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Lean design improves both healthcare facilities and processes: a literature review.

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ABSTRACT- This article presents a literature review of the possibilities and challenges of Lean design in modern healthcare facilities. Many of today's healthcare facilities are in dire need of renovation since limited financial resources among healthcare demand improved work process efficiency, safety and employee well-being. Lean philosophy has been successfully implemented into hospitals with up-and-running hospital processes, but has not been thoroughly tested as a design methodology. The principles of Lean do not contradict with user-centric, participatory or ergonomic design approaches, and thus the possibilities of using Lean as a complementary design methodology to the aforementioned approaches are discussed in this paper. Lean fundamentals are also useful when dealing with change management issues. Furthermore, the idea of using simulations alongside Lean to enhance healthcare design is briefly discussed. Lean offers a fundamentally solid ideology and a wide range of tools – many of which seem fitting to solve several urgent design problems in today's healthcare design.

Keywords- Lean, healthcare, user-centric design, participative design, ergonomics, simulations

Background

Healthcare practitioners' work is physically and psychologically intense. Due to an aging population structure in the developed countries, it is important to ensure healthcare workers maintain good physical and mental health. This can be accomplished by creating a good work environment that promotes wellness, improves coping with stress and maintains one's ability to work (Smith and Sainfort 1989; Ulrich 1991). On the other hand, poorly designed and crowded hospital work spaces are common and may cause fatigue, stress, burnout, and compromise patient safety by disrupting the staff's work performance, quality of care and lead to an increased number of medication errors (Gluck 2007; Chaudhury *et al.* 2009; Aiken *et al.* 2011; Mahmood *et al.* 2011). With the financial constraints among today's healthcare, improved cost efficiency is demanded. Many healthcare facilities are outdated and require major renovations because they have a tendency to create delays that may negatively impact patient safety and work efficiency (Mullaney 2010). Furthermore, healthcare processes are changing, which also creates need for new facility design.

By improving physical environmental dimensions of a healthcare facility (air quality, acoustics, lighting, seating arrangements, etc.), significant effects on staff health and work efficiency could be gained (Ulrich *et al.* 2004; Ayas *et al.* 2008; Salonen *et al.* 2013). A well-designed hospital increases patient and staff well-being, satisfaction, patient safety, expedites patient recovery rates (Ulrich 1999; Gesler *et al.* 2004; Gluck 2007; Haron *et al.* 2012), while reducing medical errors, hospital acquired infections, staff stress and injuries (Ulrich *et al.* 2008). Although the importance of designing safe and efficient healthcare work environments has been acknowledged worldwide, plenty of room for improvement still exists (Gluck 2007). Regrettably, today's healthcare design still tends to ignore the aspect of user-centricity (Reiling 2007). Designers with poor insight into healthcare processes are being hired to plan and scheme hospitals. New hospitals are being built, after which the staff is asked to adjust their work processes to fit in with the new facilities. This leaves the novel facilities unsuitable for their purpose and the work environments limiting work processes instead of enhancing them. Doctors and nurses have to walk excessive distances to fetch medical supplies, patients have to travel back and forth between treatment rooms or travel excessive distances inside the hospital, and staff performs administration and medication errors (Hughes and Ortiz 2005). Design modifications at later stages of a hospital building's lifecycle are expensive and sometimes difficult to achieve due to the multidisciplinary nature of design decision-making (Mourshed and Zhao 2012).

An understanding of hospital users' (employees' and patients') perception of design factors is essential for informed decision-making during early design stages since they have the deepest knowledge of the hospital work processes (Harun and Ibrahim 2008; Mourshed and Zhao 2012). They should therefore also be essentially involved in the design of the facility. Deployment of a multi-professional approach has had notable success in recent years and can thus be recommended for future healthcare design projects. It has shown promising results, but still lacks implementation tools: How can we effectively transfer information of the users' needs on to the designers? Even if this is accomplished, designers, architects, administrators and hospital staff may all have different views and opinions on how the hospital should be designed (Bromley 2012).

User-centric and participatory design approaches have been popular among healthcare design (Seim and Broberg 2010). They attempt to create an environment that enhances hospital users' well-being, coping with work, and work processes. However, healthcare design still seems to be missing a key piece in optimizing work processes for the newly built facilities. Lean philosophy has exhibited potential in improving the efficiency and quality of healthcare environments and processes. It has been implemented successfully into a growing number of healthcare facilities worldwide (Jones and Mitchell 2006; Ben-Tovim *et al.* 2007; Nelson-Peterson and Leppa 2007). Lean attempts to create more value (e.g. direct care) for the customer (patient) by removing waste (everything besides value-creating activity/non-value-adding activity) in the work process. Lean principles can have a dramatic effect on improving processes and outcomes, reducing cost and cycle times, and increasing patient and staff satisfaction (Mullaney 2010). It has often been implemented into a facility that has already been built and optimized for "old" work processes, which makes work process adjustments very challenging. However, if user-centric and participatory design approaches were complemented with Lean fundamentals, methods and tools already in the design phase, could this improve work processes and spatial solutions as well?

This paper is a literature review of over 100 research papers conducted regarding Lean and healthcare facility design. The aim of this paper is to review the current state of user-centric and participatory design approach in healthcare facilities and the associated needs and shortcomings. Then some basic fundamentals of Lean philosophy are discussed along with its implementation potential in healthcare design projects. This paper considers whether Lean, a management philosophy, can be effectively utilized in the design phase of the healthcare facility design. Also, the possibility of successfully integrating Lean approach with change management, simulations and user-centric, participatory, and ergonomic design approaches is discussed in this paper.

User-centric and participatory design of health facilities

Hospital designs are complex and possess an abundance of interrelated functions that must accommodate the constant movement of people, equipment and supplies throughout its structure (Haron *et al.* 2012). A well-designed, user-centric healthcare design that focuses on spatial layouts, accessibility, workflow and people behavior provides several benefits: It improves the users' understanding, well-being, and satisfaction, and renders the usage of the space safe, efficient, effective, productive, user friendly and comfortable (Gesler *et al.* 2004; Poldma 2009; Rechel *et al.*

2009; Haron *et al.* 2012; Mourshed and Zhao 2012). There is an urgent need for creating new, user-centric healthcare facilities (Crow *et al.* 2002; Dinç 2009). Sometimes this may mean questioning some of the dominant, unwieldy solutions used nowadays. Optimization of an already constructed healthcare facility may prove difficult, frustrating and expensive as well as time consuming, and to top it off, the outcome may still be sub-par. Post occupancy evaluation techniques help assess the users' satisfaction and experiences (e.g. "RUKA 1", (Samah *et al.* 2012)), but the main focus should be shifted towards pre-emptive design techniques. It may thus be wise and cost-efficient to rebuild an entirely new facility by utilizing up-to-date knowledge on user-centric hospital design. The new healthcare facility may even become cheaper in the long run than upkeep of an outdated one due to i.e. new HVAC systems, which significantly improve energy savings (Bizzarri and Morini 2006; Vanhoudt *et al.* 2011; Ascione *et al.* 2013; Reijula *et al.* 2013). Investment in new, patient-centered healthcare design has been seen to improve provider-patient communications and relationships, involve patients more thoroughly in medical decision-making, empower the patients, and enable the physicians to better fulfill the patients' wants, needs and preferences (Bensing *et al.* 2000; Berwick 2009; Mayes 2009; Bromley 2012).

User-centric way of thinking has only relatively recently begun to gain momentum in healthcare facility planning, but has gathered worldwide support (Laine and Davidoff 1996; Duggan *et al.* 2009). Basic starting points in user-centric facility design are considering the goals of the organization and the requirements of the work processes which are systematically analyzed. The goal is to find ways to ensure that the facilities meet the users' (employees' and patients') needs and support well-being and productivity (Rechel *et al.* 2009). User-centric design doesn't necessarily have to mean participatory design. User-centric design may be based on the evidence based research data or knowledge which a researcher collects from the users for example using questionnaires and checklists (Becker and Parsons 2007). The user could be quite passive without any actual participatory action in the design process (Sanders and Stappers 2008). Instead, participatory design is a process, where different stakeholders are involved in the design process in order to improve the design process itself or the outcome of the design process (Granath *et al.* 1996). Participatory design appears in different versions and with different implications. The degree of participation in the process may vary. User involvement could be representative or direct and it could relate to the whole design process or only to a certain part of it. In participatory design, organization members are brought together to analyze problems in the organization, describe their situation, redesign the work organization, and learn from each other. Methods to facilitate participation include e.g. project teams, workshops and conferences which search for common grounds and improvement ideas (Gustavsen 1992).

In the deepest meaning of participation, user involvement could be called "collective design" or "co-design". In a collective design process the different actors' expertise, knowledge and values formulate the design result in a collective way (Granath *et al.* 1996). The users are regarded as experts of their own work and their participation is based on their relevant knowledge (Granath *et al.* 1996). In hospitals, healthcare providers constitute the most frequent facility user group who spend most of their working time in hospital indoor environments, and are thus familiar with the physical aspects of their environment and with the requirements of their own work (Mourshed and Zhao 2012). Hence, their opinion on the design of a hospital provides invaluable information and expertise to hospital designers. They play a significant role in knowledge development, idea generation and concept development as well (Sanders and Stappers 2008). The focus in the facility design process is multidimensional: Spatial, technical and organizational issues are discussed. The common knowledge and the objectives are questioned and developed and the participants have a genuine possibility to contribute to the goal setting and solutions (Granath *et al.* 1996). At its best, the collective design process is a multidisciplinary learning dialogue between the different users of the facility (Adler *et al.* 1995). All upcoming employee groups should be represented in the design phase: Architects, interior designers, engineers, ergonomists, facility management, local authorization, medical planners, healthcare professionals and patients should all share their knowledge in the pursuit of optimizing facility design for work processes (Clements-Croome 2004; Seim and Broberg 2010; Haron *et al.* 2012). This way everyone has a say in the new hospital design, which may be seen as a positive thing in several ways: Some fundamental flaws in the design phase may be avoided, employees feel that all opinions are heard, which may instill a feeling of belonging and togetherness, resources can be saved, job satisfaction can be improved, the patients viewpoints will be better accounted for, and benefits in participatory leadership can be established (Wilson and Haines 1997; Sanoff 2008).

However, this idea has proven to be difficult to realize: Due to patients' and clinicians' lack of knowledge about the design process, their input might have limited benefit in the design process (Hignett and Lu 2009). Furthermore, healthcare professionals and architects may perceive they have insufficient knowledge of hospital work processes as a whole – spanning from the arrival of patient until the moment of his/her departure from the facility – for planning a patient-focused hospital (Jensø and Haugen 2005). They may also possess insufficient abilities to take the patients' perspective in patient-centered hospital planning (Jensø and Haugen 2005). Even if they do, they may be unable to convey this information to the rest of the design team. Furthermore, architects seldom have knowledge on the work clinicians perform and vice versa. This calls out for ergonomists to facilitate the involvement of clinicians and patients to engage with future designs of healthcare environments (Hignett and Lu 2009). Increased monitoring of the healthcare personnel, communication gap, coupled with lack of trust between the design team and the various user groups are still some of the major challenges in participatory design and have led to a stifling effect on healthcare design (Sanders and Stappers 2008; Hignett and Lu 2009). Thus, there is a need for methods for design and communication that bridges over differences in language among the participants.

Lean fundamentals

Implementation of Lean may provide useful insights into user-centric and participatory facility design. Some see it merely as a tool-box for quick fixes, but contrary to these beliefs it is actually a comprehensive management philosophy. It should be utilized throughout the entire organization; knowledge rippling from senior executives to all workers in different levels of the hospital. This, top-down topology has worked well in many Lean implementation projects among healthcare thus far (Womack and Miller 2005) and the results have been promising in cases wherein Lean has been implemented comprehensively and systematically and into the hospital (Radnor *et al.* 2012). Basically, Lean seeks to provide maximal value (high quality treatment) to the patient with the given effort. This is carried out by eliminating as many excess steps (waste) from the work process as possible. Lean practitioners have identified eight forms of waste: (i) defects (e.g. lost laboratory specimens), (ii) overproduction (e.g. too large batches of medication), (iii) transportation (e.g. moving materials, patients or information files), (iv) waiting (e.g. patients waiting for their appointment), (v) excess inventory (e.g. expired supplies), (vi) unnecessary motion (e.g. excess walking by the staff or patients), and (vii) excess processing (e.g. re-writing paper-based patient forms) and (viii) the failure to develop human potential (e.g. physicians preparing patients for surgery) (Ohno 1988; Womack and Jones 2003; Chalice 2005).

Lean offers a plethora of tools for work process optimization, such as the Value Stream Map (VSM), 5S, JIT and Zero-Quality Control. Elimination of waste is a never-ending journey, as the whole company learns to understand the philosophy of continuous improvement (Reijula and Tommelein 2012). The performance effects of Lean increase along with higher levels of environmental complexity (leading to higher levels of waste) (Azedegan *et al.* 2013). More information on the basics of Lean philosophy can be found from following references (Liker and Meier 2006; Reijula and Tommelein 2012).

Toyota, the company mainly responsible for the development of Lean has defined five core values for "Lean thinking": Teamwork, Respect, Kaizen, Genchi Genbutsu and Challenge (Liker 2003). These can be seen as fundamental cornerstones of Lean as well and are thus worth explaining to give the reader a deeper understanding of the Lean ideology.

In order to create a mutual understanding and a sense of togetherness, Lean emphasizes **Teamwork** and **Respect** among all employees. It is important to listen to employees from different areas of work when carrying out user-centric design, especially in a patient-centered field of expertise such as healthcare. All employees should be encouraged to speak out and point out flaws in the work processes instead of hiding the process shortcomings (Dekker 2007). This doesn't just happen by ordering everyone to speak out. Lean focuses on changing the culture and atmosphere of the workplace so that these new improvement ideas will be listened to and that the foremen will respect the workers for speaking out. Even in today's work culture, healthcare professionals are reluctant to inform their foremen of process flaws and present improvement ideas due to fear of malpractice and litigation concerns (Donchin 1995). Some even fear we are shifting towards a blame culture (Hignett and Lu 2009). Lean sees work processes as always being imperfect and incomplete; improving them will ultimately decrease the chance of human error. Moreover, one should not be afraid to admit and point out mistakes because they can be an invaluable source of information for the rest of the company. Togetherness, loyalty and respect among co-workers, business partners and also the community are emphasized, and only an atmosphere of trust can guarantee positive results. Everyone – not only the management – is held accountable for the results and is taught to work together towards a common goal. Lean focuses on teams and also rewards them instead of individuals. This is seen as a much more effective means to gain positive results than individual punishment. Lean believes this will lead to users' improved motivation and commitment to continuous improvement ("Kaizen").

Kaizen is a Japanese word meaning continuous improvement. As no process can ever be declared perfect, there is always room for improvement. The process of Kaizen can be separated into four steps: creating stability, flowing work, standardization and incremental leveling (Liker and Meier 2006; Reijula and Tommelein 2012). This is a never-ending loop that starts over from the beginning once completed. There are several Lean tools for continuous improvement. Visualization is a basic fundamental of Lean and provides an effective way for all healthcare professionals to learn and store information. Value Stream Map is a useful Lean visualization tool for healthcare professionals for not only understanding their own work processes but also those of co-workers. It helps avoid waste such as back and forth (and other excess) movement for both people and inventory and optimize the logistics inside the healthcare facility.

Genchi Genbutsu means going to the source of information to find the relevant facts and to make correct decisions. This is a key concept in Lean and in short it means finding the source of error and fixing it; it can be work processes or anything that interferes with efficient work. It is crucial to locate and identify the problem in person in order to correctly deal with the issue. Relying on hear-say can lead to poor error descriptions leading to wrong solutions and costly mistakes. Genchi Genbutsu helps doing things right the first time; even if this means extra effort and slightly decreased work performance from the staff in the initial stages of Lean transformation.

Challenge has been defined to maintaining a long-term vision and meeting all challenges with the courage and creativity needed to realize that vision. This is prominent considering many of today's healthcare design projects with sub-par execution and final results: Healthcare facilities are being designed with a short-sighted vision of what the building costs are and when the facility is going to produce income. This may mean investing less initially to ensure budget margins stay positive throughout the entire project, which leads to an initial compromise and a visibly less-than-optimal outcome. Lean thinkers must be persistent from start to finish and willing to invest thoroughly in order to gain profits in the long run. Higher design costs and lower profits during the first few years of operating must not be seen as a threat, but rather as a long-term path towards higher rewards. Toyota has used this mindset with outstanding financial success, being the industry benchmark of automakers (Bergenwall *et al.* 2012).

Change management

When changing from an old way of hospital design towards a user-centric and participatory facility design, the users of the facility become the center of attention. Resistance to change among employees drastically reduces the success of any venture (Mana Gonçalves and Pereira da Silva Gonçalves 2012). Thus change management must be thoroughly understood and is one of the first challenges to conquer for the hospital management. A vast amount of literature exists on the difficulties of change management (Carignani 2000; de Oliveira and Serra Pinheiro 2009; McDeavitt *et al.* 2012). In order to improve work processes, new, right patterns of work must be developed, and the reasons behind the change understood. What can be accomplished, what will be the demands and costs, and what will be the short and long-term effects of the change? Change management is difficult – especially for managers (Plenert 2007). Most organizations tend towards bureaucracy, which suppresses change (Plenert 2007). People may be resistant towards change; especially so if the goals of the organization and the motivations behind the (Lean) transformation are not comprehended by the staff (Plenert 2007; Buesa 2009). People may become uncertain, insecure, anxious and even depressed due to fear of losing privacy, own personal territory and even jobs (Greenglass and Burke 2001; Buesa 2009). Employees may worry about constant disturbances and interruptions that may follow a more hectic work pace. Especially those accustomed to old work routines and patterns in the company are often against change. There may also be pessimistic people, those dissatisfied with the old work processes, but also skeptic about the change and future work processes. There is always resistance, but with conscious, determined effort to inform and enlighten employees and increase their knowledge about the changes by opening and maintaining clear channels of communication this opposition can be minimized (Mana Gonçalves and Pereira da Silva Gonçalves 2012). Motivating the personnel by stimulating their innovation and creativity is beneficial (Plenert 2007). Directness, openness, honesty, commitment to the success of others and willingness to acknowledge problems and errors have been seen as behavioral keys to successful change management (Howard 1990). Emphasizing diversity in the workforce, recognition of individuals, ethical management practices and worker empowerment have been seen as keys to success by the business visionary Levi Strauss (Howard 1990). On the other hand, it is good to remember that resistance can also be seen as a warning signal which draws attention to aspects of change that may be poorly thought and which need alternative action models or solutions (Waddell and Sohal 1998).

Lean workshops (also called Kaizen Blitz) have been found to be an efficient way of informing staff of the upcoming change in work processes. The workshops aim at teaching the staff the basic fundamentals of Lean. Unless the employees understand the main reasons behind the change, they will not likely buy into the idea, which may ultimately lead to failure in the Lean implementation project. Lean workshops have also instilled a sense of togetherness and increased social interaction and networking among the employees in previous Lean implementation projects (Liker and Meier 2006). Co-operation is a necessity for flowing Lean work processes. Finally, the employees must understand the concept of continuous improvement. It is not enough to just develop new processes; they must also be continuously improved to maintain a steady incline in work efficiency.

Educating the staff on their future work processes and goals helps establish belief in the new facility design and changed work processes. This relieves much of the resistance towards change. Instilling values of togetherness and teamwork into the staff builds trust and mutual understanding between the workers, which helps coordination of teamwork when the new facility is put into operation. The goal of user-centric and participatory design is not just delivering facilities to the users. Rather, it should also be to inform the staff how to work in the facility, how to take advantage of new innovations, and most importantly, how to develop as a user of the space within time. Optimization of work processes takes time, while requiring perseverance, longevity and ability to perform various adjustments at a short notice. The quest for improvement is never over and a Lean thinker must be ready to overcome new challenges each day.

Ergonomic healthcare design to promote well-being

It is common that work environments are designed without specific user and task requirements in mind, which leads to costly problems that need to be corrected afterwards (Bergman *et al.* 2013; Bäckstrand *et al.* 2013). Lean strives in making work processes and environments productive, safe and suitable for workers in order to avoid unnecessary rework and other forms of waste. The Toyota Production System even has a principle, “Right first time” (Liker 2003). Much alike, ergonomic design aims at doing things effectively and right the first time and sparing the extra effort, time and cost of fixing mistakes that were made in the design phase. Proactive ergonomic considerations in healthcare design can also help reduce physical demands of the staff (Mehta *et al.* 2011). Ergonomics has great potential to contribute to the design of work systems with people. Ergonomics takes a systems approach, is design driven and focuses on outcomes, i.e. performance and well-being (Dul *et al.* 2012). As mentioned earlier in this paper, several health outcomes are indeed linked with a hospital's physical environment. Therefore both Lean and ergonomics can be seen to complement one another.

Information on ergonomics is already needed in the healthcare facility design phase. Seeking to promote well-being in a hospital; what are the main ergonomic design factors to improve the physical space? Some research results among this field have pointed out to the importance of designing safe, comfortable, functional, error-free, easily controllable and private healthcare environments (Huisman *et al.* 2012). Others emphasize good indoor environment qualities such as acoustics, heating, ventilation and air-conditioning systems, the visual environment and furniture (Fransson *et al.* 2007; Frontczak and Wargocki 2011; Salonen *et al.* 2013). In addition, several studies concern user-centered design of workstations and work tools in healthcare (Nevala and Ketola 2012; Nevala *et al.* 2013; Sormunen and Nevala 2013). According to Ulrich, the work environment should be relaxing, rejuvenating, healing, and able to reduce stress, fatigue and enhance employees' creativity (Ulrich 1991; Ulrich *et al.* 2004). Good hospital design can also enhance hospital ergonomics by making the facility more affective and appealing to patients and other visitors (Ayas *et al.* 2008). For instance, making sure hospital users' have enough privacy, colors, child play-areas and green plants in hospital waiting areas has been shown to instill a feeling of calmness among them (Ayas *et al.* 2008).

Hignett and Lu (2009) have identified a need for ergonomic designers to produce evidence to support safer working practices relating to spatial requirements. It was suggested that by using a set of generic room sizes for future guidance, desperately needed standardization in healthcare ergonomic design might be achieved (Hignett and Lu 2009). This type of guidance has a good chance of yielding design creativity. Bromley (2012) has researched patient-centered design solutions to alter the image of a traditional hospital. Some interesting solutions include i.e. treating patient as more of a customer than a patient – in short, meaning improved patient service – and ensuring that patients and visitors rarely see technical devices and applications as well as excessive hospital equipment (Bromley 2012). In fact, the hospitals may even be transformed to look like a luxury yacht club, giving patients and visitors a "Disney"-like wow-feeling instead of the cold, sterile and mechanized life-enhancing facility that most of us think a hospital looks like (Bromley 2012).

Poorly designed work environments lead to injuries and difficulties to perform tasks (Bäckstrand *et al.* 2013). For instance, numerous manual patient handling tasks lead to high physical demands and have a statistically significant correlation with the development of low back disorders and pain (Mehta *et al.* 2011). Bergman et al. (2013) have developed a design support tool named "Workstation Design Navigator" to assist workstation designers in avoiding aforementioned problems. The Workstation Design Navigator is supposed to help create more efficient and ergonomic workstations and a more efficient design process. The Workstation Design Navigator should help the designer ask right questions, gather useful information, define requirements, assist in decision-making and support evaluation of goal fulfillment (Bergman *et al.* 2013). Thus Bäckstrand et al. (2013) recommend taking a proactive, problem preventing approach rather than a reactive, problem solving approach in ergonomic workstation design.

From an ergonomic perspective, work processes should always include a certain amount of variation. If not, the work may become in repetitive. Automatized and mechanical work processes may lead to repetitive work tasks, which may cause significant strains or injuries (Gilad 1995). This, in turn, is costly for the hospital management as it amounts to sick-leave days. Doctors' and nurses' daily routines include non-value-adding activities such as walking, changing equipment and preparing a patient for surgery. These activities create variation for the physicians work routines. If Lean is implemented, a significant portion of these non-value-adding activities are eliminated and as a result the physicians may ultimately have less variation in their work routines (Reijula and Tommelein 2012). If these new, Lean work processes are not designed with ergonomic considerations in mind, a risk of strain or injury may occur. However, if healthcare facilities and processes are designed ergonomically, implementation of Lean and one piece flow may in fact lead to an increase in variation among the physicians' daily tasks.

Simulations as a tool for user-centric design

Simulations are the most commonly used tools to introduce and teach basic concepts of Lean (Mehta and Monroe 2006). Various applications and programs for virtual modeling of hospitals have been developed (Märkle *et al.* 2005; Trebble *et al.* 2012). For instance, Peck and Kim (2010) have successfully used hospital simulations to test and validate the use of an axiomatic design approach to improve patient flow through emergency department fast tracks. In another example, Arnolds and Nickel (2013) have developed mathematical models to generate ward layouts according to the varying demand for different-sized bed rooms in multiple periods. Furthermore, Robinson et al. (2012) have utilized discrete-event simulation (DES) as a complementary methodology in implementation of Lean in healthcare. As a result, they have created an approach named "SimLean", a combination of DES and Lean that aims to address a demanding healthcare issue; stakeholder engagement with simulations.

The goal of these simulations is to create a three dimensional virtual environment that enables users to virtually move within the space and inspect certain parameters of the building and the spaces (i.e. functionality, feasibility, accessibility, ergonomics) before they are being constructed. The applications usually feature a realistic 1:1 aspect ratio and allow the users to freely move inside the building and present feedback and design solutions. Below, a picture of a lately developed, user-centric and evidence-based hospital simulation method named VALO is presented.

Figure 1

Figure 1 - In the Finnish VALO method, a realistic 3D-simulation of a hospital is projected on the wall. The user wears 3D-glasses and is able to explore the hospital environment by navigating inside the hospital using i.e. a mouse controller.

Simulations offer several advantages compared to traditional user-centric and participatory design methods. Simulations enable learning complex tasks and the study of phenomena that are not easily observable in real space (Park *et al.* 2009). Simulations can be performed from virtually anywhere in the world. They can be carried out quickly, anonymously, and users can work in either groups or single-handedly. This would allow experts and specialists from all over the world to co-operatively design user-centric healthcare facilities. For instance, a group of Lean, healthcare, accessibility and ergonomics specialists along with architects and designers from all over the world could simultaneously commence a virtual "Gemba walk": This means going to see the actual hospital processes and learn the work being performed, ask questions, share ideas and figure out ways to optimize the work environment and its processes before it the facility has been constructed. It would also enable future users of the space to distribute significant input on the design of the facility or even design their own work environments. Furthermore, simulations could provide a method to convey the users' needs to the architects and engineers: The users could wander virtually inside the hospital and make change suggestions by simply clicking a mouse button on a target they wish to alter. This information could be immediately accessed by architects and designers, who could use this information to improve the hospital design. The users would also get hands-on experience in the hospital's work processes before the facility has even been constructed. By incorporating hospital simulations into workshops (Kaizen Blitz), the users could be efficiently instructed on Lean work processes and tools.

Another aspect for creating virtual environments is creating dynamic simulation settings (Gorini *et al.* 2011; Villani *et al.* 2012). This means creating dynamic virtual models of hospital staff and patients. These models would move in real-time, and realistically perform hospital processes. This would enable calculation of the duration, speed and efficiency of hospital processes, as well as realistic evaluation of the facility design. Hospital professionals could move inside the virtual environment observing and evaluating these processes. This would hugely benefit both the hospital management and designers in making initial decisions for the upcoming healthcare facility, but also in finding and eliminating waste inside the work processes, when the facility is completed and running. The Lean toolbox includes an effective but a rather unorthodox method named "Hula-hoop" for eliminating waste and optimizing work processes. This means Lean employees have to observe their work from a circle, a hula-hoop drawn near their work spot and think of ways to improve this work process. Unfortunately, workers have experienced standing in a circle for a long time interval (between 0,5 and 4 hours) frustrating and some have even found it demeaning. Thus simulation of the workplace offers a very alluring alternative for easy and effortless observation of work processes.

The simulations can also enhance accessibility design. Some researchers have developed and used "age simulation" outfits to simulate movement as an elderly person in healthcare settings (Trust 2012). This means a heavy and usually uncomfortable outfit that makes movement slower, more clumsy and difficult. By using these outfits – and possibly also a walker or a wheelchair alongside – designers, accessibility and ergonomics specialists are able to simulate movement of a disabled person in the virtual space and develop accessible and ergonomic solutions. This way both accessibility and ergonomic factors could be taken into consideration early in the design phase.

Benefits and Challenges of Lean healthcare design

The goal of today's designers and architects is to create a space that enhances employees' flow of work as well as their perception of physical and psychological well-being (Reijula *et al.* 2011). User-centric and participatory approaches have exhibited vast potential in creating these spaces, but they are still lacking a **common framework** as well as tools and methods for their implementation. Lean philosophy could offer the necessary context for these two approaches and can be seen suitable for hospital design from several aspects.

Lean, user-centric and participatory design approaches are all **fundamentally very similar**. The primary objective for a Lean, participatory and user-centric approach is improvement of organizational effectiveness and employee well-being (Ruohomäki 2002). Lean, participatory and user-centric healthcare projects have all demonstrated multi-professional collaboration, participatory planning, learning, problem-solving, flexibility and teamwork (Ruohomäki 2002; Liker and Meier 2006). A significant factor for these results has been utilization of project teams, workshops (i.e. Kaizen Blitz) and conferences (Ruohomäki 2002). They have provided a great platform for socialization, togetherness and creating improvement ideas. A major challenge for Lean remains, whether it can fill the communication gaps and improve the issue of distrust between different user groups in multi-professional design and co-operation.

A need for **standardization** has been identified in hospital design (Hignett and Lu 2009). Some basic Lean, ergonomic, user-centric and participative principles may be used during the design process, but not in a structured way (Bäckstrand *et al.* 2013). This may lead to designers using their own processes parallel to the design process the company uses (Bäckstrand *et al.* 2013). Also, when Lean is discussed and/or implemented, "what" needs to be done may be discussed but "when" and "how" are often omitted (Bäckstrand *et al.* 2013). A major, well-acknowledged challenge for hospitals is to respond to the vastly varying demand of hospital capacity (Carey 1998). This creates costs due to hospitals having to maintain costly but rarely used standby capacity in order to be prepared to meet peak demand at all times (Gaynor and Anderson 1995; Lynk 1995). By standardizing work processes Lean enables a steady and predictable work process delivery flow, which leads to more efficient hospital space usage. Decreased hospital demand variability, in turn, decreases hospital capacity requirements, operating expenditures, and therefore also hospital costs, making operation of the hospital more cost-efficient (Baker 2004). Although there are some who are skeptical about Lean healthcare (Waring and Bishop 2010), it does offer an efficient and easily comprehendible methodology and tools for any institution willing to thoroughly invest in it.

A growing concern among healthcare is a need for elimination of medical errors and rapid improvement of patient safety in hospitals (Grout 2007). Misdiagnoses and treatment errors performed by hospital physicians are alarmingly common (Aronson 2008; Font Noguera *et al.* 2008). Making matters even worse, some of them are fatal (Dettmeyer *et al.* 2001; Tournel *et al.* 2006). In order to improve patient safety in hospitals, a new design approach is needed (Grout 2007; Grout and Toussaint 2010). Lean offers pre-emptive tools (e.g. "Jidoka" and "poka-yoke" (Liker and Meier 2006)) that are designed to **mistake-proof hospital processes** and enhance patient safety. By utilizing these tools already in the design phase, the hospital processes, facilities, furniture and space solutions can be effectively "mistake-proofed" from the get-go. This will likely be more efficient than applying them afterwards. By decreasing the number of medical errors, significant cost reductions can be achieved alongside improved patient safety (Grout and Toussaint 2010).

Hospitals are often complicated places, in which **navigation** is a frequent problem for patients, visitors, suppliers and the hospital staff (Huelat 2007; Mollerup 2009). In fact, healthcare design presents a complex challenge due to several factors, including the large amount of uncoordinated regulation and guidance (Hignett and Lu 2009). Due to poor architecture and hospital design patients and physicians have gotten lost in the complex hospital facilities or otherwise been confused with whom the next appointment will be with and where to proceed within the hospital (Mollerup 2009). Frankly, today's hospitals often provide either too much information at inappropriate places, confusing information, or insufficient amount of information for the user (Huelat 2007).

The problem is further emphasized on patients with sensory deficits such as impaired sight, hearing, mobility, increased anxiety and reduced mental capacities. Thus making a hospital accessible for everyone is a major aim (Lid 2013). Hospitals also have a need for increased **accessibility** since the amount of appliances and insufficient space too often results in an unnerving mess of appliances, cables and tubes (Garde and Van Der Voort 2008). The resulting blinking lights and alarm beeps only make the situation worse (Garde and Van Der Voort 2008). The technical and confusing appearance of this jumble complicates the work of nurses and doctors and may even strike fear into patients and visitors (Garde and Van Der Voort 2008).

A cornerstone for Lean is making the workplace as **visual** as possible. This does not only mean simple, clear, visible and audible navigation paths but also work processes that are clearly and visibly illustrated. Lean tools such as the 5S (standardizing and organizing the workplace) may help alleviate this problem. In addition, innovative, wireless solutions – which can be seen more and more in among today's hospital design – have become invaluable.

In order to accomplish a Lean hospital design, requirements of the work processes must be charted by using experts such as consultants, who play a key role. In Lean they are called "**Lean Champions**" and their goal is to create an understanding of what the goals of the organization will be and how these can be accomplished by using Lean methods. In Lean, but also in user-centric and participatory design approach, the role of these Champions or consultants is to function as an expert and/or a facilitator (Ruohomäki 2002).

Lean is beneficial when focusing on **long term change philosophy** for organizational development. The focus is not on the low-hanging fruit but on the continuous improvement ideal (Ruohomäki 2002). The hospital managers must thus be prepared to invest enough money and be prepared for negative budget balances for the first few years, until investment in Lean begins to pay dividends. Even though Lean requires patience and commitment to the Lean methodology, it has no "magic tricks" or instant "fix-it-all" solutions. The methods use can be comprehended using common sense and the main idea is to crop out everything that does not add value to the customer. Thus for designers, the design process becomes increasingly linear and goal-oriented.

Conclusions

In order to improve crucial factors such as efficiency, safety and well-being in modern healthcare buildings, new innovations are desperately sought after from healthcare designers. Lean has shown great promise in enhancing work process efficiency in healthcare implementation projects but has not yet been validated as a complementary healthcare facility design tool. Although Lean does not offer instant solutions, it may offer significant advantages and benefits in work facility, process and environment optimization compared to most traditional methods of healthcare facility design.

User-centric and participatory methods have shown to be promising amongst healthcare design. Lean has very similar principles than the two aforementioned ones. This significantly eases the work of user-centric and participatory designers as they attempt to design a Lean healthcare facility. Lean fundamentals can be easily comprehended and they do not exhibit radically differing methods compared to ones used before. User-centric healthcare design will benefit from Lean-ideology and it should thus be implemented. However, also Lean may benefit from the soft and "humane" participatory and user-centric design methods for work processes.

Lean provides a fundamentally solid ideology that may prove to be handy in helping leaders of the healthcare facility cope with change management: Directness, openness, honesty, commitment to the success of others and willingness to acknowledge problems and errors are key features of Lean that most likely will appeal to the staff in adopting new facilities and work processes. Lean does not seek instant results; the results of Lean implementation projects can usually be seen within a few years. Thus perseverance is required from those trying to establish a Lean hospital. A semi-committed Lean implementation project is almost always doomed to fail. However, with adequate effort and sustainability, Lean has shown to deliver outstanding results.

Simulations offer a fascinating tool for modern hospital design. They can be quickly and efficiently used to create and simulate a dynamic hospital environment and processes in order to implement Lean methods and tools beforehand into the upcoming hospital. This way costly design mistakes can be avoided. With modern technologies and high-bandwidth wireless data transfer rates, simulations can be effortlessly accessed from practically anywhere around the world in real-time.

Ergonomic and accessibility factors must be taken into consideration when designing new healthcare facilities. With relatively cheap, minor ergonomic and accessibility investments in the design phase, major results in user well-being and also work efficiency can be achieved. This issue is further emphasized with the aging population structure, especially in the developed countries. Reactive approach should thus be replaced with a proactive one; preventing problems as early as possible. Hence, when looking at the optimal place to start a Lean transformation, why not focus on the work environment design phase?

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