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New Karolinska Hospital

Leveraging lifecycle building information modelling (BIM) to optimize the construction, handover, and operations and maintenance of the largest-ever public-private partnership for a hospital

The challenge

The hospital public-private partnership faces difficult circumstances, including a tight timeline, intense public scrutiny and the ongoing operations of the old hospital, and needs to be flexible enough to accommodate future trends in healthcare.

The New Karolinska Solna (NKS) Hospital project is considered the world's largest public-private partnerships, involving an overall investment of $3.0 billion (including $1.6 billion for construction). Construction started in 2010 and is expected to be completed as well as to 2017. When completed, the hospital – which will cover 320,000 square metres – will have over 12,000 rooms, 35 operating theatres and 17 magnetic resonance imaging (MRI) units.

In addition to the core hospital building, the project includes a parking garage, research building, technology building (to handle the energy supply and deliveries for the hospital), cancer treatment (radiation building), as well as new roads connecting the buildings and an entrance to a new subway station. Located in the north of Stockholm, Sweden, the integrated hospital and research complex will contribute crucially to the development of the new Hagastaden neighbourhood.

To complicate matters, construction has to take place without disrupting the normal operations of the old Karolinska University Hospital and the research-focused Karolinska Institute, which are located nearby. Meeting the relevant noise, dust and traffic level requirements was no easy task.

Moreover, given the significant public investment and the institution's global reputation, the project is under close scrutiny from the media and the general public, and is highly political. As a result, all parties involved are under considerable pressure to complete the project on time and on budget.

The construction of the NKS hospital should be viewed in the wider healthcare context. Several trends are relevant here. Populations in urban areas – Stockholm is no exception – and an ageing population are raising and changing the demand for hospital services; older patients account for about half of hospital-bed occupation globally. Advances in medical equipment and healthcare delivery are producing a shift towards outpatient care. The shortage and discontent of healthcare staff obliges hospitals to improve working conditions. Over the lifetime of the new hospital, these trends will play out further.

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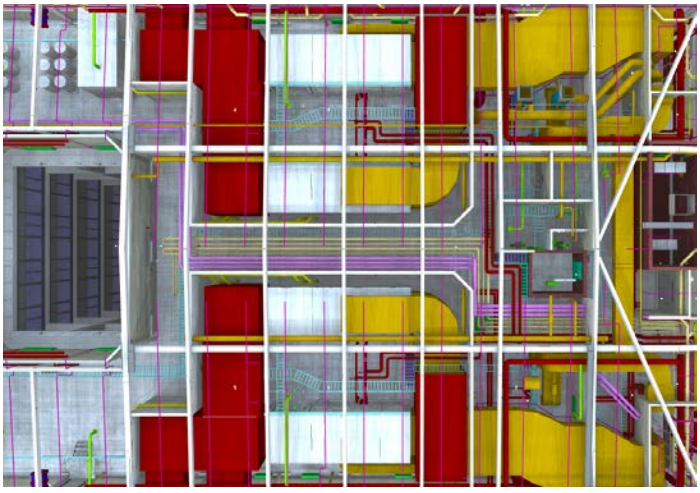
The idea

Leverage building information modelling across the entire lifecycle to enhance design, construction, operations and maintenance, and patient care, and reduce the environmental impact by means of methodical planning and the optimal use of prefabrication and green technologies.

NKS aims to set new standards in patient care, integration of healthcare and research, adaptability to future needs and sustainability. The planners benchmarked leading hospitals to identify optimal care procedures, workflows and working conditions. The project incorporates many innovations in the construction process and in operations and maintenance (O&M), and now itself serves as the benchmark for large and complex healthcare projects.

NKS is being delivered as a turnkey project under a public-private partnership scheme in which the Stockholm City Council signed an agreement with the dedicated project company Swedish Hospital Partners – a joint venture of Skanska Infrastructure Development and the UK pension fund Innisfree – for designing and building the hospital and operating it until 2040 (possibly even extending the contract until 2055). Swedish Hospital Partners in turn contracted Skanska Healthcare for the building contract and Coor Service Management for the facility management. The actual patient care – and everything directly related to it, such as procuring medical equipment – is the responsibility of the Stockholm City Council.

The contract mandated the use of building information modelling (BIM). Mindful of the project's vast size, complexity and tight deadline, Skanska adopted an advanced BIM model across the entire lifecycle, creating a single data platform on which designers, contractors and eventually facility managers could collaborate (BIM Level 2). Starting with entering the design specifications and performance requirements, the architects and designers create 3D designs; every object is then digitally stored in the model, with its key attributes and exact location. Once completed, the object list will contain about one million items.



The list and the model can be accessed from anywhere via a Sharepoint System, enabling construction workers, project managers, auditors, project owner or O&M staff to access all information on their smartphones or tablets – to inspect building plans, for instance, or check on the progress of a specific construction task via BIM 360 Field software also plays a key role in preparing handover, by providing for "digital snagging" – identifying potential issues and communicating them in the form of a virtual punch list by by referencing the BIM model (i.e. linking issues and location) – and allowing digital quality control and virtual handovers. The BIM model is also linked to an environmental library, with all relevant information about all materials used in the building; it expedited environmental certification, and it can track materials for future replacement.

The comprehensive BIM model, populated during design and construction, will then enhance O&M, making that phase as efficient as well as operator and patient-friendly as possible. By providing quick access to all relevant data about objects – installation date, exact location, actual usage – the BIM model will enable predictive maintenance. By providing access to repair manuals as well as identifying spare parts and indicating remedial procedures, it enables faster and more effective responses to typical failures. And by providing a digital 3D representation of the building, it enables better planning and quality control of daily operations, e.g. cleaning.

The project includes 29 automated guided vehicles (widely used in the automotive industry), which will autonomously conduct logistics within the hospital and between the different buildings – for instance, delivering medical supplies or transporting laundry. To minimize on-site traffic, the vehicles will use separate underground tunnels wherever possible. There is a central drop-off point for deliveries. Staff will be informed of deliveries via their mobile devices. For this purpose, the BIM model's object list serves as an address book.

The Stockholm County Council takes environmental protection seriously and has made sustainability a priority for this project, both in construction and O&M. The site is classified as a Skanska Green Site with sustainable solutions at all stages, and the construction process was carefully planned to minimize the environmental impact: an on-site concrete plant pre-empted 20,000 truck trips during the first three years, and an on-site crushing plant reduced off-site transport activity as well as landfill quantities. Where required, hybrid and lower-emission trucks were used, and deliveries are scheduled to minimize interference with local traffic patterns. Construction waste is systematically analysed with the aim to reduce it to zero (in 2010, only 5% went to landfill). The work cabins are "environmental cabins", minimizing energy consumption through heat pumps, and there is a recycling facility on-site.

Once completed, NKS will be climate-neutral, thanks to its energy-efficient insulation, a geothermal energy plant (with more than 160 bore holes, many of them 230 metres deep), the collection of food waste for biogas, and energy-saving lifts. Inside the building, emissions from chemical substances and compounds will be reduced, and the entire building will be moisture-proofed to create a healthy environment for staff, patients and visitors. All waste will be separated and transported to an on-site recycling facility through an underground piping system.

To avoid disrupting normal operations at the current Karolinska University Hospital and the Karolinska Institute, and to speed up the construction process and exploit scale effects, the planners strove to identify building components that were standard and if possible prefabricated. The new hospital's over 12,000 rooms consist of about 650 different standardized room types. Or consider the 740 bathrooms pods, completely prefabricated and pre-fitted by a supplier in northern Sweden, which were transported in sealed containers to the local storage facility and delivered on site "just in time", and lifted and pushed into position; all that remained was for the workers to connect the pre-fitted cables and wiring to the rest of the building (bathroom modules of this kind are standard practice in

hotel construction, but had never before been used in hospital construction). Prefabrication has been applied to other components too, and helps to reduce manual labour and avoid the need for scaffolding; prefabricated mechanical and electric modules, for example, are simply lifted to ceiling level and welded together in situ, and prefabricated structural concrete elements and façade modules are simply lowered into place by cranes.

The impact

The project has shown how the BIM model and prefabrication can boost the speed and quality of construction and commissioning, and has taken a certified leading role in sustainability.

The use of BIM was contractually mandated, and the business case for it has not yet been formally proven here, but all project stakeholders agree that it has been indispensable to the success of such a complex project. Without it, the documentation and the building work could never have reached the same quality. Evaluating the business case for BIM can be compared to evaluating the business case of using mobile phone: the benefits are numerous, diverse and obvious, yet hard to quantify exactly. Both costs and benefits are distributed among participants and increase with the number of users (network effects).

On a project involving over 12,000 rooms and a tight schedule, the snagging and smooth handover would be almost impossible, were it not for a cloud-based and mobile-accessible BIM solution. Thanks to BIM 360 Field, project managers and sub-contractors can communicate and collaborate easily and productively, trade contractors can digitally report completed works, and project managers can pinpoint potential issues before handover. Skanska (as main contractor) and the specialized trade contractors can access up-to-date information and jointly resolve issues very fast, coordination is much smoother and speedier, and there are far fewer costly errors and omissions, re-works and delays in commissioning. In addition, auditors can access from anywhere and at any time a detailed progress report of each task and object, so handover of nearly finished rooms and floors (95% completed) can proceed accurately and efficiently. Note that the BIM model confers its complete range of benefits, and repays the investment fully, only over the full lifecycle of the building: it reduces O&M costs, boosts the quality of healthcare provision through preventive maintenance and effective repairs, and reduces operations costs by enabling the use of automated guided vehicles.

The prefabrication strategy too has had a strong positive impact on construction: it has reduced costs, facilitated logistics, accelerated installation, improved the quality of the building, and enhanced the health and safety of the workforce. The prefabricated bathroom modules illustrate these advantages. Traditionally, finishing a bathroom requires a number of different trade inputs and components – floor slabs, tiles, handrails, towel hooks, washbasins and shower units – to be applied in a very small room, resulting very frequently in delays and quality issues.

In regard to sustainability, Skanska is not only meeting the terms of Sweden's Green Building Council certification (Miljöbyggnad) as required by the Stockholm City Council, but actually going beyond them, in line with its ambition of becoming the world's greenest construction company. With parts of the main hospital building already completed, NKS has achieved the accolade not only of a preliminary Miljöbyggnad Gold rating, but also of a LEED Gold rating (for the first part of the hospital, pending verification after completion of the entire building) – one of the first hospital buildings in Europe to do so.

In its normal operations, the building will be climate-neutral with a heat-recovery system and its geothermal plant (meeting 65% of the hospital's heating and cooling demand), as well as green roofs that will provide insulation and retain surface water. The hospital's energy consumption will be 110 kWh/m2 requiring 40% less energy than a comparable building constructed according to current building norms. The purchased energy will come from renewable energy sources. Note that the Miljöbyggnad certification is based not just on environmental protection, but also on a healthy indoor environment – admitting sufficient daylight, for instance, and cutting hazardous pollutants. Guided by the Swedish Schedule 19 certificate and Byggvarubedömningen (as part of the contract requirements – a building materials assessment – the project team closely collaborated with suppliers to eliminate controversial materials. For example, they managed to secure PVC-free flooring, and placing a large order stimulated the production of different colours.

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The barriers to innovation, and the solutions

When a hugely complex and demanding project relies heavily on technological innovations, the successful implementation of those innovations depends in turn on effective knowledge exchange between the key stakeholders, early and pragmatic collaboration between project partners, and skills-building among suppliers.

The capital project is of very long duration – from the tender process in 2008 and financial closing in 2010, through to completion of construction in 2017 (and O&M until 2040) – so the project team has had to be amenable and flexible, particularly in regard to integrating new technologies. Consider again the BIM solution outlined above. Thanks to technical advances and declining costs, staff can now readily use mobile devices to access the BIM model on-site. The BIM 360 Field solution was actually introduced at NKS only in mid-2015, shortly before the handover of the first part of the main hospital building. The technology now enables project managers to inspect and sign off 250 rooms per week – a remarkable pace that was almost unimaginable eight years ago.

The driving force behind the introduction of the software was Clive Howard, Skanska Completion Manager, who had gained experience of cloud-based mobile snagging solutions on previous projects, and realized that the technology would help enormously to prepare and handle the commissioning of such a complex project. This transfer of personal experience from earlier projects has emerged as a key theme of the NKS project, and has been deliberately orchestrated by Skanska.

The building contract was awarded to Skanska Healthcare – a joint venture between Skanska Sweden and Skanska UK, which would exploit their experience of UK hospital projects. Ulf Norehn was selected as managing director for the project company Swedish Hospital Partners, specifically because of his prior experience in delivering public-private partnerships for hospital projects in the UK. More broadly, Skanska staff members from several countries (notably the UK, the US, Norway, Poland) have brought to the NKS project their experience of working on BIM projects elsewhere, and will no doubt effect a reversed knowledge transfer in due course, contributing their NKS experience to other Skanska projects in future.

Within the NKS project, systematic learning takes place, by transferring personnel from phase to phase. In particular, lessons derived from work on the first part of the main hospital building (Phase 4) are now being applied in Phase 5 and are facilitating all the remaining building work – even before Phase 4 itself is actually completed. A simple example: Fire safety consultants are now being engaged in the very first general audits in order to identify potential issues early on (eliminating a major source of delays in the previous phases).

One key challenge for the roll-out of BIM in the project (and in the industry as a whole) is the diversity of the subcontractor landscape. Many smaller (trade) contractors and suppliers lack the skill-sets and financial resources to invest in basic BIM, let alone to handle competing BIM systems with their rival standards and data formats. To get sub-contractors and suppliers to adopt BIM, therefore, Skanska had to put much effort into persuading them of its benefits and providing training courses in its usage. In the future, BIM competence will be a criterion for selection of sub-contractors and suppliers, and will be included explicitly in their contracts.

Much effort has also gone into encouraging open communication and increasing transparency about risks and errors – not to assign blame, but to identify issues and to jointly address them before they become critical and more costly. Sub-contractors and suppliers have duly become more open and collaborative, and can appreciate the benefits; for instance, by adding photos of the finished works and digitally signing off, they can cite later on-site damage (a common problem) as the source of a problem.

A major challenge in the construction industry as a whole is to reduce the lifecycle costs of assets. Normally, a contractor's responsibility ends when the construction phase ends. At NKS, the long-term public-private partnership contract – valid until 2040 – intensified the need for a longer-term perspective. One helpful step was to secure the early and active involvement of the facility manager, Coor Service Management. Facility managers are often presented with a fait accompli, whereas Coor was able to contribute operator expertise far sooner, during the project's design phase. And the company will be able to commence the O&M phase with the backing of a comprehensive BIM model – something unprecedented in the hospital sector.

One example of longer-term cost-reduction through the effective collaboration is the change in the IT landscape. The original plan specified different physical servers (one for each building control system), but the revised plan specifies a common platform with standardized virtual servers complemented by a common storage and backup solution. This consolidation will reduce IT costs during operations, but it was not budgeted for, so Coor Service Management and Skanska agreed to cover the additional costs jointly.

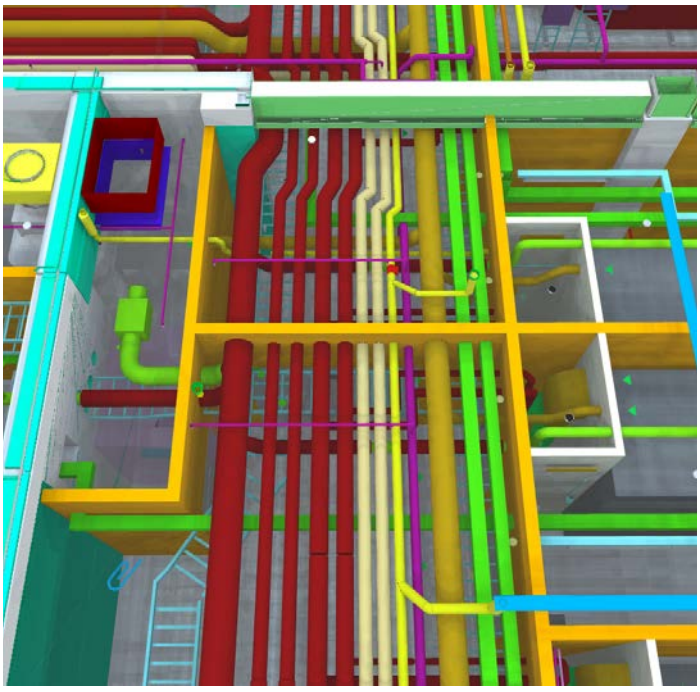
A recurring challenge for all BIM projects is the lack of standardized data formats and systems. At NKS, about 400 design consultants were involved, all

working on their own preferred system. The input from these disparate systems had to be integrated into one model. The BIM model, with its single data standard, enabled a smooth transition from the construction phase to the O&M phase, but if the original design consultants are required to adjust design aspects in future, they might struggle with the different format.

The recent transformative changes in the engineering and construction sector is even outpaced by the rapid changes affecting the healthcare sector, particularly the ongoing changes in healthcare equipment, processes and client demand. Various corresponding challenges have arisen for the NKS project; for example, the Stockholm City Council has several times required the relocation of heavy medical equipment. In anticipation of such shifts, the building was designed for flexibility, and can readily accommodate changes in usage. Some examples: vertical load-bearing columns are placed at both ends of the building, so the room layout can be adjusted fairly easily; parts of the façade can be removed fairly easily if large equipment has to be moved into or out of the building; slabs are sufficiently reinforced throughout the building in case heavy medical machinery needs repositioning at short notice (a MRI scanner can weigh more than 10 tonnes); and the piping and wiring have a built-in overcapacity of 20% to allow for extra demand or innovative uses in the future.

Lessons learned

- **Involve the facility manager or operator early on in the process in order to improve lifecycle performance**
  Selecting and promptly engaging the facility manager Coor Service Management has helped the planners to take a holistic, full-lifecycle perspective of the project, and to ease the transition between phases, especially between construction and O&M.
- **Rotate personnel across countries, projects and project phases to enhance knowledge transfer**
  Innovation works best when those leading and implementing it keep increasing their own expertise and sharing it with others. By seconding staff that have BIM experience on similar projects elsewhere, the NKS project has fostered knowledge exchange and optimized its own implementation of the new technologies.
- **Deploy BIM across the project's entire lifecycle and its stakeholders to maximize the benefits**
  Every BIM model requires upfront investment, and the benefits are spread over the lifecycle of the project. BIM can speed up and enhance the handover and commissioning. It is important that contractors and facility managers should co-invest in the model, and planners need to find the right funding mechanism for that purpose.
- **Educate suppliers and sub-contractors on the benefits of BIM, and provide training courses to enable them to use it effectively**
  The project has shown how powerful a tool such as BIM can be, especially when it is also used by sub-contractors and suppliers. It is worth putting considerable effort into persuading them of the benefits of the BIM model, discussing their concerns openly, and helping them with relevant financing and training if necessary.



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