Industrialization of Building Processes – a chance for timber to take the lead

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Industrialization of Building Processes - a chance for timber to take the lead

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ABSTRACT: All over the world the same phenomenon is observed: People are moving towards the cities. As a result, most of the cities are growing and suffer from sufficient housing capacities. Upon others this leads to prohibitive prices for flats compared to the income of most citizens. Therefore - especially for social housing - cheap and effective solutions to build more residential buildings are desperately needed but must be combined with acceptable and sustainable architecture! For building solutions, a real industrial standard is needed - useable by architects, engineers, developers and builders. Company-based solutions are not sufficient. In a recent research project, it is shown that at least 25% of the building costs is related to additional and unnecessary design. As a result, a BIM based general design model based on 3D-planning and building units should be established. While timber is a perfect material for prefabrication and wood building industry is already trained in prefabrication including partly installation of building services, further development is a big chance for timber to take the lead in a future industrialization process of the building industry.

KEYWORDS: Industrialization of processes, BIM, prefabrication, sustainable architecture, details of construction

1 INTRODUCTION

All over the world additional buildings for residents at affordable prices are urgently needed. But building costs are increasing, inter alia due to scarcity of resources and increasing prices for building materials. Meanwhile demographic pressure is increasing steadily in agglomerations: in 2008 more people worldwide were living in cities than in rural areas according to the UN. According to Oltmer [1] and Birch/Wachter [2] in 2050 over 2/3 of the world population, meaning about 6.3 billion, will live in agglomerations. The big cities in developing and emerging countries are growing particularly fast. Rural-urban migration is currently a huge topic in China and the African continent. In 1976 about 82% of China's population was living in rural districts. Already in 2011 over half of the population lived in cities [1]! Shanghai for example is expected to grow by 2.5% each year between 2011 and 2025. In the same period of time, Istanbul has an estimated growth rate of 2% and Paris 1% per year. The really big cities, or ‚megacities', will be forced to rely on building residential high-rise buildings on a large scale due to the plain lack of space.

Figure 1:*Typical housing development in China's big cities, here the Shanghai area*

Mostly due to fire safety regulations but also because of common construction methods (steel and reinforced concrete constructions), most of these buildings are not built as timber constructions or timber hybrids.
At least they mean a step towards industrial construction because a comparatively large amount of buildings is erected on basis of one single planning.
However, the prefabrication level is low and the predominant part of the construction takes place on the building site. Further, constructing the same type of building over and over again holds the threat of urban monotony.
Even though European cities are far from these explosive growth rates, cities like Munich grow at an annual rate of 0.7 % to 1.0% (approx. 10.000 new residents per year). And prognosis had to be adapted over the past years since the for 2020 predicted number of 1.5 Mio was already exceeded in 2017.
Focusing on big- and mega-cities, might shade the view on smaller and middle-sized cities with around or below

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half a million residents. Medium-sized centers (urban poles) in rather rural areas, like Fulda in eastern Hesse, Germany (approx. 65,000 residents) with an annual growth rate of 0.6% to 1.0% or Joensuu in northern Karelia, Finland, which is growing by 2,000 residents per year with a population of 77,000 residents in 2016, are growing at similar rates. Incidental remark: As in the smaller cities residential buildings are usually designed up to 7 - 8 storeys a wide application of wooden constructions is possible.

For the increasing number of urban residents, living space will be needed in a relatively short period of time. With the actual and still quite archaic building process in addition to the shortage of workforce both in the planning and building sector, this can't be realized in reasonable quality.

So there is a number of reasons to look into the potential of a real industrialization of building processes. Plus, not least, it is a question of economic efficiency whether building the needed housing will be feasible. E.g. in Germany an actual gap between the costs/m^2 and the amount to be refinanced economically is about 400 - 600 €/m^2 including VAT (m^2 = rentable net area of a flat). The average costs in social housing projects to built the building structure (cost group 300) and the building services (cost group 400) without costs of design, property and other side costs are actual (2017) around 1,800 € /m^2 including VAT. In addition, the property costs in conurbations amount from 800-1,000 € /m^2 rentable net living space.

In Germany and many other European countries, the design of multi-storey buildings for social housing is very often a 'one - design' and even though prefabrication has increased for the structures itself (prefab concrete, timber and steel structures) a lot of work is done on site (non-prefabricated concrete e.g for basements and underground-parking, masonry, building services installation, drywall installation etc.). In addition, costs up to more than 25% of the building costs are created by so called 'adaptation design', necessary to adapt the design of architects and engineers to building processes and prefabrication.

To analyze the situation and to develop proposals for solutions a research project 'Bauen mit Weitblick' was worked on at TU Munich in cooperation with prefabrication companies from concrete and timber sector, housing associations and a team of architects, civil and HVAC engineers, designers and BIM specialists. The main results will be discussed in this paper.

2 ACTUAL SITUATION

The following findings refer to industrial construction especially for multi-storey social housing.

Of course the question is not new. Le Corbusier (Vers une Architecture, 1923), Gropius and Wachsmann (General Panel System, 1941) or more recently Kieran and Timberlake (Refabricating Architecture, 2003) just to name some prominent examples, addressed the problem – and failed! One main reason why will be explained later.

Also prefabrication and standardization are not new at all. The production of the building products – bricks, concrete, (partially) prefabricated parts, plasterboards or wood based panels, sanitary installations, fittings, electric switches etc. are made industrially and for stock.

Further steps follow depending on the specific material and construction up to prefabrication and standardization. Especially in timber structures there are a number of successful examples, like industrial hall systems, cattle sheds or prefabricated houses in Germany and all over the world.

Definitions

Industrial construction [3]

„Industrial construction" is also described as the combination of process and strategic measures.

On the process side this can be solved by standardized construction techniques, building parts and materials, the use of prefabricated construction parts and increased automatization on building sites (e.g. construction robots).

On the strategic side industrial construction means using an optimized program for production and offers, the support with planning new building projects and increased preparation of workflow.

These strategies can be implemented by using CAD- and CIM-Systems, process-oriented organization and cooperation networks.

System [4]

A system is a consistent whole out of various parts.

System construction kit

A system construction kit is a construction kit for a specific system, e.g. a special construction system. The system construction kit allows the creation of products for a certain usecase. The usecase for the research project is the industrialized social housing construction. Thus, a system construction kit can be a modular construction system.

Module

A module is a completely planned unit that can be built repetitively without changes.

But especially the prefabricated houses industry lost in a wide range the basic idea of industrialization: Producing a high number of equal pieces of a product based on one completed design. Forced by the increasing wishes of the one-family house customers for individualization, they face nowadays also a high amount of necessary adaptation design.

Also prefab concrete systems reached in the past a high level of industrialization as e.g. in former GDR, but combined with a not longer accepted loss of architectural quality.

The lack of an industrial building standard for residential buildings with sufficient options for individualization

resulted in one-design planning also for multi-storey buildings to keep architectural individuality.
Yet there is a main difference between buildings and industrially manufactured goods. Classical examples are cars, which are industrially manufactured with a certain degree of individualization. The constructed environment however is shaped to meet the needs of the industrial good ‘car’, e.g. the routing and width of roads are designed to be passable just fine for cars.
A building on the other hand has to be able to fit the constructed environment. Especially in inner-city districts, properties are shaped quite individually and should be used with the optimum ratio of property to living space due to the financial reasons mentioned above.
Combined with the wish for architectural individuality, the necessity to adapt leads to more and more individual planning. The industrialization of building processes has to create a cost benefit (considering life cycle costs) to compensate the usually not perfect use of the property’s space in order to be financially worthwhile.

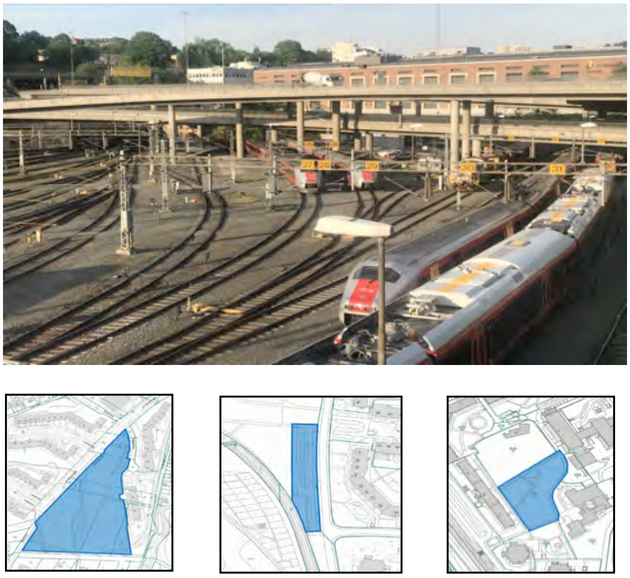

Figure 2:*The constructed environment is shaped to meet the needs of vehicles, buildings have to fit the constructed environment*

In addition to the reasons mentioned above there are other important arguments to increase prefabrication and standardization: the lack of design and production capacities, the significant lack of qualified workmanship throughout the building sector and increasing problems to hire long-term workers for building sites that are dependent on weather conditions and rather uncomfortable. That of course could be addressed by raising loans but that would also raise the overall costs. Building sites can’t be moved to seemingly cheap labour – the buildings have to be erected on-site.
Therefore, it is absolutely reasonable to review industrial construction under contemporary conditions – and investigate especially how today’s possibilities of digital design and computer-based fabrication and controlling can play their part.

At first glance it seems odd that such an economically important segment as housing construction with its high use of resources and energy and related high costs did not yet put forth a higher level of industrial production of its buildings.
Previous research on industrial construction often focused at other industries e.g. automobile, ship or aircraft construction. They make sense as a model because (partially) standardized industrial products are put together as assemblies with different levels of prefabrication. Those assemblies in turn can be combined as complex structures.
The research project ‘Bauen mit Weitblick’ fell also back on relevant prior projects in order to analyze the present workflows of the industries mentioned above and – if suitable – borrow their knowledge [6].

But one major difference has to be taken into account: aircraft and automobile construction allows a certain degree of individualization (e.g. interior design) but shape and composition of the product stay unchanged. Further, the products are mobile and not bound to a certain site.
However, ship construction makes a pretty good model for the building sector because e.g. for cruise liners the interior and the shape of the ship are being modified while the level of standardization is high. In addition, many functions are similar: living, supply or gathering.
The building sector however requires an even higher level of flexibility. Social and geometric reasons, urban development issues and significantly more heterogeneous clients as for aircrafts and ships demand a high rate of customization.

3 POSSIBLE STEPS TOWARDS INDUSTRIAL CONSTRUCTION

Inspired by other industries the idea was born, to use consequently the methodology of ‚system construction kits’ (sck) also for planning and construction of buildings of social housing projects. Useful flat groundplans with fixed sizes from a one-room to five-room flats must be feasible, as well as the desired mix of flats, the adaptability to the available building site, the construction based constraints of the type of construction (span, loadbearing capacity, fire safety, noise insulation, etc.), the conditions of productions (prefabrication, transportation weight, etc.) and the possibility of an architectural individualization by different building typologies, additions or changeable sizes of windows and facade systems.

Therefore, a system construction kit is required, which is able to fulfill diverse requirements by enabling moderate individualization, which is available in the form of a configurator for the design teams of the client (architects, civil engineers, building physicians, building services engineers) and finally generating not only tender- and contract documents but also provide the builders with all necessary information to transfer planning into building.

That sounds like squaring the circle. And often enough such systems failed. From the author’s present point of view the main reasons for former failure are the following:

+ the specification of a too strict size system

+ the missing liberty of design and therefore the rejection of the system which is in addition often directly connected to a company driven system

+ the missing consideration of the third dimension by shafts for building services if at the same time a certain mix of flats per building is approached

+ missing digital instruments, especially the absence of interfaces

At the beginning, aim of the research was the development of **one** system construction kit for industrialized, multi-storey, social housing. The system construction kit should be designed to enable the realization in different building materials (concrete, timber, hybrids, etc.) by serial produced elements. In ideal case there should be **one** configurator to be used by clients and their design teams to generate multi-storey buildings using variable construction systems.

But this only **one** system construction kit is not feasible: A system construction kit must map one **specific construction system**. And this specific construction system must correspond to one **specific type of construction**, e.g. prefabricated concrete, timber framing or a hybrid type of construction. A generic system construction kit, able to map many different construction systems, would require the mapping of a variety that even todays available digital methods wouldn’t be able to represent and would be very confusing in design.

By the way - a system construction kit must not compulsory be connected with prefabrication. Of course, widely prefabrication is useful, but it is not necessary. Theoretically a system construction kit could be developed for pure on-site erection. De facto a system construction kit always will be a mixture out of prefabrication, pre-cut and additional work on-site.

The **3D-module** represents the highest grade of prefabrication. In an ideal case the 3D-module is completely equipped - including furnishing - packaged, stored and delivered ′just-in-time’ to the building site. Due to limited sizes and weights for transportation, large flats need switchable modules.

Panel constructions provides a slightly higher degree of parametrization (by size) compared to 3D-modules but are limited also by span of floors, sizes and weight. And more on-site work is necessary.

Also, a mix of panel construction and 3D-modules is possible to minimize on one hand the transport volume and to completely prefabricate highly installed sections in the factory on the other hand, as the integration of building services in prefabrication is a special challenge.

A next logical step is the development of a **system bathroom**. Therefore, bathroom configurations were an important task in our research project and were evaluated to achieve compatibility to serial, industrial fabrication processes. The high number and quick sequence of (wet) crafts should be replaced by a simplified assembly process. The technical complexity will be reduced by a modular system.

Based on the requirements of different shapes of bathrooms a modular system was developed, which can be integrates in system construction kits. The system bathroom may be further developed as an individual, industrial product.

Like bathrooms all other components of building services have to be integrated in system construction kits. Heating, warm- and cold-water supply, waste water disposal, ventilation and electricity supply must be shown in a complete design.

But system construction kits can only mirror the building parts producible in their specific type of construction - so normally the standard storeys. Basements and underground storeys with their very variable usage (shopping, kindergarten, energy supply, parking, etc....) have to be designed individually.

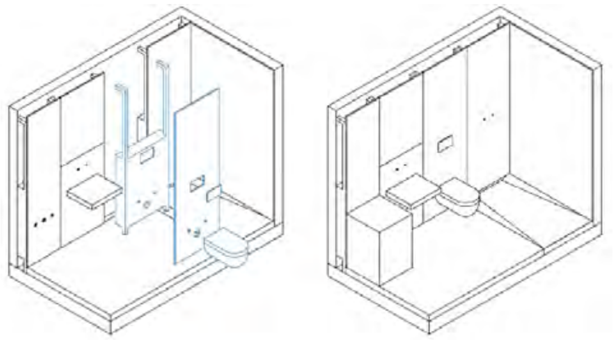

Figure 3: *System bathroom with modular basics, combination of sanitation object, wall surface and sanitation technology to a functional unit [5]*

For the design of the system construction kit itself assemblies are used and two different approaches are followed:

The system **assembly-building** (assy-B) and the system **assembly-storey** (assy-S).

The basic proposition of the assembly systematic is: With a defined number of different but unchangeable parts it is possible to design situation related, individual buildings with complete cost transparency and secured realisability.

The **assembly** is a **complete designed unit**, containing all elements of construction, fitout and building services. It may be extended by furniture, and additional technical equipment, e.g. kitchen devices. At its geometrical borders all interfaces to the next assembly are completely defined, e.g. at separation walls, floors and roofs. An assembly forms at least one flat (assembly-flat (assy-F)) (see figure 4), but usually a number of flats arranged either parallel or one upon the other.

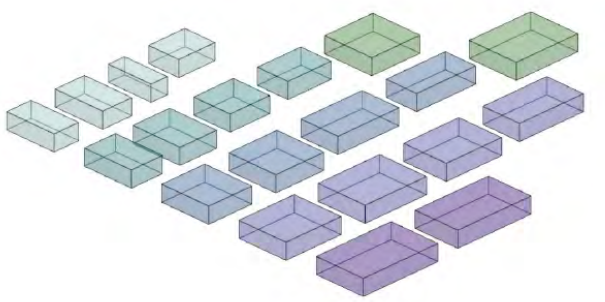

Figure 4:*Assembly-flat (assy-F) as smallest meaningful unit [5]*

Assemblies-building (assy-B) are three-dimensional attached (flat-)units (figure 5), assemblies-storey (assy-S) are two-dimensional arranged units (figure 6) of assemblies-flat.

During the development it was noticed, that the placement of shafts - and therefore the third dimension - must be observed very carefully.

Figure 5:*Assemblies-building (assy-B) as a combination of assemblies-flat (assy-F) [5]*

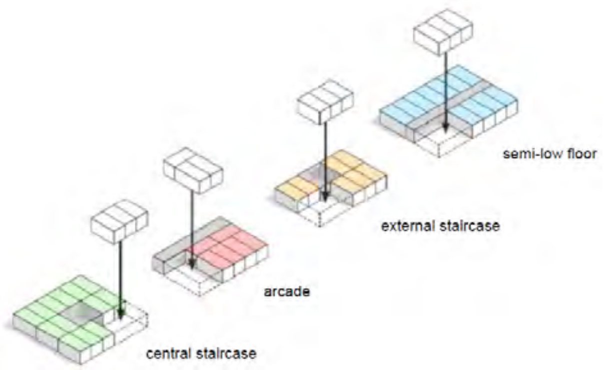

Figure 6:*Assemblies-storey (assy-S) [5]*

The common building typologies must be developable out of a limited number of assemblies - using in addition assemblies-infrastructure (assy-I) - i.e. the types of building semi-low floor, external staircase, arcade, central staircase, etc. They are extended by using assemblies-addition (assy-A), e.g. for balconies or solar panels. The assemblies are included in digital configurators, enabling the design by assemblies and including compatibility testing.

The system of sizes of the assemblies is mainly identical with the common size system of the used building materials (e.g. in timber framing e = 625 mm) but must not follow necessarily a fixed module dimension. E.g. assemblies for flats at building corners may have other width compared to regular flats. Sizes of windows, height of parapets or type of facades can be parameterized in fixed limits.

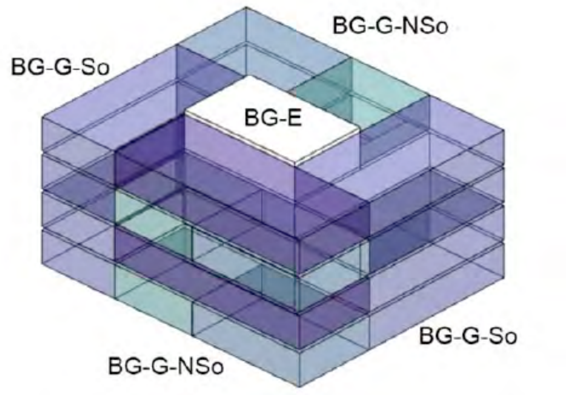

Figure 7 *Example of a combination out of assemblies-building and assemblies-infrastructure [5] (BG-E = assy-I, BG-G-xx = assy-B-xx-type)*

The easiest way to arrange assemblies is the arrangement of equal assemblies-flat one on top of the other (single origin assembly, see figure 5 left).

Unfortunately, with this method the required mix of flats is not achievable. Therefore, also flats of different sizes must be combinable - i.e. non-single-source assemblies-building (assy-B) must be designable. In the research project it was proofed by an appropriate layout of flats, that this is achievable. In rare cases blind shafts have to be accepted. Assemblies-building (assy-B) are therefore larger, three-dimensional units with a verified fit. With these assemblies architects are able to design complete buildings of various configurations. The sysematic is similar to a SOMA®-cube or a 3D-Tetris.

Figure 8: *SOMA® cube as an example of a '3D-tetris' system, providing 254 possible solutions out of 7 pieces [source: Winter, S.]*

All assemblies can be depicted finally in a BIM-system, in this case - compared to a ‚one-design' - a reasonable effort. All crosspoints of building elements (separation walls, floors, etc.) and to assy-I and assy-A elements are geometrical and regarding their loadbearing capacity fixed (figure 9). Additions by new assemblies are therefore easy to configure. Compared to automobile- or ship construction the methodology is exactly the same.

The industrial partners in the project generate system construction kits based on the developed method using the systematic of assemblies-building (hybrid timber-concrete-panel-construction) as well as of assemblies-storey (3D-concrete modules).

With these adaptations the methodological principles were successfully verified, using reference buildings and by designing different building typologies.

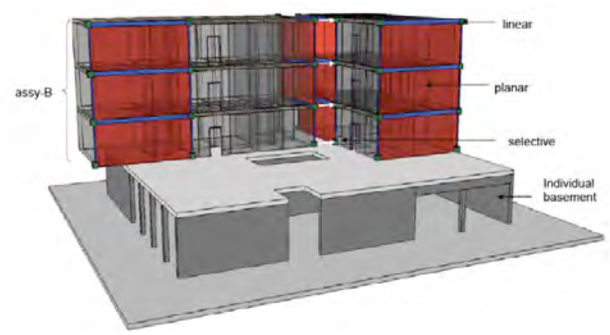

Figure 9: *Geometrical interfaces of assemblies [5]*

4 OPEN SOURCE SYSTEM CONSTRUCTION KITS AND THE POSSIBLE SPECIAL ROLE OF TIMBER STRUCTURES

One of the also historical mistakes in the development of industrial building is probably the always - sometimes implicit - assumption that an industrialized building system must be linked to a specific company and therefore provided by a single source. Indeed, this would also allocate the responsibility for the construction process directly to the producer of the system construction kit, who is normally also the general contractor. And the assumption is deducible from other industries. The assumption therefore was also a starting point for the research project ‚Bauen mit Weitblick' - amongst other reasons to be able to evaluate exact costs. Ultimately it also led to the choice of project partners.

In the end it was proven, that the system can be adapted successfully in practice, but also a number of disadvantages were discovered:

- To develop a company specific system construction kit a high amount of design capacity is needed
- Linked to the planned ratio of prefabrication high investment is necessary
- Based on high initial investments, fast cost-effects cannot be realized, as the releasing company will follow the rules of free market economy in a situation of high market demand and will try to re-finance the invest as soon as possible
- From the start of the design process on the customer and the design team have to focus on one supplier. In public tender processes this requires an expensive, two-stage process.
- Using 3D-modules in prefabrication in most cases fixed length and therefore fixed width of buildings are given. To enable optimized use of property the use of those prefab buildings should be considered in urban planning.

Therefore, the development of type-of-construction specific but company independent system construction kits is the next logical step to an industrialized building process.

They are in the purpose of figure 9 closed system construction kits. And they are configured using the proposed assembly-systematic with a specific type of construction. But they are using, in opposite to figure 9, a type of construction, whose building elements different companies can produce. In an ideal case with comprehensive available production facilities, not needing additional or only minor investments.

That's not existent? It is – and it's combined with a great know-how of prefabrication in the timber sector.

The simplest possibility is a system construction kit based on timber framing. Up to building class 4 (5-storeys) you may immediately configure assemblies-building. The single elements like floors, roofs, interior- and exterior-walls can be delivered by any well-equipped carpenter or prefabricating houses industry company and be used according the building regulations.

Same is valid for hybrid type of constructions made out of timber frame elements and prefab concrete floors or for a hybrid type of construction made out of CLT and glulam post-and-beam structure with highly insulated exterior elements for walls and roof, which may also cover building class 5 (7-8 storeys).

	Benefits	Disadvantages
Manufacturer	• Low internal variety with comparably high external variety • Reduction of complexity • Low cost of variants • Better product quality • Lower storage costs	• Usually higher development expenses • Increased expenses with changes • Limited possibilities to meet individual customer wishes
User	• Shorter delivery times • Better product quality • Possibility for later additions or modifications	• Increased need for product storage • Limited possibilities to meet individual wishes

Figure 9*:Benefits and disadvantages of system construction kits [7]*

Also, the integration of 3D-bathroom modules including the system bathrooms above mentioned is possible, as they are also producible by different producers. The erection onsite may be realized by an independent company specialized on mounting - as usual in prefabricating housing industry today - or the main deliverer.

Indeed, this would be a radical change - but why not follow this to the end? It is the timber structure sector, which is leading without doubts (2018) in prefabrication in the building sector. It starts with the prefabrication of the elements and includes the integration of building services. And due to digital based planning and prefabrication the highest precision in size accuracy is achieved. Why is it not possible, that based on a system construction kit, giving by exact designed assemblies (e.g assy-B or assy-I) all necessary design- and production data based on a configurator, carpenter A delivers all floor- and roof elements, the prefabricating house factory B delivers all insulated exterior walls inclusive windows and facades and the 3D-modul factory C delivers the bathroom and kitchen modules while mounting specialists of company D are responsible for mounting and fixing? And all of them will have a direct contract with the customer, so no risk add-ons of general suppliers are necessary.

This is only an example. Of course, other configurations are imaginable, like delivering and mounting only by one company. The timber sector is able to do that, presumably this is undoubted. The production facilities of the existing companies are absolutely fit to act in this direction.

If acting like this, the companies could concentrate more on the optimization of production and organization, the partly annoying distinction to supposed competitors by again and again new element structures or variants could become unnecessary. And with it the specifically for newcomers totally incomprehensible and highly confusing variety of different element constructions in the timber sector.

Only one central organization would be necessary to develop those open source system construction kits and put it on the market. The specific available configurators are usable by independent designers. As also the complete construction drawings are generated, adaptation design is not necessary.

An additional main advantage of an ubiquitous available system construction kit is the design of contracts in line with public tender rules. Many independent suppliers are available.

The final coordination of the building process can be managed by the responsible architects, as they are doing already if the contracts are placed to different trades. But combined with the use of a system construction kit the process of tendering and site control is enormously simplified. The ongoing necessary individual design of underground parking, basements with special use etc. stays by the way in the responsibility of the design teams - the system construction kit is only adaptable to the ‚normal' storeys.

In principle this procedure is equal to the process of trade related tendering when different trades are combined, as it is common even today. E.g. the combination of all groundworks and concrete works or the allocation of subjects of building services to one company. But by using a system construction kit all regular storeys are completely planned after configuration of the assemblies and the intermittent, very time-consuming coordination of all participants in the building process is drastically reduced - a big advantage for the design teams. If they would agree to forward a part of their saved expenditures to the client finally a ‚win-win'-situation is achieved. Especially for the tenants searching for affordable flats.

An open-source system would be ideal, if it is provided by an independent organization, so the further development and addition of assemblies is enabled - this would lead to a real industrialization. Discussions who should be participating in such an organization are currently ongoing in Germany. A number of configurations are thinkable - certainly producers should not be directly involved. The independence from single companies would also increase the acceptance by architects. Based on a databank, which could be used similar to the electricity exchange market to manage offers and requests, the necessary (mean) price information can also be given by the system to receive first price information during configuration of the building.

Of course, such an attempt also includes risks. E.g. a big player could try to establish price dumping for specific elements, as it is able to produce elements like interior walls nearly automatically. In the perspective to achieve more affordable prices a partly wished-for effect, but SME will see those developments more critically. But they should have in mind, that those are products of big volume, so the transport costs and -logistics have a major influence. And the market is very big, a single producer will only be able to fulfill a small part of the market's needs. And we are talking only about the segment of multi-storey housing. The additional production for this market can also be seen as a gap filling instead of an alone standing business objective.

5 SUMMARY

To achieve an area-wide industrialization in building processes a rethink by all sectors is necessary:

- Designers will have to learn to deal with more defined elements / assemblies and to invest their creativity in the design with these buildings – in return, the invention of a new detail every day is redundant. And they should take the role as a coordinator of the complete process.
- Producers will have to learn to strengthen their market position not only by modifying the ‚company -own' product, but by an optimization of their production and organization, resulting in attractive prices, quality and ability to supply.
- Customers will have to learn to adapt other strategies of optimization. The maximization of floor area should not be any longer the only decision criteria. Quality of the end product and speed of delivery as well as the standardized application of Life Cycle (Cost) Assessments should be taken into account.
- The Federal State and the Provinces will have to create the regulatory framework for industrial

building by e.g. harmonization of building codes, rules of social housing allowances or higher flexibility of urban planning.

A big step forward towards industrial building processes is possible today based on the digital evolution - but everybody has to participate! Due to the high experience of prefabrication and the precision of fabrication the timber sector can take the lead!

6 ACKNOWLEDGMENTS

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7 LITERATURE

[1] Oltmer, J.: Welche Folgen hat das weltweite Wachstum der Städte für die Migrationsverhältnisse? Bundeszentrale für politische Bildung, 09.09.2013. www.bpb.de

[2] Birch/Wachter (2011, S.3): United Nations Department of Social Affairs, Population Division (2012b, S.3)

[3] Bärthel, Jan (2002): Industrielles Bauen. Leitfaden für KMU-Geschäftsführer. Zürich (vdf HochschulverlagAG)

[4] Nitsche, H. (1952): Grundlagen von Normensystemen; Dissertation TH Hannover

[5] Winter, S., Lechner, M. et.al. (2018): Bauen mit WEITBLICK - Systembaukasten für den industrialisierten sozialen Wohnungsbau, Abschlussbericht, TU München,, www.bauen-mit-weitblick.tum.de

[6] Integrale Holzbauplanung, Abschlussbericht, TU München, gefördert durch die DBU, 2016. (unveröffentlicht)

[7] Schuh, G. (2012): Innovationsmanagement, Springer Vieweg