SMART HOSPITAL CONCEPTUALISATIONS BY EXPERTS IN TEAMS

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Abstract

Objective – The concept of Smart hospitals looks to future hospitals as infrastructures for effective and efficient clinical processes as well as infrastructures for supportive social interactions between patients and health professionals with the objective to design places that increase health service quality, productivity and patient's positive experience. This requires teams of experts that bring in knowledge from different disciplines like medicine and healthcare sciences, Information and Communication Technology, Social Sciences and Architecture.

Background - One of the biggest challenges in healthcare is the rising demand for services, while there is a decrease in workforce due to an aging society. Given the current budget constraints, healthcare systems are therefore under pressure to provide cost effectively high-quality services which requires fundamental reforms. When healthcare process data becomes more detailed and accurate, leveraging the concept of smart hospitals could contribute to better use of healthcare resources, including the hospital buildings.

Research question - What is a smart hospital? How can various disciplines contribute to smart hospitals? How will healthcare processes change by applying smart technologies?

Methodology – 5 interdisciplinary student groups of in total 28 students (12 medicine, 5 economy, 5 social sciences and 6 Technology) explored the concepts for future Smart Hospitals during a 4-week intensive course in Experts in Team. The projects included 3 phases: (1) conceptualisation; (2) writing an article based on literature research and; (3) integrating the findings in a proposal for a product.

Results - The 5 projects reflect the students' research on the application of smart technologies in future hospitals, ranging from: (1) the use of drones for acute healthcare: (2) application of artificial intelligence for improving diagnosis; (3) use of Building Information Models to optimise use of healthcare resources; (4) reducing hospital acquired infections by tracking flow of objects and people and; (5) home delivery of diagnostic services to reduce number of patients in the hospital.

Conclusion - The link between healthcare services and the physical environment has the potential to be re-invented through digitalisation and analytics of hospital process data leading to predictability and reduction of variation to support decision making. This requires cross-cutting solutions from healthcare management, logistic management and facility management in combination with ICT and social sciences.

Keywords: *smart hospital | Enterprise Building Information Model | Experts in Team| architecture research | education*

One of the biggest challenges in healthcare is the rising demand for services with meanwhile a decrease in workforce due to an aging society. As a consequence, healthcare systems face many challenges to produce the same quality of healthcare services in the future within a challenging labour market [1]. In Norway for example, the proportion of the population aged over 70 increases from 12% in 2018 to 21% by 2060 [2]. This increasing proportion of elderly patients will lead to an increased demand on hospital services. According to the Norwegian Ministry of Health and Care Services, spersons over the age of 70 use twice as many healthcare services than people in their 40's. Compered to today, estimations show that in Norway there is a need for an additional 25% full-time healthcare employments in 2035. Currently, approximately 11% of the working population in Norway works in the healthcare sector, based on the statistics, this percentage increases to more than 30% in 2060 [3].

Given the current budget constraints, health systems are under pressure to provide cost effectively high-quality healthcare which requires fundamental reforms in healthcare services [4]. New innovations and treatment options increase the expectations of the performance of hospital services [5]. At the same time, it is assumed that technological solutions can help to increase effectivity and efficiency of healthcare systems. When healthcare process data becomes

more detailed and accurate, leveraging the concept of smart hospitals could contribute to better use of healthcare resources, including the hospital environment.

Next-generation smart hospital technology has the potential to redefine healthcare services. Smart hospitals are conceptualized as infrastructures for effective and efficient clinical processes that support social interactions between patients and health professionals. The main objective of future smart hospitals is to design places that increase health service quality, productivity and patient's positive experience. Realization of this concept requires teams of experts that bring in knowledge from different disciplines including medicine and healthcare sciences, Information and Communication Technology, Social Sciences and Architecture. Increased knowledge on Smart Hospitals, applied to how hospital buildings support or impede optimal delivery of healthcare services, assumes a great societal impact on the quality of healthcare outcomes as it contributes to efficient working conditions.

Therefore, the research question of this paper is threefold:

- What is a smart hospital?
- How can various disciplines contribute to smart hospital design?
- How will healthcare processes change by applying smart systems?

One of the innovations that are tested in this context, is the use of Building Information Models (BIM) for operational purposes during the operational phase of hospital buildings Smart management and organisation of healthcare services can benefit from applying EBIM and ICT technology to better understand and manage patient-professional interactions, healthcare processes and the physical setting in which all this takes place. Now indoor track and trace of equipment becomes possible on a large scale due to IoT technologies; the time is ready for a breakthrough in the development and utilization of analytical, simulation and design tools for the efficient operation of hospitals, in which 'monitoring' healthcare services is vital for management and planning to filter out workflows that are at face value efficient but are too demanding on personnel.

Core to this approach is the development of knowledge about, and innovation of, an Enterprise Building Information Model (EBIM) for hospitals that connects patients' treatment processes to healthcare professionals' working processes related to the physical built environment [6]. EBIM uses a virtual representation of the built environment (BIM) for the organisation and optimisation of facility management and healthcare management processes. So far, many architectural offices and construction companies have used Building Information Models (BIM) for design and construction phases of the buildings' lifespan. EBIM on the other hand looks how these models can be adapted to optimise healthcare delivery for the purpose of economic and effective use of resources during the occupancy phase of the buildings' lifespan, i.e., the time that the hospital buildings are used for actual patient care. The use of EBIM makes it for example possible to measure the use of equipment in the hospital, how professionals currently are using the available spaces and how this can be improved in the future based on big-data analytics.

Experts in Team

During an intensive course of four weeks in January 2019, five interdisciplinary student groups of in total 28 students (12 medicine, 5 economy, 5 social sciences and 6 Technology) explored different technologically innovative concepts for future Smart Hospitals.

Experts in Teamwork (EiT) is a compulsory master's degree course for all students at the NTNU Norwegian University of Science and Technology in which students carry out a project and meanwhile develop interdisciplinary teamwork skills by reflecting on and learning from specific cooperative situations. Students work in teams with participants from diverse disciplines on relevant societal and scientific problem areas. In these interdisciplinary teams, the students get an opportunity to sharpen their skills on major real-life challenges facing society. Each member of the team contributes his or her own academic competence. The aim is that students will take advantage of the interdisciplinary skills in their team to find solutions for a specific project. The results achieved by the teams are often used to benefit internal and external partners (https://www.ntnu.edu/eit).

The projects included three steps: (1) conceptualisation; (2) writing an article based on literature research, and (3) integrating the findings in a proposal for a product.

Conceptualisation of smart hospitals was the first step for the students in this project. This started with one day of developing individually ideas and brainstorming in couples and groups. After this the teams were created, and the team were free to choose their own focus area within the given topic.

Conceptualisation has many different meanings, within this project it is used in the connotation of the act of creating something by thinking, i.e., ideas or actions intended to deal with a problem or situation by the formulation of plans and important details. As such, conceptualisation is used in this research to describe an elaborated concept coming from an abstract or general idea derived from specific instances. This is similar to the use of concepts in architectural design, which can be linked to the ideas about design thinking.

The second step in this project consisted of writing an article based on a literature search within the involved disciplines. In this step, the teams elaborated the initial concept.

In the third step of this project, the students were challenged to find a way of presenting their research in a proposal for a product that contributes to future smart hospital environments. The five projects reflect the students' research on the application of smart systems in future hospitals, ranging from: (1) Drones to support acute healthcare: (2) Artificial Intelligence to improve diagnosis; (3) Building Information Models to optimise use of healthcare resources; (4) Tracking flow of objects and people to reduce hospital acquired infections, and (5) home delivery of diagnostic services to reduce number of patients in the hospital.

Below, the five EiT projects on the conceptualisation of Smart Hospitals for the future are summarised following the three steps

Research results: Five conceptualisations of Smart Hospitals

1. eDrones for better patient flow in acute situations

A. Lilleeidet Røyland, I.A. Legran, N. Aanderaa, N. Molnes Hol, P.A. Nordlund, Ås. Heir

Concept – the application of drones as tool for improving patient flow in acute healthcare. As concrete example, this project focussed on the situations of opium overdoses and heart failure in Trondheim. The emergency drone (eDrone) reduces the time that patients can receive the antidote in case of an overdoses or a defibrillator in case of heart failure, and as such reducing complications.

Research – Besides literature and calculations of response time and spread around Trondheim, the project group interviewed personnel from the Emergency call centre. Although automated drones might be a future possibility, the use of eDrones would require drone-pilots at the emergency call centre to fly and navigate the drones. Especially in remote areas in Norway, drones might be a good addition to the ambulances, helicopters and boats that cover currently the area. A previous study shows the benefits of using drones for transporting defibrillators to people with heart failure, which could reduce reaction time and as such complications afterwards [7]. Given the condition of the patients, the emergency department regarded this a more realistic scenario compared to situations of opium overdoses.

Product – In this project, an interactive simulation model calculates response times by drone and ambulance for the Trondheim area for the two situations of overdoses and heart failure. Further research is recommended in the development of drone technology, patient safety, economic consequences and organisation. Crucial question should be how to get acute care the fastest way to the specific place. In addition, the drones could give people instructions how to handle until the ambulance personnel arrives. This requires cameras and communication possibilities, in addition to equipment such as for example ECG to give ambulances information ahead for arrival. The drones can also help with localisation of patients and routing for ambulances.

2. Artificial Intelligence in healthcare

E.C. Gudding, E. Hjort Mathiassen, C.H. Svedsen, J. Bjaarstad Nikolaisen, K. Erlendsdotter Urke, M. Galta

Concept – The application of Artificial Intelligence (AI) as support-tool for medical specialists to reduce over-diagnostics and prevent unnecessary diagnostic test due to better access to latest literature on evidence-based medicine. Research – This project reviews literature on Artificial Intelligence in the context of healthcare diagnostics. Alan Turing describes AI as the science and technology to create intelligent machines, especially intelligent data programs [8]. Simply explained, AI applies computers to do intelligent assignments that normally are done by humans, like planning, analysing, communication and interpretation of pictures. Deep learning based on Artificial neural networks is often used as AI technology in healthcare [9]. The biggest benefit of deep learning is the possibility of AI to understand and manipulate large amounts of data. The developments of AI in healthcare are progressing fast and current results show that, for example in the case of screening for diabetes retinopathy, AI performs better on determining whether or not a patient needs treatment based on an Iris-scan, compared to traditional screening by medical specialists. Another application area for AI is efficient use of time of healthcare professionals. Studies estimate that nurses lose 10% of their time due to inefficiencies in the physical infrastructure [10]. Based on analyses, efficiency of medical specialist could increase with 17% and nurses with 51% by using AI in their working processes [11].

Product – This EiT project proposes a support tool that gives medical specialists the possibility to orally discuss their diagnosis with an AI digital assistant, which can answer questions, connect information and knowledge from literature to the specific patient's health record and advice on possible diagnosis or treatments. The final decision is up to the medical specialist, however, based on better and more accurate information.

3. AI-BIM - optimisation of resource distribution between departments in a hospital

J.F. Korneliussen, R.X. Hagen, S. Knutsen, M.c. Løver Thu and M. Kristinesdatter Bolstad

Concept – Application of Artificial Intelligence in combination with Building Information Model (BIM) of the build environment to optimise the distribution of resources within the hospital. Hospitals face large challenges related to allocation of physical equipment between departments, which results in lack of required equipment, or opposite, place consuming congestion of unused resources.

Research – Connecting smart sensor technology, AI, informatics and telecommunication to BIM builds the platform to analyse and estimate the use of resources within a hospital building. Within a hospital, there is a lot of data available, however the big challenge is to change this data into information, information into knowledge and knowledge into wisdom [12]. St Olav Hospital applies an Enterprise Building Information Model (EBIM), which is an extension of existing BIM models with a focus on a digital integration of building related information and healthcare processes during the entire lifespan of the building. The EBIM model of St Olav Hospital includes buildings and transportable equipment. The system is based on Wi-Fi and communicates by sensors attached to the equipment.

Implementation of BIM is time-consuming and costly. However, the visualisations of information connected to the model server makes the development of integrated individual applications possible, which are now often supported by separate systems. Implementation of EBIM makes it possible to analyse where and when certain equipment is being used in the hospital. It can contribute to changing the architecture of patients' rooms or support management in decisions on infrastructural and process changes based on real-time data on hospital performance [13]. There is a broad consensus that the technological development of sensors, informatics and communication will make it possible to collect large amount of medical and context related data. Both timeliness as accuracy will increase. Observations of medical personnel shows that nurses use up to 30% of their time for searching for necessary equipment [14]. Tucker [10] observed different hospitals and concluded that it would be possible to deliver more patient oriented healthcare with less personnel if processes were organised differently. She refers to the automobile sector, where they estimate the amount of equipment that is needed each day in order to reduce time for searching for equipment. Product – This EiT project proposes a hospital AI-BIM and presents this concept by a case-study of one patient, which shows how AI in combination with BIM and patient records could predict the need for resources for one specific patient, based on patient journeys of previous patients with similar diagnosis, age and gender. Another application possibility is to use the same technology for allocation of resources on regional or national level. One of the main objectives of this proposal is to increase bed-side time of nurses, by reducing the time for searching after equipment. This could result in more attention for patients, shorter stay and an increase of the hospital's capacity to treat patients. Developments within AI would make it possible to better predict the needed resources per patient, based on previous similar cases. AI could define more efficient procedures based on big data analytics of existing processes and experiences.

4. HospiPal to reduce nosocomial infections in smart hospitals

E. Hernes Berre, N. Buer Haugen, T.C. Ottersen, S. Vatn, M. Høiberg ødegaard

Concept – Reduction of nosocomial (hospital acquired) infections by the use of a Building Information Model connected to a track-and-trace system for portable equipment and persons in the hospital.

Research – This research focusses on reduction of infections in a hospital in a post-antibiotic era by analysing flow of equipment in the hospital. It looks to different sources of infection, like equipment transported through the hospital, hand hygiene and infection control in case of an outbreak. The project shows how smart-BIM could contribute to the safety of patients a reduction of hospital infections. Already in 1945, Alexander Flemming warned about the potential risks related to over-use of antibiotics. Since 2013, we live in the post-antibiotic era, which implies that the antibiotics we have relied upon for decades, are not effective anymore [15]. Knowledge on flows of equipment and people within a building can contribute to improve procedures and compliance to the procedures of hand hygiene and cleaning of rooms and equipment, which could reduce the risk of antibiotic resistance [16]. Research shows that patients in a room that was used previously by infected patients, have 40% more risk of infections [17].

Product – This EiT project proposes a HospiPal system that includes a Building Information Model with a 3D virtual representation of the buildings, track and trace sensor technology, tagged equipment, a program that analyses the data, and interfaces that communicate the information to the users. The proposed application areas are a warning system for hand hygiene to help healthcare professional reminding to wash their hands; improving cleaning routines for portable medical equipment related to their actual use in infected areas, and isolating infections by mapping all rooms, equipment and persons that had been in contact with an infected patient.

HospiPal is presented by means of a board game which is similar to a combination of Monopoly and Trivial Pursuit, with questions that makes the players aware of the issues related to nosocomial infections and how the application of HospiPal could contribute to reducing risks.

5. EIR – an Automated Healthcare Mobile Diagnostic Unit

K. Bekkeheien, I. Aschehoug, I. Heimdal, S. Haugen, T. Torvik and L. Fønhus

Concept – Using existing technology on AI, automated cars and wearables as start point, Eir introduces a concept that transports simple hospital functions to the homes of patients. Supported by continuous monitoring of personal health data AI, patients receive diagnostic tests and treatment at home.

Research – This project gives an overview of existing technologies and integrates these into a vision of what becomes possible if these technologies were combined. In their description of smart hospitals, Frost and Sullivan [18] predict that in the future patients do not go to the hospital anymore, healthcare services will be brought close to the patients home and working environment, performed on a distance by the service provider. Research shows that already 46% of today's treatments in hospitals can be done at home [19]. Treatment at home has many positive effects, like increased patient satisfaction, reduced risk for infections, reducing costs and more effective use of existing capacity in the hospital buildings [19]. Within healthcare, new technologies become available on large scale that makes continuous monitoring of basic functions of the body possible, like for example blood pressure, pulse, infection- and inflammation parameters [20]. Implementation of AI makes it possible to automatically analyse these body functions data, more effective and precise then health professionals [21].

Product – This EiT project combines continuous monitoring of body functions with AI analytics to support automated and mobile hospital services. The mobile units can include different functions and services that can be done without healthcare personnel. Patients will be guided through their diagnostic process or treatment by voices, virtual persons on screens or holograms. Based on the requirements, different units can be created for different diagnostics and treatments. A basic supply of medicine will be available as well or could be delivered afterwards.

Reflections from the Experts in Teams

People are a social species with complex desires, among which personal human contact is one of the most important. Patients within a health system are often confronted with insecurity and worries about their health situation. One of the questions to keep in mind in the development of smart hospitals is how the use of new technologies have a positive impact on the interaction between patients and professionals, with mitigating the negative impact that these new technologies could have as well.

Collecting bigdata on healthcare processes within a hospital could have implications for personal health data, as even anonymised data could be sometimes retraced to individuals. How to deal with patient-data security is therefore a very important aspect of future smart technologies, which requires the development and utilisation of high-level data-security and encryption systems for a system in which secure storage and exchange of personal data is guaranteed and in which patients determine themselves the purposes for which their personal data can be used.

Each implementation of new concepts, innovations and organisational changes has to deal with the tendency that people resist and are sceptical towards alterations of their work processes. Therefore, it is important that both patients and healthcare professionals understand how the new developments improve both on individual level, as the quality of patient care on the level of the healthcare system.

Whether or not smart hospital technologies can be realised in the future, is also a economic question both on the level of individual patients and society. In addition, the pace of development of new technologies is also something to take into account. For example, it is difficult to predict when Artificial Intelligence will be at the level of real implementation for performing planning and other intelligent tasks. However, some researchers predict that this will be possible around 2050 [22].

Implementing new systems and technologies means that employees need to change their working day and introduce new routines. In complex organisation like hospitals, several reforms take place in parallel, and this is often burden on the employees. To avoid this, it is important to find the evidence of the positive consequences that smart technologies will have on individual level in an easy-to-understand and educational manner.

The notion that the introduction of smart technologies often requires large initial investments is obvious at the purely technological level, but also applies to larger expenses on the staffing, as highly educated employees at hospitals need time to learn to work with new technologies, instead of spending their time on what they specialized in. However, when there is evidence that implementation of smart technologies in the long run proves to be beneficial, this could motivate hospitals and releases additional funds for the initial phases.

In addition, systems using AI work initially less optimally than it will eventually. This is due to AI's nature, namely that it takes time before the system has acquired sufficient information and that it only can learns while it "works".

Another contemplation is that optimisation of efficiency and effectiveness in healthcare has two sides. One side is that increased efficiency could result in lower needs, and therefore less money could be allocated to the individual health organisations. This might have positive financial outcomes at a national level but will not benefit the hospital and the patient. As, for example, nurses do not need thirty percent of their working days to search for equipment, this does not necessarily mean that all this time will be spent on extra bed-side time. It may be that time is spent on other work tasks, or that a health service under financial pressure plans less nurses to patients. Therefore, it is important that when implementing smart technologies, it is important to focus on the importance of increased direct patient care.

Conclusions

Besides the exploration of relevant literature and technological developments, the combination of these Experts in Team projects on Smart Hospitals for the future show a diversity of conceptual application possibilities of smart technologies in future hospitals. The link between healthcare services and the physical environment has the potential to be re-invented through digitalisation and analytics of hospital process data to support hospital design and hospital management optimization.

The strength of the conceptualisations is their interdisciplinary character which directly results from the course setup which first and fare most stimulates the use of knowledge form different disciplines into one integrated project. All proposed concept and products come from existing technologies that are combined within a hospital setting. This requires however cross-cutting solutions from healthcare management, logistic and facility management in combination with ICT, architecture, and social sciences.

The combination of concepts sketches a broad spectrum of hospital services from acute treatment, diagnostics, effective and efficient use of resources, increasing safety by reducing infections in a post-antibiotic era and availability treatment and diagnostics at home. The use of AI to support better, safer, effective, efficient and more patient oriented healthcare seems to be a common factor in all projects. In connection to AI, the use of big-data and patient information to predict outcomes and resources seems to be an important aspect. In connection to the build environment, also the use of Building Information Models and the possibility of smart sensors to register events within a hospital building as source of information about equipment and processes can be perceived as new technology to make future hospitals smarter.

This study is first and fare most an exploration of future smart hospital concepts, which is also directly its most important limitation. The interdisciplinary approach resulted in many different perspectives and contemplations, which are, however, due to the short period of only four weeks not all fully developed. Nevertheless, the conceptualisation of smart hospitals resulted in different perspectives and ideas for application possibilities, which can be basis for further research and development. The conceptualisation of these ideas was an important step in understanding the broadness of smart hospitals and the variation of application possibilities. Although the teams had different ideas, some shared aspects can be recognised, such as the use of AI, the application of sensor technologies and the way this can optimise the effective and efficient use of healthcare resources.

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