The social production of design space

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Abstract:

The production of design space refers to the activity of an individual or a group of individuals considering alternatives and possibilities for a design brief. Design studies often consider constraints to be a major determinant of design space, yet this paper introduces the notion of contradiction to underscore a dialectical determination of design space. The intention is to characterise the production of design space as a socio-material rather than a cognitive process. This is accomplished through an in-depth look at a medical imaging centre project and an experiment with design students about the same project. In comparison to the original project, the students' activity reproduced the same contradictions faced by practitioners.

Keywords: design activity; parametric design; architectural design; design space.

Previously seen as an outcome of design (especially in architectural design), space is being studied increasingly as a locus where design happens. The available studies can be divided into two streams: one that focuses on the interactions of designers, clients and users as it happens in offices and elsewhere (Botero, 2010; Luck, 2014; Sharrock & Anderson, 1994; Westerlund, 2009) and another that studies the cognitive activity of designers exploring and redefining an abstract space of possibilities (Gero & Kumar, 2006; Goldschmidt, 1997; MacLean, Young, Bellotti, & Moran, 1991; Mose Biskjaer & Halskov, 2013). This paper brings the perspective of the first stream — in particular, historical analysis (Engeström, 2015; Lefebvre, 1991) — to study the research object of the second stream — design space. The goal is to look at the social production of design space, the contradictions faced by its multiple producers and the attempts to overcome those contradictions.

Design space is a term used vaguely in design studies to the many possibilities a project has to produce an object. When taken seriously as a research object, design space has been considered to be a definite (Gero & Kumar, 2006) or indefinite (Goldschmidt, 1997) set of shapes and functions for a particular object or kind of objects. Since these shapes and functions sometimes are considered to solve a problem, design space is also equated to problem space and solution space described by problem-solving studies (Biskjaer, Dalsgaard, & Halskov, 2014; Dorst & Cross, 2001; Goel & Pirolli, 1992). This space grows together with the activity of an individual designer working with an object or with collective designers sharing a tradition with the same kind of object.

From this, it is possible to say that design space has a dialectic relationship with design activity. Design space is produced by design actions — such as imagining, sketching, visualising, weighting, generating or rejecting, but design actions are also restricted by design space. This restriction has been attributed so far to constraints, which are explicit definitions of criteria, requirements, needs and other limitations imposed by the conditions for production (Gross, Ervin, Anderson, & Fleisher, 1988; Lawson, 2005; Mose Biskjaer & Halskov, 2013). Constraints are considered the determinants of design space for this pragmatic function, but their origins and transformations are rarely investigated. Previous studies have looked either at design space determining design activity or design activity determining design space, yet none have taken them in a dialectical relationship. To unravel this dialectics between design activity and design space, it is necessary to look at what is behind constraints.

Constraints rise in design space because design activity is a social activity connected to many others in society (Dilnot, 1982). Design activity has to respond to management, marketing, distribution and others involved with the production of the object and also to the diverse activities that use the object once it is produced. The relationships among these activities are not necessarily coherent and explicit. Quite to the contrary; they are often incongruent and implicit. Unfair, unbalanced and awkward relationships harbour contradictions, which are tensions that accumulate along the history of an activity (Engeström, 2015; Foot & Groleau, 2011). Previous research has identified contradictions of design activity (Blau, 1984; Cuff, 1992; Ehn, 1990), but little has been done to identify contradictions of design space.

This paper experiments with the notion of contradiction as a driving force behind the social production of design space. This goes beyond the notion of constraints as determinants of design space. Constraints, issues, problems, solutions and other cognitive frames approach contradictions from one of their sides. The aim of this paper is to ground these abstract components of design space to the concrete social process that produces them. This is expected to contribute to design studies by expanding the scope of research on design space to the underlying production of design space.

The first part of the paper presents a case study on how the design activity of a specific medical imaging centre reproduced contradictions of the Dutch healthcare system in the design space. Ethnographic data reveals the social construction of its design space and the attempts to overcome the contradictions. The second part of the paper reports on a teaching experiment in which students reconstructed the design space and dealt with its inner contradictions. Even if they had different constraints to deal with, they reproduced the same contradictions faced by practitioners. The implication of these findings is that it is necessary to reconsider the determination of design space from constraints.

1. The production of design space

Design space is often referred as a mental, individualistic, abstract space where design ideas are generated and considered. One of the most concrete descriptions of design space is a network of cognitive states that the designer moves to and from (Goldschmidt, 1997, p. 444). Every move in design space arises from the intention of the designer, even if this be random (Goldschmidt, 2006). The moves are restricted by two factors: 1) constraints imposed by project definitions, such as criteria, requirements, needs and goals (Gero & Kumar, 2006; Lawson, 2005; Mose Biskjaer & Halskov, 2013); and, 2) the designer's cognitive processing capability (Simon, 1991; Woodbury & Burrow, 2006). The designer is supposed to move from the initial state to the goal — a preferred state, but the path to get there is not clear. Some researchers believe that it is possible to determine the states from the imposition of constraints to the design space (Chien & Flemming, 2002; Woodbury & Burrow, 2006), whereas others believe that design space is indeterminate due to the possibility of creating previously unknown states (Goldschmidt, 1997, 2006).

The concept of design space has been mainly used to analyse how designers think alone, but there are new attempts to use it for analysing collaborative design as well (Binder et al., 2011; Botero, 2013; Luck, 2014). In this case, design moves are not triggered solely by personal intention and cognition, but also — and perhaps even more — by interaction with other people. People explore and negotiate possibilities through design moves in conversations, messages and co-design workshops. Some possibilities are implemented in the object; some are left for the future. In this social perspective, the production of design space is implied in design activity.

Design activity can be defined as a set of coordinated actions of individuals and collective of individuals to produce a new object (Bødker & Grønbæk, 1996; Brereton, Cannon, Mabogunje, & Leifer, 1996; Dilnot, 1982; Luck, 2010). The activity is bound to cognitive, technical, economic, social and cultural conditions that limit the possibilities of designing (Westerlund, 2005). When people engaged in design activity realise these conditions, they may or may not translate them into constraints to design space, depending on their cognitive skills to process these conditions (Simon, 1991). The limitation to perceive and process these conditions is currently being addressed by computational tools that expand the designer's capability to explore, remember and combine objects (Woodbury & Burrow, 2006). These tools describe the design object in terms of parameters, which can be combined in many possible ways (Monedero, 2000). Constraints are typically used as filters in parametric design to reduce the amount of possibilities to a manageable level.

There is a contradiction here between the space of possibilities and the possibilities of space (van Amstel & Garde, 2016). Design space is infinite in a collective level, but quite limited when assessed by one individual. If that is the case, then it is just a matter of determining the cognitive capabilities of an individual to determine design space and all its possibilities. However, design activity, as it happens in practice, is hardly carried on by a single person (Botero, 2010). Even when working alone, designers are under financial, technical, social and cultural conditions that are not necessarily cognised and explicitly set as constraints. Many constraints are taken for granted, or perhaps, they are not yet constraints.

Previous studies of design space looked at constraints through the lenses of cognitive psychology (Goel & Pirolli, 1992; Mose Biskjaer & Halskov, 2013; Savage, Miles, Moore, & Miles, 1998), computer science (Gero & Kumar, 2006; Gross et al., 1988) and ethnomethodology (Luck, 2009; Oak, 2011). These studies have effectively shown how design activity uses constraints to expand or reduce design space; however, they do not offer a comprehensive explanation on how constraints rise from design activity. The next session looks at the origin of constraints through the lenses of cultural historical activity theory and production of space theory. These theories are based on the concept of contradiction, which is crafted here to study the dialectical relationship between design activity and design space. The notion of contradiction is expected to provide a deeper understanding of the phenomenon than what constraints afforded in previous studies.

2. Contradictions of design activity and of design space

Cultural historical activity theory (Engeström, 2015; Foot & Groleau, 2011; Kuutti, 2011; Leont'ev, 1978) and production of space theory (Lefebvre, 1991; Stanek, 2011) are comprehensive theories of societal development that shares the notion of contradiction as a continuous source of change. The first theory has already been employed in design studies to highlight the role of instruments in graphic design activity (Tan & Melles, 2010) and to describe how an organization develops design capabilities across the years (Mutanen, 2008). The second theory, to the best of our knowledge, has not been employed in design studies yet, but is often used to study the restrictive role of space in architecture (Awan, Schneider, & Till, 2011; Stanek, 2011) and in organizational studies (Dale & Burrell, 2008; Taylor & Spicer, 2007; Watkins, 2005). Combined, these two theories allows for uniting research threads on design activity and design space under a common (social) framework. In the following lines, a model from cultural historical activity theory will be introduced in parallel to the corresponding notions of the production of space theory. This parallel will be used to analyse contradictions in two design projects.

The best known model from cultural historical activity theory can be summarized as *a subject that pertains to a community transforming an object by means of instruments, bound to rules and a division of labour* (Engeström, 2015; Leont'ev, 1978). To study design activity, we derive from this model that the *object* of design is the thing being designed and the *subject* is one person (or more people) who invest motives in this *object*. The transformation of the object is the concern of a *community* of stakeholders, which develops certain methodological *rules* and a *division of labour* to transform the object.

Different activities can interact, for instance, when the outcome of one activity becomes the object of another (Engeström, 2015) or its main instrument (Kuutti, 2011). The latter is a common connection to design activity, which conceptualises the connected as "use" or "user activity" (Suchman, 1994). Design activity interacts with user activity to produce design space using methods, such as briefing (Barrett, Hudson, & Stanley, 1999; Luck & McDonnell, 2006) and parametric design (Monedero, 2000), which aim to set constraints to design space. These relationships are put together using the activity system model (Figure 1) devised by Engeström (2015) and applied to design activity by Kuuti (2011).

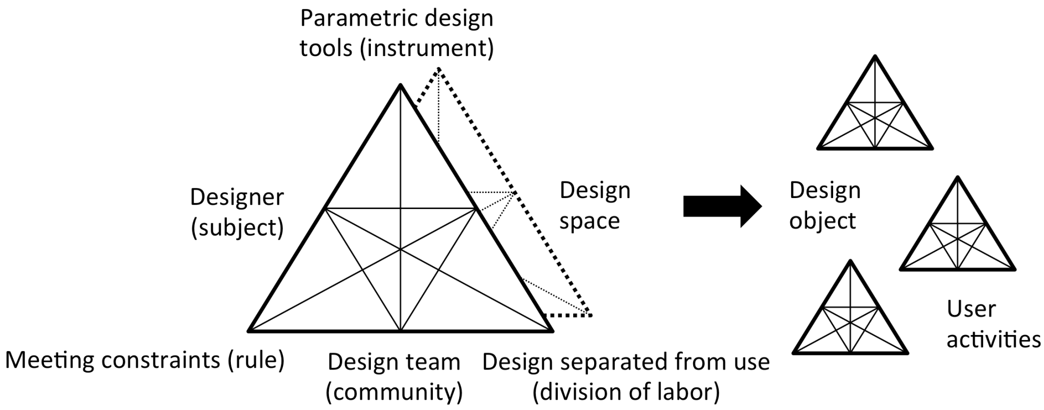

Figure 1 - Design activity producing a design space for a design object, which becomes an instrument for user activities.

According to cultural historical activity theory, activities change due to contradictions, which are tensions accumulated in the history of an activity or between multiple activities. These accumulating tensions can be measured at four levels (Engeström, 2015; Foot & Groleau, 2011). At the primary level, the most basic contradiction of society — between the individual actions and the collective activity — appears in each element of an activity (subject, instrument, object, community, rules, and division of labour), for example, an individual who wants to produce an object the collective does not grant with an exchange value. This is also described as the contradiction between exchange value and the use value, typical of capitalist societies (Marx, 1993). At the secondary level, contradiction appears in the relationships between the model elements, for instance, between instruments and rules that do not match. When the activity has a major development, the contradiction achieves the tertiary level, when the old and the new version of an activity collide. At the quaternary level, the contradiction spread among different activities. Figure 2 depicts the contradiction levels using the activity system model (Engeström, 2015).

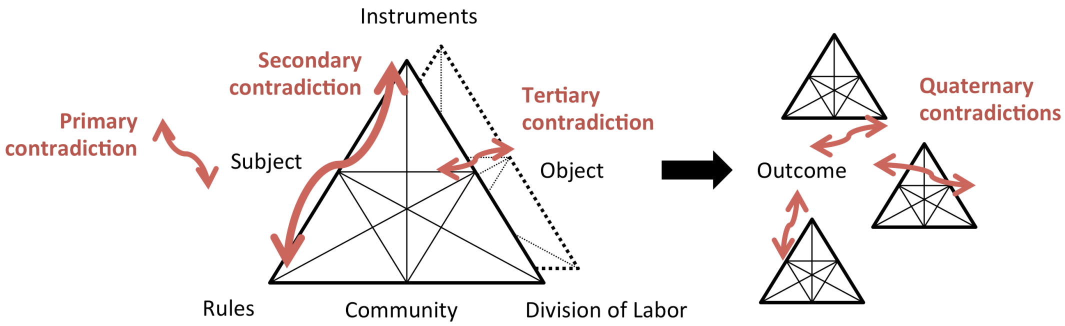

Figure 2 - Four levels of contradictions (in red): intrinsic to an element (left), between two or more elements (middle), between a new and old version of the activity (middle), and among different activities (right).

Applying this framework to the previous studies on contradictions of design activity gives a glimpse on how constraints rise. The primary contradiction is the work of specialist designers which distracts from the collective action of society to build the design object (Cuff, 1992; Tschumi, 1996; Yaneva, 2012). Such concealing job does not typically let constraints emerge in design space directly from the primary contradiction. Constraints appear at the secondary level, when the design object evolves beyond its representation instruments (Till, 2009; van

Amstel, Zerjav, Hartmann, van der Voort, & Dewulf, 2015). To corral the object, constraints are added for people segregation, technical compatibility, norm compliance, division of labour and quality control. If the object manages to expand towards future activities despite the added constraints, new constraints may rise from concerns of usability, legacy, implementation and flexibility. This is also known as the contradiction between tradition and transcendence (Ehn, 1988), which easily aggravates to the quaternary level, between multiple activities. This level is characterized by conflicting constraints about shared resources, exchange protocols, boundary crossing and network domain.

This framework is useful to trace constraints from design activity, yet it does not elucidate how constraints appear and disappear in design space. The production of space theory complements cultural historical activity theory with the notion of contradictions of space, which we use as the origin of constraints. We propose a parallel between the contradictions of activity identified through cultural historical activity theory (Engeström, 2015; Foot & Groleau, 2011) and the contradictions of space discussed in the production of space theory (Lefebvre, 1991), including specific contradictions of design space.

The primary contradiction of space is between the fragmentation of local spaces and the homogenisation of global spaces (Lefebvre, 1991, p. 355). This relates to the designer trying to produce a local identity by combining fragments of globalised symbols, such as consecrated architectural types. When this local affirmation reaches a peak, it gets in the way of the production of things in space because people from other places do not appreciate the extreme localism. This is the secondary contradiction of space between the production of space and the production of things in space (Lefebvre, 1991, p. 354). As for the tertiary level, the order of a new production running against the current experience of production relations generates a contradiction between the concrete lived experience of space and the abstract order of a new space (Lefebvre, 1991, p. 52). This is better known as the difference between the user experience and the designer's plan for that experience (Redström, 2006). At last, the quaternary level refers to the uneven distribution of power, knowledge and capital over space (Lefebvre, 1991, p. 333). The by-product of this contradiction is the allegedly scarcity of resources (Till, 2014), which severely reduces possibilities in design space (see Table 1 for a summary of this parallel).

Level	Contradiction of activity (Engeström, 2015)	Contradiction of space (Lefebvre, 1991)
Primary	Between individual actions and the activity system	Between the fragmentation of local spaces and the homogenisation of global spaces
Secondary	Between the elements of an activity system (tools, rules, division of labour etc.)	Between the production of space and the production of things in space
Tertiary	Between the old and the new version of an activity	Between the experience of production relations and the order of a new production relation
Quaternary	Among different activities	Among the uneven distribution of power, knowledge, and capital over space

Table 1 - A parallel between the contradictions of activity pointed by cultural historical activity theory and the contradictions of space pointed by the production of space theory.

The above parallel enables the study of contradictions of design space in relation to contradictions of design activity. Since design space is produced by design activity, the contradictions of design activity are also reproduced in design space, becoming contradictions of design space. These manifest as constraints, problems, paradoxes, conflict, controversy, incongruity or uneasiness. Once contradictions are embedded into space, they last longer and keep bothering activity, even if contradictions of activity have been alleviated or overcome (Lefebvre, 1991). Nevertheless, there is always the opportunity for change in reproduction. Contradictions of space may alleviate or help to overcome contradictions of activity. According to the production of space theory, contradictions can only be completely overcome if they are overcome both in activity and in space, configuring a spatial-historical breakthrough (Lefebvre, 1991, p. 54). For the purpose of studying how contradictions are overcome, we define a spatial-historical breakthrough as *overcoming the four levels of tension of both contradictions of activity and contradictions of space*.

3. Research design

Collecting empirical evidence of contradictions requires a specific research design for three reasons. First, contradictions are not just objective phenomenon; they are both objective and subjective, since they affect and are affected by the observer. Second, contradictions are both the cause and effect of a social situation and, therefore, constantly changing. Third, contradictions are not immediately observable by abstract measures, such as variables. In both cultural historical activity theory and production of space theory they are grasped by first looking at the historical constitution of the situation, then applying abstract measures and, finally, reconstructing the whole phenomenon as over-determined or, in other words, determined by too many causes (Engeström, 2015; Foot & Groleau, 2011; Lefebvre, 1975).

With this in mind, the research design is setup in two parts: a case study about a medical imaging centre and a teaching experiment in a design course. The case-study is based on a formative intervention (Engeström, 2011) performed by the researchers in the project of a medical imaging centre. The researchers followed the meetings scheduled by the design activity, analysed the available documentation, interviewed the designers, developed computer visualisations to support the participation of users and joined user workshops in which these visualisations were employed.

The researchers' notes were stored in an Issue Based Information System (IBIS) and linked to research questions and theoretical concepts. This formed a map of controversies around the project (Kunz & Rittel, 1970; Selvin et al., 2001; Yaneva, 2012). A specific map was made with the contradictions identified through the application of the activity system model in the four levels of tension (Figure 3). The primary contradictions are lined at the bottom of the map and connected to their aggravation in the second level, and so on. The data fragments are connected to the contradictions as their observable manifestations, which are then classified as pros and cons in the IBIS notation. This distinction is necessary to avoid framing contradictions as inherently good or bad for the project. The map only contained contradictions of activity and not contradictions of space as these are identified in a different way.

Based on the study of design activity, a hypothetical construct was formed[i]: if contradictions were intrinsic to design space, then reconstructing the design space in another activity would reproduce the same, or at least, some of the contradictions from the original activity. In our case, if the student's activity would display similar contradictions of the practitioner's activity, this would serve as an evidence of the existence of intrinsic contradictions of space.

To test this hypothetical construct, an experiment was organised in the context of a facility design bachelor's course. The experiment followed the double stimulation method (Engeström, 2011; Vygotsky, 1978), which focuses on reconstructing learning from the process more than the outcome. The first stimulus is a contradictory situation and the second stimulus is an ambiguous tool that may be used to overcome contradictions. The experiment looks to how subjects develop concepts to overcome contradictions. The purpose of the tool is to objectify the concepts, helping not only the experimenters, but also the learner.

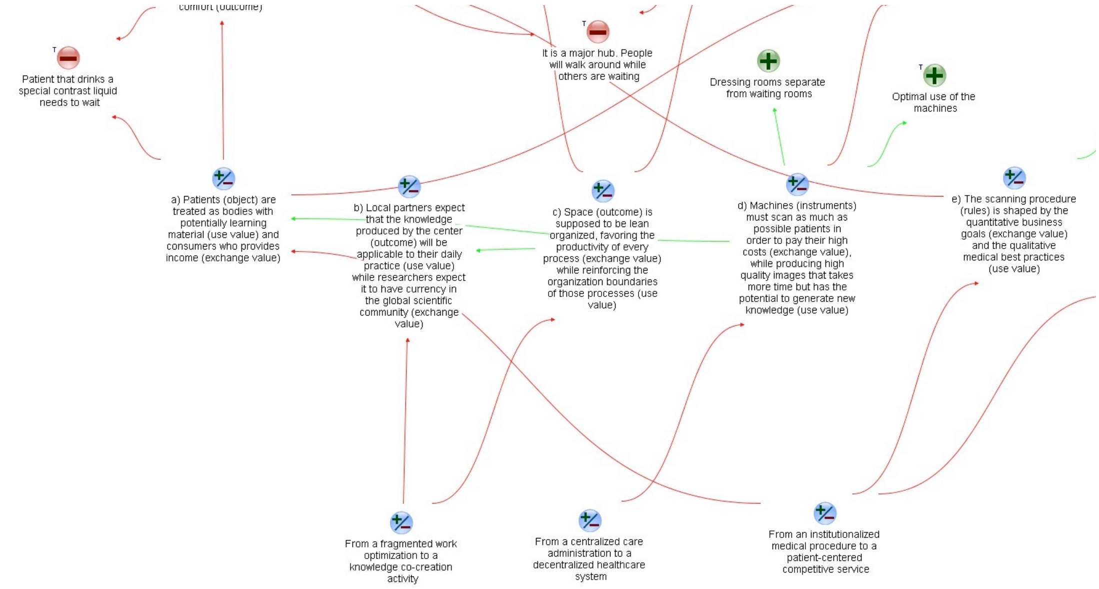

Figure 3 – Fragment of a graphical map with contradictions of design activity (+/-), related to their pros (+) and cons (-). The nodes are aligned bottom up according to its tension level (primary, secondary, tertiary, and quaternary).

The students were tasked with reconstructing the design space and making changes to the design object. If contradictions were intrinsic to design space, their moves would be driven by the same contradictions that drove practitioners. In order to track the moves, a parametric design tool (Autodesk Revit) with a specific plug-in — a custom-tailored family to represent the walking paths of nurses and patients across the facility — was provided. The parametric design feature generates real-time information about travel distances, waiting times, and room connection. Activity is modelled in the same interface as space, therefore, enabling iterations in design between these two dimensions (Figure 4).

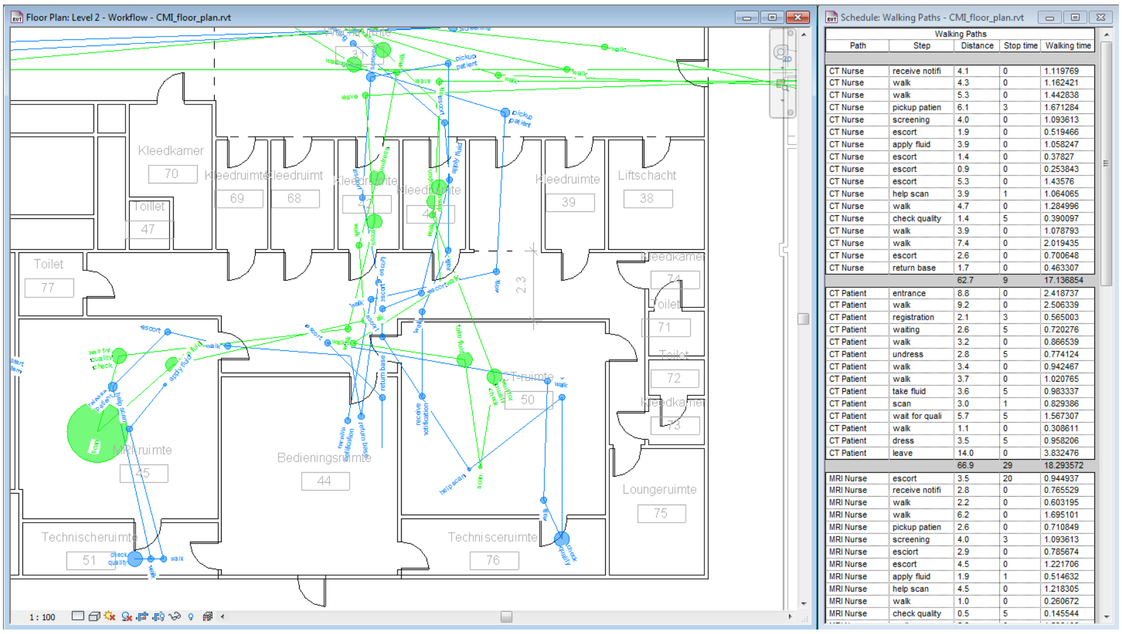

Figure 4 - Walking paths parametric design family for Autodesk Revit with walkability performance for patients (blue) and nurses (green).

This tool was used for three reasons. First, to reconstruct the floor plans and the walking paths designed by practitioners with the purpose of identifying contradictions of space. Second, to trace the production of design space by students and, third, to setup two groups of students: one with initial walking paths, and another with no initial walking paths. This variation was done to check if having extra constraints — walking paths — in design space drives the production of design space towards a different direction. The tool was ambiguous in many ways: a) it did not calculate the optimal path based on the shortest distance; b) it did not show how to connect and how to layout the rooms according to the workflow logics; and c) it did not represent the path of one particular person in a particular moment, but a path that is followed by many people in different moments — a spatial representation for a historical phenomenon. This ambiguity was important to let students develop their own second stimulus, which corresponded to new moves in design space.

The images reconstructed from the three datasets were stacked to visualise and compare design space. The stacked images revealed the parts of design space that changed the most along the process — the most controversial among the designers. Even though the images do not represent all the possibilities created and considered by design activity, it stands as a material trace of contradictions of design space. Following the parallel made in Table 1, we triangulated the visual evidence of contradictions of space with the ethnographic data of contradictions of activity and generated a dialectical analysis of both sides.

4. The design space of a medical imaging centre

The case study concerned a forthcoming medical imaging centre in The Netherlands that will offer state-of-the-art diagnosing machines based on techniques such as Magnetic Resonance Imaging (MRI), Positron Emission Tomography (PET-MRI), Computed Tomography (CT) and Electroencephalography (EEG). This case study covered a small part of the design process: the evaluation and final adjustments of the floor plan, which happened between July 2012 and January 2013.

When applying the activity system model to identify contradictions across the four tension levels, many contradictions were identified. In short, we concentrated on one contradiction that stemmed from the undergoing changes of the Dutch healthcare system since its last reform in 2006 (Pavolini & Ranci, 2008). The reform diminished the role of the state in providing healthcare and the consequent need for partnering among care providers. The medical imaging centre arose in this context, offering shared facilities and knowledge co-creation for nearby hospitals, educational institutions and technology developers. However, the centre had to be also self-sustaining and optimised to diagnose as many patients as possible.

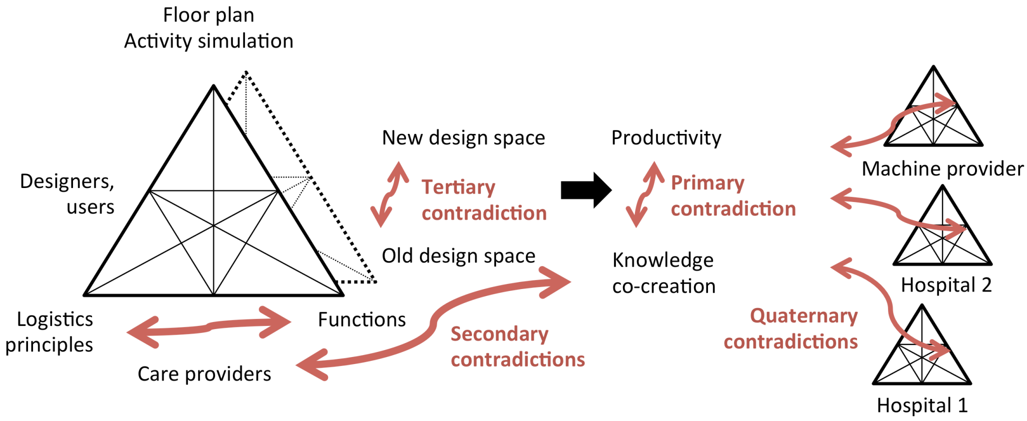

Figure 5 – Contradiction between knowledge co-creation and work optimisation aggravating inside the design activity (left) and towards use activities (right).

This contradiction manifests at the primary level as the medical imaging centre (outcome) is supposed to be logically organised, favouring the productivity of every procedure, while leaving space for the spontaneous co-creation of knowledge. The procedures were already very much optimised in their origin. However, in the new centre, they should produce knowledge that goes beyond optimisation. When this aggravates to the secondary level, the functions of the rooms (division of labour) are defined, not according to the best logistic principles possible (rules), but by the political compromise of assuring a separate space (outcome) for each care provider (community). At the tertiary level, the care providers who used to compete for attracting patients (old object) now are trying to learn with each other in this venture (new object). Finally, at the quaternary level, the activities involved in the project are not sure how the outcomes of the centre will help them fulfil their expectations. Figure 5 traces the contradiction spreading through the activity system model.

The primary contradiction was not visible to the designers at the beginning of the project. Nevertheless, they reproduced them in design space. The business plan and machines' technical requirements were taken as the main constraints, guiding the definition of isolated functions and exclusive spaces, despite the cornerstone idea of sharing machines to promote knowledge exchange between research and clinical practice. This secondary contradiction became visible in design space when the machine users were invited to participate in a workshop with the designers. They suggested transforming some of the exclusive spaces into shared spaces by adding doors and corridors to connect them.

The reconstructed image reveals that the dressing rooms were the unstable part of the design space (Figure 6). The designers doubted if there should be so many small dressing rooms — to afford more patients per machine — or less dressing rooms — with more space each. Also, they wondered if there should be a bathroom nearby, or even an allotted waiting room for each scanning machine. The researchers supported the workshop by providing a deterministic simulation of nurses and patients conducting routinized procedure in the facility, which gave some input for their discussion.

After trying many different moves, designers and users realised that the most important constraint would be to connect the different areas of the facility to allow sharing dressing rooms and knowledge. For that, they created a large internal corridor that connects all dressing rooms. The designers moved away from the paradigm of compartmentalisation of functions to a paradigm of multi-functionality — a tertiary contradiction. This move raised further questions regarding the marginalisation of the care practice, which would not have an optimal facility to work and, instead, would have to work in what was considered best for knowledge co-creation — a flexible environment. The radiographers worried that the increased connectivity between the rooms would make it easier for imaging researchers to look over their shoulders all the time, and not let them do their work alone.

They could have added more constraints to the design space, but the workshop ended too soon for that. The practitioners did not overcome the contradiction at the quaternary level, so the tension kept accumulating until the construction of the building was cancelled. The users who joined the design process considered the place unsuitable to deal with patient emergencies and demanded to transfer the medical imaging centre to their own hospitals. This constraint was brought to the design space only after the contradiction accumulated enough tension to make the building appear unfeasible to the partners. At this level of tension, the designers could no longer adapt the design object to the late constraints and the whole centre had to be redesigned from scratch.

The main finding from this case study is that the determinants of the design space were not the constraints set in the briefing phase, but imperative economic, political and cultural conditions that contradicted each other. Designers and users had to deal with these contradictions, even if they had not been set as constraints in the briefing phase or during the workshops with users. We observed a couple of times the participants bothered by something they could not understand and translate into clear constraints. Their design moves were triggered by confusion, unexpected technical problems, controversy, uncertainty and late requirements. This served as initial evidence of intrinsic contradictions of design space.

If that was the case, then reconstructing this design space in another activity would reproduce the same contradictions and guide design activity towards similar moves. A teaching experiment explores this possibility using the walking paths tool to manifest contradictions in design space as explicit constraints.

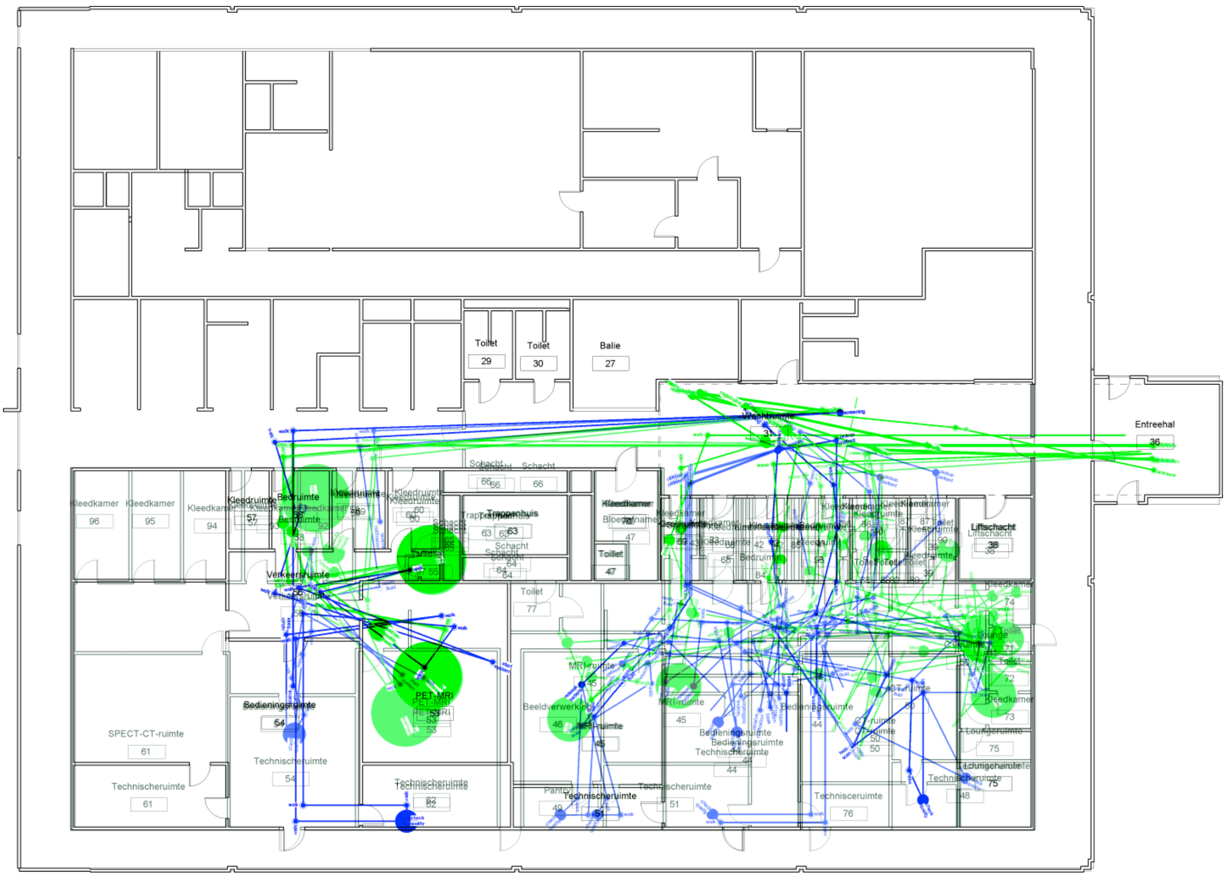

Figure 6 - The four versions of the floor plan produced by practitioners with the respective walking paths stacked in a single picture. The darker lines appear in all four versions, whereas the lighter lines appear in some of them.

5. The design space extended to a teaching experiment

The course Methods and Strategies for Facility Design of University of Twente's Bachelor in Civil Engineering had related topics to those observed in the case study. As such, the authors brought the project to the course as a practical learning experiment. The project was introduced as such:

> *The business case specifies the diagnosing machines that will be available and the amount of patients to be treated per year in each machine. The managers are wondering how to optimise the facilities to meet these numbers. (Data fragment).*

This is neither a problem nor a solution, but an issue related to the contradiction between knowledge co-creation and work optimisation. However, its historical background was not given. Instead, the experimenters provided students with the results of a deterministic simulation they made to support practitioners in the original project. Students received a copy of the animation generated by the simulation, with the use activities happening along half a day of operation. The use activities were simulated in a very simplified way focusing on the walking paths of nurses and patients around machines. A spreadsheet with performance figures, such as machine capacity usage, waiting times, and room occupation, was also provided.

The experiment consisted of two sessions. In the brainstorming session, students were organised into teams of four and tasked with formulating problems and solutions. They had to reconstruct design space in an explicitly social manner: team work. The design space has been explored in a rather abstract way, in the format of written problems and solutions. In the second session, the design space had to be explored in a more concrete way, as a parametric model. This was important, not only for students to realise the material resistance for implementing their solutions, but also to measure their production of design space through a standard format that favoured comparison. Students were then introduced to the parametric design tool which they could develop the design further, either alone or in pairs. For most students, this was their first experience with the software and the duration of the experiment was only one hour, so they could not explore too many features.

The experiment was repeated in two editions of the course. In the first edition, students received the initial floor plan reconstructed from case data as a digital file. One sample path was included in the file. In the second edition, the full walking paths for nurses and patients were provided, overlaid on the floor plan. This constraint came from the primary contradiction, between the flexibilization of workspaces and the spatialization of the workflow. Deriving from that difference, two groups are considered: participants who did not have built-in activity constraints (Group 1, n=31) and participants who had built-in activity constraints in the shape of walking paths (Group 2, n=28). Both groups received the first version of the floor plan captured from the medical imaging centre and a brief statement with the constraints that rose from the secondary contradiction, between exclusive space and shared space. After the experiment, the previous session's teams gathered again and received the educational assignment to write a report with the lessons learnt, which was also taken into account to interpret the results.

The software used in the experiment was configured to save automatic backups every five minutes, generating more than one image per student. This was done to track the production of design space across time as in the case study, but in a much shorter interval. All images, from all students, were stacked into one, again in the same way as in the case study. The difference here was that the combined images did not reflect the social production of design space by one team, but by many teams.

6. Experiment results

Group 1 had the extra task of drawing the paths from scratch in the same amount of time. This resulted in fewer paths and focused production (Figure 7). This group began by moving the reception closer to the entrance and then delving in the dressing rooms distribution between MRI and CT (right part). The corridor solution observed in the case appeared only in two designs of Group 1 and not at all in Group 2.

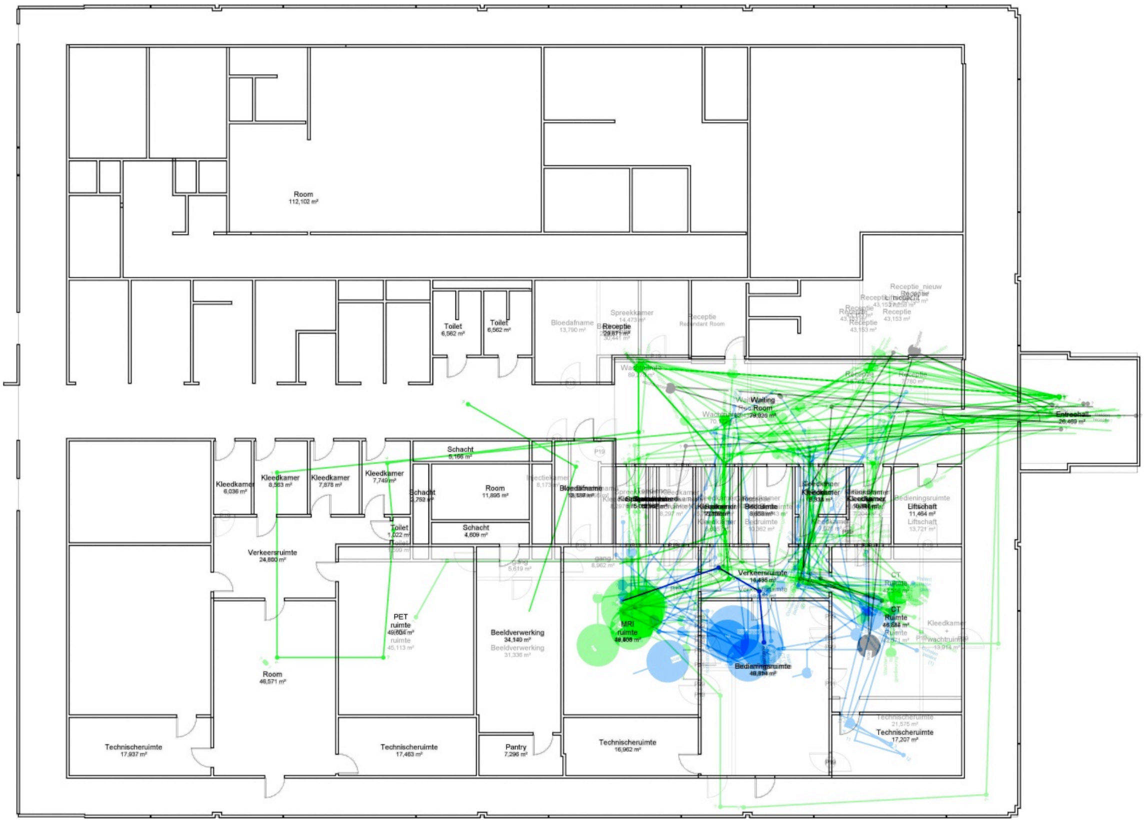

Figure 7 - The design space produced by Group 1, with no initial paths, stacked in a single image.

As for group 2, most students began by changing the PET area (left part) due to the performance figures provided (Figure 8). They framed the longest paths from the entrance as the best opportunity for improvement. After that, they began to look at the dressing rooms allocated for PET.

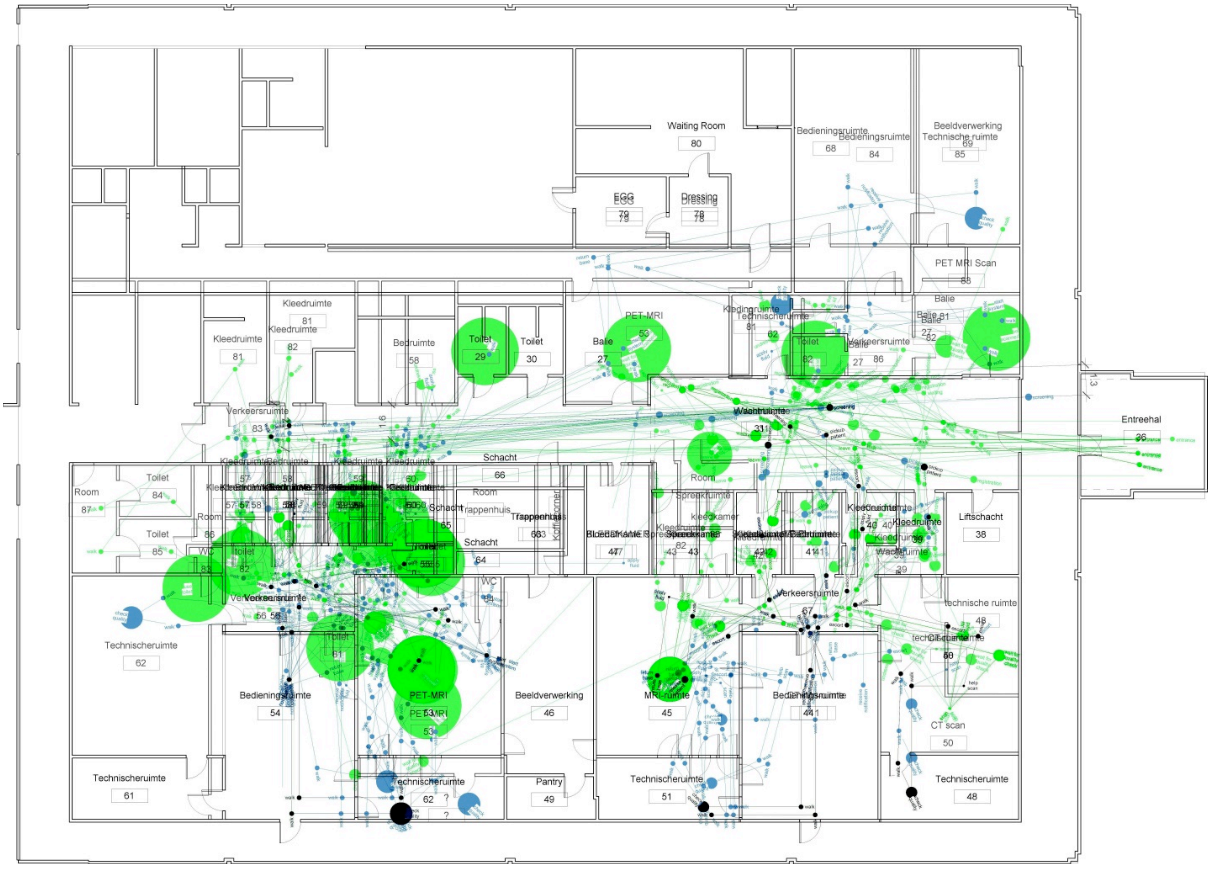

Figure 8 - The design space produced by group 2, with the initial paths already given, stacked in a single image.

In both groups, the dressing rooms were the unstable part of the design, pretty much as was the case in the original project. Some students proposed to change them into alloted waiting rooms to avoid patients and nurses having to go back and forth during the intermediate waiting steps of the scanning procedure. One student proposed a coffee-room in the middle of the facility to increase the level of comfort for both staff and patients. Many doors were opened in both groups to minimise space fragmentation.

Instead of restricting production, the extra constraint in Group 2 let students consider different ways of rerouting patients and nurses. The production of design space was much more diverse and less focused. Some steps in the walking paths were decoupled or aggregated and the undefined upper part of the layout was occupied, which did not happen in Group 1. It seems that the given constraints were not taken for granted by students, being changed or ignored by their design moves. One student report included the following:

> *During the assignment some of the routes seemed very odd, that it seemed as if some detours were functional. […] Unless it was made clear by certain keywords, which were used in the model that the detour had some reasons, these detours were eliminated. (Data fragment).*

The students were aware of the walking paths' constraint, but they chose to ignore them. Even more, some students of Group 2 occupied the undefined area at the top part of the plan, which was discouraged to explore by the briefing. With more constraints to work with, Group 2 students ended up exploring and creating more possibilities than Group 1 students. Remarkably, they reproduced the same contradictions. The rooms created in the undefined were single-purpose spaces connected by the workflow logics with extra waiting rooms around them, similar to the rest of the layout. The students tackled some of the contradictions of the original project, but many contradictions were not addressed and kept accumulating in the design space. A comparison between practitioners and the groups shows the same moves for the primary contradiction and similar moves for the secondary contradiction (Table 2). As for the tertiary and quaternary level, the students had little information about new developments and interactions of multiple user activities and, hence, did not overcome these contradictions.

Tension level	**Contradictions of activity**	**Contradictions of space**	**Practitioners' moves**	**Group 1 moves**	**Group 2 moves**
Primary	Co-creation of knowledge X Optimisation of work processes	Flexibilization of workspaces X Spatialization of the workflow	Splitting dressing rooms	Splitting dressing rooms	Splitting dressing rooms
Secondary	Workflow streamlining X Political compromise	Exclusive space X Shared space	Flexible dressing room space	Moving rooms closer to the entrance, splitting waiting room into many	Moving rooms closer to the entrance, occupying undefined part of the plan
Tertiary	Competition X Collaboration	Compartmentalisation X Multifunctional	Large internal corridor	Small internal corridor	Dedicated waiting rooms
Quaternary	Outcomes X Expectations	Knowledge centralisation x Practice marginalisation	Circulation area for spontaneous knowledge sharing	Reduced segregation of functions	Occupying undefined part of the layout

Table 2 - Contradiction of activity and space identified in four tension levels together with the design moves by practitioners and students addressing them.

The parametric design tool seemed to be insufficient to deal with the contradictions of the tertiary and the quaternary levels. The reports written by one of the student teams acknowledged this:

> *The situation modelled is an ideal situation, where everything behaves as planned. There is no scenario for emergencies. Users of the building will not behave as the parameterisation. The modelled walking paths are the ideal paths: patients or staff will not always follow them, because of the current situation and their own choices and preferences (Data fragment).*

The student reports were quite critical about the tool. They pointed to its poor usability, automation, efficiency and simulation capabilities. On the other hand, they recognised the experiment as an opportunity to learn about the social production of design space:

> *The last thing we have learned is that every individual gets to a different practical solution with the software, even though the whole group conceived the theoretical solution. This is due to the different ideas of the best implication of the solutions every individual has (Data fragment).*

The contradiction between the wish to co-create knowledge and the need to optimise work processes was both present and clashing in the teaching experiment, albeit in a lower tension than found in the case study. Students worked with constraints that stemmed from this contradiction, but they did not mention the contradiction of design activity in their reports. They mentioned the contradiction of design space in their reflections about the difficulty of balancing the flexibilization of workspaces and the spatialization of the workflow. The contradiction between compartmentalisation and multi-functionality, as well as the contradiction between knowledge centralisation and practice marginalisation, were not addressed. Nevertheless, these contradictions still drove their design activity towards open spaces, with extra connections and functions — favouring collaboration among partners and, at the same time, towards fragmented, streamlined, and optimised spaces — favouring competition among partners, much in the same way practitioners did. The experiment results display further evidence of intrinsic contradictions of design space, which drive design activity even if not consciously.

7. Discussion

The main advantage — and limitation — of double stimulation and formative intervention methods employed by this research is that they do not isolate cause and effect relationships (Engeström, 2011; Vygotsky, 1978). Instead, they investigate phenomenon as being determined by too many causes, or in a word, over-determined. The present empirical work demonstrates that it is possible to determine a design space, provided that the determination is dialectical and that contradictions are taken into account. The following relationships were considered to determine design space: the economic imperative of productivity, the cultural trend of knowledge co-creation, the engineering design tradition, the optimisation bias of the tools used in the experiment, and the formal characteristics of the design space; all being understood as manifestations of contradictions in history (Engeström, 2015) and in space (Lefebvre, 1991). The resulting over-determination could work as a better argument against prescription and modelling than indeterminacy (Goldschmidt, 1997).

These multiple determinations were mediated by the design moves of individual and collective students working together to produce the design space. They did not just respond to the conditions, but also created new possibilities by challenging the existing constraints. For this capability of creating new states and opening new paths in design space, the sequence of design moves cannot be described as exploration of (a given) design space (Goldschmidt, 2006; Maher & Poon, 1996; Woodbury & Burrow, 2006) but, as production of (an emergent) design space. This space is not produced by a lonely designer — even he or she is working alone — but, by the multiple activities connected to the object being designed — the user activity being just one of them. Looking at this social production of design space may help design studies going deeper than the paradoxes found in design discourse (Dorst, 2006).

Contradiction seems to be a key concept to understand the erratic (Dorst & Dijkhuis, 1995), mediational (Bødker, 1998; Tan & Melles, 2010), and dialectical (Goldschmidt, 1991) characteristic of design activity, as well as the becoming ontology of design space (Cicmil & Marshall, 2005; Luck, 2014). However, contradictions are difficult to study empirically. Contradictions are described as situated phenomena (Foot & Groleau, 2011), which are hard to grasp in an experiment. In retrospect, seeing traces of contradictions was much easier while the researchers were engaged in the project, rather than when conducting the experiment with design students. The deterministic bias of the tool was not fully realised until students criticised it in their reports. We researchers could not stay above contradictions and look at them from distance; we were already reproducing contradictions by interacting with them. In comparison to the design activity of the medical imaging centre, academic research is doing this the other way around: emphasising work optimisation at the expense of knowledge co-creation in order to boost publication indicators, which are increasingly used for academic evaluation in The Netherlands (Groot & Garcia-Valderrama, 2006). The convergence of healthcare and research in the medical imaging centre is not a coincidence, but a cause and effect of the contradictions present in their activities.

8. Conclusions

The design space produced by a design activity is not determined by explicitly defined constraints. Instead, design space is determined by multiple conditions that contradict each other: economic, cultural, stylistic, cognitive and others. These conditions are neither internal, nor external to design activity, but constitute the material base where from which design activity emerges. This means design activity is not an individual cognitive activity, but a social pragmatic activity aimed at changing these material conditions. Design space consists of the possibilities considered, but also created by design activity to change these conditions. Each move in design space contributes to reduce or expand design space. In fact, they produce design space. However, design moves reproduce contradictions of design activity onto design space, as contradictions of design space. These contradictions of space can even bother other activities beyond the activity that produced it in the first place.

We found evidence of contradictions in design space in a case study of a medical imaging centre. This was verified further by an experiment with design students. A parametric design tool was developed for this experiment, to visualise in a crude way the forces behind design moves; arguably the contradictions of activity and the contradictions of space. Using this tool, students ended up stuck and boosted by the same the contradictions that practitioners faced in the industry project, despite not working under the same conditions and constraints.

Contradictions are different than constraints because they do not need to be cognized to be effective. Constraints rise when people perceive contradictions in design space and try to limit its reproduction. This may or may not work, depending if design moves under such constraints are able to overcome the contradictions. In the situations we observed, the rise of conflicting constraints preceded the creation of possibilities that overcome contradictions. However, these new possibilities went against the intentions behind the constraints, for example, when the students occupied the undefined area of the layout or when healthcare partners demanded moving the medical imaging centre into their own hospitals. Constraints are instruments used by the many involved with the production of design space to overcome its underlying contradictions. They seem to be effective inasmuch as they escalate through the four tension levels of contradictions, yet this claim needs further confirmation from future research.

Contradictions offer, therefore, a deeper understanding of design activity and design space than constraints. Contradictions cannot be removed, nor solved; rather they can be aggravated, alleviated, or overcome when reproduced in design space. In any case, contradictions do not go away. Any alleviated contradiction keeps accumulating tension without notice, until it surfaces again in design space. Thus, design activity struggles with contradictions in design space, but not without changing them. The advantage of recognizing the socio-materiality of contradictions in design space is that multiple determinations can be taken into account within one concept, including overcoming these same determinations.

The study results are consistent with the view that design space is a space of becoming (Luck, 2014). Any design considered in design space is not just a possible one, but also an actual one coming to life. It already exists and affects design activity, as does any material in the physical world. Each move in design space expands or contracts the potential to change the world. Making sense of design in this way can strengthen the emerging approach to design research that pays more attention to artefacts, practices, and history rather than inscrutable cognitive processes (Kuutti, 2011). This could, perhaps, lay the basis for a design approach that is concerned, not only with overcoming contradictions of design space, but also with overcoming contradictions of design activity. Then, the role of design activity and design space in reaching spatial-historical breakthroughs may become clearer (Lefebvre, 1991). For that, we recommend design practitioners, design students and design studies to permanently cross boundaries between different social activities and social spaces, dealing with contradictions as a change force instead of a constraint.

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[i] A hypothetic construct is an aggregate of variables that measured together provides an understanding of a systematic phenomenon. In Psychology, "construct validation was introduced in order to specify types of research required in developing tests for which the conventional views on validation are inappropriate" (Cronbach & Meehl, 1955, p. 200). The conventional view is the isolation of intervening variables.