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Contradictions in the design space

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Abstract

The design space is a concept often used to encompass all possible designs for a given brief, impossible to be determined, but passive of manipulation by creative designers. The concept as such cannot prevent deterministic accounts of design activity. With the aim of overcoming determinism, this concept is reconsidered beyond the cognitive realm, as part of the social production of space. This renewed perspective is applied to study a medical imaging center project in The Netherlands. The boundaries found in this design space were not self-imposed constraints, but imperative economic, political, and cultural conditions that contradicted each other. To reveal the materiality of the design space, the project has been brought to a teaching experiment, where students analyzed the project drawings and proposed changes using a custom parametric modeling tool. Students faced similar contradictions, despite working under different conditions, supporting the claim that the design space has intrinsic contradictions even if not cognized.

Keywords

Design space; problem-solving; constraints; architectural design; activity theory.

Introduction

Previously seen as an outcome of design, especially in architectural design, space is moving towards a locus where design happens. Contrary to the common sense, the so-called design space does not refer to the offices where designers work, but to the range of possibilities that designers consider (or not consider) for a certain design task. This range is called a space by its property to contract — by adding constraints — or to expand in many directions — by adding new variables (Gero & Kumar, 2006). This space reflects the indeterminacy of design (Goldschmidt, 1997): there are so many possibilities for any design task that trying to determine its outcome before it actually happens is unproductive.

On the other hand, the design activity has cognitive, technical, economic, social, and cultural conditions that limits the possibilities to be considered (Westerlund, 2005). These limitations may or may not be imposed to the design space as constraints. Since constraints are first processed by cognition before they enter the design space, the single limitation that can be considered intrinsic to the design space is the cognitive (Simon, 1991), currently being addressed by computational tools that expand the designer capability to explore, remember, and combine the possibilities (Woodbury & Burrow, 2006).

There is a contradiction here between the space of possibilities and the possibilities of space. The design space is infinite in a global 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 the design space and all its possibilities. However, design activity as it happens in practice is not restricted to cognitive processes and 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 cognized and explicitly set as constraints. Many constraints are taken for granted, or perhaps, they are not yet constraints.

This paper articulates the notion of contradiction as an intrinsic feature of the design space, going beyond the notion of constraints. Contradictions are understood as accumulating tensions in a certain activity that provokes instability and change (Engeström, 1987; Foot & Groleau, 2011). They can be cognized, but do not depend on that to exist. 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 notions to the concreteness of specific social processes.

The first part of the paper presents a case-study on how contradictions in the Dutch healthcare system are reproduced by the design of a specific medical imaging center. Ethnographic data reveals the social construction of its design space. Based on this study, a hypothesis is put forth regarding the reproduction of contradictions in the design space. The second part of the paper reports testing this hypothesis in a teaching experiment where students reconstructed the design space and dealt with its inner contradictions.

The design space

The design space is mainly conceived as a mental, individualistic, *a priori*, abstract space where design ideas are generated and considered. One of the most concrete descriptions of the design space is a network of nodes representing states in a cognitive process (Figure 1). Every move in the design space arises from the intention of a single designer, even if random (Goldschmidt, 2006). Boundaries are self-imposed, coming either from adopted criteria or from dependences, such as mutually exclusive options (MacLean, Young, Bellotti, & Moran, 1991) and cognitive processing capacity (Simon, 1991; Woodbury & Burrow, 2006). At last, the ultimate power of intention in the design space leaves movement to the arbitrary.

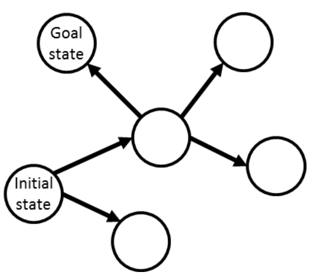

Figure 1 – A design problem space composed of a network of states. Redrawn from Goldschmidt (1997, p. 444).

The design space has been mainly used to analyze how designers think alone, but there are new attempts to use it in collaborative design as well (Botero, 2013; Luck, 2014). In this case, design movements are not only bounded by personal intention and cognition, but also — and perhaps even more — by interaction with other people. Moves in the design space are actually part of that interaction: they are motivated by the social and cause effects back then, not in arbitrary way.

The division of labor between one activity as "design" and another activity as "use" (Suchman, 1994) should not cover the contribution and dispute of both to shape the design space. Both are trying to use the possibilities for generating value, and both are subject to the inherent contradiction of exchange and use value. The possibilities in the design space cause effects in the social because they already have a potential value, which is or will be the subject of dispute and leverage among many other activities. Due to this materiality, the design space can be considered both abstract and concrete, "abstract inasmuch as it has no existence save by virtue of the exchange ability of all its component parts, and concrete inasmuch as it is socially real and as such localized" (Lefebvre, 1991, p. 341).

In this perspective, the design space is not an ideal space with all thinkable possibilities waiting to be harnessed, but an ongoing production of practical possibilities to change activity conditions. One of the possibilities is to draw ideas from other activities, other design spaces, but such reproduction also implies the production of adaptations, hacks, or hybrids to the immediate condition. As a matter of fact, this production is not realized by the mind, but by the entire social activity that constitutes "design" or "use". To understand how the design space is socially produced, we turn to cultural-historic activity theory (Engeström, 1987; Leont'ev, 1978) and production of space theory (Lefebvre, 1991).

Contradictions in the design space

Design is an activity that happens in a particular place, but also develops along history. In cultural-historic activity theory, the basic notion of activity is *a subject transforming an object by means of instruments* (Leont'ev, 1978). The object of design is the thing being designed that has the potential to fulfill a need and the subject might be one or more persons that invest motives in this object. The transformation of the object is the concern of a community, which develops certain rules and a division of labor to transform the object. These relationships are put together in the activity system model (Figure 2).

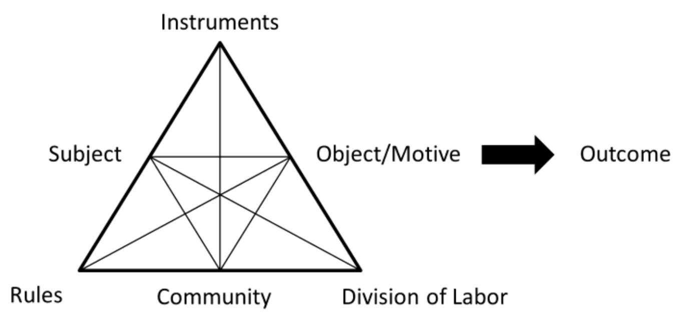

Figure 2 - The activity system model. Redrawn from Engeström (1987).

Different activities can interact, for instance, when the outcome of one activity is the object of another, such as performance evaluation or instrument development (Engeström, 1987; Kuutti, 2011). The latter is a common connection to design activities, which conceptualizes the connected as "use" or "user" activity (Suchman, 1994). The design activity interacts with the use activity to produce a design space using methods such as briefing (Barrett, Hudson, & Stanley, 1999; Luck & McDonnell, 2006), which aims to set constraints for the design space.

The design space is grounded in the use activity and, therefore, its contradictions are also reproduced. In reproduction there is always the opportunity for change, tough. The contradictions *in* space become contradictions *of* space, aggravating or alleviating the situation in the aforementioned activities. Once contradictions are embedded into space, they last longer and keep bothering activity even if the original contradiction has been alleviated or overcome. Contradictions can only be completely overcome if they are overcome both in activity and in space, configuring a spatio-historical breakthrough (Lefebvre, 1991, p. 54).

There are four tension levels that must be overcome by spatio-historical breakthroughs (Engeström, 1987; Foot & Groleau, 2011). In the primary level, the most basic contradiction of society — in the case of capitalist societies, the contradiction between exchange value and use value — appears in each element of an activity (subject, instrument, object, community, rules, and division of labor). The commoditization of subjects in the labor market (exchange value), for example, can generate powerful contradictions regarding their work quality (use value). At the secondary level, contradiction appears in the relationships between activity elements, for instance, between instruments and rules. 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 3 depicts the contradiction levels in the activity system model.

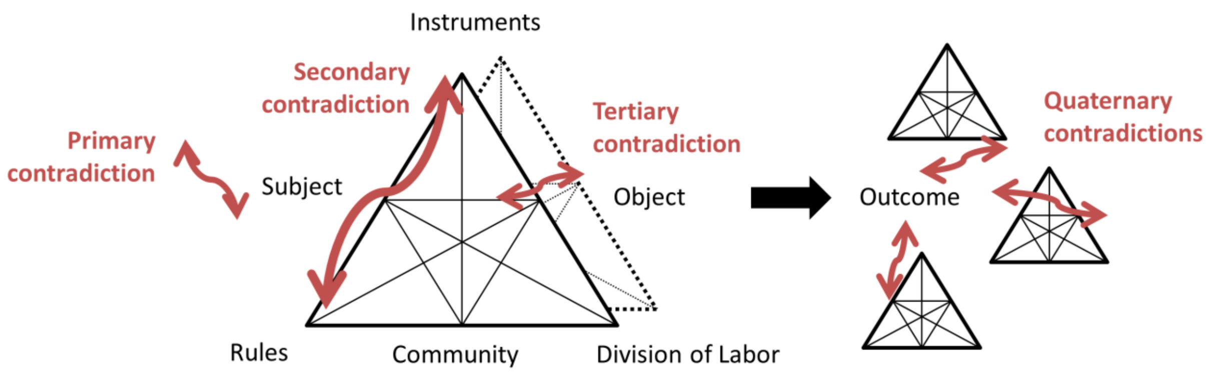

Figure 3 - Four levels of contradictions (in red): intrinsic to an element (left), between two or more of an activity (middle), between a new and old version of the activity (middle), and among different activities (right).

Research design

Collecting empirical evidence of contradictions in the design space requires an unusual 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 cause and effect of a social situation, 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 overdetermined, or in other words, determined by too many causes (Engeström, 1987; Foot & Groleau, 2011; Lefebvre, 1975).

With that in mind, the research design is setup in two moments: a case-study about a medical imaging center and a teaching experiment in a design course. The case-study is based on a formative intervention (Engeström, 2011) performed by the first two authors in the design of a healthcare facility. The researchers followed the meetings of the design activity, analyzed the available documentation, interviewed the designers, developed computer visualizations to support the participation of users, and joined the workshops where these visualizations were employed.

The researchers' notes were stored in an Issue Based Information System (IBIS) and linked to research questions and theoretical concepts, forming a map of controversies around the project (Kunz & Rittel, 1970; Selvin et al., 2001; Yaneva, 2012). A specific map has been made with the contradictions identified in the data with the activity system model, in the four levels of tension (Figure 4). 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 classified as pros and cons in the IBIS notation. This distinction helps to avoid framing contradictions as inherently good or bad for the project.

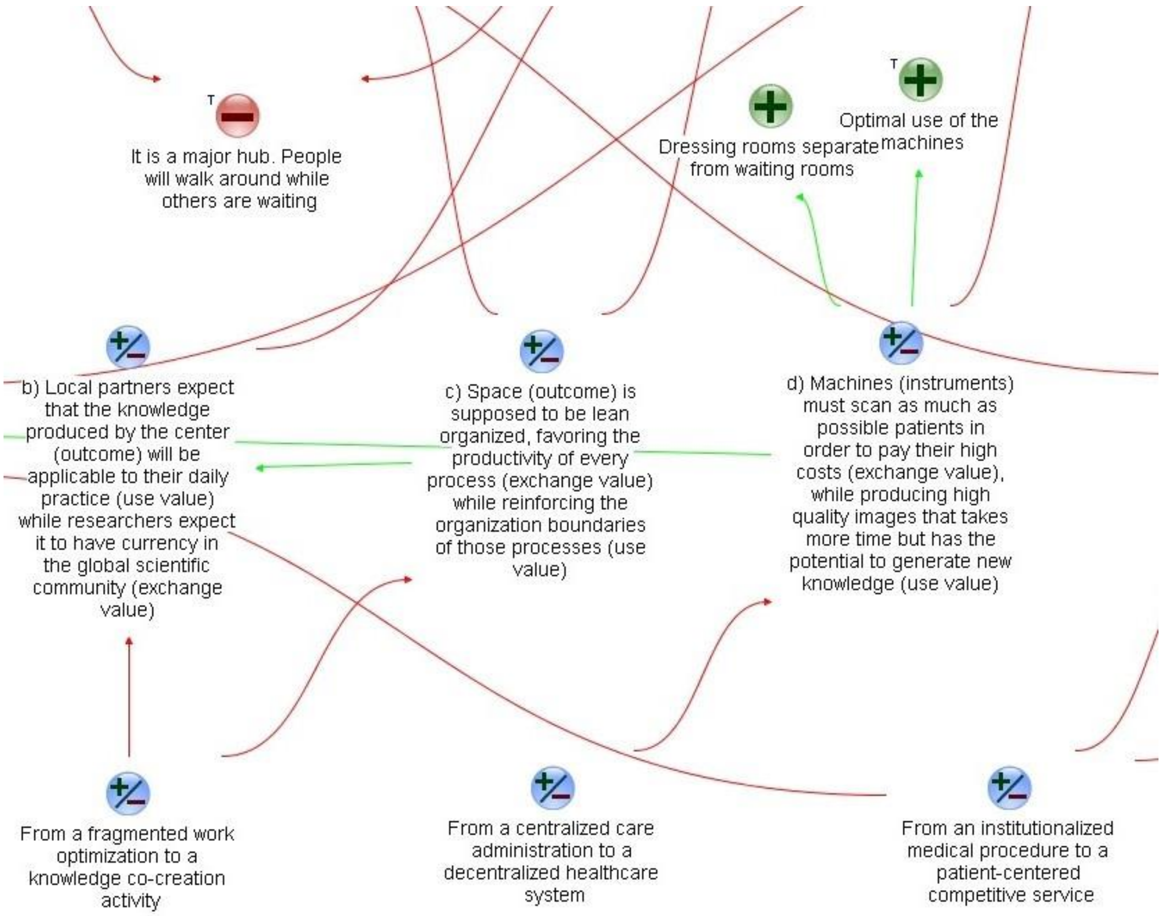

Figure 4 – Fragment of a graphical map with contradictions (blue nodes) found in the project, related to their pros (green) and cons (red).

Based on this study, a hypothesis has been formulated: if contradictions are intrinsic to the design space, reconstructing the design space in another activity would reproduce the same, or at least, some of the contradictions from the original activity. To verify this hypothesis and explore how such process unfolds, an experiment has been organized in the context of a facility design bachelor's course.

The experiment was organized according to the double stimulation method (Engeström, 2011; Vygotsky, 1978): the focus is on reconstructing learning, taking more into account process rather than 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 on how subjects develop concepts to overcome contradictions. The purpose of the tool is to objectify the concepts, what helps not only the experimenters but also the learner himself.

The leaners had the task to reconstruct the design space and to continue its expansion. In so doing, they would face contradictions *in* space and *of* space. A tool was developed to manifest contradictions *in* space as walking paths, paths that people would take inside the facility while following routine procedures. This is a very simplified way of representing activity, but perhaps sufficient to avoid students dealing only with contradictions *of* space. The tool was setup differently for two groups of students: one with initial walking paths and another with no initial walking paths. This was done to check if having more constraints in the design space, or in other words, explicit manifestations of contradictions *in* space, would help dealing with contradictions *of* space.

The tool given is Autodesk Revit — architectural design software — with a custom family designed to represent the use activity as walking paths[1]. The family profits from the parametric design features of the software, generating real-time information about travel distances, waiting times, and room connection. Activity is modeled in the same interface as is space, therefore enabling iterations between these two dimensions (Figure 5). This tool was also used to reconstruct the floor plans and the walking paths designed by practitioners, based on video-recorded explanations of the plans.

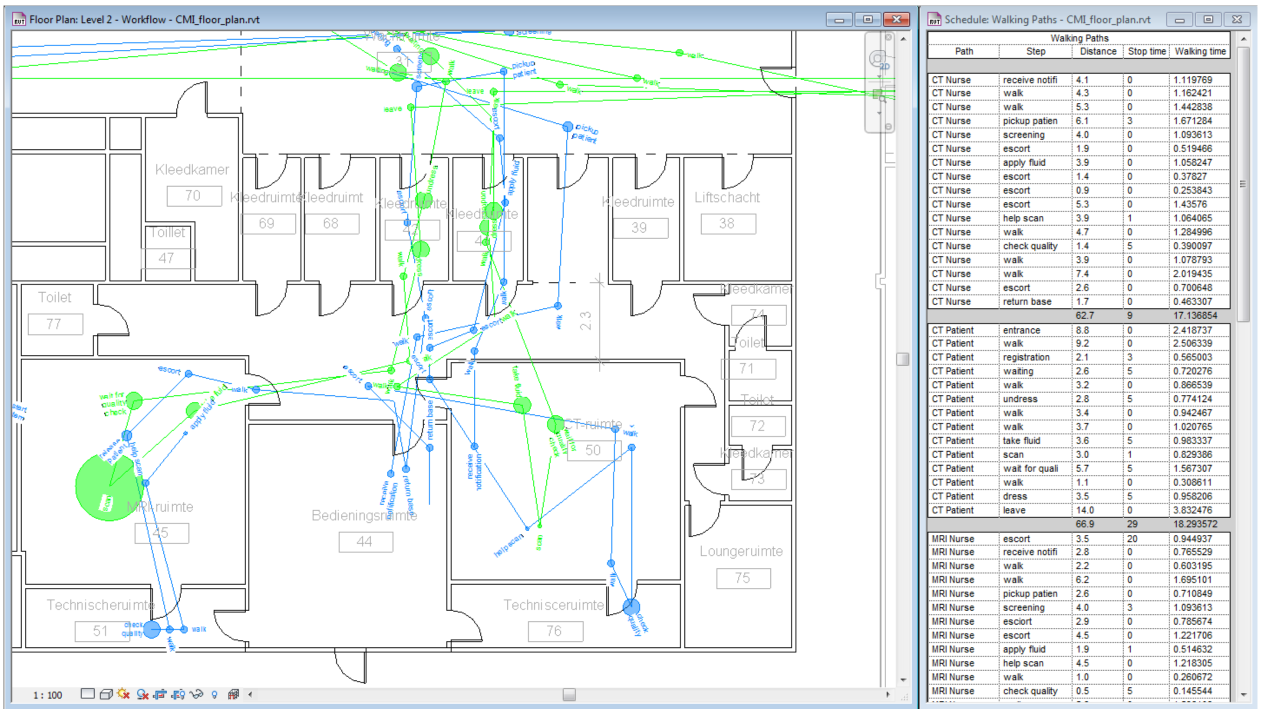

Figure 5 - Walking paths parametric design family for Autodesk Revit with walkability performance for patients (blue) and nurses (green).

The images reconstructed from case data and the images generated in the experiment were stacked to visualize and compare the parts of the design which changed the most, or in other words, the most controversial parts of the design. The controversy is related back to the contradictions found in the case to check if they can be explicated by them.

The design space of a medical imaging center

The case study that follows is a forthcoming medical imaging center in The Netherlands. The center 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 covers a small part of the design process: the evaluation and final adjustments of the floor plan, which happened between July 2012 and January 2013.

Many contradictions have been found in the case, but for the sake of space, we concentrate here in one, tracing it from the primary to the quaternary tension level. The contradiction is related to the

[1] The custom family is licensed under Creative Commons and can be downloaded at http://www.utwente.nl/ctw/visico/

undergoing changes of Dutch healthcare system since its last reform, in 2006 (Pavolini & Ranci, 2008). One of the points is the diminishing role of the state and the consequent need for partnering among care providers. Income is now attached to the actual care delivery, and the providers need to grow by their own (Cramer, Dewulf, & Voordijk, 2014). The medical imaging center arose in this context, with the value proposition of offering shared facilities and knowledge co-creation for nearby hospitals, educational institutions, and technology developers. Each engaged partner would have to face the uneasy transition from their optimized work procedures to a shared knowledge co-creation activity.

This contradiction manifests at the primary level as the space (outcome) that is supposed to be logically organized, favoring the *productivity* of every procedure (exchange value) while reinforcing the *organizational boundaries* of those procedures (use value). The procedures were already very much optimized in their origin; however, in the new center, they should also produce knowledge that go beyond optimization. When this aggravates to the secondary level, the functions of the rooms (division of labor) are defined not according to the best *workflow* 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 that used to compete for attracting patients (old object) are now trying to learn with each other in this venture (new object). And finally, at the quaternary level, the activities involved in the project are not sure how the *outcomes* of the center will help them fulfill their *expectations*. Figure 6 trace the contradiction spreading through the activity system model.

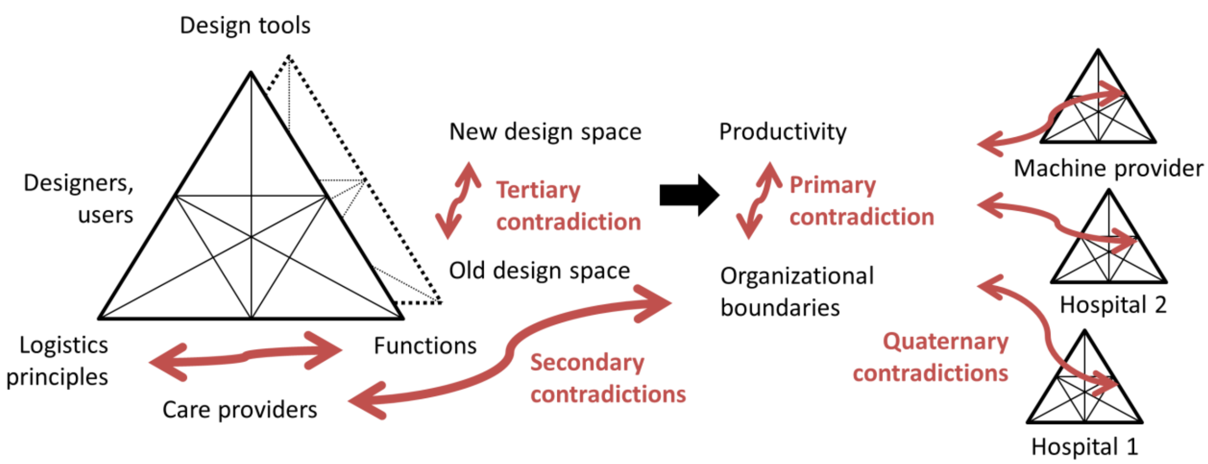

Figure 6 – *From optimized work procedures to knowledge co-creation activity* contradiction aggravating inside the design activity (left) and towards use activities (right).

These tensions were not visible to the designers at the beginning of the project; nevertheless, they reproduced them. The business plan and machines' technical requirements were taken as the main constraint, guiding the definition of isolated functions and spaces, despite the idea of sharing machines to promote knowledge exchange between research and clinical practice.

Including users in the design was seen as an opportunity to get the commitment of the hospitals to join the venture. In a participatory workshop, the so-called users joined the design activity in modifying the design, since the actual plan was overcrowded due to sharing. The reconstructed image reveals that the dressing rooms were the most unstable part of the design space (Figure 7). There was a doubt if there should be many small dressing rooms — to afford more patients per machine — or less dressing rooms — with more space each. Also, if there should be a bathroom nearby, or even a dedicated waiting room for each scanning machine. After trying many different moves, designers and users realized that the most important thing would be to have a corridor that connects the different areas of the facility, allowing for sharing the dressing rooms and to also informally share knowledge in the breaks.

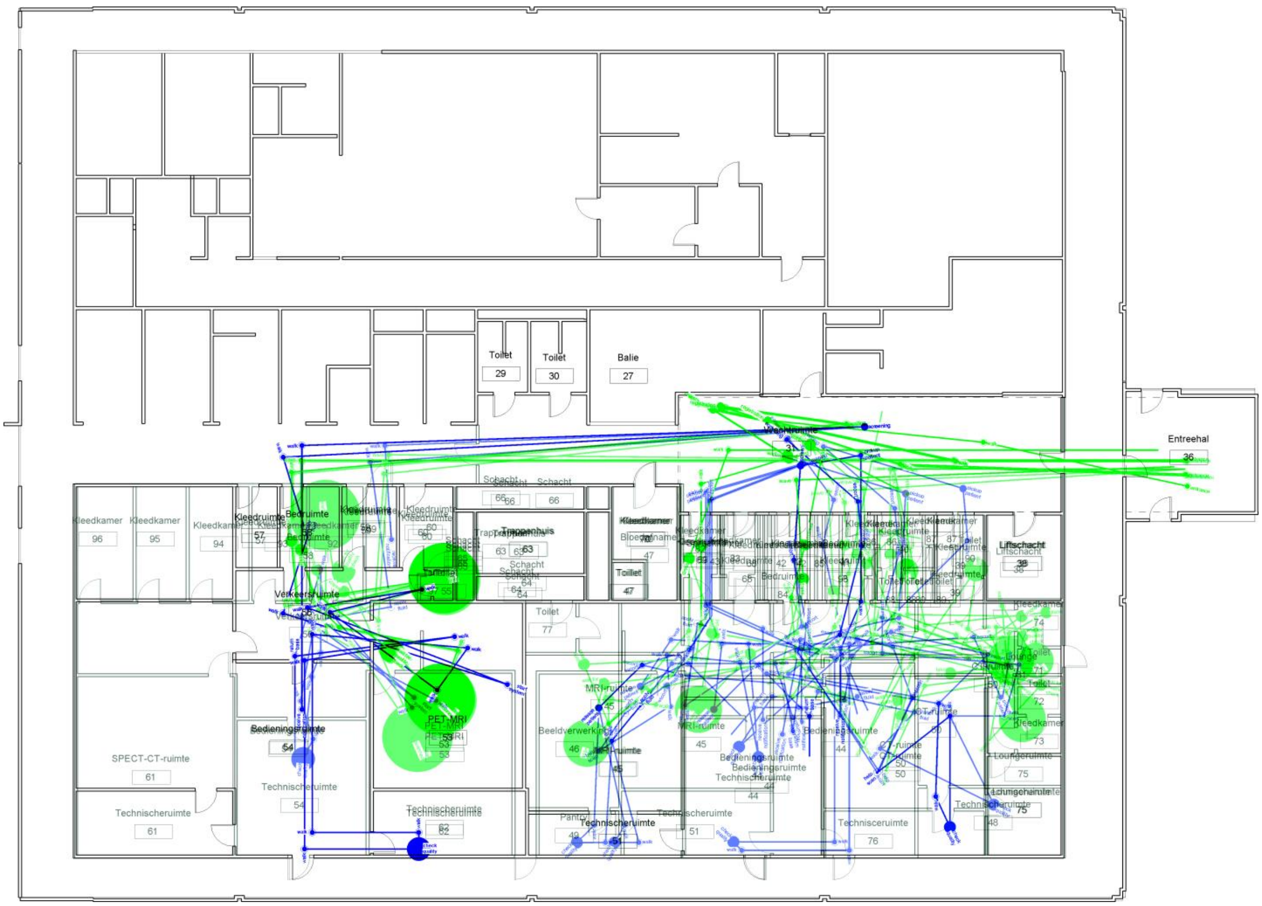

Figure 7 - The four versions of the floor plan with the respective walking paths stacked in a single picture, excluding the upper part.

The main finding from this case-study is that the boundaries that defined the design space were not self-imposed constraints, but imperative economic, political, and cultural conditions that contradicted each other. Designers and users had to deal with these contradictions even if they did not set as constraints in brief phase. Their moves in the design space alleviated, aggravated, and overcome these contradictions.

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

The design space extended to a teaching experiment

The course Methods and Strategies for Facility Design of University of Twente bachelors in civil engineering had related topics to what was observed in the case-study, so the authors brought the project to the course for a practical learning experiment. The context 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 optimize the facilities to meet these numbers. (Data fragment).*

This is neither a problem nor a solution, but an issue related to the contradiction *from an optimized work procedure to a knowledge co-creation activity*; however its historical background is not given. Instead, the experimenters provided students with the results of a deterministic simulation they made to support practitioners in the original project (Figure 8). 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 in the movement of nurses and patients around machines. A spreadsheet with performance figures such as machine capacity usage, waiting times, and room occupation was also provided.

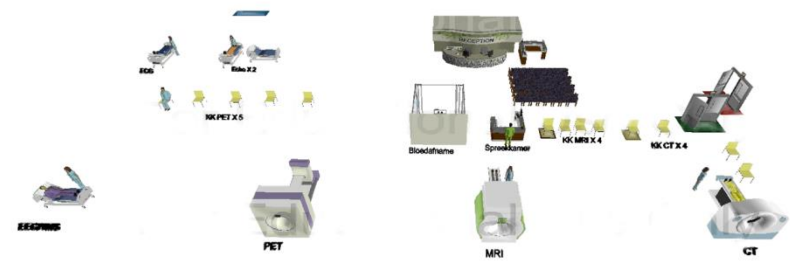

Figure 8 – Deterministic simulation of the medical imaging center scanning procedures.

The experiment consisted of two sessions: brainstorming and modeling. In the brainstorming session, students were organized into teams of four, with the task of formulating problems and solutions. They had to reconstruct the design space in an explicitly social manner: team work.

The design space has been explored in 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 realize the material resistance for implementing their solutions, but also to measure their explorations in the design space through a standard format that favors comparison. Students were then introduced to the parametric design tool with which they could develop further the design, alone or in pairs. They did not work in teams like in the previous session due to the software/hardware limitation for real-time collaborative modeling. For most students, this was a 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 walking 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. 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). 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.

Experiment 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 exploration of the design space across time, like in the case-study, but in a much shorter interval. All images, from all students, were stacked into one, in the same way as in the case-study. The difference here is that the combined images do not reflect the exploration of one team, but of many teams.

Group 1 had the extra task of drawing the paths from scratch in the same amount of time, what resulted in fewer paths and focused exploration (Figure 9). 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.

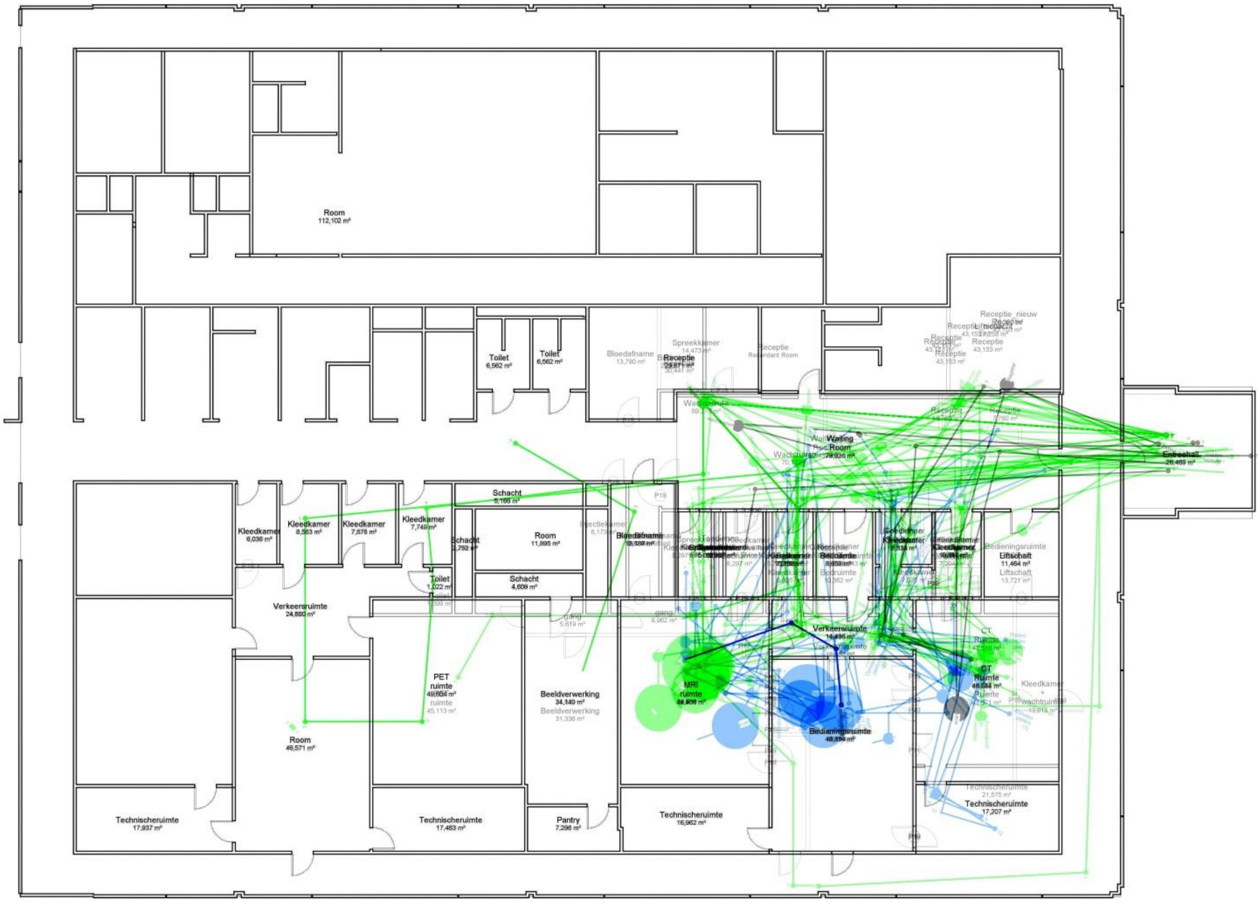

Figure 9 - The designs generated by group 1, with no initial paths, stacked in a single image

In group 2, most students began by changing the PET area (left part) due to the performance figures provided (Figure 10). They framed the longest paths from the entrance as the best opportunity for improvement. After that, they began to poke with the dressing rooms allocated for PET.

In both groups, the dressing rooms were the most unstable part of the design, pretty much like in the original project. Some students proposed to change them into dedicated waiting rooms to avoid patients and nurses 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 so as to increase the level of comfort for both staff and patients. Many doors have been opened in both groups to minimize space fragmentation.

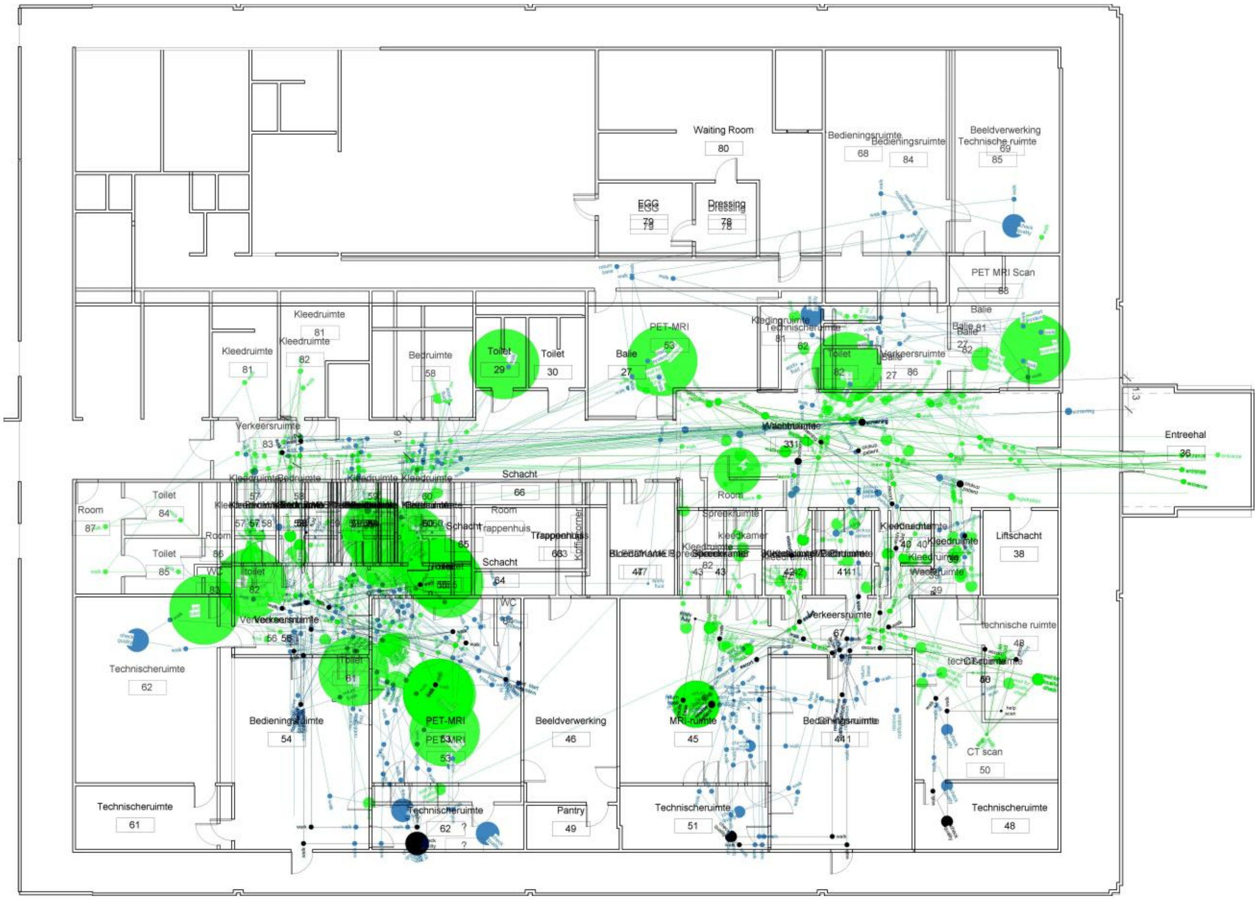

Figure 10 - The designs generated by group 2, with the initial paths already given, stacked in a single image

Instead of restricting exploration, the extra constraint in group 2 let students consider different ways of rerouting patients and nurses. The exploration of the 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, what did not happen in group 1. It seems that the given constraints were not taken for granted by students, being changed or ignored by design moves. One student report stated:

> *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 did not have explicit information about contradictions; nevertheless, they aggravated and alleviated some of them with their designs. Many contradictions found in the original project were not addressed and kept accumulating in the design space. A comparison between the groups and practitioners regarding the origin and impact of design moves reveals no significant differences in interactions with one contradiction (Table 1). Other contradictions are not explored here due to the lack of space; however, the preliminary data analysis suggests that a design move that alleviates one contradiction often aggravates another.

Table 1 – Aggravating tensions of *from optimized work procedures to knowledge co-creation activity* contradiction and related design moves by practitioners and students groups.

Tension level	Contradictions *in* space	Contradictions *of* space	Practitioners' moves	Group 1 moves	Group 2 moves
Primary	Productivity X Organizational boundaries	Layout fragmentation X Path homogenization	Simulating procedures to find bottlenecks	Splitting dressing rooms	Splitting dressing rooms
Secondary	Workflow optimization X Political compromise	Exclusive space X Shared space	Flexible dressing room space	Moving rooms closer to the entrance	Moving rooms closer to the entrance
Tertiary	Competition X Collaboration	Compartmentalization X Multifunctional	Large internal corridor	Small internal corridor	Fewer steps in walking paths
Quaternary	Outcomes X Expectations	Knowledge centralization x Practice marginalization	Participation in design	Splitting the waiting room into many	Occupying undefined part of the layout

Students did not directly address tertiary and quaternary contradictions since they depend on project historical background, not given. That did not prevent these contradictions to influence their designs, on one hand guiding them to more open spaces, with extra connections and functions — favoring collaboration among partners and, on the other hand to more fragmented, streamlined, and optimized spaces on the other — favoring competition among partners.

This contradiction was also reproduced by the tool introduced in the experiment, what was acknowledged by a student team in their report:

> *The situation modeled is an ideal situation, where everything behaves as planned. There is no scenario for emergencies. Users of the building will not behave as the parameterization. The modeled 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, pointing to its poor usability, automation, efficiency, and simulation capabilities. On the other hand, they recognized the experiment as an opportunity to learn about the social construction of the design space:

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

The logic of optimization and the dialogue about knowledge co-creation were both present and clashing in the teaching experiment, even if in a lower tension than found in the case-study.

Discussion

Contradictions are situated phenomena, hard to be grasped in an experiment. For the researchers, seeing contradictions was much easier while engaged in the project rather than in the experiment. The deterministic bias of the tool was not fully realized until students criticized it in their reports. Not surprisingly, researchers could not stay above contradictions and look at them with distance. They were already reproducing the contradiction by interacting with it. In fact, the research activity was already facing this contradiction in the increasing emphasis of publications indicators in Dutch universities (Groot & Garcia-Valderrama, 2006). In comparison to healthcare activity, academic research is doing the other way around: *from a knowledge co-creation activity to an optimized work procedure*. The convergence of healthcare and research in the medical imaging center is not a coincidence, but a cause and effect of the contradictions present in their underlying systems.

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, overdetermined. The present empirical work shows that it is possible to determine a design space, provided that the determination is socially constructed and that contradictions are taken into account. The following relationships were considered to determine the design space: the economic imperative of productivity, the cultural trend of knowledge co-creation, the engineering design tradition, the optimization bias of the tools used in the experiment, and the formal characteristics of the design space, all understood as manifestations of contradictions in history (Engeström, 1987) and in space (Lefebvre, 1991). The resulting overdetermination could be a better argument against prescription and modeling rather than indeterminacy (Goldschmidt, 1997).

Conclusions

A parametric design tool has been developed and tested to visualize in a crude way the forces behind the design moves, arguably the contradictions *in* space and *of* space. Using this tool, students ended up stuck and boosted by the same — but not all — the contradictions that practitioners faced in the industry project, despite not working under the same conditions. The data suggests that the contradictions of a project are intrinsic to the design space, even if they are unknown.

Contradictions are concrete despite any abstractions, such as problems or solutions. They are constituted by the systemic tensions that accumulate and drive a certain activity, provoking trouble in many different ways. Contradictions cannot be removed nor solved; rather they can be aggravated, alleviated, or overcome. In any case, contradictions won't go away. Any alleviated contradiction will keep accumulating tension without notice until it surfaces again in the design space. Even before that, the same move that alleviated one contradiction can aggravate another. The design activity, thus, bounces between contradictions in the design space, not without changing them.

We propose to reconsider the design space not as a space of possibilities, but a space of becoming (Luck, 2014). Any design considered in the design space is not just a possible one, but an actual coming to life. It already exists and affects the design activity, like any material in the physical world. Each move in the design space expands or contracts the potential to change the world, already implying the contradiction between use and exchange values. Making sense of design in this way can strengthen the emerging approach to design research that pays more attention to artifacts, practices, and history rather than inscrutable cognitive processes (Kuutti, 2011).

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