Contradictions in the design space

Abstract
The design space is a concept often used to avoid the optimization perspective over design. The design space is described as the sum of all possible designs for a given brief, floating in a world of ideas, peacefully waiting to be discovered and materialized by creative designers. The concept as such cannot go much beyond optimization. To go beyond, it is necessary to break through the cognitive paradigm and see the social construction of the design space, fueled by the contradictions that are inherent to the world of human beings. This renewed perspective has been applied to map the design space of a medical imaging center in The Netherlands. The boundaries that defined this design space were not self-imposed constraints, but imperative economic, political, and cultural conditions that contradict each other. To explore this question, the design space has been extended to a teaching experiment, where students analyzed the project drawings and proposed changes using a custom parametric modeling tool. This tool was also used to track and compare the design space exploration by practitioners and students. The comparison reveals that they faced similar contradictions, despite working under different conditions, what suggests that contradictions are intrinsic to the design space.

Keywords
Design space; contradictions; constraints; architectural design; activity theory.

Introduction
The concept of space is increasingly being used in design research to explicate the indeterministic characteristic of design activity (Goldschmidt, 1997). 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 preferred to be called a space by its property to contract — by adding constraints — or to expand — by adding new variables (Gero & Kumar, 2006).

This space reflects the indeterminacy of design: there are so many possibilities to any design task that becomes unproductive trying to determine its outcome before it actually happens. On the other hand, these possibilities are not necessarily all considered when design happens, due to many limitations (Westerlund, 2005). The cognitive limitation is being addressed by computational tools that expand the designer capability to explore, remember, and combine the possibilities (Woodbury & Burrow, 2006). The other limitations — financial, technical, social, or cultural — are considered to be outside factors that may be brought into the design space as constraints. Since the constraints are first processed by cognition before they enter the design space, the only limitation that can be considered intrinsic to the design space is the cognitive (Simon, 1991).

There is a contradiction here between the space of possibilities and the possibilities of space. The design space is infinite for all designers, but quite limited when assessed by an individual designer. If that is the case, then it is just a matter of determining the cognitive capabilities of a designer to determine the design space; however, design as it happens in the world is hardly the work of a single person (Botero, 2010). Even when working alone, designers work under financial, technical, social, and cultural conditions that are not necessarily cognized and explicitly set as constraints. Many constraints are just taken for granted, or perhaps, they are not even constraints.

This paper articulates the notion of contradiction as an intrinsic feature of the design space. 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 contradictions.

The first part of the paper presents a case-study analyzing how the contradictions in the Dutch healthcare system are reproduced in the design of a medical imaging center. Ethnographic data reveals the social construction of the 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 conceived as a mental, individualistic, *a priori*, in a word, abstract space. It is described as a network of nodes representing states in the cognitive process of the designer (Goldschmidt, 1997). In this vision, there is no convincing explanation why design moves from one state to another (Figure 1). Everything seems to happen by the will of a single designer, limited by her cognitive capability. Further than logical, there are only random moves, which are also considered to be intentional (Goldschmidt, 2006).

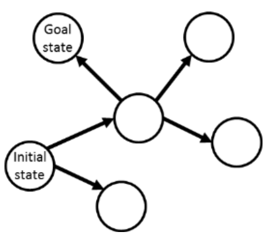

Figure 1 – A design problem space composed of a network of states. Redrawn from Goldschmidt (1997, p. 444).

The design space has demonstrated to be a useful concept to analyze how designers think alone, but there is still some doubt if it can help explaining how designers work in teams (Botero, 2013). The movement of the designer across the design space is not shaped solely by her will and cognitive capacity, but mainly by the interaction she has with other people involved in a project. Her moves in the design space are also part of that interaction; even if they are not synchronic. Such movement is concrete, not just abstract: it is motivated by the social world and causes effects back then. If we agree with Botero (Botero, 2010, 2013) that the design space is also a social space and with Westerlund (2005) that there are many design spaces, then concreteness is achieved by considering not one activity network, but by considering many (Lefebvre, 1991, p. 50). The network of design spaces are thus connected by the activities that fuel the dominant economic system. In the case of capitalism,

> *The paradigmatic (or 'significant') opposition between exchange and use, between global networks and the determinate locations of production and consumption, is transformed here into a dialectical contradiction, and in the process it becomes spatial. Space thus understood is both abstract and concrete in character: 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).*

Space understood through this lens is not just enveloping social relationships, but also reproducing and realizing them. Relationships *in* space are embedded into space, thus becoming relationships *of* space. In other words, social relationships perpetuate or change through space. To understand how this inversion happens, the social relationship between design and use are elaborated through a combination of cultural-historic activity theory (Engeström, 1987; Leont'ev, 1978) and the theory of the production of space (Lefebvre, 1991).

Contradictions in the design space

Design is an activity, as much as the use activities it addresses. It happens in a certain social situation, but also develops along history. The space where design unfolds is socially constructed and reproduces the contradictions of both design and use activities. In cultural-historic activity theory, the basic notion of activity is *a subject transforming an object by means of instruments* (Leont'ev, 1978). The subject can be an individual or a group of individuals; the object is the thing that has the potential to fulfill a subject's need if transformed in a certain way; and the instruments are the means by which the object is transformed. Each subject may have different motives to transform the same object. Henceforth, the transformation of the object is a 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). Different activities can also interact, for instance, when the outcome of one activity is the object of another (e.g. evaluation activities). In the case of the design activity, the outcome may be an instrument for another activity (Engeström, 1987).

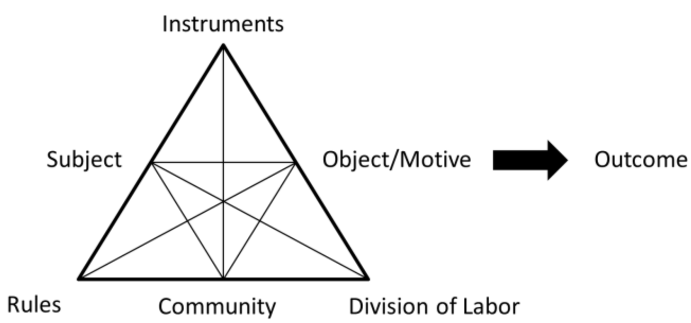

Figure 2 - Figure 1 - The activity system model. Redrawn from Engeström (1987).

Let's see how this happens in a historical fashion. The contradictions in one activity push to develop new instruments. An internal design action or an external design activity is engaged. In the latter, the design activity conceptualizes the original activity as a use activity. The design activity interacts with the use activity to define a design space to work on using methods such as briefing (Barrett, Hudson, & Stanley, 1999; Luck & McDonnell, 2006). One of the outputs of briefing is setting up constraints for the design space.

The design space is grounded in the use activity; therefore its contradictions are also reproduced, even if not explicitly stated as constraints. 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 in contradictions (Engeström, 1987; Foot & Groleau, 2011). In the primary level, the most basic contradiction of society appears in each element of an activity (subject, instrument, object, community, rules, and division of labor). In the case of capitalist society, this is the contradiction between the exchange value and the use value. The commoditization of subjects in the labor market, for example, can generate powerful contradictions that aggravate to further levels. 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.

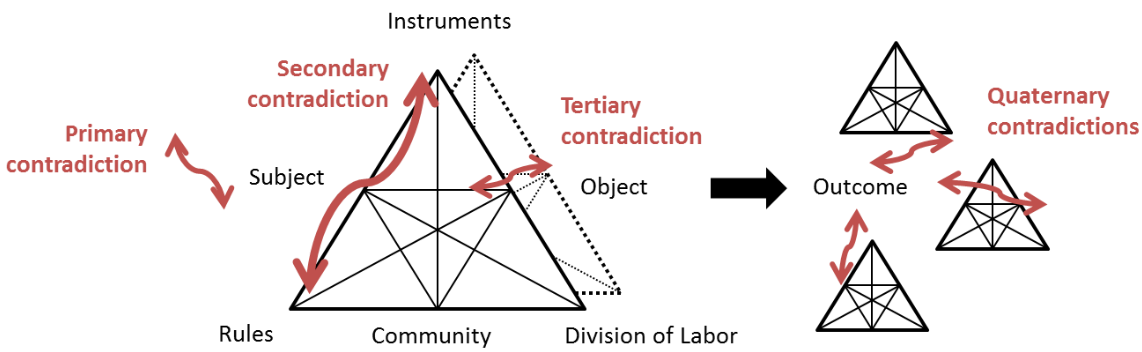

Figure 3 - Four levels of contradictions (in red): the primary level intrinsic to an element (left), the secondary level in the relationship between two or more elements inside the activity (middle), the tertiary between a new and old version of the activity (middle) and the quaternary level, among different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

Research design

Showing empirical evidence of this continuity between contradictions in design/use activity and contradictions in the design space requires an unusual research design. 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. Contradictions can only be grasped by looking at the historical constitution of the social situation, applying abstract measures, and subsequently reconstructing the whole phenomenon as overdetermined, or in other words, determined by too many causes (Lefebvre, 1975).

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) where they were linked to research questions and the aforementioned theoretical concepts in a map (Kunz & Rittel, 1970; Selvin et al., 2001). A specific map has been made about contradictions found in the project, tracing how they aggravate in the four levels (Figure 4). These contradictions became more apparent during workshops when different actors intervene in the design space, not so much during individual interviews.

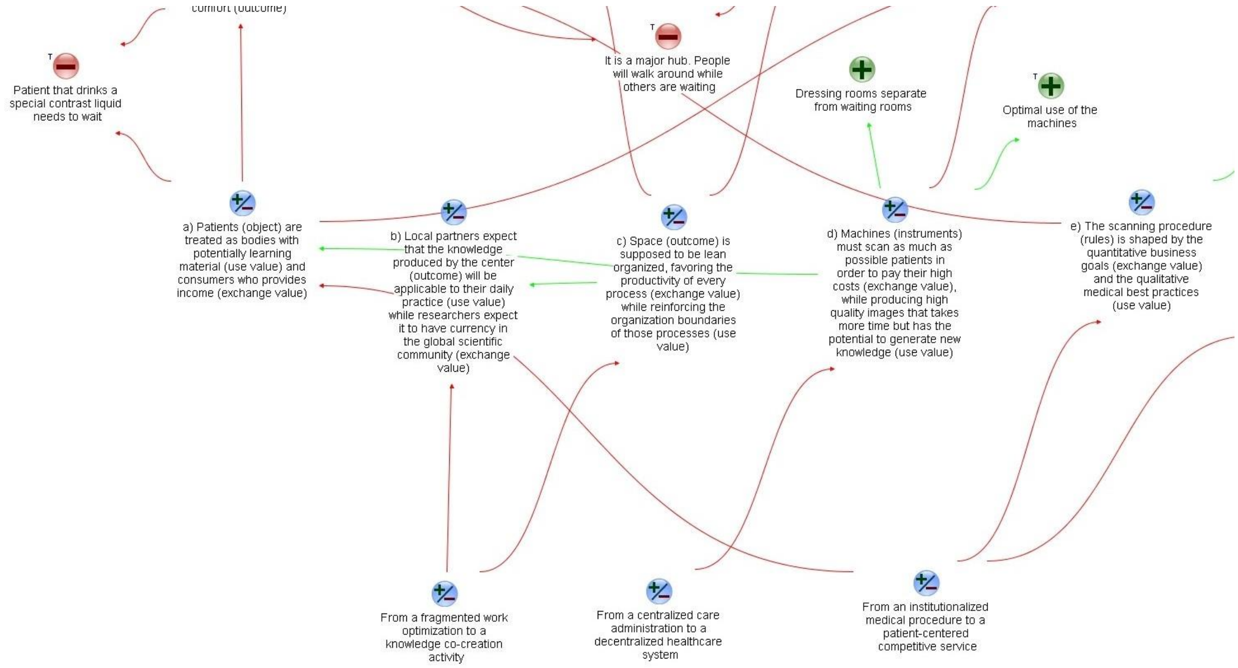

Figure 4 – Graphical map about contradictions (blue nodes) found in the studied project, related to their pros (green) and cons (red).

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

The experiment was designed 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 the subject develops concepts with the help of the tool to overcome contradictions. The tool purpose is to objectify the concepts, what helps not only the experimenters but also the learner himself.

The tool given is Autodesk Revit, an architectural design tool with a custom family to represent the use activity as walking paths. The family profits from the parametric design capabilities 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 shown by practitioners in the project studied. The reconstruction relies heavily on video recordings of practitioners explaining the plans and showing the user walking paths.

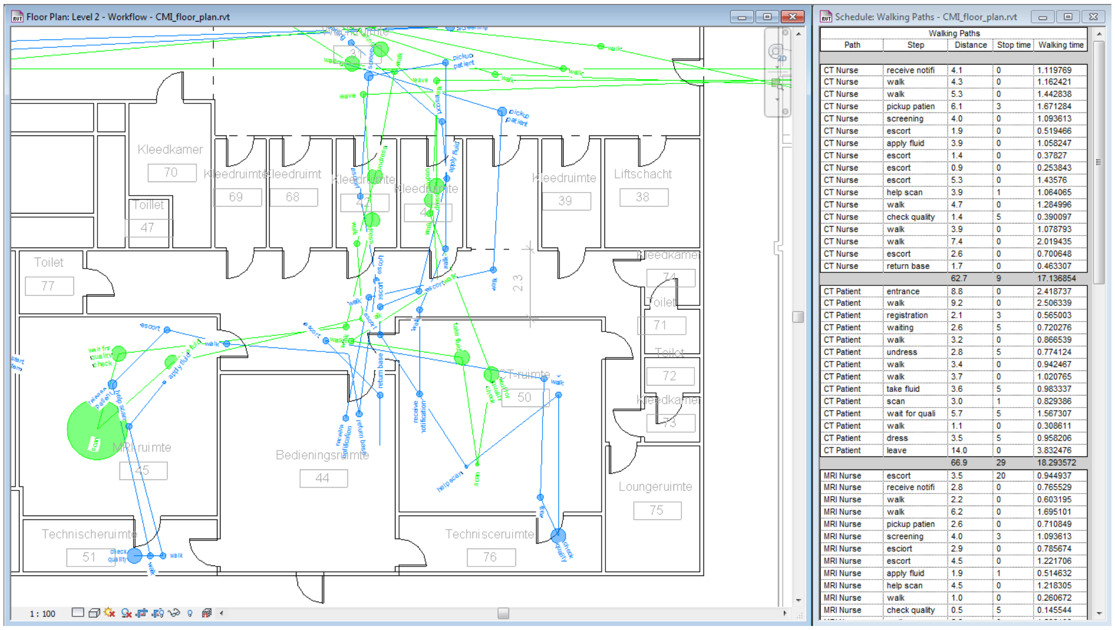

Figure 5 - Walking paths parametric design family for Autodesk Revit with related figures to the walkability performance. In this example, the green lines represent patient paths and the blue lines represent nurse paths.

This tool was used in both situations because it crudely visualizes how contradictions in activity affect contradictions in space and vice-versa, helping to understand the forces behind the design moves. The reconstructed images from practitioners and the generated images from students were all stacked in a single image to visualize 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 explicate them.

The design space of a medical imaging center

The design project 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. For the sake of space, we concentrate here in tracing one that aggravated from the primary to the quaternary level. This contradiction is related to the undergoing changes of the Dutch healthcare system since its last reform, in 2006. One of the points is the decentralization around 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. The medical imaging center project arose in this situation, offering shared facilities for nearby hospitals, educational institutions, and technology developers. Each partner would have to cope with the transition from their optimized work procedures to a knowledge co-creation activity.

This contradiction manifests at the primary level as the space (outcome) that is supposed to be lean organized, favoring the productivity of every procedure (exchange value) while reinforcing the organization 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 grow. Figure 6 trace these contradictions in the activity system model.

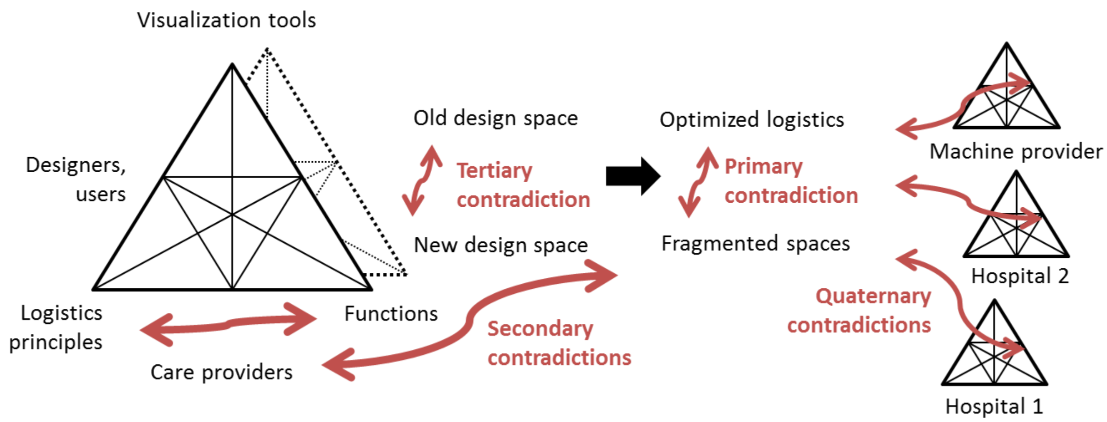

Figure 6 – “From optimized work procedures to knowledge co-creation activity” contradiction aggravating inside the design activity (left) and in its relationship to use activities (right).

These contradictions 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 constraints, guiding the definition of isolated functions and spaces. The business plan relied on the idea of sharing diagnosing machines to promote knowledge exchange between research and clinical practice. The center was situated in between two medium-sized cities and could serve as an outreach for two hospitals. Including users in the design was seen as an opportunity to get the commitment of the hospitals for joining the venture.

Once the design was presented to healthcare practitioners from the hospitals, it had to be reconsidered, since some spaces would be used by both activities and they might become overcrowded. In a participatory workshop, the so-called users joined the design activity in sketching the design and the issue of knowledge co-creation came to the fore. The healthcare practitioners saw the possibility of exchanging knowledge among each other in the new facility, what led them to ask for a corridor that connects the once separate activities.

The image created by stacking all the reconstructed floor plans with their respective walking paths 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 designs for that, 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.

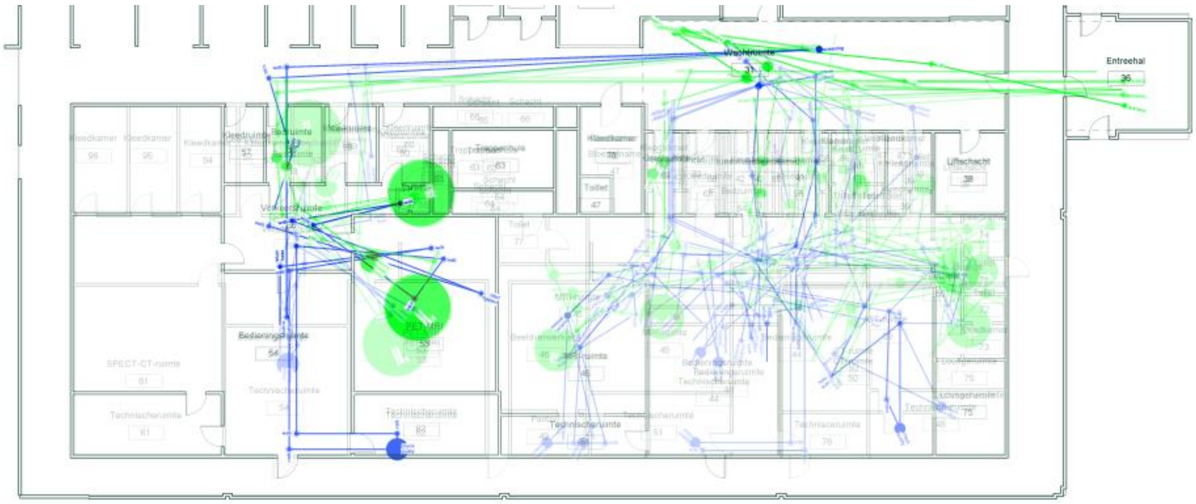

Figure 7 - The four versions of the floor plan with the respective walking paths stacked in a single picture, excluding the upper part. The darker lines represents stable parts of the design, while light lines represent unstable parts.

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. The designers had to deal with the contradictions instead of taking them away of the design space. They were intrinsic to the design space.

The design space extended to a teaching experiment

In the University of Twente bachelor's in civil engineering there is a course in facility design. Since the topic is related to what was observed in the case-study, the project has been brought to students for a practical learning experience. The situation found at the beginning of the study was communicated to students as an issue:

> *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 a 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 discrete event simulation they made to support practitioners in the original project. Students received a copy of the animation generated by the simulation (Figure 8), 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, limited by a pre-defined capacity. Aside from the animation, a performance spreadsheet was also provided.

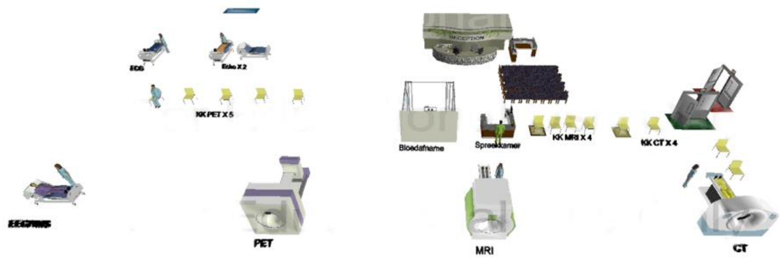

Figure 8 – Discrete-event simulation of the medical imaging center scanning procedures.

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 in that situation. They had basically to reconstruct the design space in an explicitly social manner: team work. A short note of remark is valid here: the double stimulation method differs from traditional problems solving methods, where the problem and/or the solution are known beforehand, allowing for performance comparisons. What is compared in the double stimulation method is the learning process, not exactly the learning performance. Therefore, the problems and solutions found by students were not known by the experimenters before the experiment was organized, since the experiment goal was actually to track how the design space was going to be reconstructed.

In the second session, students were introduced to the modeling tool with which they could develop further the design, alone or in pairs. They did not work in teams due to the limitation of the software/hardware for real-time collaborative modeling. For most students, this was a first experience with the software and the duration was only one hour, so they could not explore software capabilities other than the floor plan design and the walking paths family.

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 single example 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. Derived from this difference, two groups are considered: participants who could impose their own activity constraints (group 1, n=31) and participants who got some initial activity constraints, in the shape of walking paths (group 2, n=28). After the experiment, the initial teams reassembled together 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

In the first part of the experiment, the design space has been reconstructed in rather abstract way, in the format of problems and solutions. In the second part, the design space had to be reconstructed in a more concrete way, as a 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.

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 across time, like in the case-study, but in a much shorter interval. Each parametric design file was exported as an image. All the images, from all students, were then stacked into one, in the same way as done in the case-study. The difference here is that the combined images do not reflect the exploration of the design by one team, but by many teams.

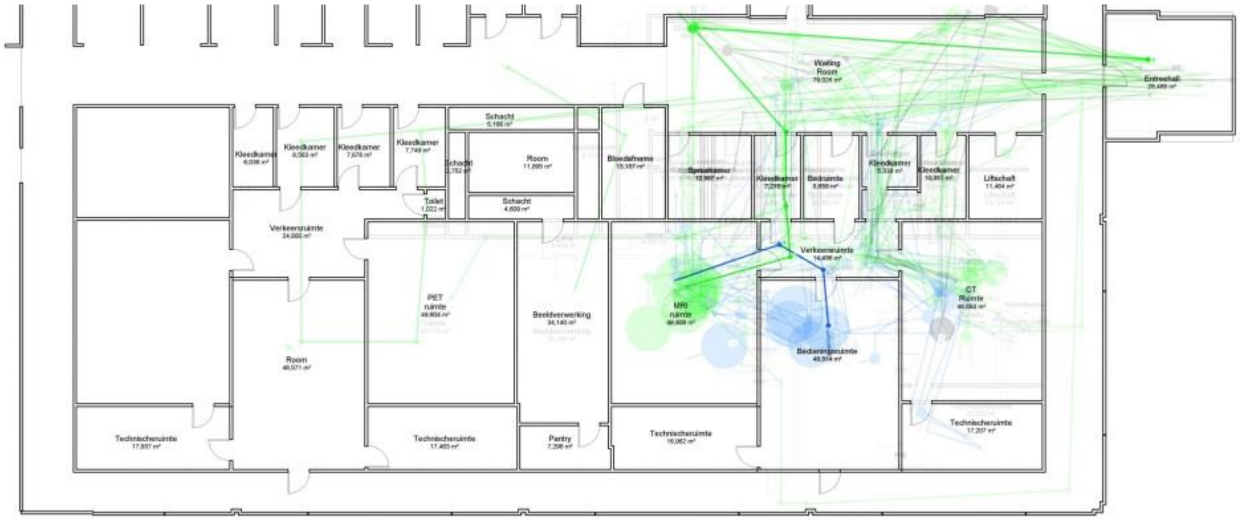

Figure 9 - The designs generated by group 1, with no initial paths, stacked in a single image

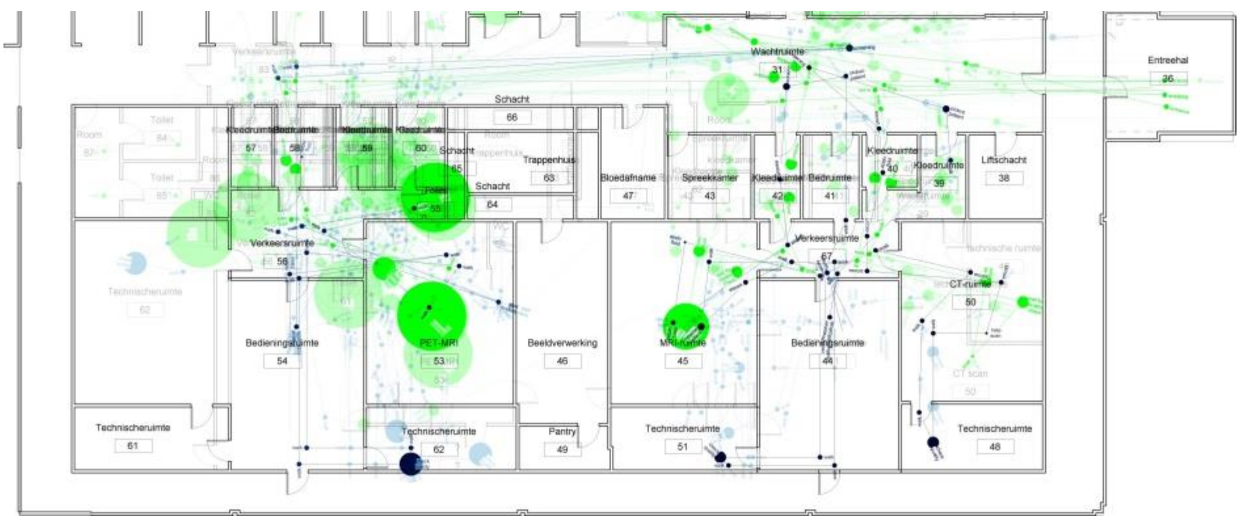

Figure 10 - The designs generated by group 2, with the initial paths already given, stacked in a single image

Group 1 had the extra task of drawing the paths from scratch in the same amount of time, what resulted in less paths and a much focused exploration. The dressing rooms around the PET and CT machines were the most unstable part of the design, pretty much like in the original project. The corridor that allowed for sharing the dressing rooms in the original project appeared only in two designs of group 1. In group 2, the corridor did not appear at all; however, the exploration of the design space was more diverse. Instead of restricting the exploration of the design space, the extra constraint of the walking paths let students consider different ways of rerouting patients and nurses. Most students began by changing the PET area (left side) due to the performance figures provided. They perceived it as the best opportunity for improvement, since they had the longest paths due to being further from the entrance. The dressing rooms were also controversial. 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; however the issue of knowledge co-creation did not come up in their designs or reports.

The students did not have full 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 regarding the contradiction discussed in depth in the case-study 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 data analysis suggests that a design move that alleviates one contradiction often aggravates another.

Table 1 – The average interaction of students design with "From optimized work procedures to knowledge co-creation activity" contradiction.

Contradiction level	Group 1	Group 2
Primary (lean organized space X organization boundaries)	Alleviated	Aggravated
Secondary (workflow optimization X political compromise)	Alleviated	Alleviated
Tertiary (competition X collaboration)	Accumulated	Accumulated
Quaternary (outcomes X interests)	Accumulated	Accumulated

Students did not touch tertiary and quaternary contradictions since they depend on project historical background, not given. That did not prevent these contradictions to influence their designs, guiding them to an optimization mindset, with no much regard to how activities interact, patient comfort, and knowledge exchange opportunities. This contradiction was also reproduced by the tool adopted 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 the contradictions was much easier during the engagement in the project rather than in the experiment. The optimization bias of the tool was not realized until students criticized it in their reports. It was not possible for researchers to stay above contradictions and look at them with distance. The work optimization versus knowledge co-creation contradiction was also reproduced in the research activity. In fact, the research activity was already facing this contradiction due to the increasing emphasis on publications indicators in academic evaluation in Dutch universities (Groot & Garcia-Valderrama, 2006). In comparison to healthcare activity, academic research is doing the other way around: from knowledge co-creation to an optimized work procedure. The convergence of these activities in the medical imaging center is not a coincidence, but a cause and effect of the contradictions present in academic and healthcare 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. Many causes and effects relationships are considered, using the common ground of (social) history and, with our addition of the theory of production of space (Lefebvre, 1991), (social) space. Overdetermination could be an interesting alternative for design research to the indetermination argument against prescription and modeling (Goldschmidt, 1997). The present empirical work shows that it is possible to model a valid design space, provided that the model is socially constructed.

Conclusions

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 accumulated, 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.

The 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. They cannot be tackled by optimization per se, but by the entire social activity that constitutes design.

We propose to reconsider the design space not as a space of all possibilities, but a space of becoming. 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. Making sense of design in this way can give rise to a new approach in design research, one that pays more attention to artifacts, practices, and history rather than inscrutable cognitive processes (Kuutti, 2011).

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