Understanding Complex Construction Systems Through Modularity

Tor Clarke Jensen, Baris Bekdik and Christian Thuesen

Abstract This paper develops a framework for understanding complexity in construction projects by combining theories of complexity management and modularization. The framework incorporates three dimensions of product, process, and organizational modularity with the case of gypsum wall elements. The analysis finds that the main driver of complexity is the fragmentation of the design and production, which causes the production modules to construct and install new product types and variants for each project as the designers are swapped for every project. The many interfaces are characteristics of an integral system, rather than a modular, although the industry forces modular organizational structures. This creates a high complexity degree caused by the non-alignment of building parts and organizations and the frequent swapping of modules.

Keywords Modularity · Complexity · AEC · Construction · Project-based production (PBP)

1 Introduction

The architecture, engineering, and construction (AEC) industry differentiates from other production-based industries by its unique properties. The project-based production (PBP) nature of the construction industry combined together with size of the projects causes high complexity. Researchers such as [1] and [2] define the projects as hyper-complex, but do not explain where this complexity arises and evolves. Although sub-products such as gypsum walls are produced according to mass production principles, the final construction product is very much tailored

T. C. Jensen · B. Bekdik · C. Thuesen (✉)
Department of Management Engineering, Technical University of Denmark (DTU), Copenhagen, Denmark
e-mail: chth@dtu.dk

T. D. Brunoe et al. (eds.), *Proceedings of the 7th World Conference on Mass Customization, Personalization, and Co-Creation (MCPC 2014), Aalborg, Denmark, February 4th - 7th, 2014*, Lecture Notes in Production Engineering,
DOI: 10.1007/978-3-319-04271-8_45,

according to the highly varied PBP requirements. Therefore, the uniqueness of each construction project involves great challenges in terms of mass customization. The ambition of the paper is to explore the construction industry from a system perspective, as a complex production system. The main idea is to understand the project-based environment of construction through concepts such as modularity and complexity management, which have been developed as a system analysis for operation-based businesses, and thereby potentially enables the application of mass customization principles in construction.

2 Methodology

The research is conducted through an abductive case study combining theories of complexity and modularization with empirical material from a standard construction practices: gypsum walls. The empirical data were collected through semi-structured interviews [3] with the various parties such as architect, project director, and carpenters, which all participate in the design and production gypsum walls. A detailed analysis of a gypsum wall (sub-product) being assembled (process) by a carpenter (organizational unit) will be the core point of this paper.

3 Literature Study

The two theories, complexity and modularity, that the research is based on encompass similar and compatible concepts. They both have a focus on product, process, and organizational aspects (PPO). In this paper, the two theories are brought together in the attempt to understand the highly complex production systems within construction.

3.1 Complexity

Complexity and complex system are not necessarily about large numbers. Appelo [4] describes how small systems such as a single water molecule are complex, because its actions are not easily predictable. This is in opposition to causality, which says that a certain cause will have a specific effect, which characterizes linearity, predictability, and determinism. Complex systems are thus nonlinear and very difficult to predict.

Wilson and Perumal [5] argue that understanding and analyzing complexity is crucial for developing organizational efficiency. In their perspective, products, processes, and organizations are related and all have their own role of complexity; however, managing each subject alone will not provide much improvement compared to a combined approach.

The Product Complexity arises from a variety available to the end customer. It is a tough balance between having enough variety and too much variety; too little will send market shares to competitors, while too much will make products cannibalize on existing products' market share [5]. The actual introduction of new packages, products, or other product-related innovations also increases process complexity, as this results in increased variety through the whole value chain [6]. Wilson and Perumal [5] subdivide product complexity into external and internal, where the external is the actual product range. The internal product complexity is derived from the elements, which are used to create the product such as parts, specifications, and instructions.

The Process Complexity arises through the amount and dependencies of processes within a production chain. The more direct the production chain is, the less the complexity costs are associated with the product, while rework and work-around are consequences of too much complexity. Reducing process complexity is very similar to the lean concept of process waste and non-value-adding processes. Wilson and Perumal [5] say that process complexity and non-value-adding costs can be treated as equivalent at a practical level, but technically they are different.

The Organizational Complexity of a company is related to the amount of organizational units, systems, and assets, which the company involves in performing its processes. The complexity of the organization and the processes are strongly linked, and the organizational complexity usually arises to cope with the increased complexity of the processes [5]. Ashkenas [6] describes how incremental change can increase the organizational complexity, as small tweaks keep adding complexity and this often goes unrecognized.

Intersection between different types of complexities. Wilson and Perumal [5] argue strongly that the main reason for complexity to arise is the relations between the three dimensions of product, process, and organization. These are related through the complexity cube, which is a three-dimensional diagram with an axis for each dimension as shown in Fig. 1. The further from the center, the more the complexity, and this means that the complexity is multiplied rather than added for each dimension. As Wilson and Perumal [5] treat complexity costs and non-value-adding costs equally, this also means that the degree of non-value adding will increase steadily with the company generating less revenue.

Product/process face—Where complexity arises. The product variety strains the performance of processes producing the product, and this influences the profitability of the product. As the processes are required to deliver the product, these constitute a substantial part of the product cost. The processes are, however, not isolated to a single product, but are connected to a series of products, which accumulates the overall cost of delivering the products.

Process/organizational face—Where complexity hides. As the process is how a work is delivered, the process/organization face is about how the organization deploys its resources to execute these processes. This face is the least tangible, as processes are dispersed between organizational functions, which may be divided into silos, and the holistic view of the processes is thus lost. The amount of resources required for a given process is thus not visible without any in-depth analysis.

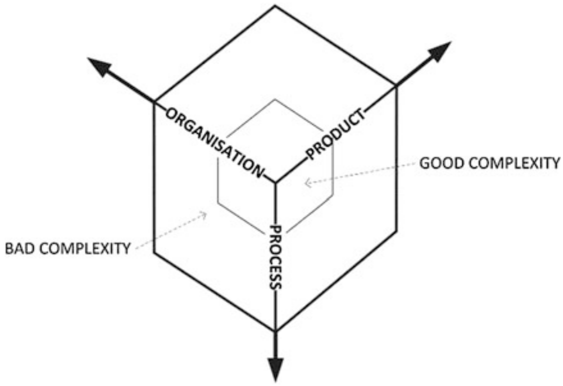

Fig. 1 The complexity cube. Modified by author from original in Wilson and Perumal [5]

Organizational/product face—Where complexity takes root. This is where organizational resources are allocated to the products of an organization. These resources include physical assets, organizational structures, and supply chain partners. This face has the largest need of investment and thus holds most assets such as facilities, technology, and IT systems, but also increased cost with a fragmented supply chain and rivalry between functional units. The organizational/ product face will always seek to optimize itself according to the given conditions, so the organization and products become dependent on each other. The roots occur through a series of iterations, where the product portfolio cannot be reduced because the assets will be obsolete and the assets cannot be reduced because these support the product portfolio. The complexity thus becomes trapped and cannot be controlled unless both the product and organization are considered simultaneously.

3.2 Modularity

According to Campagnolo and Camuffo [7], there exists no single accepted definition of modularity, but a series of common traits which are generally applied. The main trait as Simon [8] describes is that systems consist of hierarchies of modules and interdependence within a module is stronger than the interdependence between modules. The modules interact with other modules through standardized interfaces, which also allow a decoupling of modules. Campagnolo and Camuffo [7] argue that a modular system is in opposition to an integral one, which provides an axis of analysis, measuring systems according to modular versus integral structure.

Given the broad acceptances of the concept, Campagnolo and Camuffo [7] argue that every system is modular to some extent. This gives rise to different ways of understanding and describing modularity.

In Campagnolo and Camuffo's [7] review of the concept of modularity, they identify three streams of literature clustered around three different units of analysis: (a) product design modularity, (b) production system modularity, and

(c) organizational design modularity (p. 260). Based on Thuesen [9] reinterpretation of the modularity concept, these categories are in the following referred to as product, process, and organizational modularity.

Baldwin and Clark [10] describe how modularity is a strategy to manage complex products and processes. Managing modularity deals with hidden and visible information, where the hidden information covers the interdependency within the modules. The visible information is concerned with the overall architecture, interfaces, and standards, which all cover external information for each individual module. In this relation, architecture is the dominant aspect of modular systems, as this describes the modularity principles, functions, and interaction. In order to manage modularity, the architecture has to be apparent and this has to be in control of the architect [10].

3.3 Complexity and Modularity in Construction

A construction project is unique, while a mass production is repeated. Bertelsen [2] accepts that projects can be defined as production, but says that in order to understand the construction projects, a complexity approach also has to be applied. He defines construction projects as complex systems which cannot obtain optimality: neither in design nor in production. Projects are thus unpredictable and nonlinear and cannot be followed through specific linear phases and with independent organizations.

The complexity of construction projects means that traditional learning through experience does not necessarily increase efficiency over time. Traditional construction always incorporates a number of crafts into the construction organization. Depending on the project and contract type, the client will hire the contractor/contractors to perform the actual production as well as consultants to perform the program and design. The contracting organization may be organized in different configurations (or architectures), but are generally divided into subcontractors consisting of individual companies or organizational units according to crafts or professions. Relations between a client and contractors or main contractor and subcontractors are usually established through tenders, and the ensuing relationship is upheld through contracts.

The organization is thus modular to the extent that crafts can be interchanged and the contracts act as standardized interfaces and their also exists a number of platforms. Standards for organizing projects, such as AB92, exist for the Danish construction projects, so this matches the definition of modularity of Baldwin and Clark [10], but in particular, the architecture is difficult to translate into a project environment. The modularity combined with complexity together with the advantages and challenges in the application of construction sub-product will be analyzed in the following section.

4 Analysis of Gypsum Walls

The detailed analyses of the gypsum wall production as a construction sub-product are studied in this section. As explained earlier are the empirical data collected through a series of interviews. Figure 2 illustrates a general overview of the gypsum wall production including the process and the involved organizations.

Gypsum walls have become the standard choice for partition walls, as it is the easiest method of establishing partitions between rooms. They also have a low cost compared to their high acoustic and fire protection rating. In addition, they have a good constructability as they are very flexible and easy to get into the building. An example of a gypsum wall is shown in Fig. 3.

4.1 Case Analysis

The gypsum wall application case will in the following be analyzed with a product, process, and organizational focus.

The product focus. The products or sub-products in question are the gypsum walls, which are divided into a series of variants/types. The gypsum walls consist of steel profiles with screw-mounted gypsum boards with insulation material in between. In addition, the walls are plastered and painted and some include technical installations, mainly electrical installations. The gypsum wall types are differentiated by the components: three types of steel profiles, two types of gypsum boards, and three types of insulation (more component types may be procured). The structure also differentiates between single or parallel steel profiles, number of boards, boards on one or two sides, and single or double insulation. The actual sub-product module is defined as all internal or directly mounted components on the gypsum wall without other interfaces.

In addition to the actual module, a series of interfaces connect the gypsum wall to other sub-products. The most direct interface is with the (concrete) slab elements, as in Fig. 3, which supports the wall at bottom and top. The penetrations of technical installations are also considered interfaces as well as ceilings, floors, glass walls, (concrete) wall elements, and façades. This leads to two kinds of interfaces: penetrating interfaces and mount interfaces, which could be subdivided into line and point (for TVs, etc.). Internal electrical installations should also have an interface to the electrical supply system. The product interfaces are not specified on components or material, but are established on-site according to the erected sub-products. The main means of performing the actual interfaces are through screws, glue, or sealants. Each single wall may have different interfaces, as these are determined by the different designers.

Although the initial product coming directly from factory is a mass production product fitting pick-to-order (PTO) scenario, the variety between the gypsum walls and their established interfaces could mean that all walls are individual and therefore follow an assemble-to-order (ATO) process.

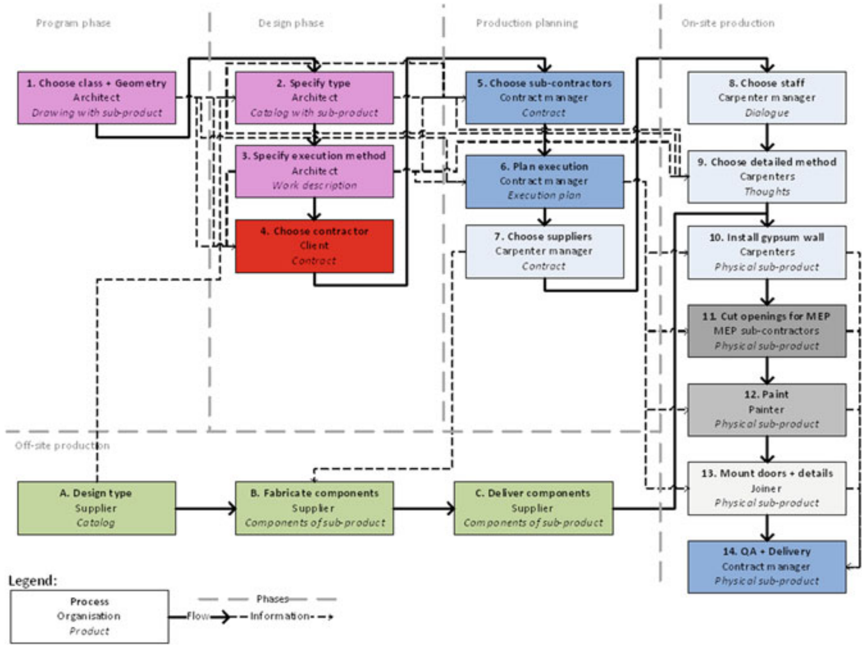

Fig. 2 The value chain of gypsum walls including products, process, and organizational entities

Fig. 3 Gypsum wall production from different perspectives

The process focus. The processes are generally derived from the current product structure and by the crafts traditional work method. The gypsum walls have a set of production processes described in the supplier manual and design information. These processes include erecting steel structure, installing insulation, mounting gypsum boards, installing electrical installations, plastering, painting, mounting doors, and detailing/finishing. These processes are delegated to the crafts according to their traditional domain. The actual production process is thus dominated by the product, which specifies the processes, while the organizations are chosen according to specified processes. Specifying wall type mainly involves creating information on the specific requirements for the individual wall and otherwise following the supplier's manual for attaining these properties. This would suggest a simple process of specification to construction, but as architect explains how information generated may change through the design phase, this will have consequences for the production processes. A process module with similar input and output could be swapped and shared. Knauf Danogips [11] describes mounting gypsum boards: These can both be fixed with screws or glued in place. This does not change the previous process (erection of steel profiles) or subsequent process (plastering), but the three processes cannot be swapped.

The processes themselves are not specifically defined. Both carpenters say that the individual task can be performed in many different ways. The process of aligning the steel profiles is not described. This would imply that the process interfaces are standardized across crafts, but not within them.

The architecture of the project and the amount of interfaces may result in the final gypsum wall product to contain the characteristics varying from ATO process to even engineer-to-order (ETO) process of mass customization scenarios presented by Hvam [12].

The organizational focus. By following the value chain, the main organizations who are involved in the construction of the gypsum walls are architect, carpenter contractor, electrical contractor, painter contractor, and joiner contractor. Other organizations are more indirectly involved, and these include gypsum supplier, consulting engineer, design–build contractor, technical contractors, and possibly other contractors. The departments or project teams of the companies who are involved in the project are defined as organizational modules. The organizations involved in the project also work on other sub-products. The architect is involved in all the non-technical sub-products, while the carpenter is also responsible for construction of ceilings, floors, window sills, and skirting.

Although some of the organizational modules have continuous relationships, these are not actually predefined partnerships. Project director states that although the carpenter contractors are part of the case company, they are only considered if they can perform at a competitive price, and otherwise, another carpenter contractor would have been chosen instead. The architect and consulting engineer are neither permanent partners, so these will also be swappable.

The organizational modularity is evident according to the swap-within and share-across aspects. The question is whether the standard interfaces occur. As these are defined as interaction between organizational modules, the interaction must be standardized. An example of this could be the project clarification, which is used by the carpenter to clarify inconsistencies or alternatives in the architect’s specification.

A topic, which has not been described by the literature, is the individual’s role within the organizational modules. Both complexity management and modularity are based on industrial production or service companies, which mainly work through operations and permanent employees. The project organization of construction systems creates an environment, where the craftsmen do not follow specific organizational units and the different types of functional organizational modules can consist of different companies from project to project.

The PPO-module. The modularity of the product and organization is clearly not aligned, because the sub-products are designed and produced by several organizational units and the organizational units design or produce a series of sub-products. The process modularity dictates which and when the organizational modules are applied. The PPO-modules, which include all three dimensions, cannot follow the described modularity.

The different organizational units only deliver part of the product. The architect delivers a design represented by drawings; the carpenter contractor delivers a steel structure clad with gypsum, the painter delivers plaster and paint to the surfaces, and the joiner delivers doors. The electrician may also install some components within the wall. Meanwhile, the organizations and individuals are split on a series of other sub-products with other associated processes. This provides a structure where the products are divided into materials which dictate processes and organizations.

The PPO-module of carpenter contractor/gypsum wall will include the processes of steel profile erection, insulation installation, and gypsum board mounting. The gypsum wall will, however, also all have PPO-modules of architect, electrical contractor, painting contractor, and joiner contractor. All PPO-modules of the gypsum walls are presented in Fig. 4. The modules will thus be a clustering of processes, and these will also determine the sequence of PPO-modules. The carpenter contractor and individual carpenters will also be part of a series of other modules.

Assessing interfaces. The PPO-module of gypsum wall/carpenter contractor has been analyzed, and the definition of interfaces along the three dimensions has been established. This creates a total of 32 interfaces with 15 other PPO-modules as shown in Fig. 4. The figure is based on conservative estimations of the empirical data and may include more as many of the other sub-products and organizations have not been investigated in any detail.

Product interfaces. Figure 4 shows the 13 product interfaces for the gypsum wall/carpenter contractor, which corresponds to the following:

- Internal: architect drawings, gypsum components, electrical, plaster/paint, doors, details/finish
- External: concrete slabs, concrete walls, façades, glass walls, technical installations (HVAC, electric, sprinkler, etc.), ceilings, floors

The internal products' interfaces all appear in the supplier's manual and are regular. The external interfaces are more irregular, but interfaces with the concrete structure and technical installations are described in the manual. Architect says that mainly interfaces toward the façades and glass walls are specifically designed for the project, which suggests that these are irregular.

Process interfaces. Figure 4 shows the seven process interfaces with for the gypsum wall/carpenter contractor, which corresponds to the following:

- Previous: specifying wall class and specifying wall type, manufacturing components, mounting slab elements
- Subsequent: installing electrical installations, plastering/painting, mounting doors, and detailing/finishing

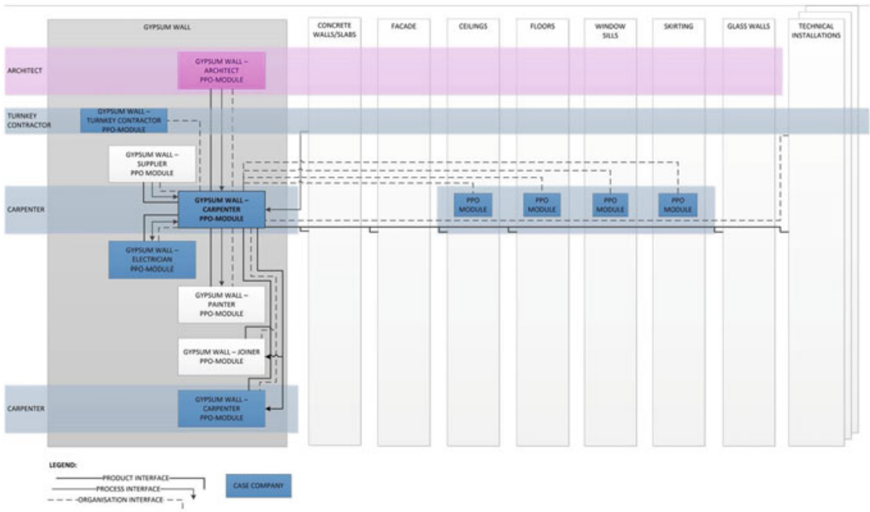

Fig. 4 Interfaces of the gypsum wall/carpenter contractor PPO-module

The process interfaces follow a sequence caused by the process constraints. These mainly follow the supplier's manual, but processes where the supplier is not involved are not described. Architect says that the specification process consists of dialogue with different organizational units such as the client, consulting engineers, and carpenter contractor, which must lead to a series of iterations and thus limits the consistency of the process. The product interfaces which are not regular such as the façade and glass walls will thus not be regular in the process of establishing these interfaces.

Organizational interfaces. Figure 4 shows the 12 organizational interfaces for the gypsum wall/carpenter contractor, which corresponds to the following:

- Internal: design–build contractor, electrical contractor, carpenter (finishes), carpenter (ceiling), carpenter (floor), carpenter (window sills), carpenter (skirting)
- External: Architect, Technical Contractors (HVAC, Electric, Sprinkler etc.), Painting Contractor, Supplier, Joiner

The organizational interfaces are mainly performed through the management such as project director. The main exception to this is the electricians, and this creates a less regular interface from an organizational view, as each individual carpenter thus has interaction with the electrician module instead of this going through the management.

Assessing variety. The variety within the case project should be determined across the three dimensions. The possible variety within the PPO-module will be 14 different wall types, 80 different carpenters, and up to 80 different methods. The carpenters and methods are, however, connected to each other, as each carpenter has their own method, but only if one carpenter works on each wall. The wall types will thus contribute to the highest variety for each individual carpenter. The walls are, however, determined not only by type, but also by geometrical variety. The variety of geometry will increase the variety way above the 14 types. The placement of doors and other components of the wall is neither part of the type, so will increase variety. So when all instances of walls are considered, these will potentially lead to all gypsum walls as unique.

The PPO-module across projects. Although most interfaces are regular to a certain degree and the variety is mainly limited to the different types and geometries, this is only for the case project. Through the interviews, a strong focus has been on the variety of products and processes as well as relationships of organizational units across project. The gypsum wall/carpenter contractor PPO-module is set in the center when assessing it across projects, so other PPO-modules will be swapped rather than gypsum wall/carpenter contractor.

The wall types must be similar, as they are based on the suppliers' manual, and although different suppliers advise the architects, the case company only has a single supplier. The architect, however, dominates all decisions regarding geometry and extra components, which increases variety further.

The organizational interfaces are not as similar across projects as the product and process interfaces. Only few of the organizational units have worked together before, and these are not permanent partnerships. Although it is an advantage that the individuals of the organizational units know and trust each other, the main determinant of an organizational unit's involvement is the price. The main representatives of the organizational units are the managements, while the craftsmen are not permanent employees within the companies.

4.2 Assessing Structural and Operational Complexity

The variety of the gypsum walls is very high as almost all walls will be unique through their geometry or embedded and mounted components. This creates a high structural complexity for the sub-product. Although the detailed methods are very varied, these do not increase structural complexity as methods are embedded within each carpenter, so as long as carpenters are responsible for each wall, this will not result in a large increase. Across projects, the amount of structural complexity will increase even more, because of the unique geometry. The carpenter contractor's permanent agreement with the gypsum supplier reduces not only the sub-product variety, but also the processes. Contrary, the individual carpenters may change company from project to project. The structural complexity is thus high within the case project driven by the sub-product, while both the organizational and sub-product varieties will increase structural complexity across projects.

The interfaces of the gypsum wall/carpenter contractor are very numerous, which leads to a more integral than modular system. The interaction between the carpenter and electrical contractor is especially strong, and the regularity is mainly controlled by the individuals knowing each other. Across projects, this interface will be a strong driver of uncertainty, as the two interacting PPO-modules may be exchanged from project to project. This will create different relations between the PPO-modules and thus increases uncertainty. The rest of the interfaces are managed through the contractors' managements and so will not increase the uncertainty when assessing the case project, but across projects, this will accumulate and increase operational complexity further. This results in a high operational complexity between the gypsum walls' carpenter and electrical contractors, while the other interfaces only provide a medium operational complexity.

5 Discussion

As the current construction system is neither optimal from a modular nor an integral approach strategies for managing, both operational and structural complexities are proposed. This is summed up and related to other ideas for developing a new construction system. The product modularity and organizational modularity are currently misaligned, as the product modularity and organizational modularity follow different hierarchies. This creates many individual PPO-modules and many strong interfaces and thus increases the operational complexity.

If a more integral organization was to be applied, these strong interfaces could provide more regular interfaces, especially organizational interfaces. This creates Development Initiative 1 (DI1) to manage operational complexity:

- DI1: Create regular partnerships with all organizational modules and thus use similar products and processes for all projects.

This initiative maintains all current interfaces within the individual projects, but stabilizes these across projects. By letting the same individuals work together, this creates regular interfaces, and especially if the design modules use similar designs, this will influence the product and processes to apply similar interfaces. DI1 would automatically create a more integral organization, with more focus on partnerships and permanent relations than flexibility, which will have to be incorporated into the system according to the actual need.

Another approach could be to align the product and organizational hierarchies. Ericsson and Erixon [13] describe this system as "small factories within the factory" and thus following an integrated value chain for each sub-product. This would require multiple crafts within the same PPO-module and possibly also design capabilities. The PPO-structured modularity will thus comprise of less PPO-modules and less interfaces by integrating the supply chains for each sub-product into single modules. This creates Development Initiative 2 (DI2) for managing operational complexity:

- DI2: Aligning the organizational modularity with the product modularity and creating PPO-modules by integrating all processes and organization. An illustration of DI2 is shown in Fig. 5.

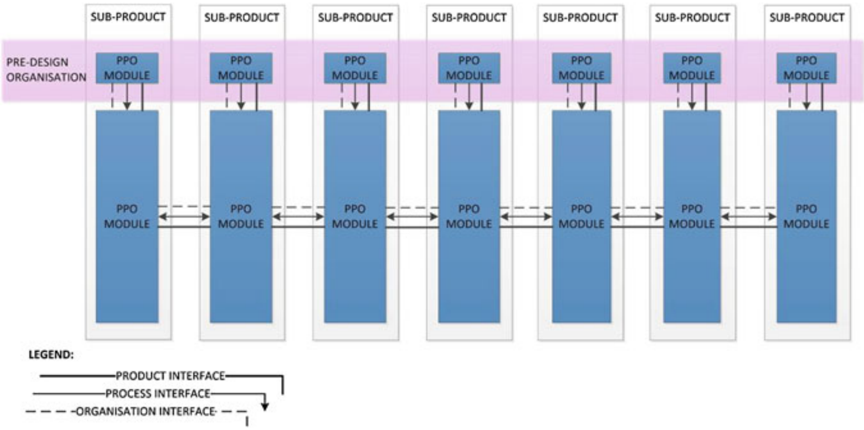

Fig. 5 An example of how the PPO-structured modularity could be implemented through Development Initiative 2. Development initiative 1 would resemble the interfaces and structure found in Fig. 4 for all sub-products

This would require sub-product contractors rather than craft contractors. The integrated PPO-modules would increase dependencies within and decrease dependencies without compared to the existing structure. DI2 will also ease procurement and outsourcing of sub-products. This will help create system architecture, so also interfaces and standards could develop. The system architecture will increase flexibility as the PPO-modules integrating a sub-products value chain can be exchanged at will.

The construction system is currently a mix of strong interfaces and flexible modules in all three dimensions. The two solutions thus go in two different directions: more integral or more modular, where either the interdependence or the exchange of modules shall be reduced. The paper has also found connections between operational complexity and modularity. As systems become more integral, the amount and strength of interfaces increases. This causes the operational complexity to increase, and when modules are swapped and shared, this operational complexity increases drastically.

Modularity is applied on many levels, and this paper has explored modularity on a holistic level, especially product modularity of industrial production requires very specific interfaces. The interfaces of construction sub-products are dominated by less-defined point, line, and surface interfaces, where sub-products can be mounted onto the bearing structure at will. Ulrich and Tung's [14] cut-to-fit modularity thus becomes dominant, while still retaining the swap-within and share-across modularity.

Based on the findings and experiences gathered through the case, it is concluded that the principles of mass customization of a sub-part can be successful when implemented stepwise. The case shows that substantial benefits can be gained through implementing modularized construction. It is especially interesting to note that these benefits are achieved through the development of a module with focus on the internal interfaces [15].

The generally craft-based organization thus seems to be a remnant of the past. Current implementations of ICT in the industry, such as BIM, do not fit well into the current construction system [16], but could be heading development toward a new system, which organizationally would be more operation based. As shown in the analysis is the current system very fragmented, and the development is difficult to implement rationally in such a system [17]. As is often said when discussing industry competition: "Supply chains, not businesses, are the competitors of tomorrow."

6 Conclusion

The complexity in construction projects arises because the system is integral, but acts modular. The integral property arises because the misalignment between the product modularity and organizational modularity and combined with the fragmented organization, variety, and interfaces cannot be managed, especially as the design and production are performed by different organizations.

The paper has attempted to show that the PPO-structured modularity can link the dimensions of product, process, and organization into a common system. The PPO-modules are developed by combining product, process, and organizational modularity into a common structure where the interfaces are also defined across all three dimensions. The PPO-structured modularity is based on the complexity cube and thus uniting modularity with complexity management. This has also added to both concepts, mainly through linking operational complexity with the modular-integral continuum. Applying PPO-structured modularity to a project environment was applicable, and the case project showed how gypsum walls have a dispersed supply chain, with 32 interfaces from a contractor perspective.

PPO-modules of gypsum walls provide variation possibilities and thus serve perfectly to individual customer needs. The different combinations of PPO-modules enable various numbers of solutions, thanks to the flexibility and creativity they possess.

This paper has also developed paths for the industry to pursue in order to manage complexity. This involves developing the construction system as either more integral or more modular, where the integral path is to standardize PPO-modules of the current system through permanent partnerships, while the modular path aligns the organizations according to the sub-products.

This will generate the level of process stability that mass customization highly depends on. Thus, modular production of the studied construction product gypsum wall contains great promises for applying mass customization principles within PBP.

References

1. Christensen, S., Kreiner, K. Projektledelse i løst koblede systemer—ledelse og læring i en ufuldkommen verden, 1st ed, København Ø: Jurist- og Økonomforbundets forlag (1991)
2. Bertelsen, S.: Construction management in a complexity perspective. Salford, UK, 1st International SCRI Symposium (2004)
3. Kvale, S., Brinkmann, S.: Interview—Introduktion til et håndværk, 2nd ed. København: Hans Reitzels forlag (2009)
4. Appelo, J.: In: Eastman, C. (ed.) Management 3.0, 1st ed. Addison-Wesley Educational Publishers Inc., Boston (2010)
5. Wilson, S., Perumal, A.: Waging war on complexity costs, 1st ed. The McGraw-Hill Companies Inc., New York (2009)
6. Ashkenas, R.: Simplicity minded management. Harvard Bus. Rev. **85**(12), 1–10 (2007)
7. Campagnolo, D., Camuffo, A.: The concept of modularity in management studies: a literature review. Int. J. Manage. Rev. **12**(3), 259–283 (2009)
8. Simon, H.A.: The architecture of complexity. Proc. Am. Philos. Soc. **106**(6), 467–482 (1962)
9. Thuesen, C.: Understanding project based production through socio-technical modularity. The Academy of Management 2012 Annual Meeting, Boston, MA, USA (2012)
10. Baldwin, C.Y., Clark, K.B.: Managing in an age of modularity. Harvard Bus. Rev. **75**(5), 84–93 (1997)
11. Knauf Danogips A/S Knauf Danogips manual, 3rd ed. Hobro: Knauf Danogips A/S, Spæncom A/S, 2011. Vægge, Hedehusene: Spæncom A/S (2012)
12. Hvam, L.: Mass customisation in the electronics industry: based on modular products and product configuration. Int. J. Mass Customisation **1**(4), 410–426 (2006)
13. Ericsson, A., Erixon, G.: Controlling design variants: modular product platforms, 1st ed. Dearborn, Michigan: Society of Manufacturing Engineers (1999)
14. Ulrich, K., Tung, K.: Fundamentals of Product Modularity, Issues in Design/Manufacture Integration, vol. 39, pp. 73–79 (1991)
15. Kudsk, A.: Stepwise modularization in the construction industry using a bottom-up approach. Open Constr. Building Technol. J. **2013**(7), 99–107 (2013)
16. Eastman, C., Teicholz, P., Sacks, R., Liston, K.: BIM Handbook, 1st edn. Wiley, Hoboken (2008)
17. Thuesen, C., Koch, C., Monrad, D., Henriks, M.: Styrkelse af dansk byggeris innovationssystem, Lyngby: DTU Management; Teknologisk Institut; Aarhus Universitet (2011)