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Industrialization in Building Construction – Production Technology or Management Concept?

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Abstract

So-called "Industrialization in Construction" is always presented as the ideal solution when the problems facing the construction industry take on survival-threatening proportions.

Hope centres on solving these problems by using state of the art on- and off-site production technologies and standardized products, elements, and modules, but this approach ignores the fact that the problems facing the construction industry are caused by fundamental structural economical deficits, which cannot be overcome simply by implementing measures such as these. Past experience has shown that attempts to "industrialize" the construction process have failed time and again, since such efforts always focus on the production aspect. The following paper attempts to demonstrate the real consequences of rigorously industrializing the construction processes, whereby production-related measures, such as automation or standardization, are not, on their own, the deciding success factors. Success depends on the ability to combine these measures, both with a product-oriented and customer-oriented approach, and the industrialized organization of all production and planning processes.

Keywords: industrial construction, project delivery model, system provider

1. Introduction

1.1 Status quo

A survey of cost structures in building construction [4] shows that the total construction costs account for only approx. 50 % of the total investment costs of a residential building (Table 1). Depending on local land prices, however, this share may differ to the high or to the low side. In the light of industrialization, however, the construction industry can influence the construction costs. However, Table 1 shows that the costs caused by the production process costs (wages, use of equipment, construction methods) amount to approx. 50 % of the construction costs, and can be influenced by industrialization of the production processes.

Table 1: Distribution of Construction and Investment Costs to the Cost Groups [9]

Cost Groups	Total Construction Costs			Investment Costs
	Share of Manpower / Equipment	Share of Material	Construction Costs	
	%	%	%	%
Land				25 %
Planning / Management			~ 10 %	5 %
Development	70 %	30 %	14 %	
Structure	50 %	50 %	36 %	
HVAC	40 %	60 %	30 %	
Finishings		40 %	20 %	
Construction Costs	~ 50 %	~ 50 %	100 %	53 %
Outdoor Facilities				7 %
Financing				5 %
Marketing				5 %
Total				100 %

The potentials of economies and efficiency respectively, which are immanent to the construction cost group, can be classified as follows:

- Increase of the efficiency of the production processes and methods
- Elimination / reduction of working hours lost due to inclement weather
- Elimination / reduction of weather-related fluctuations in performance
- Increase of efficiency by clear work flow processes
- Elimination / reduction of searching for material
- Elimination / reduction of rearranging material
- Reduction of loss of material

This would increase the value-adding activities during production and, to a large extent, eliminate the non value-adding activities (Figure 1).

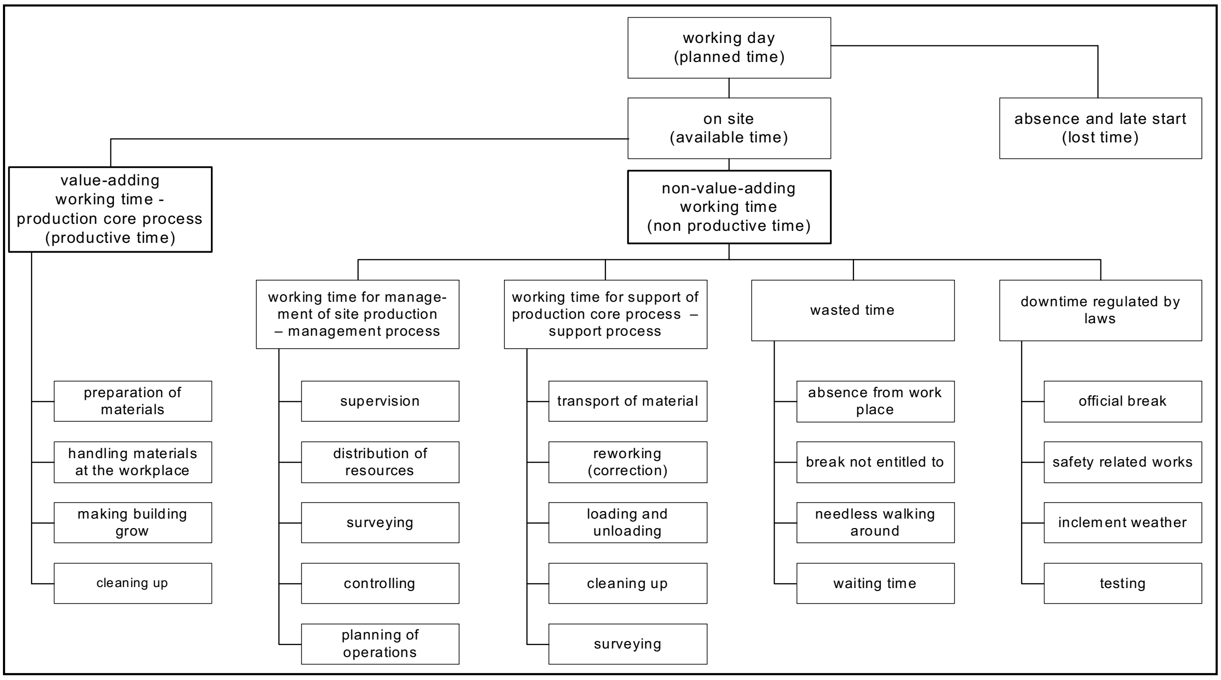

Figure 1: Systematization of working time on a construction site [14]

Boenert and Bloemeke[[2] show in a survey of building construction sites with largely parallelised structure, technical installation and finishings activities that approx. 33 % of the hours are used for non value-adding work as searching for, and rearranging of, material, which shows potential for an increase in efficiency. Potential for increasing efficiency on traditional construction sites has also been identified by Winch [14].

Not only the pure service provision process but also the support processes (Figure 2) in an enterprise can be organised in a more value-adding way by industrialisation. Potentials in the support processes arise, among others, from procurement [5] and knowledge management [3], [12] as well as from the production planning. At the time being, however, it can be ascertained in some economically important countries of the EU that the traditional, largely manual, individual on-site production is, to a large extent, undamped due to cheap labour from the new member states of the EU and Portugal. However, an adjustment of the wages is to be expected relatively fast. The industrialisation of the construction processes will then gain high momentum to systematically exploit the efficiency potential.

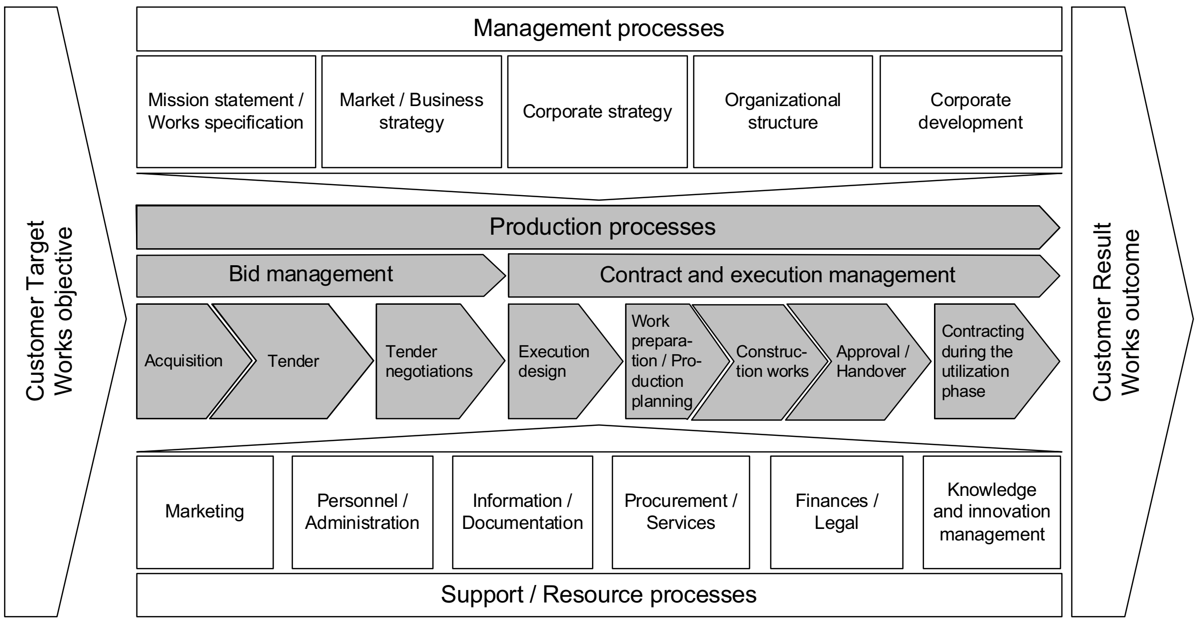

Figure 2: The processes in a construction company

On- and off-site industrialisation of the construction industry will irresistibly make its way, especially in building construction. By developing the tunnel driving machine, the processes in tunnelling have already been industrialised by:

- Mechanization of the work processes
- Logistic systems for supply and disposal in the back-up area
- Automation of the control systems of the tunnel driving machine and the logistic back-up system
- Functional separation of parallelized work processes

As the stationary industry - and not only mass production but also unicum production (e.g. turbines) - has mechanized, computer-aided, and automated its production and service provision processes as stationary in line production and integrated the support processes, a comparison with regard to transferability to construction is indispensable.

1.2 Demands on industrialized construction

A closer analysis of "conventional" industrial production reveals a similarity of the specific characteristics. Taking the particular constraints of construction into consideration, they could, for example, be applied to define the demands on industrialized construction as outlined in Table 2.

Table 2: Characteristics of industrial production and parallels to construction production

Characteristics of industrial production	**Demands on industrialized construction**
Centralized production	Pre-fabrication of components at the factory
Mass production / increasingly variable production	Development of variable basic types
Production based in standardized solutions and manufacture of variations	Standardization of components but still maintaining flexibility of design
Specialization	Focus in specific market segments
Integration of planning, production and marketing	Interaction of building design, production planning, production / construction
Optimized processes and organization	Optimization of the planning and production processes in terms of automation and mechanization

This refutes the frequently sweeping claim that industrial production is not possible in the construction industry on the grounds of its typical situation that cannot be compared with the conditions prevailing in other industries.

Previous attempts to industrialize construction primarily focused on the objectives of replacing manual labour with machinery and automating permanently recurring processes. To be successful, however, any approach aimed at creating industrial structures in the construction industry must extend far beyond these processes, and must lead to process reengineering, or even the establishment of system provision.

Industrialisation of production can be reached by:

- process oriented work preparation and production cycles
- optimized (mechanical / automated) machinery and plant for on-site as well as for off-site production

For implementation in the construction industry, business and cooperation models are required. Industrialisation of construction is a generic process with

- Standardization
- Systematization
- Flexibilization
- Rationalization

Industrialisation has different paradigms (Table 3). Realisation of the different paradigms or their combinations requires collaboration with designers and construction companies of different trades. Further, new project delivery models are required if more standardisation and off-site production is anticipated.

Table 3: Industrialization Paradigms

Paradigms	Process orientation	Design to build	On-site production	Off-site production	product orientation	sustainable product orientation
Measurements	for off- and on-site production: • using work planning and controlling tools to reduce the non-value-adding activities • production flow • logistics	• collaboration / cooperation in design between designer and contractor • standardisation of elements, details, connection • unifying similar elements and details • digital transfer to production equipment and controlling	• work planning • supply planning • work progress control • using mechanical plant • planning off-site logistics • controlling	in factory: • clear sequences of work • independent of climatic conditions • clear work-preparation • work planning • supply planning • using mechanical and automated plant	develop, produce and sell: • clients groups • process oriented production • pamper clients or cost leader • marketing	product is life cycle value oriented: • optimise product in regard to cost- and value efficiency of the life cycle • collaboration / partnering • cooperation • marketing
Marketing strategy / target	cost efficiency	cost efficiency	cost efficiency	cost efficiency	cost efficiency and / or differentiation	cost efficiency and differentiation

In case of product orientation, collaboration and cooperation are required with key designers and trade contractors with core competencies for the product in either case of investment oriented or life cycle oriented construction products. The focus on industrialisation should be in a staged manner, to improve the performance and productivity, and to create continuous improvement for small, medium, and large enterprises. Therefore, the focus is staged in

- improving and rationalizing the work preparation and execution on-site
- incorporating prefabricated products
- producing industrialized on- and off-site structures
- offering to selected client segments off- and on-site construction products

1.3 State of practice in construction production

In order to give the importance of construction production its due, a brief analysis of the state of practice follows, which focuses primarily on the processes found in building construction [9].

When industrialization in construction is mentioned nowadays it is generally linked, above all, to the deployment of computer-aided or computer-controlled equipment. Such equipment is, however, so far only common in partial areas of on- and off-site construction production. Although all levels of industrialised in line production with mechanization and automation, ranging from pure manual production right up to highly automated production plants, are found in pre-fabrication, building site production is still dominated by manual construction using different, mostly non-automated mechanized equipment.

1.3.1 On-site production

The majority of works on building sites are still performed manually to this day. So far neither mechanization concepts, nor and particularly automation concepts, have achieved any widespread acceptance. In the field of masonry construction alone there are first signs of mechanical cogging equipment being used to supplement manual labour, whereas in concrete construction the last major streamlining surge was triggered about 20-25 years ago by formwork systems. Whilst progress in the field of material technology has been ongoing, with a trend towards high-performance materials becoming recognizable, the field of material processing has more or less stagnated.

The development and continuing reduction in size of high-performance and robust DV systems, declining prices for electronic and hydraulic components and the development of service robots, for example, in space, nuclear and underwater technology are providing impetus to continue efforts aimed at automating building site processes. In extreme working conditions, easily programmable and controllable equipment has achieved very high levels of reliability and accuracy, which look promisingly like it could be transferred to building site production.

The real challenge facing on-site production therefore lies in ensuring a working environment and processes that are suited to automation.

1.3.2 Pre-fabrication / Off-site production

During the course of the first wave of industrial automation, which took place back in the 1980s, the first pre-fabricated concrete and masonry elements and modules were also developed for production. Based on in line fabrication processes with a relatively simple structure for the production of concrete pipes, concepts were developed for automated stationary off-site production that were also transferred to the fabrication of elements and modules for residential building construction over time. As such, it would theoretically be possible nowadays to use for the in line production CIM technology to construct a variably designed building completely from elements and modules that had been produced by in line production by computer-aided manipulators and equipment which acts stationary. This would allow a wide range of variability in the architectural design by simultaneously standardizing joints and connectors, reinforcement, wall sections, and, to a certain extent, the material used. The prefabricated elements and modules would then only have to be assembled on the building site with a minimum of effort. Some manufacturers even venture one step further and already offer partially or fully finished building modules like e.g. bathrooms. It is hereby of secondary importance whether the elements and modules are concrete or masonry. Correspondingly automated production machinery is available for both materials, both for use on building sites and for the fabrication of finished elements and modules. Highly-developed production planning and control support for the planning and control of the entire range of fabrication processes are, however, crucial but available in other economical sectors and need to be adapted.

The off-site fabrication of elements and modules in production and assembling lines enables not only the fabrication of simple structural elements but also fully integrated elements and modules with insulation pipes, cables and basic finishing. For the on-site assembling, special joints and connectors are required for the structure and the technical installations. In this case, the prefabricated elements and modules include all the technical and finishing works. The degree of individuality also increases with the resulting decline in the size of the series of the elements and modules (Figure 3).

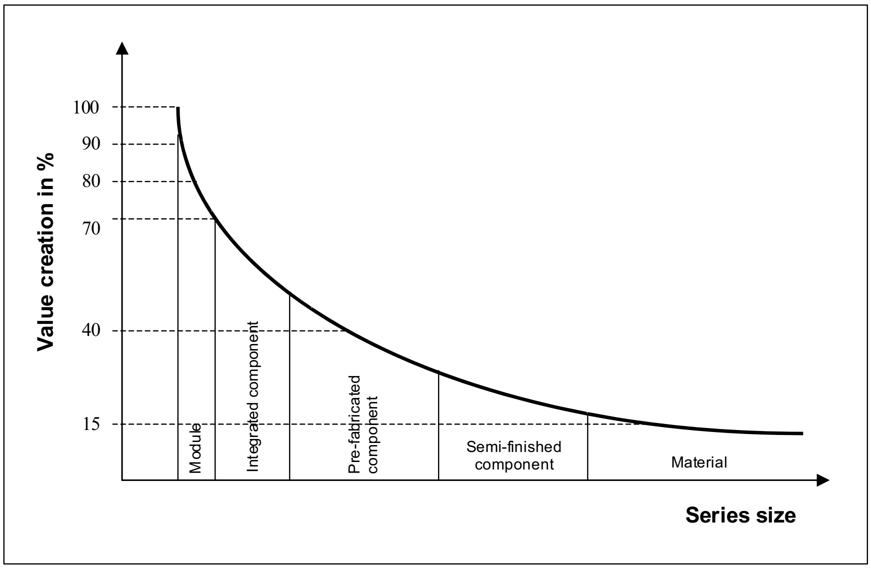

Figure 3: Value creation and series size

1.3.3 Transferring technologies and procedures from other branches of industry

A generalized analysis reveals that the work steps in construction production are very similar to those in other areas of industrial production [10]. The primary categories of work involved are the handling and transport of materials, the fabrication of elements or modules, fittings and connections, the positioning and fixing in the corresponding place, and the prior and subsequent processing steps using special tools. Equipment is already available to handle many of these work steps, and these could be adapted for on- and off-site construction production. One of the characteristics of construction production is the frequent need to work with large and heavy components, elements or modules, which places particular demands on the transport capacity and mobility of placing equipment. Nevertheless, a “peek over the fence” looks promising, given the comparability of the fundamental processes.

2. Consequences for processes and organization

2.1 Means of escaping price competition

The fragmentation of products and services in the construction industry has lead to pure price competition which is one of the primary factors that has resulted in the problems facing the construction industry today. Suppliers and products/services have become virtually interchangeable and replaceable since specific quality attributes are not developed in the manufacturer-neutral planning process. The “classic” structure of a construction contract comprises planning works performed outside the sphere of influence of the construction or prefabrication company with the property developer or owner employing a planner, a construction company, technical installation and finishing companies, whereby the companies have to implement the design in line with technical specifications without being able to accept or analyze the feasibility and optimize the same. All that is important is that the works are offered at a lower price than the competitors and performed within a timeframe stipulated by the client. Any strategy aimed at industrializing construction must therefore include approaches to overcome the fragmentation of planning and construction works, which has resulted in the current situation on the construction market.

2.2 Interactive works and production planning

A strategy aimed at making construction profitable for contractors again must also start at precisely this point. The contractor must use other differentiation characteristics in the market, and not just price, to prove his suitability for performing the works. These include, above all, offering the client total services tailored to his specific needs as a basis for the construction works, and rendering these same services quickly and with a high level of quality. Sufficient run-up time for integrated, interactive works and production planning is crucial to allow the contractor enough time to plan the working drawings and the construction production processes in detail and accurately. Potential areas of planning optimization are to be found in the integration of all requisite works into a production planning process that takes all the technical, schedule and commercial aspects into consideration.

2.3 Information flow

One of the major problems currently facing project delivery is securing a coordinated, reliable and ongoing flow of information. The coordination work involved is considerable, given the fragmented approach to delivering projects caused by numerous independent parties involved in the project who all use different computer and information systems. One means of improving construction processes, both in the planning and delivery phases, is to use a consistent database which all the parties involved in the project can access to reduce interfaces (Figure 4).

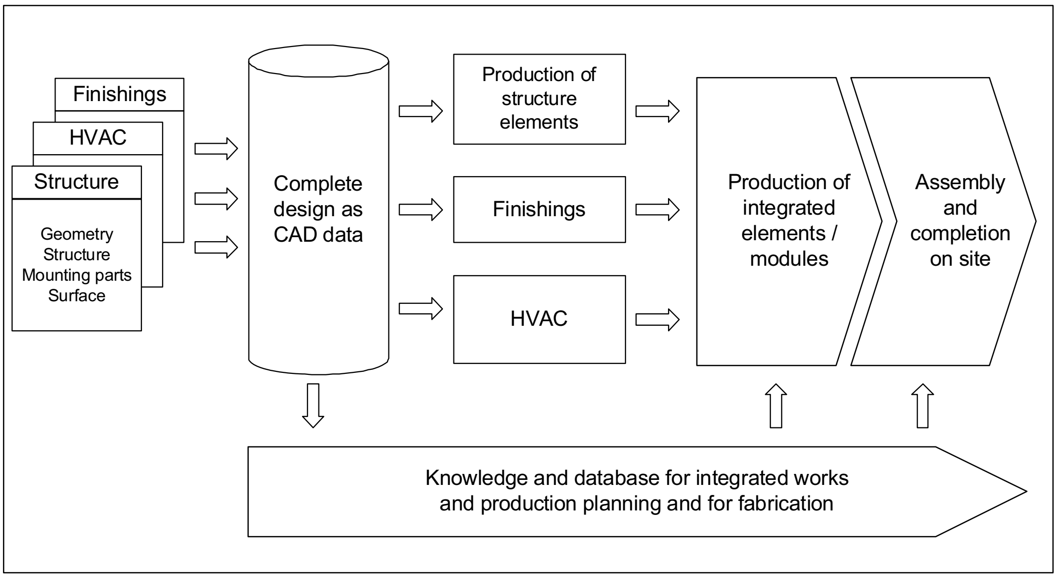

Figure 4: Structure of the planning and construction phases

These newly structured information processes require 3-D-CAD systems with linked data, and the creation of an intrasectoral standard for exchanging information. The currently common exchange of graphics does not meet these requirements at all. On the contrary, what is needed is communication among the various parties involved in the different project process phases, based on object-oriented information.

2.4 Systematic development

Aligning the planning processes to the production needs is a further step towards offering an integrated service from one source. This does not, however, mean that the production should dominate the design of a building. On the contrary, the so-called freedom of design should not necessarily be restricted, especially not in terms of architectural design. However, an analysis of the design alternatives quickly reveals that this freedom primarily exists in varying components, shapes and dimensions of the elements and modules to be produced for the building, and in choosing the fundamental layout and type of building. The technical details and schemes, such as wall or ceiling construction based on pre-defined dimensions, or sound and heat insulation requirements, as well as technical installations, offer broad scope for standardizing components.

2.5 Prefabrication, standardization, serial production

This standardization is also the basis for industrial production processes, which require a certain number of identical parts and / or elements and modules to be economically efficient. But identical elements or modules do not need to be of identical dimensions, they need to be identical in terms of the materials, the build-up of the construction from various materials, or the static impact. The material for serial production of elements or modules that is used recurringly in the same way is either kept available in storage or produced just-in-time; this can contribute to a considerable reduction in construction time since only those elements or modules that need to be manufactured individually have to be built once the contract has been awarded. To limit and standardize the material reduces storage and the bound capital.

2.6 Construction services as a product

If this approach were to be rigorously adhered to, a building could ultimately be compiled from a basic design and a choice of the various components and finishing elements. Various types or series could be compiled and then individualized by altering the parameters, as is standard practice in the automobile industry. This would result in a transition from individual structures, unique buildings that are newly developed each time, to an industrially planned and designed product. This is one of the approaches to genuinely industrializing construction, i.e. not always re-inventing each building, but the industrialized development of a product from an existing, largely standardized portfolio of components, whereby the product can be given an individual design by changing certain parameters in line with customers' preferences.

2.7 The shift from price to performance competition

The current situation in the construction industry does not allow cost benefits to be generated merely by improving methods. Each and every competitive advantage is equalled out by the competition within the shortest period of time, either by imitating the methods or by using subcontractors and, again, applying price pressure to them. The beneficiaries of this situation are the clients who only need to avoid awarding contracts under time pressure to allow them to take advantage of this cost spiral caused by the suppliers undercutting each other's bids. The consequence for the contractor is that he must avoid a comparability of his bid merely in terms of pricing and costs. Then, and only then, can his bid be assessed independently of a purely cost aspect, and in terms of its aggregate attributes and alignment to the client's requirements. In order to achieve this, the contractor may not just respond passively to tenders by submitting prices, but must sell a solution to a problem, in the widest sense, rather than just offering to perform works.

2.8 Incorporating marketing aspects

As a consequence of this approach to organizing a construction project, the opportunity arises of shifting the acquisition of contracts away from reacting to technical specifications towards active marketing and sales of customer-oriented buildings. These activities, unaccustomed for construction companies, allow them to differentiate themselves from the competitors in terms of actual performance, the range of products and services, and quality attributes [13].

A systematically developed variable building product which meets individual customer requirements with the right marketing mix can offer clients considerable benefits, since the composition of the same is known and understandable, and clients receive a precisely defined level of quality, which is not the case with today's traditional, fragmented, individually rendered services where the building with all its standard details is re-invented. In residential building construction, especially, design plays an important role. As long as a supplier is able to create a typical design with a high level of recognition, certain standardized quality attributes will be permanently and unconsciously linked to precisely this design.

3. Expanding the portfolio of products and services to become a system provider

3.1 Plan, finance, build, operate

The industrialization requires expansion of the design scope but also of the scope of responsibility of the "product" (the building) in one hand. Industrialization offers opportunities to tie in other activities that extend far beyond the actual construction. Initially it was turnkey construction and general services contracting that led to an expansion of the portfolio of products and services offered; these were followed by project development including financing and marketing services. Nowadays an integrated solution that meets the specific needs of a client is required in many areas, which can include operation and all manner of life cycle services. Irrespective of whether the building is destined for the client's own use, as a production facility or an investment, the construction industry faces the opportunity and the challenge of meeting all these needs and, in doing so, gaining access to client groups that were previously inaccessible [7].

As such, the provision of processing works is being replaced by a broad portfolio of products and services, whereby each of the areas of planning, construction, financing and operation – either on their own or combined – can open up new potential markets.

3.2 System competency, system providers

The need to develop such competency arises for anyone wanting to engage in industrial construction [7]. Companies need to be more and more flexible and able to offer integrated products and services along the value chain if clients so wish.

Industrialized system providers with specific products, services and customer segments interpreting system business as an integrated approach that affords equal importance to all the stages and components of this service, ranging from planning to construction to services, such as financing and operation, will open a window for new customer segments and for innovation. A purely construction management approach in industrialization is the wrong route to take, particularly for large corporations, because the integrated synergies and continuous improvements can not really be controlled. However, industrialization requires the integration of different key components of the value chain. The system provider needs to have the key competence in-house, but needs not necessarily to provide all performance and services by his own. The modern architecture of system providers in the industry concentrates on core competencies and a set-up of cooperation partners in a network. The future of industrialized system providers in the construction industry requires a paradigm change from stand-alone service providers with interchangeable subcontractors selected each time only on price criteria to strategic alliances with key designers, producers, and on- and off-site trades for the product and service offered [8].

The successful establishment of system competency depends on maintaining core business in-house, whilst buying in all the other expertise and components.

4. Outlook

4.1 Continuous development of construction methods

Experience from other industries has shown that the development of automated processes and robot technology, in particular, cannot be stopped once initially triggered. This surge in development requires the implementation of the requisite workflow, logistics, cost and/or quality advantages compared with conventional production and, in terms of equipment, units that can be deployed as independently as possible, and which are easy to operate and program. In the long term, the generally recognizable trend towards miniaturization in machine technology, i.e. developing smaller, lighter and simplified equipment with the same performance characteristics, but with ever more complex steering and control mechanisms, will, moreover, result in far more efficient solutions in process technology. Particular focus must be given to interoperability of different construction methods and equipments which, in general, operate in sequential but parallel workflow. Not the optimized single equipment or construction and finishing method leads to an industrialized, efficient, cost-optimal solution - to the contrary: the workflow, construction and finishing methods as well as the equipment must, in off-site and, in particular, in specific on-site construction operations, fit well together to reach an undisturbed high value creating over all processes.

4.2 Continuous development of information technology

As already outlined, the information flow will be the central element that will be used to control and link all the planning and construction areas affected by industrialization. Starting with high-performance data transfer concepts, and the integration of all parties involved in the project using EDM and internet solutions right up to the simulation of construction processes to provide prior information on efficiency, possible conflicts in the sequence of work, timeframes and costs, information technology will form the central nerve system of any industrialization.

In terms of industrial fabrication, the use of these methods and technologies requires a certain level of standardization and logistic planning to allow either the serial production and storage of frequently needed material, elements and components or the just-in-time manufacture of the same.

This offers considerable potential to reduce the construction time since only the really individual components for a specific building need to be manufactured once the contract has been awarded, whilst standard elements can be used to a major degree.

4.3 New contract and cooperation models

As a construction company's product increasingly shifts from providing processing capacities to an integrated system concept designed in line with client needs, the conventional contract models also reach their limits. New forms of cooperation are needed that are also demonstrated by new contract and compensation models. Switzerland has taken first steps in this direction with its "Smart building" [11] concept, a contract model that integrates the companies performing the works during the project definition phase already, and results in the structure being completed by work groups, where several trades are combined and offered to the property developer and performed as a "service package" by a group of companies, with the contractors who are involved being responsible for coordination within this package (Figure 5).

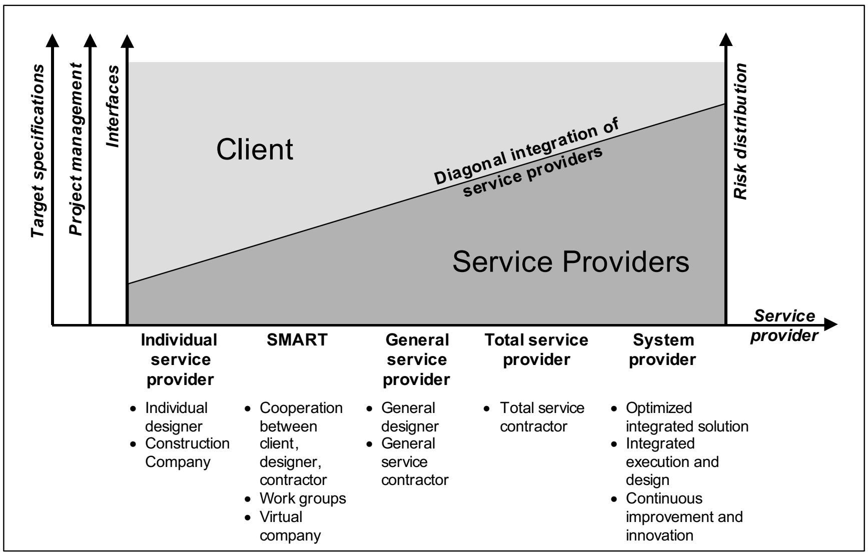

Figure 5: Project delivery models

In Europe, the growing practice of using GMP (guaranteed maximum price) with value engineering in total provision contracts (CM) [1], a contract model derived from American contract law, is a means of responding to the changed cooperation structures. With this form of contract, the client, planners and operators cooperate during the planning and execution phases openly and with the same mutual target to develop an optimized service within a fixed cost framework. This type of contracts could support the industrialization in construction industry to transfer early responsibility for the project to the contractor to allow the integration of building design in the production planning.

5. CONCLUSION

A construction company's orientation to client requirements that can extend far beyond the pure construction works forms the basis for developing industrialized system services and system competency [6]. Considerable earnings potential for construction companies can be found, especially, in providing supplementary services, since this area cannot be captured using standardized detailed specifications, but rather the contractor can use his creativity to set himself apart from the competition in terms of industrialized performance, by developing cooperative, innovative services comprising planning, construction, financing and operation, which are tailored to the individual requirements of each client.

The SysBau system services model developed by the Institute for Construction Engineering and Management at SFIT Zurich clearly illustrates this approach, thus forming a basis for integrated services within the framework of industrialized construction.

The systematic industrialization of manufacturing processes has already been implemented in all of those sectors of industry where top-quality, complex products are manufactured for a relatively clearly defined circle of customers, such as the automotive, airline or plant engineering sectors. Customers are offered all-in-one products, which demonstrate manufacturer-specific quality attributes, use cutting-edge technologies, are manufactured using state of the art fabrication methods and technologies, and, moreover, also include financing and other services incorporated in a cooperative supply chain.

The construction industry is also in the process of adopting this approach to industrialization. The future success of a company will depend primarily on its ability to identify the relevant potential areas of success and to take advantage of them, without fear of accepting new developments.

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