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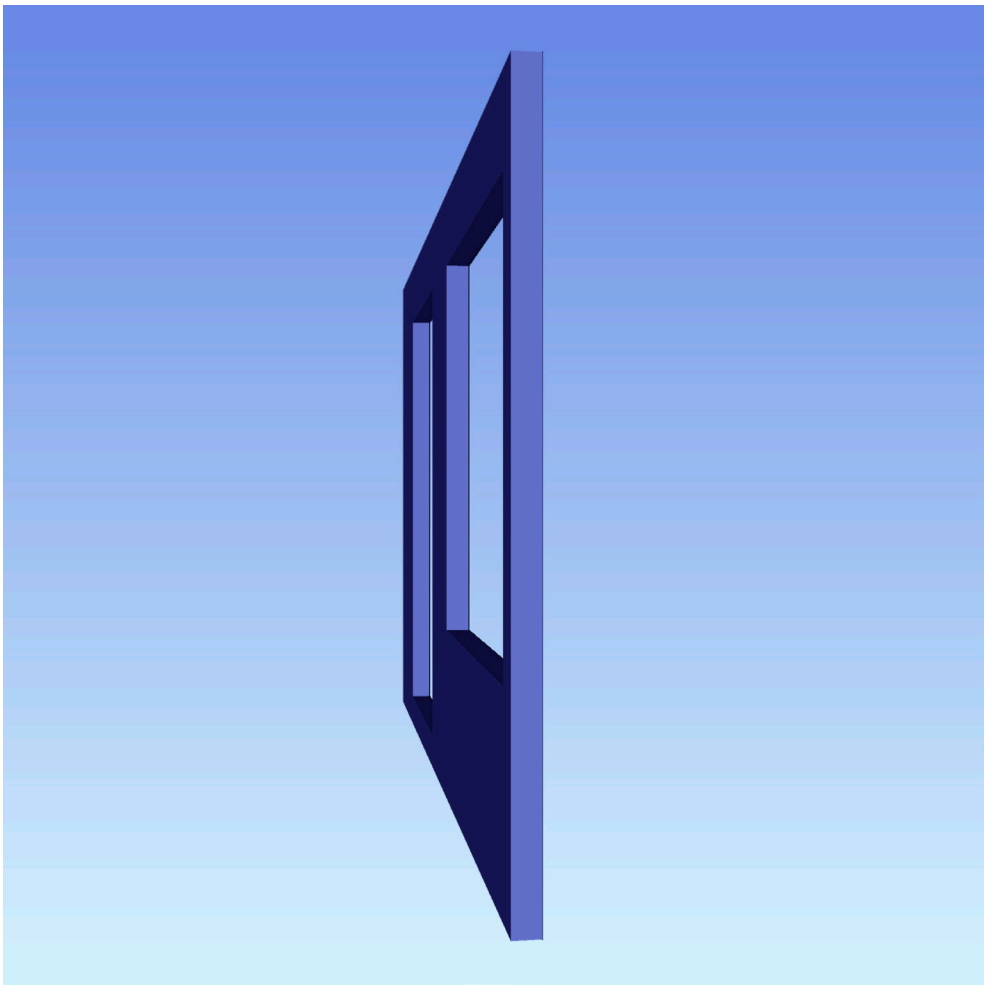

BUILD 4.0:

Practical applictions of

BUILDING SHIPS ON GROUND

Design end engineering using tools from shipyards

Today's construction processes are governed by a multitude of documents and documents. These are developed by a fragmented design organization. Data models are used, but are not complete and only complementary. This differs from other manufacturing industries where they work closely together and where the data models control, in agreements, production and machines. In this project we have tested the use of tools and working methods from a manufacturing industry, shipbuilding, on two sharp housing projects.
The results are striking.

Bygg 4.0

This project is a collaboration between a total of 13 organizations in 4 countries. It has been led by Lars Albinsson, Maestro Design & Mangement. The project has been financed by VINNOVA/Smart Built Environment (U6-2018-7), The Swedish Housing Agency (decision 6586/2018) together with Maestro. Contributions in the form of work have been made by SSI, Ndar, Vera Navis, Hyresbostäder, Sizes and Veidekke.
The work has built on previous projects within Bygg 4.0, which were financed by Smart Built Environment and VINNOVA.

The complexity of the project also says something about how challenging it is to introduce entirely new ways of working within the construction industry. The construction projects span many organizational boundaries and this is often an obstacle to renewal, which is mentioned in the report.

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1. Summary

Construction 4.0 Planning is a new way of designing and planning the construction of buildings. Methods and tools have partly been taken from shipbuilding. It benefits from modern digital tools, is iterative and creates a more effective collaboration between professionals. In this project, a shipbuilding platform and knowledge from ship designers have been applied in two sharp housing projects.

The Results show:

- It works very well to design housing in a ship platform and big profits can be made in terms of environment, time, costs and the amount of errors
- Residential house design can for example go from 6 months to 4 weeks, purchases from days to minutes and with fewer errors
- Machines that cut can be controlled directly from the model fel

But also:

- Traditional organization of planning and contracting is an obstacle. There are even reason to question today's contracting model as a whole
- The lack of central ownership of the process, the fact that investments to be counted in individual projects and that a large proportion of decisions and production are made on site, leads to unacceptable environmental consequences and costs without corresponding gains in quality
- The key is the transition from building documents to computerized production model

2. Background

In the Build 4.0 project, a new type of design has been developed, which benefits from digitalisation, to lower costs, increase quality and enable more innovative construction. As in other digital waves, new ways of working and changing roles, which are made possible by digital tools, are the key to success. It is precisely this collaboration between new ways of working and new tools that leads to radical improvement or "disruption". The new tools can also support and automate design, planning and control as well as automatic manufacturing with robots and 3D printers, for example.

Construction 4.0 achieves great effect by attacking the waste of working time and materials that today are the result of an overly fragmented and craftsmanlike organization of the construction process, where an excessive amount of planning takes place, and decisions are made during ongoing production[1][2].

This is not just a cost issue:

- Within the EU, 20-25% of all road transport is construction material[3]
- Buildings in Sweden attract as much energy as 10,000 villas[4]
- 25-30% of all waste in the EU comes from construction[5]

This resource consumption can be significantly reduced with better putting build.
Construction 4.0 is in line with the development called Industry 4.0, where the fourth refers to the fourth of the major development steps:

- 1-Mechanization and steam power
- 2-Running conveyor and electricity
- 3-Computers and automation
- 4-Digital and connected manufacturing

New methods and tools have largely been sourced from other industries, especially shipbuilding. This means that their benefits and effects are relatively well known. Ship production is more efficient than traditional construction. The decisive difference is that there you finish in detail and plan for the building before construction starts. This is made possible through digital platforms that are integrated, so that all players work towards the same data model of the ship. This differs from the so-called BIM in the construction industry, where, among other things, you send files in different formats between different actors.

There are sufficient similarities between ship and house construction to assume that ship principles, methods and technology could be applied to houses:

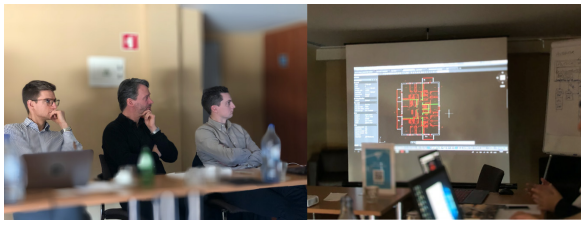
- These are individual projects, larger vessels are individual and not built in series
- Both houses and vessels largely consist of installations: electricity, ventilation, plumbing, etc.
- The shipyard itself is often a relatively simple installation site, with crane and dock, while parts of the vessels are manufactured off-site.

1 Se vår rapport "Att bygga skepp på marken"
2 Ex: Endast ca 15 % av rörmokares arbetstid utgörs av kvalificerad installation. (VVS-branschen)
3 Analysis of trends in EU road freight transport – Eurostaat
4 Bygga och bo primärenergiklokt - Fjärrsyn rapport 2013:28
5 Waste in Europe – European Comission/environment/waste

3. FEASIBILITY STUDY – DIAMANTEN

A feasibility study was conducted in collaboration with Hyresbostäder in Falköping, Veidekke and Studio Ekberg architects. SSI ShipConstructor and ship design firm Vera Navis in Lisbon lined up for a few days to find out, and if so how, one can practically draw and plan an 8-storey house as if it were a ship.

Projektet Diamanten i Falköping, vilket används i första testet



Joakim Örn - Veidekke, Micael Ekberg, Klas Rosin – Studio Ekberg, Pedro Antunes – Vera Navis samt våningsplan i ShipConstructor.
Ej i bild Peter Jormeus – Hyresbostäder, Nick Danese - SSI, Markus Tunlid, Veidekke och Lars Albinsson

The Diamanten project was used as a study object and a number of drawings / supporting documents had been sent earlier. The process used in ship design went through, similarities and differences were discussed. The ShipConstructor platform was presented with details that were considered relevant, including principles for drawings, process, roles and connections to CAD, ERP and planning systems.

Aircraft carriers: an extreme case

To give a picture of the process and tools in large-scale production, Danese gave the example aircraft carrier. Huntington Ingalls, which manufactures the US aircraft carrier, uses ShipConstructor's database for these projects. There, 12,000,000 items are stored for a hangar vessel, each of which consists of large amounts of data. Previously, the basis for such a vessel consisted of approximately 250,000 databases / files distributed among different actors. The ShipConstructor database now contains all this information and each data is stored only in one place and in one instance. A total of 60,000 people at Huntington and their 3,000 subcontractors work with or use information from ShipConstructor. This includes an advanced user management that ensures that no one changes things they are not responsible for. Of course, some parts are also secret on these warships. All changes are "printed" to each workstation at specific times to ensure that everyone works with the same data / models / drawings. Those affected are "forced" to respond to new information. This means that these tools and working methods can be scaled to very large projects, with high complexity and extensive supplier complexes.

4. TRUST THE MODEL – DOCUMENTS VS PRODUCTION MODEL

There are similarities between building design and ship construction. Many different experts have to contribute and work together. Many different organizations and companies are often involved. The overall process can also be described in both cases of gradual refinement and detailing. However, the pace is much higher in ship construction. When you work against the same data model in a common platform when "projecting" vessels, you can see each other's work, which saves time and reduces the amount of changes and changes. For example, it is possible to do so-called collision checks every six hours, at the desired pace, or even in real time.
Four points show the difference between the construction document and the production model:

The data model governs

In shipbuilding, it is the common data model that governs and is "the truth". You say "trust the model", trust the model! This means that all information about the ship / building is communicated through the data model. It is this man who signs agreements around and the one that forms the basis for approvals, certifications and checks. There is nothing that prevents you from doing the same in the construction industry, for example, according to AF (administrative regulations) you can specify the data model as governing. But it is very unusual, contracts in construction are rarely written with the model as the governing basis, which leads to the focus on description documents and drawings in PDF.

The difference between 3D and data modell is key

It is common for us to place similarities between data model and 3D model. However, a data model in ShipConstructor contains much more information than just the 3D geometry. For each item there is product data, manufacturer, responsible person, purchasing requirements etc.
You can control the entire design by setting schedules etc. In production, it is possible to enter production data such as the names and permissions of the person performing a weld, or warranty terms for a product. The model then becomes valuable even for maintenance.r underhåll.

The model is complete

The computer model is complete and this is the one you build on. A greater number of parts are modeled than in house construction. In principle all objects are inscribed. There is a big difference to construction where you often leave out details such as pipes and cables for electricity or only draw these in 2D. The reason for the higher degree of detail in ships is that one must calculate the vessel's position, balance and depth in the water. Then the weight and the center of gravity are required for virtually all the components.
This also enables detailed planning of logistics, material flow, for example so that lifting plans can be produced automatically. The shipping world also includes production planning, purchasing and cost estimates, which are integrated into the same data model. Production drawings typically have a precision of 0.2 millimeters, which guarantees that parts can be produced in different directions and still fit together.
Dsigning all parts also allows for greater variation, instead of drawing a part and then stating that it should be repeated. If drawings are needed for something, these are taken from the model, not from other systems. This differs from buildings where, for example, architect drawings can come from Revit at the architect's, while the electrical dia-

gram comes from MagiCad at the installation coordinator. There is nothing in such tools or the construction process as such, which guarantees that they work together.

DOCUMENTS VS MODEL

Construction documents in the form of a large set of documents are difficult to overlook. It is also difficult to detect if the documents are in harmony or if there are contradictions. The traditional building document becomes the principle design of a building, while a number of issues arise and must be resolved during the construction period. A production model is much more complete and can be manufactured immediately after. Ev. problems are detected early and can be solved more efficiently before materials are ordered and production has begun. A complete data model also allows the house to be verified to a greater extent from many perspectives before construction.

HIGHER DEMANDS ON CAD

To make this work, it is necessary to apply significantly stricter and forced rules for CAD work than is usual for construction projects. You create and draw objects, for example, with data, not just geometry. Data is entered for all disciplines, not just for the creator of the object. The relationship between objects is handled more carefully. If a cabinet is to be mounted on a wall, the cabinet is connected to the wall. This means that if the wall is moved, the cabinet will follow. This also applies, for example, to electrical outlets and components from different installation systems. Pipes and cables can be connected to endpoints and routed automatically by the system. If this is done in a disciplined way, the model becomes highly parametric and it is very quick to change or test different solutions. Over time, a product and object database is built up, which makes the work much faster. This makes it possible to reuse parts of projects in a very efficient way.

MANAGING THE DESIGN

The design process itself can also be controlled from ShipConstructor. You set up tasks related to objects in the model and assign them people and schedules in the platform. This can even be compelling. Some roles may be forced to choose a task when opening a model. There is a clear cultural difference here. In general, we strive for short times and to respond quickly to what happens in the process. The earlier the design is completed, the better the opportunity to buy parts at good prices, to prepare the production and plan all resources..

LOWER COSTS FOR THE DESIGN

Ship design is usually carried out at fixed prices / remuneration. According to Vera Navis, the cost of the complete design typically stands at 8-10% of the total production cost.

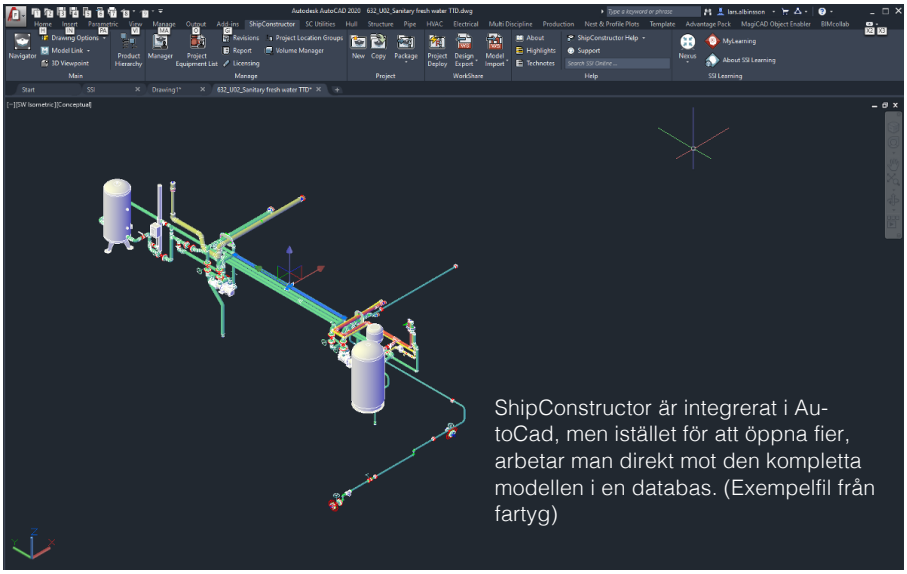
In a study[1] the design cost for the developer corresponds to about 6% of the construction cost for housing. Add to this the design costs of contractors and subcontractors. In interviews, these have been estimated at an additional 6% units. In total, the design cost of housing construction is about 12% of the production cost. Despite the fact that construction planning takes a larger share of the cost in construction, the result is less detailed. For example one study[2] of plumbing installations in apartment buildings that about 15% of the working time during ongoing production goes to planning. The conclusion is that the cost of designing ships is not higher than the cost of today's design of residential houses, rather lower, despite the considerablert mer omfattande och noggrannare resultatet.

1 Johnsson, A., 2017. Verkliga kostnader för bostadsbyggandet, Göteborg: SBUF & PEAB. För utförandeentreprenad anges kostanden till 16,6 % av byggherrekostnaden. Detta skall ställa i relation till byggkostnaden, vilket ger ca 6 %.

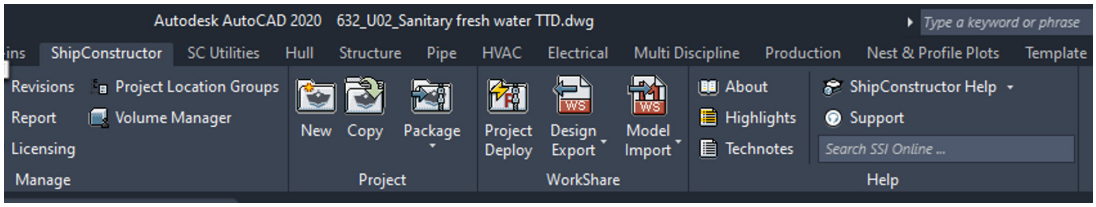
2 Arbetstidens användning vid VVS-montage, 2010, VVS branschen

5. How does it work in practice?

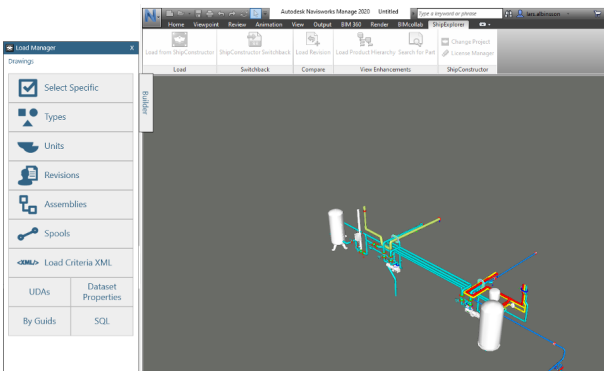
ShipConstructor is integrated into AutoDesk's CAD tool AutoCad, but instead of opening and saving files, you work directly towards the complete model in a database. Different tools with special functions also work on the same model. For example, tools for the design of EL, plumbing and ventilation. This means that ShipConstructor is experienced as "an app for drawing entire vessels". The 3D models themselves are stored in the database with a technique called associative DWG. This ensures that models, geometry and product data are always interconnected. You can choose the part you want to work on in many different ways. For example, a room, system or function. You can also search for a specific product or material and get it directly in AutoCad. This is the key to the tool and the big difference to traditional BIM work, where the information is spread out in different models, drawings and documents. It is also possible to add new types of data to the database. For example, if you want to store information about specific environmental effects. As mentioned above, different parts can be locked for different roles, so that you do not accidentally change something that you are not responsible for.



ShipConstructor är integrerat i AutoCad, men istället för att öppna fler, arbetar man direkt mot den kompletta modellen i en databas. (Exempelfil från fartyg)



The tools for all different systems are also integrated and work on the same model. (Hull and Structure is the frame, Pipe plumbing, HVAC ventiation and Electrical electricity are the same) No export / import is needed.



Externa software can be integrated. Here NavisWorks, which opens models directly from the database and can be used by people who do not have or should have access to ShipConstructor. For example, installers, buyers, project managers. Here, too, you do not have to import / export and all information is complete and updated.

Design, manufacturing and logitisc in the same model

You not only model the finished vessel but also the manufacture. Work steps also lie as objects in the model. This is handled in Ship-Constructor by creating different hierarchies between sets of objects. This can be the order of the room and the floor of the building, but also the order of production, purchase order, costs and logistics. Such hierarchies can be added freely as needed.

What is missing?

There is no general support for eg IFC. It is also not possible to directly import drawings from eg Revit, Archicad or even AutoCad, as they do not have sufficient information / data on the objects that are drawn in. You can open them, but you have to redraw them in Ship-Constructor. This is an effect of the integrated platform.

There are some simulation features that are currently used in the construction industry. eg flow and acoustics in ventilation systems. There are also many specific products, such as windows and doors, which are required in Swedish houses. These must be entered manually or by creating specific scripts.

A work ahead for Bygg 4.0 is to explore the opportunities to connect traditional BIM tools to platforms such as Ship Constructor, Dassault and of course follow AutoDesk's development of its own BIM platform.

However, connections to existing tools must not lead to "going back" to today's BIM design, without maintaining a common data model.

6. Impact on manufacturing

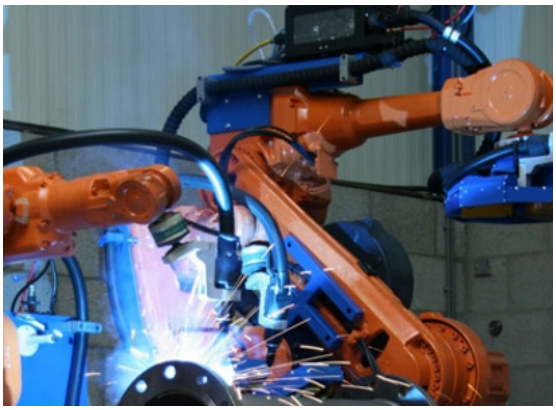
As mentioned, one advantage of the "ship design" is that you also take into account, and plan, the production. Here we list three examples that could be applied in construction.

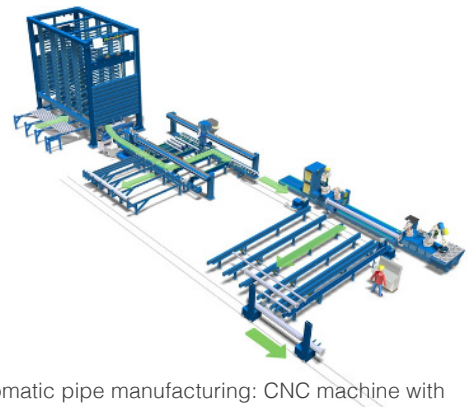
Off-site production

A special technique used is to create "assemblies" and "spools". This means that you select all parts that are included, for example, in a fan room and handle these as a complete product or module. Different subcontractors get exact drawings / models, material lists and assembly sequences, from which they produce complete parts. These are then quickly mounted on the building. A fan room can even manufactured completely in the workshop. Since everything is drawn with a precision of typically 0.2 mm, no customization or machining is required on site. This means that much can be produced in parallel and off-site, which significantly reduces the total production time. It is similar to the manufacture of bathroom modules, but can be applied to virtually anything in the building. However, it places high demands on the production of various modules. In bathrooms, for example, it is not enough that the inside is made with precision; also walls, connections and attachment points on the outside of the module must have the same precision so that the surrounding building does not have to be adapted during installation.

Less waste

By planning production in the same platform, material waste can be avoided. One example is pipes. Selection and cutting are planned to minimize waste. Remaining pipes are stored in the warehouse and the system can automatically use these in the next project. This can also be done at subcontractors. The difference between buying material for an individual project, perhaps by an individual subcontractor, transporting it to the site, cutting and installing and then "recycling" the remaining material in containers is striking.





Automatic pipe manufacturing: CNC machine with four welding robots producing finished pipe systems, in many dimensions directly from eg ShipConstructor models. These are equally effective for single tubes that get long series and produce in minutes something that manually takes several hours. (Kranendonk)

Automatic manufacturing of unique parts

Many different machines and systems can use drawing information from ShipConstructor without "translations". And precision makes automatic manufacturing easier. An important development today is that it is possible to manufacture single objects with the same efficiency as in mass production with automatic production. In the shipbuilding industry, you invest a lot in it, as you rarely have long series. Since you are already working completely digitally and with production drawings, this development goes very fast. Here is a lot that can be introduced in the construction industry.

7. Practical use – Sizes Works

Sizes Works is a newly started company that manufactures multi-dwelling houses in solid wood. It was founded specifically to build a fully automated factory, where the houses are manufactured in finished modules, with high flexibility. Sizes wants to enable varied houses that can be manufactured at low cost and with high quality. The module system is very flexible. For example, a room can consist of several modules and in a house each module can be uniquely designed.

From the beginning, a collaboration with Bygg 4.0 was established. Production started in February 2019, with a production line designed for an industrial process but with staff. The idea was to test out the steps and introduce robots etc when finding an optimal way to manufacture modules. (This can be compared to so-called 0-series in the automotive industry, where you make about 100 cars by hand to develop the production line.)

In the spring of 2019, the results of the feasibility study were presented by ShipConstructor to the company's management. The management felt that this was very close to the vision and the needs one had. Several people in management did not come from the construction industry but from ABB and the automotive industry. For these, what was presented was not as new as for those with a background in the construction industry.
A two-day workshop was conducted where Vera Navis and Ndar presented working methods, ShipConstructor and Lars Albinsson / Bygg 4.0 led the talks on how these could work in Size's operations. From this a new process and how the new platform would was deviced. After evaluation, Sizes decided to incorporate ShipConstructor as the company's project planning and platform production / control. The system was considered to fit well in the process it wants to build up and that it offers support for the continued automation of production.

Kolla Parkstad

During the summer / autumn 2019, planning was started for a housing project, Kolla Parkstad, in ShipConstructor. The first step was to set up the platform, define basic data and train primarily CAD operators. The next step was to start drawing the frame including all wood panels. This is natural as you have to start with the frame to draw the house. But the wood panels have been a problem in themselves, in the traditional design. There is a shortage of manufacturers of solid wood wood panels in Europe. This means relatively long delivery times, which makes it advantageous to book quantities in good time. The panels are purchased ready-made from the factory and each panel must be finished with production drawings on final order. Previously, these were picked out from Revit or another CAD system. From this, shopping lists were created in Excel.

This took several days. Among other things, when the risk of error was great and the whole thing must be checked many times. In case the drawings were changed, you basically had to start from scratch.

Wood panels in minutes

In the new design, this will take a few minutes, by choosing the appropriate product hierarchy. The ordering data is then also fully consistent with the model without the risk of errors. In the next step you will also design the installations in ShipConstructor.
Not only the finished house is modeled, but also the mounting sequence and work steps are added to the data model. This makes it possible, for example, to order materials with accurate delivery times, place of delivery, and even the production site in the factory.

Design in 4 weeks

It is expected that the design time for an 8-storey house will go from 6-8 months to 4 weeks when the system is fully implemented.

UTMANINGAR

Of course, it is not trivial to introduce a new way of working and completely new technology, not even in a newly started factory. The most important have been:

Arkitects drawings

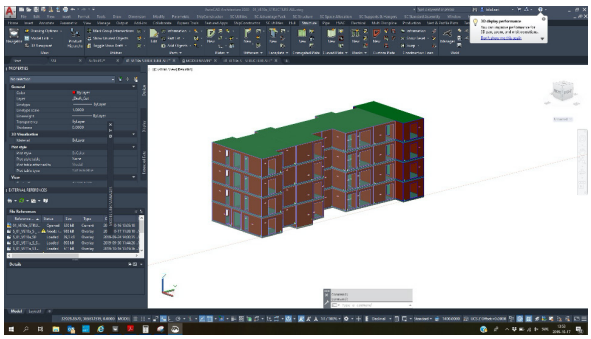
Today, there are no architects who collaborate with ShipConstructor. This means that the houses must be redrawn in the tool. It places demands on collaboration with architects, especially in order to manage changes. In addition to the digital tools, architects must also understand the terms and conditions of the modular system.

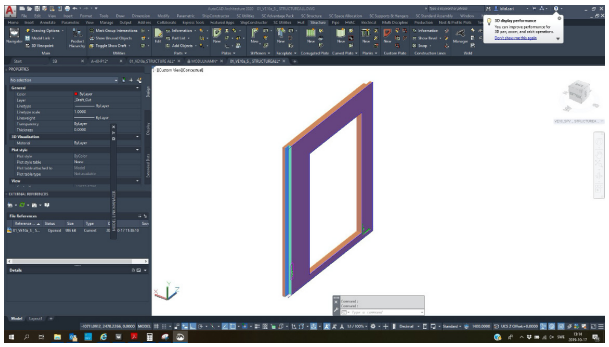
Consultants

Some expertise is used to design installations. Today, these do not work in ShipConstructor, which means that you have to manually ensure that the designs of external consultants are consistent with the model in ShipConstructor.

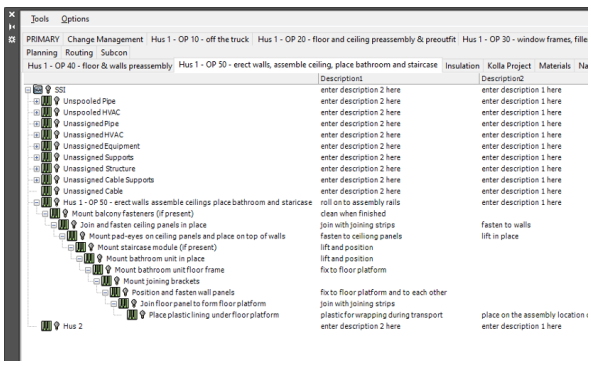
Culture

Project completion and detail is unfamiliar to those who come from the construction industry. Also, there is no routine for any problems in production to be returned to the design. This is a cultural issue, since the construction industry often chooses to solve problems in manufacturing instead of adjusting the design issue. An example is electrical installers who find that the holes for a box are too small, but instead of imposing this so that the structure can be changed, he chooses to drill the dose holes himself.
New leadership is required to lead the work, as new demands are placed on process, deliveries and tools..





Solid wood frame for a house in Kolla Parkstad in ShipConstructor. All panels are given exact dimensions and the model can control NC cutters etc. All modules can be different, the tool can easily handle the variation between these



Work steps for assembly and sequence are created directly in ShipConstructor. Then orders of materials can be automatically linked to the exact time and place.

Installation of finished house module on site, which takes about 15 minutes / per module.

DATA

All products included in Size's house must will be added to ShipConstructor, with complete data and 3D models with exact geometry, connections, mounts etc. Initially this has taken time. However, the work decreases over time, as there are fewer and fewer new products for each project you carry out. In addition, it gives better control over which products are put into the house.

EFFEKTER

The assessed effects of the new system and modular manufacturing are as follows:

- Sizes expects the design time for 8-storey houses to go from 6-8 months to 4 weeks when the system is fully implemented.
- Design costs decrease corresponding to 10% of the total cost
- The time on site decreases by about 4 months
- Reduced waste; surplus in the factory reused
- Faster production and reduced capital accumulation
- Tools and working methods contribute to the more industrial culture the company strives for.

8. Obstacles: traditional organization of construction

In the Dimanten project, which was the subject of the first study, the developer, Tenant in Falköping wanted to apply the Bygg 4.0 principle and test ShipConstructor in the design. This was not possible when a contract for a contract was already completed, without the necessary requirements. In dialogue with the planning organization we also found that this would not be possible.

Today, project planning is usually done by a large number of (10-20) different actors, who rarely do several projects in succession. This fragmentation in itself becomes an obstacle to renewal. It is not considered profitable to introduce new tools and working methods in a typical housing project. In total, the willingness to invest is very low, since the economic horizon of the players is mainly the individual project. This in itself means that the innovation in the construction industry is very low. This does not only apply to new working methods such as Build 4.0 or ship platforms. Virtually every major change faces these obstacles.

A typical design organization is decentralized in several ways. Each participant is also expected to know the design process and to collaborate with other roles / competencies. This means that no introduction of method or project management that governs the working methods is required. This is considered effective, since everyone is "self-sufficient". This is linked to issues of responsibility. Each specialist is responsible for the function within their area. This means that each expert sets requirements to ensure the individual function, without necessarily considering the effects this has on other areas or the house as a whole. The lack of integrated tools also makes it slow and expensive to explore different solutions, which results in lower quality in design and function.

A recurring example is the shaft for ventilation, water and sewage. Their size and location have a major impact on apartment design and construction costs. Since architects, ventilation specialists, plumbing specialists and those working with the body do not work in the same environment, it is not possible to effectively explore any large amount of solutions. Experience, surface efficiency and manufacturing then usually stand back for the technical function of the individual systems.

Only new digital tools do not automatically change this. Responsibility for the whole, balancing and creating better designs is a matter of leadership and business models. Today, there is no clear role that takes on these tasks.

Är det omöjligt att effektivisera traditionell entreprenad?

It should be possible to introduce a new process, new tools and a changed production, even with existing players. You do not have to switch to modular systems and house factories. But it is not possible with current business relationships that are project-based. The idea that digital tools in the design, such as BIM systems, in themselves, could greatly increase the efficiency of a traditional contract, must probably be considered on a very loose basis.

If you introduce new tools in the planning itself, and renew the organization, production and business models, this should be able to give great effect even in contracting organizations.

We will focus this in future studies and experiments.

9. Conclusion

The working method and business model are as important as the tools and they must be put together.

In conclison the two trial show that:

- It works very well to design housing in a ship platform and big profits in time, cost and the amount of mistakes can be made
- Residential house design can for example go from 6 months to 4 weeks, purchases from days to minutes and with fewer errors
- Machines that cut can be controlled directly from the model

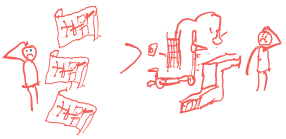
But also that:

- Traditional organization of planning and contracting is an obstacle. There are even reason to question today's contracting model as a whole
- The lack of central ownership of the process, the fact that investments to be counted in individual projects and that a large proportion of decisions and production are made on site, leads to unacceptable environmental consequences and costs without corresponding gains in quality
- The key is the transition from building action to production model

Traditionell entreprenad:

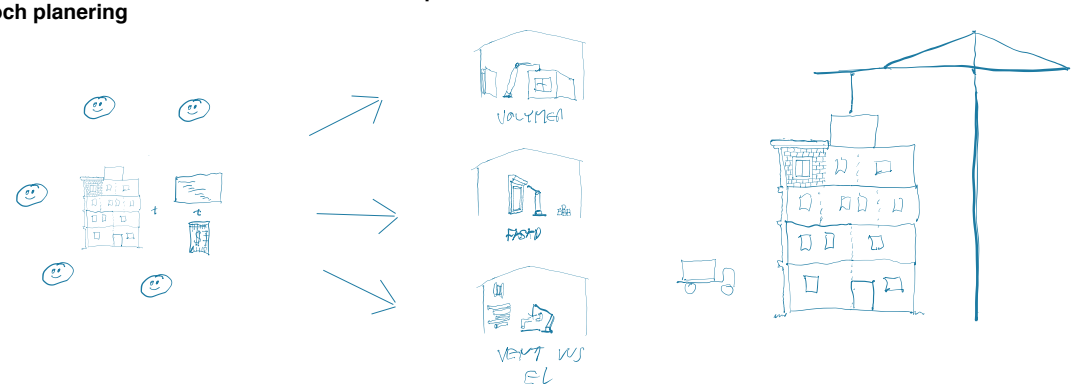
Projektering per diciplin i olika verktyg, bygghandling i dokument

Okompletta ritningar, olösta problem, bristfällig planering, onödiga transporter, materialförluster och avfall



Bygg 4.0:

Projektering i gemensam datamodell, inkl kostnader och planering

Tillverkning av monteringsfärdiga delar, parallellt i verkstäder

Endast montering på site, litet avfall, få transporter