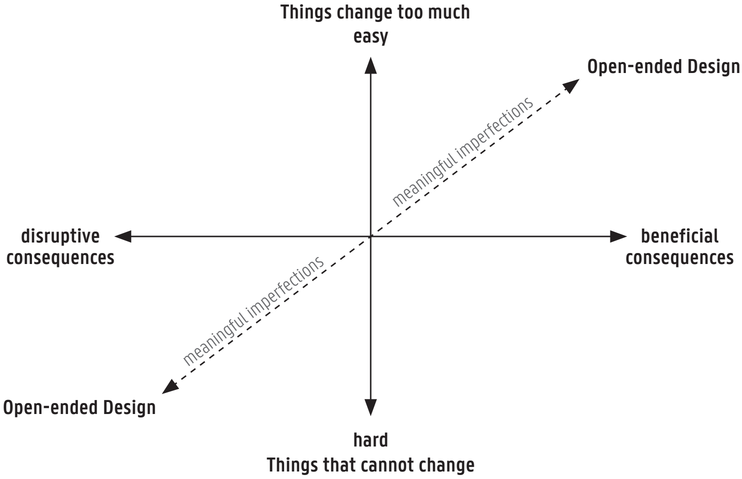


Figure 6.4. Extremes and possibilities on where to focus OeD solutions

6.2.1.5. The ten lenses

The ten lenses in **Table 6.2** and defined in **Chapter 3**, **Observation**, can help to better understand existing cases and to design new ones,. The lenses can be used all together, or one by one, or as a mix (as for example done in the previous **Study 4**) depending on the focus of the designer and his/her main goals. Here following a synthetic list of lenses, the questions they pose and the different areas of the design process they tackle.

Lens	Question	Relation
Why	Why is the product changing?	Spontaneous process (a)
Who	Who is changing the product?	Agents of the spontaneous process (a)
Goal directed	Is the main actor making a change to each a particular goal?	Intentionality of the (spontaneous) process (a)
What	What is changing in the product?	Phenomenology of the process and feedbacks readibility (b)
How much	How much is the product changing?	Dimension (phenomenology) of the process and feedbacks readibility (b)
How fast	How fast is the product changing?	Speed (phenomenology) of the process and feedbacks readibility (b)
Reversibility	Is the change reversible?	Reversibility (phenomenology) of the process (b)
When	When is the product changing?	Life Cycle (and business model) of the product (c)
Where	Where is the product changing?	Business model (c)
How many	How many products can be produced in this way?	Business model (c)

Table 6.2. List of the ten lenses and their relation with other design aspects

6.2.2. Anticipation of reality

6.2.2.1. Hypothesis formulation

Thanks to the use of the ten lenses and the constant observations, designers can formulate certain hypothesis about the behavior, in time, of their outcomes. This hypothesis will be ultimately embedded in the Open-ended Design itself, as explained afterwards. With this passage we want to underline as anticipated change is always potential in nature (see definition of spontaneous process), and should be accompanied by the awareness that other aspects, different from the identified ones, will also eventually change. The most general Open-ended Design hypothesis can be formulated as:

> "When imagined products become real, they change, as well as their perceived value.
> + If products change *meaningfully*, their value increases."

As noticeable, the previous statement starts with the spontaneous process (in general: change in products) observed in reality and it is followed by the actual hypothesis that states that to a precise design action certain effects follow. Open-ended Design, as every design act, starts with the goal of improving the actual situation (Nelson & Stolterman, 2012), therefore the hypothesis focused normally on a value increase. Examples of Open-ended Design hypotheses could be: "when products are used, then they get scratched. If scratches accumulate meaningfully, they might lead to higher product ensoulment." (Blevis & Stolterman, 2007)(Jung, Bardzell, Blevis, Pierce, & Stolterman, 2011), or "when products are produced, they are accompanied by waste. If the waste is carefully managed, it might become a resource useful for other products." (Pacelli et al., 2015), or "when ceramic products are mishandled, they break down. If the breakage is designed in order to maintain function, then the product might be conserved by the user even after breakage".

Many other examples could be brought and they can expand in complexity, merging multiple spontaneous processes and sketching different potentially parallel implications. Here following examples of hypothesis for the selected cases. As introduced earlier, to design OeD solutions means to design experiments to test the main hypothesis, and to embrace the potential nature of the firstly observed effect. Examples of hypotheses for the three selected cases are reporte in **Figure 6.3**, next page.

6.2.2.2. Creation of open-ended outcomes

Anticipation is the moment of the action. "How do we know we have arrived? Through a feeling of "all-rightness" a sense that this is "just right". This is an intuitive

Project	Open-ended Design hypothesis
Sugru	(1) If reparation is made easier, then more users will choose that option. (2) If hacking is made easier and more aesthetically pleasent, then users will adapt more products to reach higer fit. (x) ...
Post Post	(1) If deformation doesn't imply function loss, then it might become acceptable. (2) If ruined surfaces remain aesthetically pleasent, then users will retain the product even if ruined. (x) ...
Incremental house	(1) If personalization is made easier and cheaper, then more users might choose that option. (2) If change in time is non diruptive, then it can increase the house's value. (x) ...

Table 6.3. Examples of Open-ended Design hypothesis (aiming at improving resilience)

condition, an act of recognition and resolution rather than of a problem solved. […]. This reminds us that designers do not seek the perfect solution, but one that is good enough. They do this not through lack of rigor, but by recognizing that the area in which they work is ill-defined: and perfection, therefore, is unattainable. Design brings with it the concept of adequacy as a means of evaluation, rather than perfection." (Glanville, 2007, p. 1193).

In this perspective, we can finally focus again on the value that imperfection covers in Open-ended Design. In such solution small imperfections are intentional and aim at being meaningful, in the conception described before. The imperfection embedded in the product, for example its unfinished nature, becomes meaningful (instead of a defect) since it is open to embrace and support those emergent aspects of the solution, which can only be defined by the context. Also, meaningful imperfections enable or facilitate feedbacks creation and readability.

Hence, till here the proposed method aims at supporting the designer in his/her considerations. Now, the ten lenses (their answers) can be summed up and benchmarks, adopting similar dynamics according to Where? Who? What? Etc., can be used as inspiration (open-ended-design.com), but it is important to acknowledge as this is not enough. At this very moment, no prescriptive method can support the designer, while facing the creative challenge of merging the ten lenses originally answering the question How? in terms of *strategies* and *mechanisms* (see **Table 6.4**).

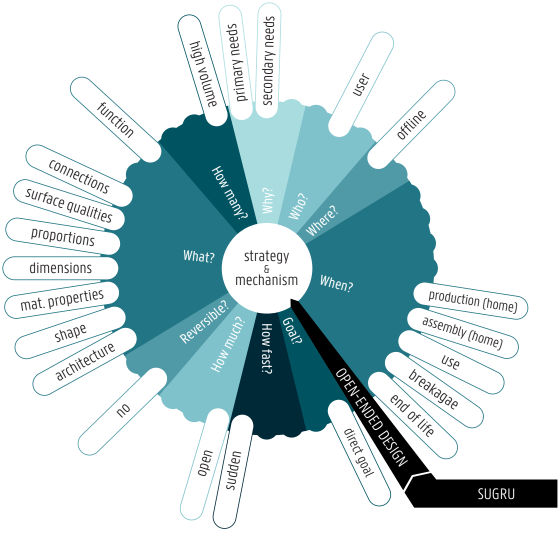
Lens	Question	Relation
How	How can we technically faciliate change (and improve its readability)?	Engineering aspects to support technical change (a, b, c, d)
How	How can we propose the product to the market?	Entrepreneurial aspects to support meaning change (a, b, c, d)

Table 6.4. How lenses: strategies and mechanisms

This limitation is in the very nature of the design activity, which is contextual, messy, intentional, subjective and often opportunity-driven (Nelson, 1987)(Cross, 2001)(Dubberly & Pangaro, 2015). In fact, mechanisms and strategies have to build upon, apart the lenses, on contextual aspects such as: engineering and technical skills, production facilities available or reachable, entrepreneurial attitude, expertise, market dimension, regulations, etc. In this way, this important creative step is extremely complex, but also deal with simplification. In fact, many strategies and mechanism identified by this research are – after all – extremely simple, which has to be seen as a value. "The Italian designer Bruno Munari is quoted on the walls of the Design Museum in London, thus: Progress means simplifying, not complicating. Simplifying is not to be confused with over-simplification: what Munari points to (as does this paper) is a process by which complex requirements can be brought together within one, unified, unitary form." (Glanville, 2007, p. 1196). Following in **Figure 6.5** (next page) a representation of the ten lenses combinations for the three selected cases.

These combinations are unique representations of the moment when the selected Open-ended Design examples were created, they represent the specific needs and skills of the designer and companies that released them, and are therefore unique in their nature. To better understand this statement is enough to go back to the main spontaneous processes: many other different ways to tackle them could be identified.

Figure 6.5. In the following page: the three examples analyzed under the ten lenses, this sum leads to the creation of unique strategies and mechanisms, reported in Table 6.5, in the following page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&
mechanism
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Who?
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How fast?
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secondary needs
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offline
function
connections
surface qualities
proportions
dimensions
mat. properties
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open
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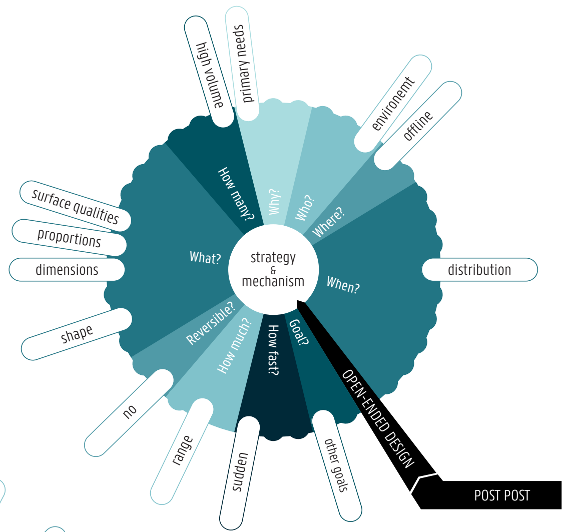
direct goal
production (home)
assembly (home)
use
breakage
end of life
OPEN-ENDED DESIGN
SUGRU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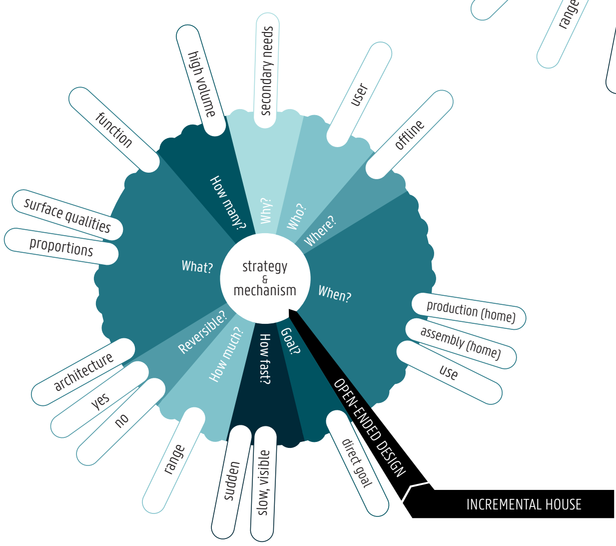
POST POST


strategy
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user
offline
function
surface qualities
proportions
architecture
yes
no
range
sudden
slow, visible
direct goal
production (home)
assembly (home)
use
OPEN-ENDED DESIGN
INCREMENTAL HOUSE

Project	Mechanism(s)	Strategy
Sugru	(1) Chemical bond possible with almost every material. (2) Silicon curing with air. (3) Flexible material.	Bring a standard, high volume, shapeless material that has to be adapted by the user. The product is simple, efficient and aesthetically pleasant.
Post Post	(1) Use a ductile material that can deform without breaking. (2) Create small cut (imperfections) in the structure in order to better control the deformation.	Produce a standard product, distribute it creating incentives for mishandling and give the value (communicated to the user) to the uniqueness of the received product.
Incremental house	(1) Using timber framing instead of bricks. (2) Providing support beams for the second floor in the open part.	Propose a standard house that is unfinished, but already functional. The limited space is to avoid wild growth in these new neighbours.

Table 6.5. Examples of Strategies and Mechanisms highlighted for the examples

6.2.3. Observation and engagement

Once the specific Open-ended Design has been released, it is fundamental to remain engaged. The importance of this passage lays on the very nature of OeD as *real-use prototypes*, created to explore a certain hypothesis. Without engagement we might miss important feedbacks, from which we can ultimately learn. The engagement as to be designed as well and, since proximity with end-user is a rare case for designers and companies, a good support can come from the networked society we live in (Manzini, 2010). By connecting previously unrelated and distant users (here we refer particularly to open-ended *after encounter*) designers can read feedbacks about the real use of their outcomes and, start taking again corrective actions when needed.

Finally, apart from the feedbacks listed in **Table 6.6**, in **Figure 6.6** we can read the traces in the products' materiality. These traces, that are physical changes in the products attributes (mainly the What? question), emerge thanks to the interactions occurring between product and his ecology. These traces became meaningful information as well, and are be supported or even enhanced by the design of specific mechanism (How? question).

Project	Feedbacks (to users and companies)
Sugru	- Bright and strong colors easily identifiable in common objects. - Incentivate users to share their repairing stories: blog (sugru.com/blog), hashtag (#sugru), creations of contests (i.e. best hack with Sugru), etc. - Social media are used to create a community and raise awareness.
Post Post	- Creation of a blog (blogpostpost.tumblr.com) where users can show the product in its arrived shape, and the distance it had to cover.
Incremental house	- The region of the house that can be up-graded is geometrically very visible. The user can choose to use different materials and colors, or to work on the same style of the starting construction. - It is potentially easy for the architect to check the progress of the houses.

Table 6.6. Examples of strategies and mechanisms highlighted for the examples

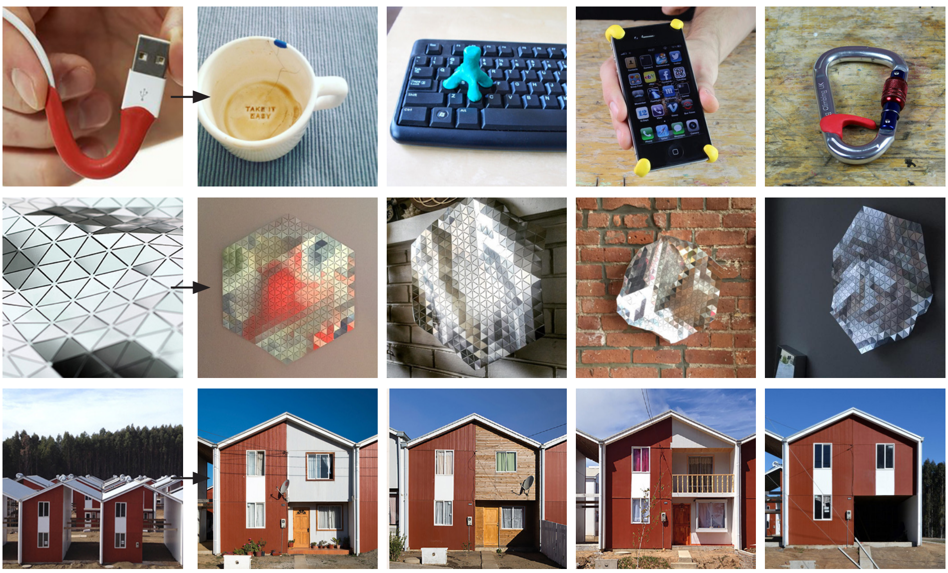

Figure 6.6. Reading feedbacks as traces in products, here reported a set of re-appropriated products of the examples

6.3. Research method

On the one hand, the presented method, based on case study research, literature review and original experiments is already what we can consider a result as it will be discussed in **Chapter 7**, **Termination**. In fact, as post factum observation, it already helped us in understanding some variables and aspects about change in design, previously ignored or misinterpreted. On the other hand, thanks to the original exploration of **Study 4** we highlighted as young designers are capable of anticipating some contextual variable aspects, and match them with Open-ended Design instances. Nevertheless, many aspects of the presented method should still be tested. With the following, and final, experiment we don't aim at reaching exhaustive answers, but rather to explore some of the following concepts:

- Can designers understand the complex dynamic of change in design, represented by existing Open-ended Design solutions, and achieve more general understandings? In other words, can designers autonomously use the propose method to analyze existing cases?
- Can designers re-apply meaningfully their understandings in new contexts?

The test involved 16 students of 3th year Industrial Design Engineering, within the framework of the course Cybernetics and Systems Thinking. This course is project-based (Lee et al., 2010) and focuses on small communities. Goal of the course is the students' interaction with a real local community which, thanks the constant use of functional prototypes and observations of the occurring interactions, should start a self-sustaining process. In other words, students have to provide a solution meant to function and last, in time, also without their presence. The described year edition focuses on composting technologies, both aerobic and anaerobic, which relates with the topic of **Study 2**, on urban gardening and farming (Ostuzzi et al., 2016). We decided to select only few of the 16 cases as example to describe the general flow as approached by students. These cases represent examples that managed to follow the entire flow and draw more general conclusions out of it. At the end of the chapter, sections describing the *disturbance* encountered thanks to this test, and the overview of results of all the 16 cases, are reported. The experiment is divided into two tasks, structured as follows.

A specific Open-ended Design case was assigned to each student. These cases were selected among the ones identified thanks to the Observation phase. The selection focused on products of our daily life (chairs, shoes, vases, houses, etc.) and not on assistive devices, for two main reasons: (1) we wanted the students to already have a tacit knowledge about those products, built in the years of interaction with them, in order to be able to highlight spontaneous processes and other dynamics and (2) we still struggle on finding good, open-ended examples, of assistive devices with enough re-appropriations already occurred and shared, with exception of 3D printed ones. The OeD method, as previously described, had to be followed in the analysis of these already existing design outcomes. In this way the whole analysis result in fact as a post-factum activity. No importance was anyhow given to the coherency of the analysis with what the designer "might have thought" in reality while developing his/her own creation. We focused on the comprehensiveness and soundness of the students' analysis, and on their capability of finding connections adopting a broader. This task was addressed as written report, inclusive of visuals and text.

6.4. Results

This task proved great interest, since students elicited various insights on the method itself and both helped in clarifying controversial aspects and valorizing some previously considered, for example, less important. Here following extracts from four students' works are reported (see **Figures** from **6.8** to **6.19**), in order to give a first overview on their approach. The examples report 1-1 extracts of words and images, as proposed by students. Specifically, the reported sections present:

1. **Spontaneous process**
2. **What can the designer learn?**
3. **Controlling solution (in its causal modelling)**
4. **Hypothesis**
5. **Open-ended solution (in its causal modelling)**
6. **Mechanism & Strategy (the How lenses)**
7. **Other examples**

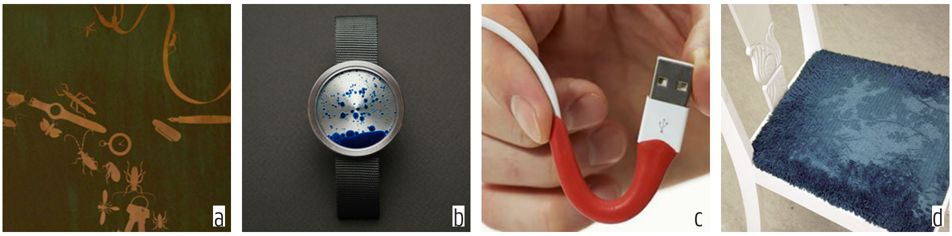

Figure 6.7. The four selected cases to present the result of Task 1

6.4.3.1. Verderame by Fioravanti, analysed by Rik Maes

Spontaneous process

"When, for example, a wooden floor is observed during its lifetime, changes can be observed because the wood will decay over time. That's why wooden floors need a finish to last longer. When this kind of floor is observed over a very long period of time, the finish will be worn off due to people walking over it and damaging the finish of the wood. When people walk over the floor they scrape off small pieces of the wood finish. This behavior is spontaneous: people cannot walk over a surface without damaging it."

What can the designer learn?

"Due to this visible decay, the designer can learn how and where people move in a certain environment. He can also see which places are more frequented than other places thanks to the severity of the decay. He can conclude that the appearance of the floor will change when it is used more frequently.".

Controlling solution (Figure 6.8)

"The whole system is already an archetype: Limit to growth. […] The controlling model as depicted in green is based on fixing the problem of the decaying process. When the decaying process of fixed, the central reinforcing loop that describes the spontaneous process will become a self-destroying process and so it will eliminate the spontaneous behavior. By adding more finish to the floor or re-do the floor more frequently, it will increase the look and feel of the floor, which will attract people whom will increase the amount of wear and tear of the floor. These fixes will prolong the inevitable, the floor will decay eventually and the spontaneous process will happen."

Hypothesis

"The appearance of the floor will change when it is used more frequently".

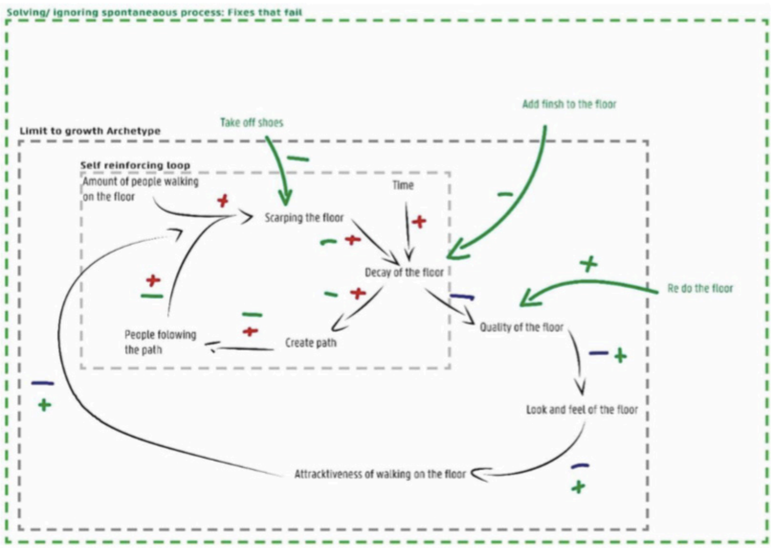

Figure 6.8. Controlling solution as imagined and visualized for the project Verderame

Open-ended solution (Figure 6.9)

"Verderame gives a clear feedback to the designer, thanks to the material properties of copper, the usage of the product is clearly visible to the designer. The designer can learn the general movement of people in a certain environment. The model above is based on assumptions and can differentiate with reality. This is a self-reinforcing loop that will balance itself out when the product is completely oxidized and the path is made. The path has to be "maintained", when there is a lack of movement for a certain period of time, the tiles will start to oxidize again, resetting the path."

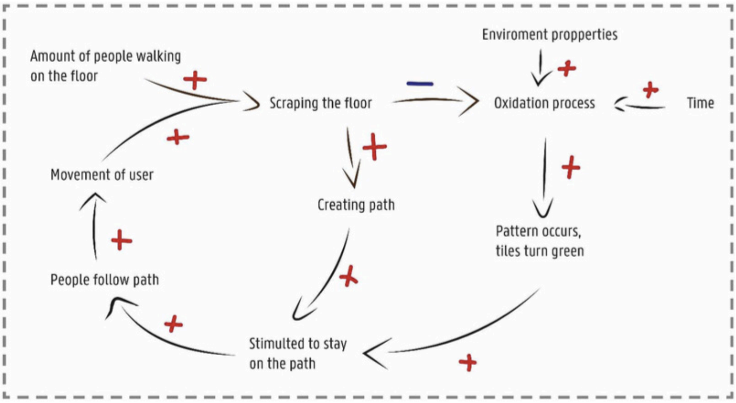

Figure 6.9. Visualization and understanding on the project Verderame

Mechanism & Strategy (Figure 6.10)

"Surface qualities can have an influence on the change of the product as well. The smoother the product, on microscopic scale, the longer it will take for the material to oxidize because the oxygen particles will have less surface to bond in comparison with a rough surface."

[There is no strategy description.]

(1) During its lifetime, every tile is produced the same, but every tile will change into a unique product thanks to the variety of usage.

(2) Secondary needs as curiosity: when people see the bright copper path in contrast to the green oxidised tiles, they will be tempted to follow this path. This will increase the change of the product, decreasing the oxidation layer.

(3) The amount of change is dependent on a couple of factors. The first change, the oxidation, is dependent on environmental factors, as stated above. This change will always be the same: the copper will turn green after some time, revealing the pattern created by the designer. The change by the usage is dependent on the intensity of the usage and the way the product is used.

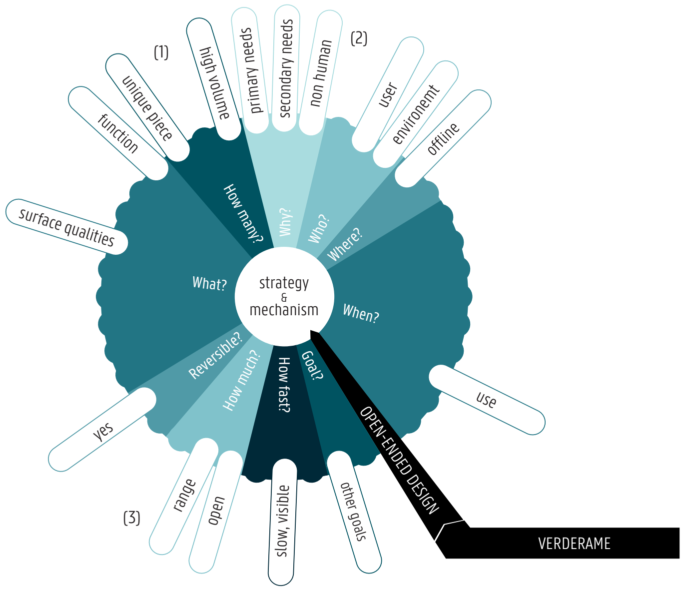

Figure 6.10. The ten lenses as interpreted for the project Verderame

Other examples

"Like Verderame [...] wear and tear is visible on many statues around the world. Another example is Verdigris, a copper table. As copper ages, it creates a green patina (an oxidation layer) when exposed to air and other agents over time. The surface design of this table is therefore always changing according to the conditions where the table is exposed (indoor, outdoor) and to the manner people use it (the use "polishes" the copper surfaces, tearing off the patina layer)."

6.4.3.2. Emulsion by Skrekkogle, analysed by Maarten Cornelis

Spontaneous process

"The spontaneous process focuses on students and other working people. [...] When students are studying they get distracted after some time, so they need new energy to study further. They can get this energy by moving. But most of the time student are to busy with studying or are too lazy and stay behind their computers. So that the distraction is still getting worse."

What can the designer learn?

"Designers can learn that when people are distracted they don't always move. They can also learn that once people are distracted they only get more distraction because they don't move. But the main thing to keep in mind is that the focus relays on the distraction. Designers can learn from this process by testing it."

Controlling solution (Figure 6.11)

"In the figure some external parameters have been added to the process. One of them is a fairly common solution: it is an alarm that goes on after a certain period of time passed by. [...] but the problem is that the alarm sometimes goes on at the wrong moment. This can be annoying when students are studying deeply. This 'bad moment' is also the limit to growth for the reinforcement loop."

Hypothesis

"We saw that the commonly use solution to trigger more movement is too much focused on the moving itself. But if we look god enough at the spontaneous process, we see that it is better to focus on the distraction rather than on the moving itself. On this way an alert can be made when there is distraction. So there will be never a distraction when a student is deeply focused."

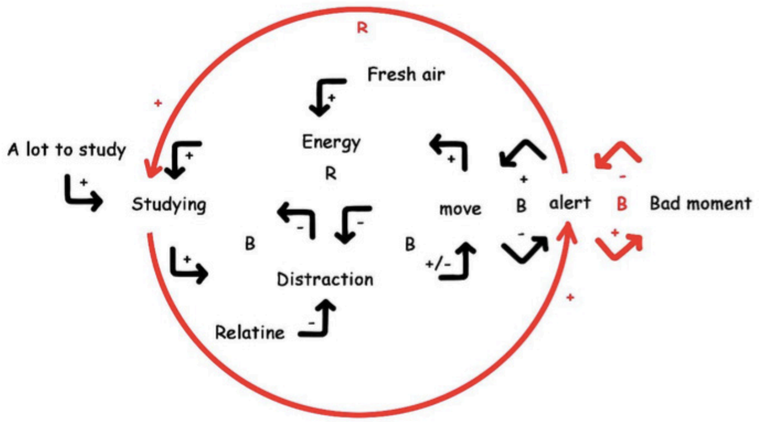

Figure 6.11. Controlling solution as imagined and visualized for the project Emulsion

Open-ended solution (Figure 6.12)

"The figure shows how Emulsion works. Only when students are distracted they will look around. So, only then they will see Emulsion and, only then, they will be alerted to move. It's better to look at the really necessary things and try to find things that fulfil their function by nature."

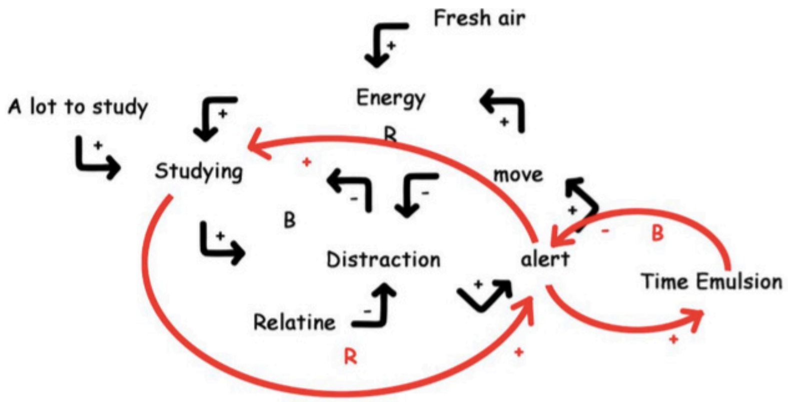

Figure 6.12. Visualization and understanding on the project Emulsion

Mechanism & Strategy (Figure 6.13)

"The goal of Emulsion is to show people when they are sitting for too long and trigger them to move more. It does this by changing its pattern when moving. When the Emulsion isn't moving, the fluid of the emulsion will merge. So the person who wears it can see that he/she has to move. The spontaneous process of Emulsion is made by the fluid in it. The fluid will spread when moving and when the fluid isn't moving anymore it will quietly merge. The longer the fluid stays still, the more the fluid will merge. This is because the fluid is made of an emulsion of 2 immiscible liquids. One coloured and one transparent, the transparent liquid slows down the coloured from merging." And "Emulsion can be made in high volume but no Emulsions will never be the same because of the fluid".

Other examples

"When I was young, I saw the same effect on a mayonnaise and I thought it was out of date. This was a spontaneous reaction of myself because the mayonnaise was changed in its structure. This is what Emulsion also wants to do, creating a reaction in the user by changing its own structure and showing that time passed by. And reminding people to move."

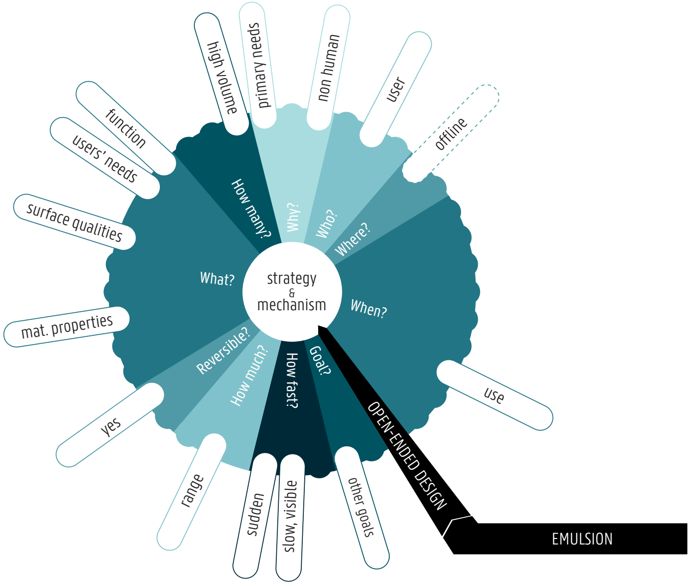

Figure 6.13. The ten lenses as interpreted for the project Emulsion

6.4.3.3. Sugru by Formformform, analysed by Stefan Lefevre

Spontaneous process

"Basically two spontaneous processes occur […]. The first is that nothing lasts forever, meaning everything you buy and use will eventually break. Most of the time this is due the fact that products are used or exposed to the environment. The material can then break or lose some important properties (spontaneous process) […]. The second process is that products don't always fit the user like they want to. This is because the designer cannot design something that is perfect for everybody."

What can the designer learn?

"Constant feedbacks of what users are doing with your design can open up more than you could first think of. Give something small to your stakeholder and see what great they can do with it. Sometimes you don't have to be the creative one but let people be creative for you."

Controlling solution (Figure 6.14)

"A controlling solution on how the designer could make the product fit a higher range of people is by increasing the flexibility of the production process which means different kinds of products can be made. This means an increase of satisfied users which will increase the success of making the producti more flexible. This means the designer will further increase the flexibility of the production line to make the customer more satisfied. This is done until the limit of the production process is reached. The increase in flexibility also means an increase in recourses needed because more machines, energy, labor etc. will be needed. The highest point on flexibility will thus mean a least sustainable solution."

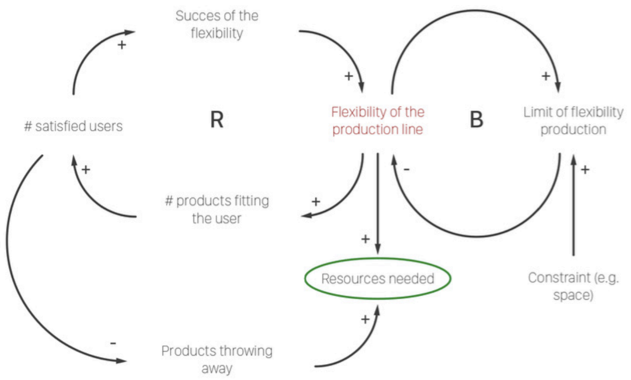

Figure 6.14. Controlling solution as imagined and visualized for the project Sugru

Hypothesis

"When something breaks then the value of it decreases which doesn't mean the product is useless. If people don't have the resources to fix it easy and quick, then the product will be thrown away quite fast. By providing them with a quick and easy solution people are more motivated to fix the problem."

Open-ended solution (Figure 6.15)

"Aside from the fact that Sugru is a kind of glue there are some big differences why someone would rather buy Sugru than glue to fix his/her problem. I think Sugru works best for people as it is advertised to stick to everything which gives you a certainty of Sugru to satisfy your desired needs. Next to this, Sugru is also easy in many ways as there are hundreds of types of glue each for its specific goal or material. This problem isn't occurring with Sugru as there is only one kind you can choose. This is supported by all the existing evidence people are using Sugru for (you literally see the product working in different contexts). It's also very easy to use because you can shape it the way you want without gluing your hands together. Because of the flexibility (not on material level) people aren't afraid to use it (no manuals, just shape it and wait. This cannot always be done if you are using glue). The Sugru can also be obtained in all sorts of colours making it a fun thing to play with. Next to all this I think the Sugru gives you a more secure feeling of it doing its function. After fixing things while using glue, you aren't able to see the connection. The glue here serves only as a substance that is keeping the two parts together. Sugru, on the other hand is an extra material that is added to the product. You can literally see the Sugru 'holding' the two parts together which can also be turned into a visible aspect (Wabi Sabi), resembling the success to the successful archetype […]. What is happening can be seen in the image. It shows how the success of Sugru is exponentially growing by constantly improving it and making it compatible with more. This however will have its limits caused by the chemical properties of the material. At some point the success of Sugru will also reach its limit."

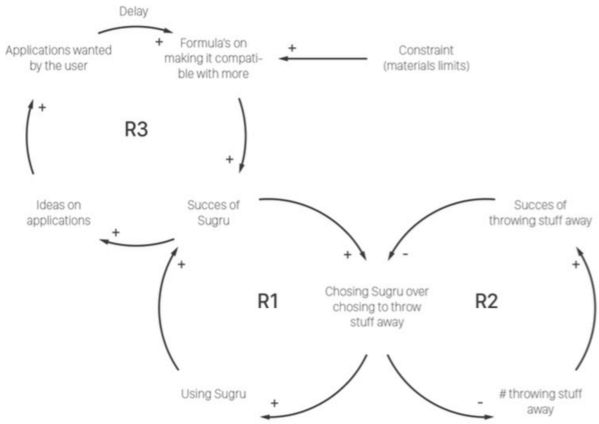

Figure 6.15. Visualization and understanding on the project Sugru

Mechanism & Strategy (Figure 6.16)

"Chemical properties of silicone." And "The change is supported by selling the Sugru in little packages with a certain volume. The user can buy these in all kinds of different colours whatever suits best for him/her. Providing these packages makes it possible for the user to do with it whatever he wants. In this way the Sugru is similar to a regular glue which you can buy and decide what to do with it."

Other examples

[There are no other examples provided.]

6.4.3.4. Underskog by Bjaadal, analysed by Lucas Wyffels

Spontaneous process

(1) "When somebody sits on the chair, his/her force and movement on the seat's textile break the threads of the textile. (2) The process of sitting down and moving while sitting that causes the threads to brake is thus spontaneous."

(1) "The change of the Sugru itself isn't reversible. Once hardened it cannot be made mouldable again. The change done to the product however is reversible because the Sugru can be removed from it (sometimes takes some misery to do so, but it is possible)."

(2) "The product can change in some different ways."
- repairing or replacing parts
- give new shape
- give new surface qualities
- change function of the product
- change material properties
- change aesthetic

(3) Always!

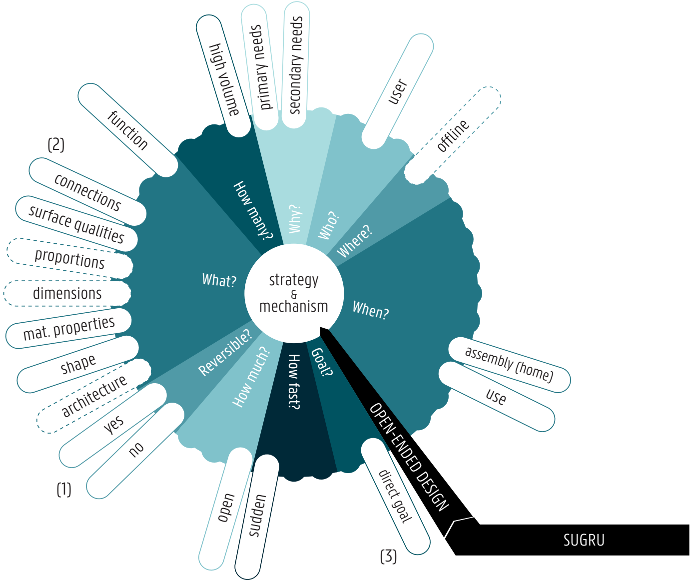

Figure 6.16. The ten lenses as interpreted for the project Sugru

What can the designer learn?

"A designer can learn three things from this: (1) A normal fabric that undergoes wear and tear becomes 'ugly'. It is one of the reasons why the chair is being thrown away. (2) When a hole appears in the upper layer, the layer underneath become visible. (3) The use of the seat over time causes the appearance to change."

Controlling solution (Figure 6.17)

"What a conventional designer/engineer is doing now is minimizing as much as possible the damaging of the chair. This by searching constantly solutions on how to make the seat last longer so the input to 'reinforce the seat' overwhelms the 'time of occupation'. For example: more reinforcement means less damaging what more attractiveness gives. This results in more occupation and again more reinforcing needed! This is an escalating situation and is shown in the following model in orange [...]. The constant reinforcing of the chair can cause designers a headache because she's being limited by time and resources. In short: there is a limit to growth. The model can be extended. A limit to growth situation can lead to a failure of the product if it cannot cater the needs of the chair. Another approach to make the chair last longer, is needed."

Hypothesis

"The product changes over time because it is being used, what makes it a spontaneous process with, in some cases, an open-ended aspect: a Wabi Sabi seat. This means that it can trigger an extra appreciation when the seat show marks of usage."

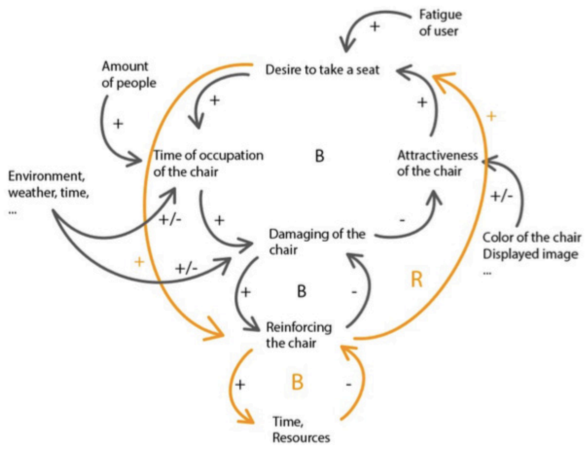

Figure 6.17. Controlling solution as imagined and visualized for the project Underskog

Open-ended solution (Figure 6.18)

"In case of the Underskog, the designer decides to not reinforce the seat, but to change the negative feedback given by the damage, into a positive feedback. This causes a reinforcing loop of the used chair. Of course, the more the image appears, the less the fur of the seat can be damaged, what causes the reinforcing loop to stabilize". […] "Again, we have here a limits to growth loop. The solution would be another extra element that neutralizes the balancing part of the loop, but we won't go further on this. What is improved? The spontaneous proces has taken over the intire loop and brings rest to the designer (no reinforcing of the chair is needed). While a normal chair will be trown away when the seat decays, this seat will be exciting for a longer period of time as seen in the graphs below."

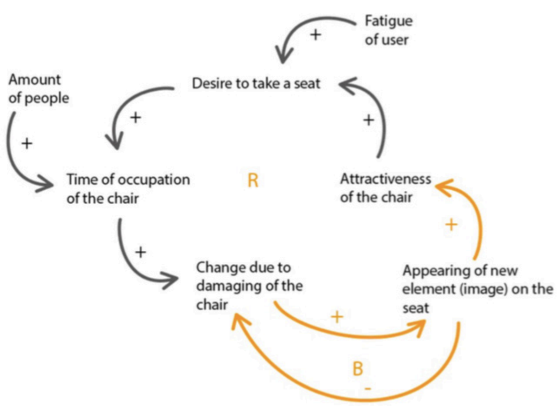

Figure 6.18. Visualization and understanding on the project Underskog

Mechanism & Strategy (Figure 6.19)

[There is no specific text provided to describe strategies and mechanisms, which were then asked during the personal interview, and are represented in **Figure 6.19**. In the text we can anyhow find a model designed to quantify the process of change. These aspect needs further study and is reported in the last **Chapter 7, Termination.**]

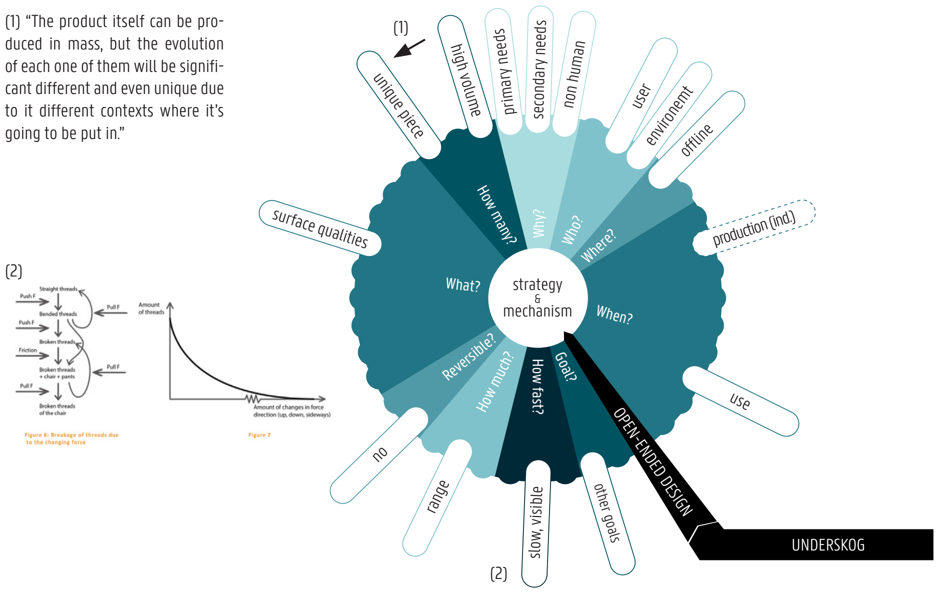

Figure 6.19. The ten lenses as interpreted for the project Underskog

Other examples

"There are two ways to enhance the worn product; first, it can look better, only because of the age (Wabi Sabi), like a working pants or All Star's. They don't look nice when they are new. […] Second is like the case of the Underskog, when something new appears due to environmental conditions. An example of that are, beside the Underskog, some garden tables from Extremis. When they stand outside, due to the weather conditions, they change color, what makes it a little bit more exiting (as Extremis says)."

6.5. Discussion

As anticipated, this final Study elicited interesting reflections and opened up new possible future studies. About Task 1 is possible to state that the overall method proved to be adopted meaningfully, and still some parts need implementations. First of all, the majority of students was able to highlight the spontaneous processes, or more, that the assigned case study tackles. This is probably due to their specific formation on systems thinking, and it should not be forgotten as to analyze post-factum creations is simpler than to anticipate not-yet-existing ones. Interestingly, some students identified spontaneous processes specifically related to their student life (i.e. distractions during study, social status of personalized shoes), this underline as they adopted a very personal view, and managed to somehow find other meanings in already existing solutions. Two students missed the identification of the process, which implies a lack on the understanding of the "Why?" lens. Similarly, one student identified the spontaneous process, but missed in understanding its relevance in more abstract terms (with reference of Una Seconda Vita, a bowl that in case of fall and breakage acquires a second function, we can read "Why in god sake would you ever drop your fruit bowl?"). Some students included images of other products of the same category, in order to highlight the occurring spontaneous processes, we imagine that almost everyone would have used more pictures of the observation if undergoing personally the first co-design process. This aspect could be further explored in future studies.

The model of reality, through archetypes, was also well developed by the majority of students, which could be again be linked with their specific knowledge. The most common archetypes used to describe the controlling solution are: limits to growth, fixes that fails, growth and underinvestment, escalation, shifting the burden. On the contrary, very little archetypes have been used to represent the new proposed solution (they just represented the circular causality, without attempting at finding patterns). This could be related with many different aspects: the assignment didn't explicitly ask for this link or, for example, students expected to see the final solution as optimal one, and therefore not failing. Only a couple of students actually highlighted the limits of the given solution, explaining how their proposed solution was also subject to potential changes in time. It might be that students failed in seeing the circularity of the process and, once analyzed the solution they considered it "final". This of course could represent a big threat, which could lead to the same dynamic with designers engaging in change in design (which is indeed something we could apply for some of the collected cases): to see only the first loop after release, and consider it as final. About the lenses only few problems were encountered: the why sometimes overlaps with the mechanism (i.e. Why does the product change? Because of a certain choice with regard of the materials). More importantly to the question "What is changing in the product?" almost every student (15 on 16) answered the question with the description of the mechanisms. Thanks to the interview feedbacks were given and an optional question resulted be "What design aspects are changing in the product?". Also the lens "When?" was sometimes misinterpreted with the exact moment, and not the general Life cycle (i.e. When is the product changing? Once the material is scratch - instead of – during the use phase). This, again thanks to the interview, resulted in the suggestion of creating more specific questions (from "when is the change happening?" to "when, in the life cycle of the product, is the change happening?"). The last lens that created some problems is the How? Strategy. This can be implied to the fact that these students have no background on business models, and therefore might miss the meaning and relevance of such perspective. On the contrary the mechanisms, therefore the technical aspects of the solutions, were clearly identified and described. About the lens Who? Many students added the designer as answer, referring to the fact that the designer him/herself changed the product at first place. This is not the intended use of the lens, but it is reasonable as an answer and therefore considered valuable to highlight as the Open-ended outcome is always result of a design choice.

Finally, to almost every student resulted hard to identify other examples where to apply the same dynamic. Indeed, this is a hard request to be done without a context and requires probably time to identify a reasonable answer. Even if examples were provided they had two characteristics: or they were the exact copy of the introduce product (i.e. the students who analyzed Verderame suggested Verdegris, a table using the same material to obtain similar effects in time), or they were actually representing a slightly different dynamic (i.e. the student analyzing Do Scratch, a lamp that functions only if scratched, suggested a comparison with the rat look of cars, which are intentionally scratched for aesthetic reasons). These dynamics were asked during the interview, where it resulted clear the difference in certain lenses.

We can imagine more difficulties in translating the learned concepts into a new context, when discussing it with students only few of them created a clear link between traces of change in their prototypes and the way they explored their hypothesis. The main problem, mentioned by the majority of students, is time related. In fact, the possible mechanisms they were coming up with required more time than the test itself (which lasted more or less one month). In this perspective it was probably a mistake from the researcher side to try to obtain similar results within a short time span, since we acknowledged already earlier as some processes cannot be speed up. On the contrary, little amount of students came up with sudden changes, with is the contrary of what observed in Study 4. This is probably due to the specific expertise of students, but will require further studies. Here following a synthetic visualization of the SWOT analysis of Study 5.

Strenghts	› Simple comprehensive method that can support designers in adopting different views on their design outcome › Practice based method applicable in diverse contexts › Re-appropriating of the method and its application proved to be feasible	› To engage with the method a background on systems thinking might be fundamental › The open-ended online platform is not yet optimized and cannot therefore give, for now, the full support as inspirational tool	**Weaknesses**
Opportunities	› Application of this method with companies and other creative professions, in order to expand its areas of influence › Improve the open-ended online platform to be tested by others	› The method might perceived rigid and prescriptive in nature › The method might be adopted literally descreasing the value of the creativity, still fundamental in a design process	**Threats**

Table 6.7. Synthetic SWOT of Study 5 and relation with future studies

6.6. Conclusions and future studies

Students applied practical Open-ended Design solutions, or second-order design solutions, to start a conversation, through design, with different stakeholders. Here, the voluntary designed imperfection of the system served as trigger for re-appropriations, which helped the designers in learning about the real interactions with the system itself. This experiment stresses the need for teaching systems thinking skills for designers, focusing on the fundamental capabilities as anticipating possible scenarios and losing control on the designed object. Also, it stresses the importance of practical examples and strategies to achieve and support re-appropriation processes in real-life experiments. These strategies cannot be taught to students as "fixed realities" being highly related to the context, but can be introduced to them as inspirational and comparative tool. By doing that, the actual Open-ended Strategies analyzed, and in some cases created, by students became the expression of their creativity as designer, and served their personal perspective in understanding the complex phenomenon of change. The main conclusion that we can delineate here is that we observed students changing, by observing the change in other products. They proved to have learned to think in the direction of time and of spontaneous processes. This mutual change is after all, the core of second-order cybernetics and main goal of second-order design, possibly in form of Open-ended Design.

In conclusion Open-ended Design is here proposed as methodology that characterizes objectives, techniques, and processes for creating new design outcomes. It provides a working routine, more similar to a pathway, rather than a strict procedure. In this perspective, Open-ended Design is hardly comparable to other approaches (i.e. co-design, UCD, etc.), not for its positioning but for its very nature. In fact, Open-ended Design advocates the engagement with Participatory Design actions, that could be conducted in many forms becoming sometimes user-centered ones, waste-centered, etc. depending on the specific context. OeD is supported by a "blend of more than one systemic methodology" (K.M. Adams, 2015) all focused on the understanding and management of the controversial nature of change (see Figure 6.4) in its unavoidable spontaneous events.

Other new questions raised from this study, which can lead to new experiments that will necessarily require more time. For example: how can other creative professions (architects, engineers, musicians, craftsmen, etc.) interact with this method? Can this method, meant for tangible products and dealing with material knowledge, also be useful for non-physical products? How can the engagement, through observation, be concretely fostered in time? These future studies are delineated in the next and final **Chapter 7**, **Termination**.

CHAPTER 7

TERMINATION

In **Chapter 7**, the final section of this manuscript, we report the general results and we discuss them both as *outcome* of the research and as *process* utilized to obtain them. We then suggest some new research trajectories, concretized in a list of future studies to be developed in the upcoming years. Finally, we conclude reporting an overview on the entire work done around Open-ended Design as an approach to intentionally support change by designing with meaningful imperfections.

7.1. Results

As introduced in **Chapter 1**, this dissertation has an explorative nature. The phenomenology of change in design, its relevance and approaches to intentionally embrace it, have been tackled with no starting hypothesis. The goal of this research was not to (dis-)prove something but rather to provide a broad picture, able to answer some research questions, specifically:

(Q1)
How can the phenomenology of change in industrially designed products be described?

(Q2)
How can we intentionally support change in industrially designed products?

In other words, the goal of this work is to provide some *knowledge-for-action*, useful to support designers in their practice, rather than knowledge *per se* (Glanville, 2007). To facilitate the reader, this thesis has been metaphorically described as the process of observation and understanding of a tree, as represented in **Figure 1.6, Chapter 1** where, from the observation of an unorganized collection of leaves, we tried to gather insights on the inner structure (roots and leaves) and on its functioning. The provided *bigger picture* and deeper understanding are, because of the very nature of the *tree*, open-ended as well, referring to the need to be further explored, as described afterwards in the **Paragraph 7.4**, **Future Studies**. Five main outcomes of this research are recognized:

1. **The creation of a theoretical framework**, described in **Chapter 3**, **Foundations**. This section, builds upon an extensive literature review, providing an original structure that relates topics that were previously disconnected. It shows the relevance for change to be considered and eventually steered, in order to create more resilient design outcomes, that can be *re-appropriated* in a real environment. It bridges the contemporary disruptive metamorphosis of the industrial production with the need for more sustainable outcomes; the emotional value of dynamic products with concepts as ambiguity, randomness and imperfection. It proposes a review on methods to increase participation in the design-after-design, and how to learn from them. This outcome represents the *roots* of the three, composed by different roots merging together in the main trunk of change in design.
2. **An overview of the phenomenon and a proposed way to reorganize it**, described in **Chapter 4, Observation**. This work builds upon more than 100 existing product (some visible at the link: open-ended-design.com, work in progress). These specific products, in their simplicity, share ingenious ways of embracing possible changes occurring to the design outcome once put in the real environment. For example, reported examples tackle the problems/opportunities of unavoidable production waste, material ageing, breakage, reparation, personalization, etc. A possible way to reorganize them has been proposed: the ten lenses. These lenses can stimulate the designer in asking specific questions about change in design, putting the focus on different aspects such as: What is changing? Why? When? etc. They have the double role of supporting the observation of reality and the anticipation of not-yet-existing design outcomes. The set of ten lenses propose a multi-perspective view, able to better recognize the complexity of such dynamic phenomena. This outcome goes from the observation of the unorganized leaves of the tree, to a proposed structure of the branches attempting at answering **Q1**. It ultimately gives first insights on how to move from leaves to branches.
3. **A proposed method to embrace Open-ended Design**, described in **Chapter 6, Study 5**. This work, has been built upon 77 originally developed case studies (20 for Study 1, 12 for Study 2, 36 for Study 3, 9 for Study 4). They followed – step-by-

step – how to generate solutions for diffused but yet diverse needs. Specifically, we looked at strategies to create suitable outcomes for each member of offline communities (**Study 1**), to transfer such outcomes to online communities (**Study 2**), to elaborate the design attributes to support change (**Study 3**) and to bring these outcomes to the market (**Study 4**). While conducting such experiments, we provided a new definition: Open-Ended Design, proposed as a design option (meaning a complementary paradigm instead of an alternative one) to be intentionally adopted in front of unavoidable spontaneous processes. In **Study 5** we converged to a closure, unifying our understandings into a method to support designers dealing with Open-ended Design. The method outlined is not rigid in its structure, and doesn't aim at being prescriptive. It is mainly grounded on the iterative learning process of observation and anticipation supported by ten lenses, as previously described. This third research outcome represents a possible way to connect the roots with the branches of the tree, for ultimately creating *new leaves* (that are, in our adopted metaphor, new cases of Open-ended Design products).

4. **A communication mean between design practice and academic research.** As highlighted in Chapter 3, practice and academic prespectives on *change in design* sometimes miss to be comprehensive of each other. With Open-ended Design, the practice is supported by theoretical model and, viceversa, those models are explained through conitinuous *materializations*. In this way, a common ground has been sketched, capable of putting into communication previously unrelated works.
5. **New research trajectories**, as listed in the following paragraph Future Studies. With the topic of change in design fairly new to the academic world, especially when tackled in its practice-base view point, we consider it important to highlight future studies focusing on specific aspects raised while developing this work. This fourth research outcome puts the focus both on methodological issues and on specific fields of application for Open-ended Design. This result is important for an explorative research, since it represents the potential future development of the *tree*, dynamic by nature, developing new branches and new roots. In **Figure 7.1** the four research outcomes have been highlighted.

Finally, it is important to highlight again that there is no intention to reach a closure *with* and *on* these outcomes, because we consider this research open-ended in its very nature. In fact, thanks to the technological, societal, economic, political and cultural developments we are positive that new foundations will be created and new strategies will rise, providing more inventive and innovative ways to create Open-ended Design outcomes. At the same time, we consider that these outcomes together already represent a solid framework, or better a *landscape*, from where to start a more open discussion about change in design.

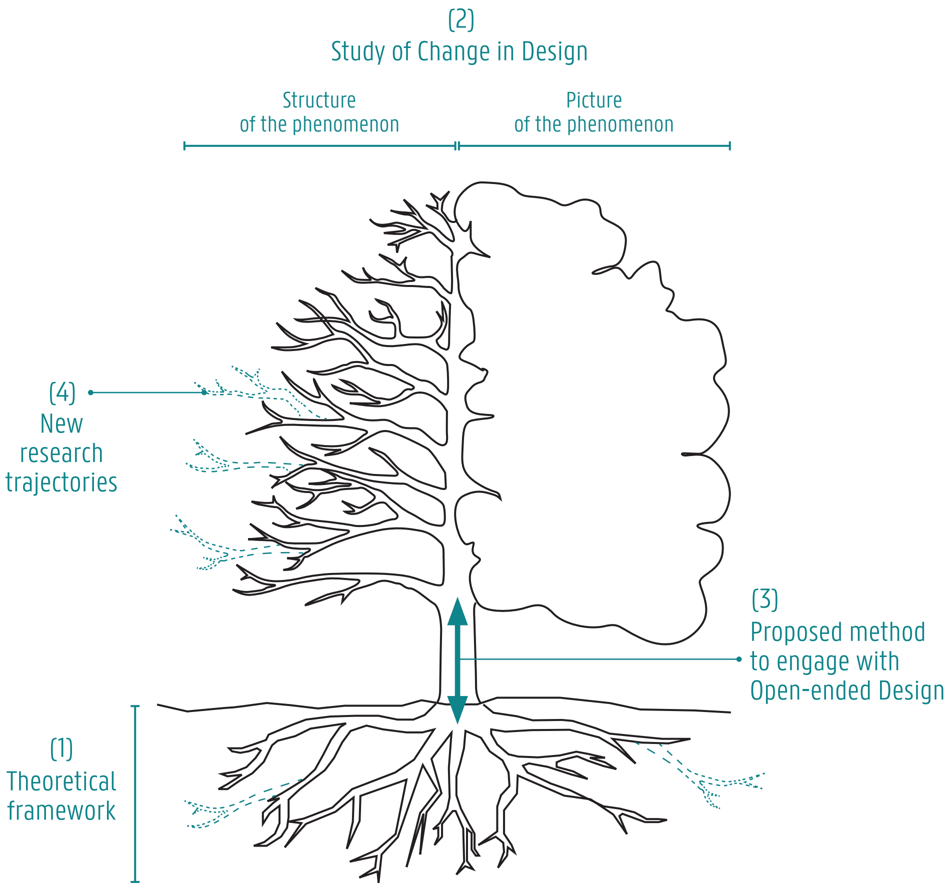

Figure 7.1. In the metaphor of the tree, highlighted the four main outcomes of the research

7.2. Valorization

This research has been object of various communications, mainly in form of scientific journal papers, conference articles, newspaper or other journals' short reports. We consider these recognitions as good proves of the value of the presented research and of its potential scalability. Here following, a summary of the obtained credits.

7.2.1. Journal papers (A1)

- Ostuzzi F., Conradie P., De Couvreur L., Detand J. and Jelle Saldien (2016) The role of re-appropriation in Open Design. *International review of research in open and distributed learning*. Vol. 17 (4), p. 121-144.
- Ostuzzi F., Rognoli V., Saldien J. and Marinella Levi (2015) +TUO project: low cost 3D printers as helpful tool for small communities with rheumatic

diseases. *Rapid prototyping Journal*. Vol. 21 (5), p. 491-505.

- Pacelli F., Ostuzzi F. and Marinella Levi (2015) Reducing and reusing industrial scraps: a proposed method for industrial designers. *Journal of cleaner production*. Vol. 86, p. 78-87.
- Ostuzzi F., De Couvreur L., Detand J. and Jelle Saldien (2017) From Design for One to Open-ended Design. Experiments on understanding how to open-up contextual design solutions. *The Design Journal*. Vol. 20 (sup1).

7.2.2. Conference papers (P1-C1)

- Ostuzzi F., Dejonghe W. and Jan Detand (in press, 2017) Open-ended Design as Second-order Design. A case study of teaching Cybernetics and System Thinking to Industrial Design students. *RSD6, Relate systems and design 6*, Oslo, Norway, October 2017.
- Nobels E, Ostuzzi F., Levi M., Rognoli V. and Detand Jan (2015) Materials Time and Emotions: how materials change in time? EKSIG 2015. *Tangible means - experiential knowledge through materials*. Kolding, Denmark, September 2015.
- Ostuzzi F., Rognoli V., Levi M. and Silvia Ostuzzi (2014) +TUO Project, 3D Printers as tool for co-design with and for users with Rheumatic Diseases. *STS Italia Conference: A Matter of Design*. Making Society through Science and Technology, Milano, Italy, 2014.

7.2.3. General public newspapers

- Article "I can 3D print my own assistive devices" (original title "Stampo i miei ausili in 3D") by Simone Fanti. Italian national newspaper *Corriere della Sera.*
- Article "In biopolymers and tailor-made: the objects for people with degenerative diseases" (original title "In bioplastica e su misura: gli oggetti per chi è affetto da malattie degenerative") by Rudi Bressa. Italian national newspaper *Corriere della Sera*.
- Article "Study on new materials applications" (original title "Studio sulle applicazioni di nuovi materiali") by Piero Altea. Italian National Specialized Journal, Laboratorio 2000, The researcher's journal on chemistry and biology (original title "La rivista del ricercatore chimico e biologico").

7.2.4. Credits to designers

In the framework of this research, many design outcomes have been originally developed. These were often created within specific design courses taught by the authors. In this way, all the here listed projects conducted a process of observation - anticipation, aiming at reaching design outcomes able to embrace diverse needs and contexts. Of course the specific outcome of every design process is, as mentioned previously, the result of creative processes, driven by tacit knowledge and intuitive decisions. In these terms, it is not the intention of the authors to take any credit away from the students' and designers' work, since without them these results would have not been possible. With this, we want to value the public recognition of their results, generally based on for the following aspects: innovation of the idea, soundness of the business analysis and definition, engagement with real end-users, capability of the presented solutions to satisfy diverse needs and the constant use of materialization, also definable as prototypes-in-contexts. This supports the belief of potential scalability of the here presented approach, as described later in the **Paragraph 7.3**, **Discussion**. Some of the following projects didn't find place to be described in the dissertation, and will represent the core for future studies and publications.

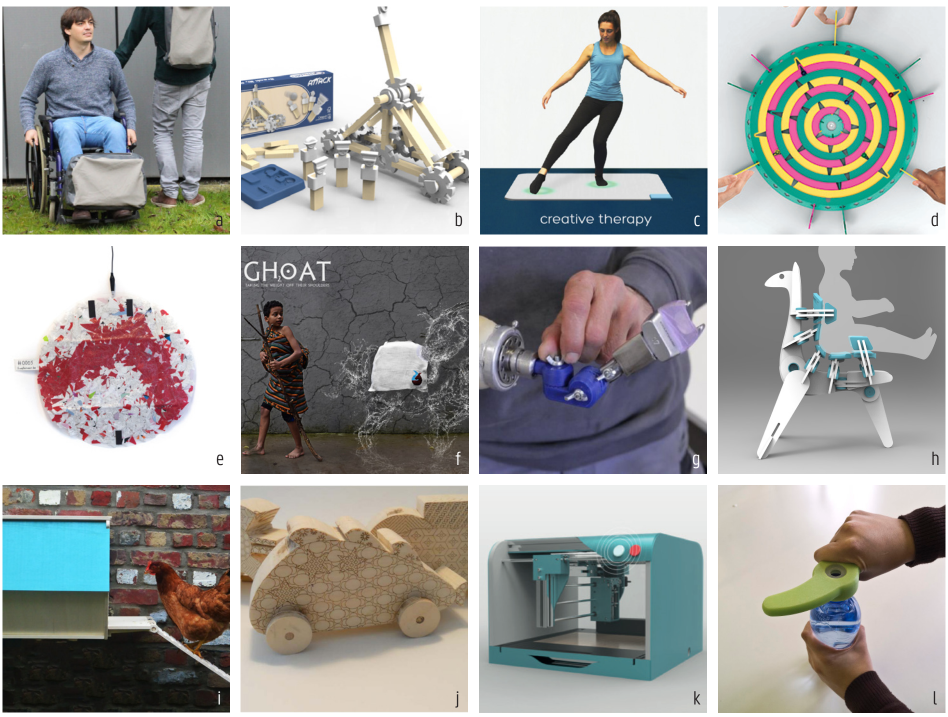

Figure 7.2. Overview on the projects that, developed in the framework of this research, received special public recognitions

(a) **Uono**, design by Jolan Soens, Kimberly Frans and Yannick Stoelen. Uono is a bag for wheelchair users, that can be connected on tubes of different diameters thanks to a smart open-ended connection, letting the user free to decide on the most comfortable configuration. Uono was selected as finalist in the contest SBP 2017, organized by Vlajo.

(b) **Wopla**, design by Thomas Vervisch, Jordi Deseure and Dries Kerkhove. Wopla is a toy that involves three main activities: molding a plastic material into connection pieces, building more complex objects with these connections, and finally re-molding the plastic again. This game, which has the goal to provide children with their first introduction with plastic processing, let the user able to build out-of-control structures, open-ended per definition. Wopla was selected as finalist in the contest SBP 2017, organized by Vlajo.

(c) **Matti**, design by Bert Heirweg, Jamil Joundi and Arno Penders. Matti is a device that supports rehabilitation exercises by making the exercises more interactive and giving direct feedbacks to the users while using the product. More importantly Matti is designed to improve through use, creating new and unique games for every patient. Matti was selected as finalist in the contest DO! Goes USA 2017, organized by Durf Ondernemen.

(d) **Amfi**, design by Thomas Gruwez, Dries de Kersgieter and Charles Degeyter. Amfi is a board game designed to be played together by people with and without fine motoric impairments. Amfi is designed to be personally configured by the user before production, thanks to the adoption of digital technologies, with the goal of decreasing the stigma and facilitating use. AMFI won the first prize in the contest SBP 2016, organized by Vlajo and participated to the JA Europe Final, in Bucarest.

(e) **Oori**, design by Pieter Dondeyne, Ward De Doncker and Gilles Missiaen. Oori is a reusable food packaging. It is made starting from plastic scraps derived from the local industries and, thanks to its Open-ended and participatory production process, it has an unpredictable aspect, which makes every Oori unique. Oori won the First Prize and the Audience prize of Battle of Talents 2016.

(f) **Gh_2oat**, design by Robbe De Clerck, Senne Van de Broeck and Jeremi Vandersstichele. Gh2oat is a backpack for Goat to be used to transport water in Africa's Sahel Region. Instead of providing a finished product, the designers opted to the let the product be manufactured in local workshops and with local materials, providing ethical job opportunities and knowledge for the people, and helping the local economy in the process. The work done on this project is to provide good instructions and design a specific building system, able to embrace the diversity of materials and technologies, of every specific local context. Gh2oat won the second prize of the Battle of Talents 2016.

(g) **Forearm measuring toolkit**, design by Robbe Terryn. This toolkit facilitates users and professionals while designing a new prosthetic forearm for specific users. It can be defined as Open-ended or adaptable prototype, that combines a modular building system and the use of digital technologies to This project won the second prize of the PRoF award 2016.

(h) **Seating measuring device**, design by Niel Liesmons. This device enables occupational therapists to dynamically measure the 3D geometry of a child's pelvis area, defining how it should be supported and transforming this information into a specific shape for a personalized seat. The seat adopts a modular approach that changes according to every users' shape and condition. This project was selected to be exposed at the exposition Interieurextra 2016 organized by Designregio Kortrijk.

(i) **Chick'in**, design by Thomas Van Glabeke, Sievert van Esch, Bert Peters, Clotilde Destrebecq and Wout Mareen. Chick'in is the solution for people who want to have chickens in small gardens. Because of the unpredictability (especially in terms of dimensions) of the final context, the product is adaptable in its configuration and utilizes digital production techniques, making it easy to be personalized by the final user. Chick'in won the first prize in the contest SBP 2015, organized by Vlajo and participated to the JA Europe Final, in Lisbon.

(j) **Wili**, design by Jonas Callewaert, Lennart Demeulemeester, Sam Van Landuyt, Thomas Popelier and Lynn Vandecasteele. Wili is an interactive playset that allows children to design their own wooden toy car in a playful way. It provides the experience of bringing your own creation alive, through the adoption of digital manufacturing and social networking together. Wili can in fact be described as a new-generation digital and participatory hand-craft, where the designer produces the outcome designed by the users themselves. Wili won the first prize of the contest Start Academy 2015, organized by Vlajo.

(k) **Tucan**, design by Lore Vandemaele, Niel Liesmons, Asha Derumeaux, Louise Dumon and Jonathan Van der Smissen. Tucan is a digital tool that, by transforming the kid's sketches into wood or cardboard pieces, aims at introducing digital technologies and the culture of the maker movement at elementary school. Also in this case the designer create an outcome at the service of the users' creativity and needs. Tucan won the second prize of Battle of Talents 2015.

(l) **3D printed bottle opener**, design by +LAB (specifically Francesco Pacelli and Francesca Ostuzzi), is a bottle opener that can be personalized in certain features in order to better satisfy the unique functional and aesthetic users' need. This product won the first prize for 3d printed objects at the Maker Fair in Roma 2014.

Figure 7.3. Results obtained by students entrepreneur, with the outcomes of Test 1 and 2. From left to right, respectively My Add On, Gh$_2$oat and Amfi

7.2.5. Reaching the market

Apart from the ones distributed via online platforms, other projects reached bigger panels of end users, by starting an up-scaling process. These projects are reported in **Figure 7.4**, in the following page, first in their prototype status and then in their up-scaled version.

(a) The project of Marie Van den Broeck, Stefan Flamand and Jonas Gheysens, developed within the course SBP and focused on up-scaling design solutions for one (Study 4), is now the first product of Marie Van den Broeck's company My Add On (myaddon.be). The product **MySleeve** is meant to solve some problems related with the normal crutches and comes in kits: it is up to the user to assemble it according to his/her needs. Furthermore, as the name of the company says, all the future projects focus on the concept of adding devices on top of existing products, in order to personalize them and achieve higher users' fit.

(b) The project **"Design of a dynamic, modular and and adaptable high rope course"**, design by Thomas Gruwez for Avanco Adventure, developed as master thesis promoted by Ellen De Vos and coached by the author, has been build and will be soon on sale in other countries. This product is also the center of an on-going study, conducted by the author and Ellen De Vos, that connects open-endedness with users' satisfaction.

(c) Currently, the pilot study +TUO Project has been up-scaled under the name **"We won't stop"** (original Italian name "Noi non ci fermiamo") conducted by +LAB (piulab.it) in collaboration with the Italian national association of people with rheumatic diseases (ANMAR), with the Italian national association of people with rheumatic and rare diseases (APMAR) and supported by Roche.

Figure 7.4. Three examples of projects that reached bigger users' panel

7.3. Discussion

In the following paragraphs the presented results will be discussed. We have decided to adopt two points of view: first to analyze in depth the results through the six criteria proposed in **Chapter 2**, and second to analyze both results and research method through a synthetic SWOT (Strengths, Weaknesses, Opportunity and Threats) analysis.

7.3.1. Discussing outcomes

The criteria proposed to evaluate the quality of the contribution deriving from a "research through design" approach, are: process, invention, relevance, extensibility, conversation, scalability (Koskinen, Zimmerman, Binder, Resdstöm, & Wensveen, 2012)(Zimmerman, Forlizzi, & Evenson, 2007)(Hermans, 2014).

7.3.1.1. Process

In design, by reproducing the same process, there can be no expectation to obtain the same results (Nelson & Stolterman, 2012)(Zimmerman et al., 2007). Anyhow, a good documentation is needed to let readers understand the assumptions behind certain choices. This has been recognized as one of the most problematic aspects of researching through design. The tacit reflections and understandings occurring while designing are hard to be identified and harder to be verbalized in the text. A good strategy could have been to report on *key incidents* occurring while designing, which might have still proved problematic since "doing and thinking are complementary and make it hard to document key incidents that steer decision-making and the inquiry process of relevant design aspects." (Couvreur, 2016, p. 242). For these reasons we decided to report the pivoting points (or key incidents) only of the co-design stages (Study 1). For the other studies, we decided to report and discuss the outcomes themselves, materialized in form of objects, business plans or instructions. In this way we attempt at highlighting the *contextual*, or *situated*, knowledge *embedded* in these outcomes, through a constant conversation with others, since "knowledge is distributed, [knowledge-intensive emergent processes] require knowledge sharing" which also means that it requires participation (Baskerville & Myers, 2002, p. 184) (Ehn, 2008)(Ostuzzi, Couvreur, Detand, & Saldien, 2017). This is a choice, coherent to the goal of understanding what conserves and what changes in the design itself. Furthermore, every study has been reported in a narrative way in order to let the reader build other personal interpretations about the given information. Finally, all the gathered knowledge about the Open-ended Design process and the nature of its outcomes have been merged and tested in Study 5, which represents a suggestion of a possible process to be used in the designers' specific contexts.

7.3.1.2. Invention

It is our belief that the here presented work manages to originally integrate different – and previously distant – subjects. We highlighted the links between the contemporary industrial revolution, communication revolution, the need for new paradigms of more resilient design outcomes and renovated design paradigms. Furthermore, the researched balance between the academic world and the design practice is considered an added value of particular invention. Only few studies have been published on this topic, adopting this double-sided (and yet *continuous*) perspective. Among these few publications some are extremely recent, proving the shared perceived need to tackle similar issues (Wakkary, Desjardins, & Hauser, 2016)(Dix, 2007)(Couvreur, 2016). Still, the dimension of the literature studies, together with the post-factum collection and ante-factum generation, can be considered of particular value in such a landscape. Finally, the definition of Open-ended Design itself can be enumerated among the object of particular invention in this research. This definition *emerged* from the conducted studies and observations, shifting the starting focus from the way we distribute our outcomes (open design) to the way we perceive, think and create them.

7.3.1.3. Relevance

The reflections proposed in this manuscript emerged from a context of crisis, financial, societal and environmental. The promotion of new models, or improvements of the old ones, can represent a reasonable reaction for such a critical scenario (Manzini, 2010), quoting Albert Einstein "do not pretend that things will change if we always do the same. The crisis is the best blessing that can happen to people and countries, because the crisis brings progress. Creativity is born from the distress, as the day is born from the dark night. It is in crisis that invention, discovery and large strategies are born". In the last few years we are, in fact, witnessing disruptive changes leading to shifted paradigms from more closed, top down, standard, ideal and static view on designing things, to more open, connected, bottom up, dynamic, decentralized and adaptable views on such topics (Bas, Lucas, & Roel, 2011)(Manzini, 2014)(Manzini, 2012)(Binswanger & Aiyar, 2003). This change is supported by the phenomenon of open design, digital fabrication, social networking, but also by resources scarcity, social inequality and improved consumerism. For these reasons, the presented work aims at covering a small piece of the broad discussion about potentially more sustainable ways to look at the design profession, as it could be in this renovated context. It proposes to shift from more consumeristic paradigms, deeply rooted in the idea of perfection and control, to more comprehensive views on the imperfect and dynamic nature of processes and things. The Open-ended Design approach aims at re-evaluating things previously considered as useless or negative, and by giving a *new name* to them, resulting ultimately in a change in the perception of the users towards them (as occurred in many of the presented cases).

7.3.1.4. Extensibility

This work aims at being open for future adaptations. For example, no attempt at listing all the possible strategies has been made, in order to openly highlight as the method can support designers in their creative process, without denying that a specific design outcome remains always the responsibility of the designer and, more importantly, subject to constant changes related to all the environmental changes (personal skills, believes, available resources, etc.). To explore this, a pilot test has been conducted, where 5 users engaged in an open interview with the purpose of exploring the extensibility of the method to others. This pilot test involved five different figures dealing with the creative processes (one engineer, one craftsman, one musician, one designer and one architect); it gave first insights on (1) the ease for experts to highlight existing spontaneous processes, (2) the tendency of adopting controlling solutions even in front of unavoidable spontaneous processes, (3) the understanding of the ten lenses and the ease in their adoption and (4) the capability, if asked, to generate Open-ended solutions. This study is in progress and will not be described here in more detail. Anyway, if the extensibility of the method is under study, we can already acknowledge that some of the outcomes are already subject to adaptations, as seen in Study 2 and 4.

Finally, we decided to focus this manuscript mainly on assistive devices, but in reality, as shown by the Observation phase, such concept can be extended to every product that is facing disruptive scenarios because of change (positive, but too hard, or negative, and too easy). Examples are provided by the following studies, developed in the wider framework of this research, but that didn't find space to be described in this work. These cases represent other contexts than assistive devices, and will represent the core for future publications.

- A study that relates the change of materials (through natural weathering) to the emotions we perceive towards them.
- A study that relates the open-endedness of products, configurable during use, to higher users' satisfaction and higher users' fit, leading to an increased feeling of flow while experiencing them (Nakamura & Csikszentmihalyi, 2014).
- A study that sees the adoption of open-ended garbage collectors, designed on the specific needs of every environment they are put in, with an increased efficiency in the sorting process.
- A study that generated an open-ended teaching tool, meant to teach the complex nature of sustainability to children, through personal engaging of the pupils and the teachers, capable of re-appropriating the method with their own knowledge, skills and preferences.

7.3.1.5. Conversation

As clearly stated in **Chapter 3, Foundations**, we consider the capability of triggering conversations (which we don't only see as verbal, but also – and mainly – as tangible, in form of action) fundamental to judge the quality of Open-ended Design outcomes. In fact, the value of the outcome itself emerges only in time and thanks to the conversations it provoked. On the one hand, we assume the publication of this work will attract the attention in public contexts and to start few up-scaled projects, etc. On the other hand, in order to start a real conversation, time is needed. In fact, if we managed in Study 2 to trigger some online conversations, we still found it hard to support conversations with the real contexts, in time. This, again, is due to a lack of resources, mainly time, but also financial ones.

7.3.1.6. Scalability

In Research Through Design a distinction in made between research artifacts and artifacts made for the real market (Koskinen et al., 2012)(Fallman, 2007)(Odom & Wakkary, 2015). In this sense, it becomes important to judge the quality of the results also in its potential marketability, which is not always evident or easy. In this thesis, on the contrary, the main focus has been given to the up-scaling potential of such solutions, especially highlighting how to support possible re-appropriations, real user adoption and identification of suitable market spaces.

7.3.2. SWOT analyses

To conclude our discussion section, we introduce here two synthetic SWOT analyses, made both on the outcomes (Open-ended Design and its method) and on the process and methods adopted for conducting the presented research.

7.3.2.1. SWOT on outcomes: Open-ended Design and its proposed method

Strengths

- The term Open-ended Design defines a known phenomenon that was never re-organized under one comprehensive view. In this way, it becomes possible for designers to include this approach in their design process, when needed, in order to broaden up their perspectives.
- Open-ended Design is an approach, and a kind of solution, that tackles the portion of unavoidable spontaneous processes of change. In this way, it doesn't conflict with the traditional way of designing (in terms for example of security, strength, feasibility, etc.), but it should be seen as rather complementary.
- Open-ended Design is therefore a simple way to refer to a complex dynamic. Even if simple is not over-simplified, referring to "a process by which complex requirements can be brought together within one, unified, unitary form. This is not to argue against functional adequacy, or sound fabrication: it is to say that the criteria by which we may value design outcomes are open, variable, chosen (optional), and not absolute." (Glanville, 2007, p. 1196). For these reasons, the method proposed is practice-oriented and not restrictive.
- Open-ended Design participates to the conversation about how to diffuse context-dependent solutions that emerge in their value through constant ad-

aptations. As advised by De Couvreur (Couvreur, 2016), this research offers insights on how design patterns on occurred re-appropriations could be interpreted, communicated and embedded in a design outcome to be constantly re-designed by other (non-)human stakeholders (Forlizzi, 2007)(Wakkary et al., 2016).

- Related to the last point, important to highlight is how Open-ended Design suggests to the designers no to limit this adaptation approach to the human components of the real environment, but to all the other possible actors, such as: production facilities, time, natural and environmental conditions (as temperatures, weather, etc.).

Weaknesses

- The presented method, even if simple, still requires a background in system thinking, important in order to understand the connection between different phenomena occurring in the real-environment. In fact, often the topics related with imperfection are – nowadays – sometimes overlapping with a more fashionable rather than aesthetic view of the presented phenomenon.
- This method requires time in order to be observed and improved, which is considered often a scarce resource by companies. And, even if in our opinion by adopting Open-ended Design solutions the time to market might decrease, the time spent in observations and remaining engaged with the delivered outcome is still fundamental in order to learn. The delay between design action and feedback (defined as buffer) might lead into misinterpretations of certain behaviors.
- Open-ended Design is proposed as a vision to put aside, or on top, of all the other functional reasoning and we consider the fact that it might be considered as a proposed unique approach to the design of things, a weak point.

Opportunity

- For now, Open-ended Design has been applied to common objects, tangible and low tech, in order to reach higher resilience, which is a solid strategy only for products that don't consume significant energy during their life-time. The next challenge is to combine the here presented method for multi-components and multi-function products, where different combined approaches are needed.
- Even if this method requires time, and observations of the design outcomes as prototypes-in-contexts, this can lead ultimately to an acceleration in the feedback gathering, fundamental for companies. It aims at helping the designers in

overcoming the paralysis due to a lack of contextual information, since in the proposed perspective there is a design act which is not a solution, but rather a way to reformulate the question and to show certain intentionality (Nelson & Stolterman, 2014).

Threats

- Nowadays, digital production, open design and especially the aesthetic of imperfection are surely a very fashionable topic. The risk we foresee is that some designers might deal with imperfection in fashionable terms, without acknowledging the ultimate goal that is to increase resilience in front of unavoidable spontaneous processes. An example could be seen in the topic of randomness and ambiguity, where no real intention to build more readable feedback (and therefore conversation) is present (Leong, Vetere, & Howard, 2006)(W. Gaver, Bowers, Kerridge, Boucher, & Jarvis, 2009)(W. W. Gaver, Beaver, & Benford, 2003). Another typical example is represented by the trend of producing and selling already aged products, this is not adding any support to their dynamic nature, and often requires an increased amount of energy input in the system.
- As highlighted in **Study 1**, Open-ended Design aims at limiting the *uncritical diffusion* of devices by including the products' ecology as active participant in the creation process (Binswanger & Aiyar, 2003, p. 33). This is particularly important to face the possible risks occurring, for the end users, while using a device that is not appropriated for their specific case. Interestingly, these risks can be encountered both on devices created with bottom-up dynamics and with top-down ones. Therefore, discussing the role and designers' responsibility becomes crucial in order to understand how to deal with, for example, the delivery of instructions, the delivery of a DIY kits, the production of standard - but intentionally open-ended - devices or the production of unique ones (i.e. 3D printed in a local FabLab), etc. This topic, already partially addressed in literature, will need further studies (Leon Cruickshank & Paul Atkinson, 2015; Atkinson, P, 2010; Dorst, K., 2006; etc.).
- Another possible threat is that designers might embrace this approach, without preserving the fundamental balance between open and closed instances. Open-ended Design doesn't mean to fully open up the design outcome, on the contrary the whole process has the goal of understanding the balance between what conserves and what changes in the design outcome (Dubberly & Pangaro, 2015), where the latter case is what we defined as *context-dependent*.
- The previous point can be seen as profoundly related with the potential sustainable nature of the designed outcomes (as also mentioned in the last point of the following paragraph **Weaknesses**). *Designers for sustinability* should uti-

lize various existing methods (both efficiency and sufficiency oriented) and consider the here proposed OeD methodology as a perspective to be adopted (in addition to the other possible methods) when facing *unavoidable spontaneous processes*. In other words, Open-ended outcomes cannot (alone and *a priori*) bring to more sustainable scenarios and this concept, if misunderstood, could imply also unsustainable rebound effects.

- Finally, the out-of-control nature of certain aspects of the Open-ended outcomes might be scary for some designers and companies, which might prefer "controlling solutions" even in front of those unavoidable spontaneous processes. This possible threat was also confirmed by our small pilot study, conducted with regard of the project's extensibility.

7.3.2.2. SWOT on process: adopted research method

Strengths

- The method is based upon a solid literature review, and produced public scientific results, proving the scientific solidity and the interest of the community for the presented topic.
- The method is strongly based on design cases, adopting a Research Through Design and inductive method in order to create new models, and explore applicability of the theoretical insights also to the design practice, aiming at covering the gap between academia and practice, as highlighted in **Chapter 1**.
- With this methodology, we showed the possibilities and different dynamics of up-scaling design outcomes initially created for one specific user, to more stakeholders, also distant and unknown.
- The big amount of data gathered with regard of the originally developed outcomes is available to everyone (on demand). This makes our method transparent and, potentially, easy to be re-interpreted by other peers.

Weaknesses

- The method focuses on design outcomes delivered, in most but not all, cases by students in design. This represent a limitation, even if it could be reasonable to think that more experienced designers have more tacit knowledge of spontaneous process, due to their years of experience and observation. The focus on students was anyhow needed due to the lack of resources necessary in order to engage with professional designers. As reported afterwards, future studies will focus on this aspect.
- Another limit of this research is that the economic evaluation of possible

up-scaling scenarios is not included in the manuscript, even if developed within the experiment of Study 4. This is a choice based upon the intentional focus given on the kind of solution, rather than on the business model behind it. Furthermore, the background of the author also requires to conduct the future studies focused on those aspects in multidisciplinary teams.

- Only a little number of assistive devices is used during the observation phase, which mainly focuses on daily use objects. The reasons behind this choice are the ease in communicating these objects for everyone, and the fact that few devices are up-scaled in an open-ended manner.
- Finally, we introduced in Study 0, first in this manuscript, the ten lenses in order to provide an overview on the results through which possibly read the various experiments. In reality, that study progressed in parallel with all the other studies and converged just in Study 5, considered as the main conclusion of the work. This might be confusing for the reader, since some experiments didn't acknowledge some information already presented in Observation. This anyhow has to be seen in the very nature of an explorative PhD as learning process where every experiment is done in order to learn more, and not to confirm something.
- Another weak point regards the collected products as post-factum observation (Study 0). These products are not always functional or sustainable *per se,* on the contrary, they can be sometimes consiedred trivial. What is common among all those products is, undoubtedly their strong value of representation – in a simple and daily used object – of very complex dynamics of anticipated change. This weak point might distract the attention of the reader from the message we want to deliver with them, which was always to be recognized in the strategies and mechanisms they adopt to embrace change.

Opportunity

- The research focused mainly on hardware low tech products. Many reasons have to be seen behind this choice: first of all, the coherence with these products and the strategy of prolonging their lifespan (strategy not evident or advisable for other products categories, i.e. energy consuming ones), secondly their availability in our daily routine (which increases the ease of communicating through them) which makes them easy to be understood, as explained previously. An important opportunity is then to merge this approach to other more complex products, for example with electronic and smart devices, which suffers from low emotional attachment in time (Odom, 2008).
- As mentioned before, a weak point is the focus of the research on mainly

students. But, since Open-ended Design is proposed as a learning process, it could be interesting and relevant in our opinion to focus the attention on the education level, related both on *how to teach* this approach to students and on *what are the educational goals and outcomes of it*.

- This leads to another opportunity which can be defined as *train the trainer*. In fact, if we want to let this approach become integrated in our future designers' generation by introducing it in the curriculum of industrial design engineering, we should clearly start by understanding also how to teach it, and let it be re-appropriated, by the teachers themselves.

Threats

- In our opinion a possible threat linked to the research method has to be seen in the explorative research that started without hypotheses and, through an inductive method, aimed at the creation of *knowledge-for-action* rather than new theories. This might be interpreted as a less solid approach especially when compared with traditional sciences. This decision has been anyhow clearly supported by literature in **Chapter 2, Research Methodology**.
- Another threat can rise by the nature of the obtained knowledge, which emerged from our specific context, and could therefore lead to different results, once re-appropriated in different contexts. Also this, even if for complex and wicked problems, is in line with the design process itself, it is not oriented at showing that certain conditions are always right or wrong, but rather as they can be sometimes one or the other, underlining again the potential nature of what we anticipate as designers (Nelson & Stolterman, 2012).

7.4. Future studies

As mentioned in **Chapter 1**, with the example of **Figure 1.8**, some specific studies have been developed in these years. These studies focused on very specific phenomena of change in design, which we represent as the branches of the tree and on applications of Open-ended Design concepts on newly developed case studies. These studies mainly focused on: other co-design for small off line communities dynamics (with main focus on crutches), the spontaneous ageing of plastic materials and the change in the perceptions we have of them (part of this study has been published (Nobels, Ostuzzi, Levi, Rognoli, & Detand, 2015), the spontaneous processes occurring in production, mainly of scraps also defined as systematic waste (also in this case, part of this study has been published (Pacelli, Ostuzzi, & Levi, 2015), the construction of networks among companies to share these scraps, the value of imperfect and puzzling design instructions (work related with what developed by Shiro Inoue et al. (Smith, Inoue, Spencer, & Tennant, 2017)(Inoue, Rodgers, Tennant, & Spencer, 2016), the application of Open-ended on specific products, as listed previously: open-ended trash collectors, open-ended high rope courses and open-ended teaching device in from of game. This, shows how this work can be applied more broadly, in terms of fields, and more detailed, in terms of kind of studies. On the one hand, some of the previously mentioned studies will be further explored with more iterations and will represent focus of research outcomes (publications in different forms). On the other hand, we already recognize many other branches to be explored or even defined, as well some methodological improvements are here advised. Therefore, the proposed future studies are either focused on applications of OeD outcomes and method, or on fields of explorations. For example:

- **Explore the intentionality of designers already engaging with Open-ended Design outcomes.** We propose to contact the designers who already originally developed an OeD (mainly the ones listed in **Chapter 4, Observation, Study 0**) and explore their own experience, understanding their level of intentionality with regard of the obtained out-of-control solutions. This study locates itself in the Post Factum area, and aims at gathering more knowledge about the methodology already adopted, if any, and the market considerations raised thanks to there already existing Open-ended Designed products.
- **Explore values and dynamics of Open-ended Design for companies and for the market.** As mentioned, we conducted (specifically for Study 4) economic considerations on how to bring Open-ended Design solutions to the market, within a sustainable Business Model. This exploration requires more attention. In fact, it would be relevant to engage with already existing companies, in order to release some intentionally open-ended outcomes to the market and track their behavior in time. This broad research trajectory has to focus also, when dealing with human stakeholders, to focus on the actual triggers needed for users to re-appropriate products. Here, in fact, these aspects are entirely built upon literature. This broad research path locates itself in the Ante Factum area, aiming at creating new outcomes from which to learn, in time.
- One specific field of interest in our opinion is to **apply the Open-ended Design method to electronic devices**. In fact, these devices are normally characterized by extreme flexibility and dynamic behavior in their software components, which is proven to not necessarily enhance the emotional bond in time, reaching longer lasting products (Odom, Pierce, Stolterman, & Blevis, 2009). For this reason, it would be interesting to apply the same dynamic nature to the hardware components of such devices. This is surely a big challenge already attempted by a big company as Google to create a real modular and Open-ended

phone. This big challenge concluded, for now, in a failure without reaching the market (see: atap.google.com/ara). Another benchmark is the Fair Phone (see: fairphone.com).

- **Explore extendibility of the Open-ended Design method to other professions dealing with creative processes**. As showed before, we just started a new study focused on understanding the value and feasibility for other professions dealing with the creation of something new (which is, in our opinion, the broad definition of design itself) to engage with the Open-ended Design method. From our first results, we highlighted as some professions, typically the craftsmen, are already due to consider and embrace out-of-control processes in their work. In this perspective, the proposed study is seen as a mutual learning process. This study focuses more on the methodology itself, and aims at enlarging the view obtained till now.
- Methodologically speaking, another important study could **focus on the problem of quantifying the evidences of change in Open-ended Design solutions**. This potential interest raised while conducting **Study 5**, Task 2, where many students considered the readability of material feedbacks still too blurry to derive from it any numerical conclusion.
- Focus and **test of the OeD methodology on the material aspects of the designed outcome**. Specifically, on the lines of *design for traces* (Giaccardi E. et. al., 2014 and 2016) and on the broad topic of DIY materials (Rognoli V. et al., 2015) and (Parisi S., 2016), with possible specific focus on growing materials and growing design (i.e. mycelium as in the example with corpuscoli.com and magmanova.com, last accessed on October 2017).
- Finally, as introduced earlier, future studies will be focusing on the **ways that the method can be taught to students and designers**. This topic already represented an underlying focus of part of the presented research. For this reason, we acknowledge the importance to better structure the teaching challanges of such complex process of observation and anticipation, bridged by constant design actions.

7.5. Conclusions

The aim of this dissertation was to gain more insights about the phenomenon of *change* in design, referring with change to the difference between products belonging to the *ideal design space* – abstract, stable, under control – and to the *real environment* – concrete, dynamic, out-of-control (Nelson, 1994)(Hermans, 2015). The phenomenon of change has been here recognized both under its disruptive consequences of products rejection or early abandonment, but also under its beneficial potential of allowing the creation of design outcomes able to change, adapting themselves or being adapted (or, as it has been here defined, *re-appropriated*), thanks to and by the changing environment (Wakkary et al., 2016)(Dix, 2007)(Dubberly & Pangaro, 2015)(Ostuzzi, Conradie, Couvreur, Detand, & Saldien, 2016).

Chapter 3, Foundations. Firstly, an extensive scientific literature review was developed, thanks to which the phenomenon of change was put in relation with the current design landscape characterized by shifting paradigms such as the digital industrial revolution that moves from top down, standard and closed design approaches to bottom up, unconventional and open ones. This review gave centrality to the advocated research for more resilient and emotionally durable design outcomes, rather than thrown away versions of them. Finally, ways to transform the design theory in design action, and the design action into relevant conversations among every stakeholder, is reported, underlying for links to Second-order cybernetics (Francis, 2001).

Study 0. To better understand the dynamic nature of products, a constant observation of design outcomes intentionally made to *meaningfully change* (meaning limiting disruptive changes and supporting beneficial ones) has been conducted. This observation, that we defined as Post Factum activity, gave further insights on how the *knowledge* of what changes and what conserves in certain design outcomes was skillfully and intentionally embedded by the designers in their products (Dubberly & Pangaro, 2015)(Von Hippel, 1994)(Sanders & Stappers, 2012). To support this understanding a set of ten lenses has been developed, for which the dynamic of change represents the main center of study (i.e. When is the change happening? How fast? Where? Why? Etc.). These lenses have the double role of helping the designer while observing reality and while anticipating it. These insights provided the supporting framework for the development of five original studies, defined as Ante Factum activities, meaning experiments focused on the creation of *non-yet existing products*. These studies focused on the small steps needed for the intentional creation of products able to meaningfully change. The studies, even if reported sequentially, often proceeded partially in parallel, as visible in **Figure 2.3, Chapter 2**.

Study 1. We started with a focus on the dynamics of context-dependent outcomes of creation. Meaning outcomes made for one user, and recognizable as reaction to outcomes made for all, since "effective solutions cannot be generated on a global level. Universal solutions need to be appropriated from the environmental, ethical, cultural, social, political and economic contexts." (Couvreur, 2016, p. 277). In this way, we explored how to achieve a conversation with the real context from the very beginning of the design process through participatory co-design and co-production processes. In this study, by iteratively designing and producing a set of devices, we highlighted as communities with shared needs (i.e. to open a bottle) still might require several adaptations in order to satisfy the specific user's need and as some of these adaptations were actually focusing on the same design attributes. This process was developed in a proximal, off line area.

Study 2. We then focused on how to transfer similar context-dependent solutions to other contexts, distant but connected, in order to understand how re-appropriation works and how the adapted outcomes changed thanks to the new environment. This study gave us insights in the complexity of such online distribution, which might lead to uncritical diffusion, where the solutions *for one* are just copied, rather than adapted and re-appropriated. Anyhow, since we also highlighted that a more global conversation was triggered thanks to our design outcome, we felt the need to meaningful re-organize the information regarding our design outcomes, especially focusing on the information that cannot be predicted by the designer, emerging only from the real context.

Study 3. This study aimed at exploring the possibilities to anticipate what might change and what conserves in the design outcome. This study, which also focused on reducing redundancy by the hierarchical identification of design attributes, identified three kind of design attributes: *undefined*, *defined-fixed* or *contextual*, where the contextual are the design attributes that need to change, in order to fit in the new context of use. This helped us in better defining the What lens and ultimately led to the identification and definition of a different kind of design outcome: Open-ended Design. Open-ended Design, has been defined as a design product intentionally sub-optimal, error-friendly, unfinished, Wabi Sabi, contextual, context-dependent and is characterized by its inner flexibility due to the voluntary incomplete definition of its features, also defined as its imperfection (Manzini, 2012)(Fischer & Giaccardi, 2006)(Juniper, 2011). Open-ended Design is seen as a manifestation of a unique mix of the ten lenses, generating creative *strategies* and *mechanisms* that allow the products to meaningfully support change by opening-up the before mentioned context-dependent attributes. By making negative change less disruptive, and positive change easier, the aim of Open-ended Design is to start out-of-control conversations with the real environment, and therefore to reach more resilient solutions. Resiliency not only in functional terms, but also emotional ones, within a narrative aesthetic of the emergent; "it is most beautiful when it comes straight from your life – the things you care for, the things that tell your story" (Alexander, Ishikawa, & Silverstein, 1977, p. 1166).

Study 4. At this point we started another study focused on the up-scaling of highly solutions that were firstly created to be for one and where the context-dependent attributes have been already highlighted. This up-scaling aimed at reaching solutions suitable *for each*, meaning solutions where the goodness of fit (as defined by C. Alexander) is reached only by constant conversations between the form, given by the designer, and the context, which defines the problem itself. "In other words, when we speak of design, the real object of discussion is not the form alone, but the ensemble of comprising the forms and its context. Good fit is a desired property of this ensemble, which relates to some particular division of the ensemble into form and context (Alexander, 1964, pp. 22–23)." The up-scaling process aimed therefore at reaching solutions were the fit occurred, in time, through adaptations both of the product and of the context. "Adaptations are seen as the dynamic between misfits and good fit. […] Time is the essential condition by which equilibrium of fit occurs." (Wakkary et al., 2016, p. 503). This works moved therefore in the direction of a *transformational economy*, creating business models and design solutions that recognize in the collaboration (between academia, industry, government and especially local users and communities) the possibility of meaningfully tackling the large-scale and diffused issues reported at the beginning of this manuscript. "Local solutions to big collective issues cannot be created without intimate, empathic knowledge of the local context, needs and culture, nor can they be created by a single stakeholder." (Gardien, Djajadiningrat, Hummels, & Brombacher, 2014, p. 132).

Study 5. Finally, all the phases explored within the first 4 studies have been merged into one unified Open-ended Design method, which was then tested in its usability. The proposed iterative method is based on observations of existing realities, post-factum, and anticipation of potential (but not yet existing) ones. The observation phase requires engagement of the designer with reality, in its dynamic expression and emergence. In order to facilitate this phase, the ten lenses can be used to better understand the observed design outcomes. How much do they change? How fast? Who is changing them? Why? What attributes are changing? Etc. The anticipation phase is then developed to intentionally support and provide ways on how to design to facilitate re-appropriations, which could be physical changes, but more importantly change in *interpretations*, or change of meaning. "Rather than trying to prevent such subversion [of appropriation] the designer can deliberately aim to expose the intention behind the system." (Dix, 2007, p. 2). The anticipation mainly transforms the insights coming from the observation into precise design choices, materialized in one design outcome through a creative act, made in order to facilitate the conditions for this conversation with the real context to happen, which is ultimately a design act done *by others*, meant as non-designers including non-human actors, a second-order design is advocated (Dubberly & Pangaro, 2015)(Krippendorff, 2007). Specifically, to think in order of Open-ended Design, or second-order design, means to anticipate what, of the proposed design object, changes (can potentially change or should possibly change) once put in contact with reality. These design attributes, that we define as context-dependent, in an Open-ended Design outcome are deliberately and meaningfully left open, giving space to the context to take part of the design process, fostering conversation and letting this information emerge from reality instead of imposing them. All the other design attributes should be, on the contrary, defined and imagined as stable, since Open-ended Design is created only through balancing controlled and out-of-control, and should not drift to completely open and un-organized design outcomes. The proposed method then concludes, or better starts again, with a renewed observation phase, meant to verify our starting hypothesis and learn from the occurred re-appropriations. In this way, we can state that Open-ended Design starts from reality and aims at reality, creating a loop of information (feedbacks and feedforwards) that can reinforce or balance each other, helping the designer in overcoming the possible paralysis occurring when facing complexity. In other words, it supports the designer in understanding what can be left open, being never completely imagined, or *unimaginable*, but yet possible and probable. Finally, Open-ended Design proposes therefore not a different way to distribute design outcomes, but a different way to look at them and to conceive them.

With this, we concluded our explorative phase, and reached a closure of the presented dissertation. The dissertation, being of explorative nature and providing a first *bigger picture* of a broad and complex phenomenon, doesn't aim at being conclusive, on the contrary. For this reason, we decided to conclude with a summary of the insights we gained about Open-ended Design, in form of Decalogue or Manifesto, considered good tools to be used as conclusion of Research Through Practice researches, desiring "to build an account of a practice to be pursued in the future." (W. Gaver, 2012, p. 938) and to trigger further conversations about the here presented topic.

1. Open-ended Design **is generated as reaction** of existing and observable phenomena, that we defined as unavoidable spontaneous processes. "Every beginning is only a sequel, after all, and the book of events is always open halfway through" (W. Szymborska).
2. The observation of reality **occurs in time**, which is the most important dimension for Open-ended Design outcomes. "Only in time there is space for me" (C. Lispector).
3. "If taken seriously, the wicked nature of these types [of design] problems leads to paralysis" (Nelson & Stolterman, 2012, p. 16), for this reason Open-ended Design outcomes can be seen as a learning processes, far from being a solution, they rather **aim at better defining the question** (Glanville, 2007).
4. Observation and anticipation create a continuum bridged by hypotheses generations, which are then explored in real-life experiments based on tangible

in-context-prototypes, that are Open-ended Design. The general hypothesis for Open-ended Design experiments is "If the product becomes real then it changes from its ideal status. If the products change meaningfully, then the perceived value increases." (see **Chapter 6, Study 5**). This refers specifically to the resilient capabilities of dynamic products.

5. The ultimate goal of Open-ended Design is to **improve resilience** of certain outcomes, by **embracing the diversity** of the products' ecologies, and transforming them as actors of the design process. The outcome then emerges in time, which can also be seen as possible product ensoulment (Blevis & Stolterman, 2007) (Jung, Bardzell, Blevis, Pierce, & Stolterman, 2011).
6. Thanks to the suboptimal nature of Open-ended outcome, **imperfect by intention**, we aim at triggering the conversation with the real environment (or products' ecologies), meaning both human and non-human actors. The imperfection, mechanism for open-endedness, should lay only on those aspects defined as context-dependent, being unimaginable and impossible to predict by the designer. Open-endedness should not become an excuse for poor design, in fact only in a good balance between open and close aspects we can explore hypotheses.
7. Open-ended Design asks then, to the designer, to **lose control** on certain aspects of his/her own design outcome, which is a process of **trust and participation**, often occurring after design. "Design is too important to leave to designers alone" (McDonald, Keesler, Kauffman, & Schneider, 2006, p. 185). In this perspective, the role of the designer him/herself changes by adopting this view on design things. The designer should be optimistic, and should trust the process.
8. Even if the emergence of certain design attributes is out of the designers' control, he/she should **remain engaged** in the observation since it is fundamental to "continually try to know at what point a trigger is appropriate" (Nelson, 1987, p. 357). In fact, being an Open-ended Outcome experiment in the real environment, it has the goal of teaching us something.
9. In the Open-ended Design approach **change is always potential in nature**. It is up to the real environment to take, or not take, action in order to activate or speed up some re-appropriation process. These actions might be different from what was anticipated by the designer, which again represent a learned lesson
10. It is through this circular process of observation and anticipation that the designers can tackle problems of great complexity and ambiguity, by producing **rather simple outcomes**. "Some (including some designers) may claim they [the outcomes] are complex. But that complexity lies in what is embodied and contained in the outcome: the outcome itself is more often than not simple". (Glanville, 2007, p. 1196).

ACKNOWLEDGEMENT

I would like to thank my promoters Prof. Jelle Saldien and Prof. Jan Detand, who supported me in the realization of this research giving always useful feedbacks and meaningful insights. They supported me in these last three years, not only with my PhD, but also integrating me in the IO research group. I want to thank my former colleagues from Politecnico di Milano, where my passion for imperfection and sustainability has started. Thank you, Giuseppe, for coaching me so passionately, on a daily basis, always pushing me to reach higher. It took time to see the value of such effort, and I'm glad that it is finally so clear to me. Thank you, Valentina, for helping me in hard times, giving support, having fun together and providing always a different perspective on my available options. Thank you, Marinella, I acknowledge that - without you - I would not be here. I need to thank you for giving me some of the most profound lessons that are still inspiring me, especially as teacher. Thank you, Massimo, for sharing some good moments together. To Jennifer, for becoming a real friend and for sharing crazy experiences, especially during our holidays. Thank you, Gianmarco, Raffi, Diego, Carmela, Federico, Piero, Serena and other former colleagues, to embrace our designers' team so kindly. I sometimes still miss our fun lunch and coffee breaks!

I also want to thank my colleagues from UGent. First of all, the "IO Playazz" guys, who manage to make me confused and puzzled with their Flemish jokes! It is nice - and important - to have such good colleagues as Cesar, Bert, Peter, Davy, Marina, Olivier and Bram.. with you I feel I can always speak transparently and, if needed, get real support. Especially, I want to thank Ellen and Yannick since we shared some interesting teaching assignments and, more importantly, you were always open to other-than-work kind of conversations. I also want to thank all my IPO colleagues! Specifically Bart (and Nils!) for helping me with my Ducth (ehm...), Becky for the intensive experiences of the intensive programs, Jurgen, for no clear reason (ahah). Thank you Karen Dejonkehere for helping me for the course SBP and for sharing fun time when abroad. Thanks to other professionals I collaborated with: Jan from Regenerative Design, Liesbet from OVAM, David from the Green Office, and many more fortunate encoounters of these last three years.

Lieven, thank you for "bringing me here"! I know, it was unintentional, but with your work you really inspired me and I'm grateful to be able to share thoughts every now and then (never enough, but we will improve ;-) Walter, I have learned so many things from you... amazingly, all these understandings cover every aspects of our lives. This makes me passionated and still eager to learn. For this reason, I'm extremely glad that you are still willing to teach me!

In Gent, I need to thank first of all Peter and Saskia, for introducing me to the city and many controversial cultural aspects that I would have never understood by myself. Thanks to Klaartje for opening up her house, showing me around and being always an honest and generous friend (and also for Charlie, the most amazingly-smiling kid I know). Thank to my Italian friends Giulia, Andrea, Silvia, Federico and Vally to share the understanding on how sorry we are for the things we might say during such long and harsh winters. Thanks to Roma and our inspiring lunch meetings, and to Gabriele to show me around in my very first days here! Thanks, to Petra and to Alessandro for the insightful talks (which are just not happening as often as I would like to). Thank you, Jevgenji, for the out-of-control talks, and for walking together. Thanks to the Stiltekamer in NEST, a wonderful project, made by wonderful people. Without such a place of silence and peace I would probably not have finished this manuscript.

Time to thank "my" students and alumni. I need to thank you all for the passion you put into your work of designing and learning. At first I had the illusion that this research, all these reflections, were done for you. Well, now I know that I'm doing them *because* of you, since without your participation I would have never learnt enough! Among others, I want to thank Lotte, for discussing with me as only my old friends and family can, to Chick'in and Amfi team for the nice experiences abroad, to Dries for helping me with better understanding methodology, to Jolan for revising my presentation and to Thomas, for taking the challenge of teaching me how to climb. Special thanks to all my master students who worked with me on Open-ended Design: Niel, Robbe, Niki, Jolan, Arno and Katrijn. Probably this is what I like the most, the fact that by teaching I also continuously learn from you and your creativity!

Finally I want to thank my family, putting in this "file" the broader set of people to whom I feel deeply connected. My mother Manuela, who taught me to do what I like, till I like it, decreasing the guilty feeling of obligation to live lives that are not *ours*. Thanks to Silvia, for starting this together, but more profoundly for understanding me since I was a little rebel. Especially in my incapability of giving back to all what you did – and still do – for me. Thanks for the talks on freedom, action, choices, voids, etc. Giovi, Silvia and Lavinia, thank you for being open for the most diverse discussions and for opening up your house when I was in need for company in the last months and weeks! As you know well, thanks to Lavinia - that I love very much! - I felt the need for more family time: the perfect motivation to reach a closure with this PhD. Finally thank to my father Roberto, who also taught me how to respect myself and embrace complexity, especially of human behaviours.

Thanks to Luca for reading, revising and helping me seeing my work differently every time we spoke. Of course, this is not all, thank you for being a good friend since we were 11 years old, which means thank you for growing together, without never growing apart. This is the same profound reason why I thank Margherita, growing together from little ballet dancers (?!), to hyppies, to punk (ahah), to mod... in this parabola that brought us to the present - are we adults too wide for being defined in only one subculture? :-) time will tell! Thanks to my little sister Nina, who is not that little anymore! I love to share opinions and experiences with you, and I really hate to never have enough time to do so. Let's improve our organizational skills! Thank you, Paolo, for always supporting my view on change, respecting it and also for hating it, since it represents the full mix of controversies that caracterizes us all. I also would have not been here without your loving look at my messy life.

Thanks to Emma for supporting me, also in these long years apart, with her voice consucting also my Belgian yoga lessons. Thanks to Lauretta, which I still consider the most fortunate encounter of my life. I would not be here without your support. You helped me to profoundly embrace imperfection, and what I describe in this book as the unavoidable spontaneous processes of life. I bring your voice inside me. At last, thanks to tango, for providing mental freedom and human contact, both very needed during the finalization of a PhD. As told to many of you in these last weeks I find the PhD, and especially its closure, one of the hardest experiences possible. You are asked to "contain" and close a years-long experience that is a scientific work, a learning process and therefore a process of change. It feels impossible to truely close it, and it feels as well impossible to really thank everyone and everthing that helped to make it real.

Gent, October 2017
Francesca Ostuzzi

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