Andersen, L., 2016. "Design and Engineering – Material" *Proc. 24rd Ann. Conf. of the Int'l. Group for Lean Construction*, 21-23 July, Boston, MA, sect.1 pp. 83-92, available at www.iglc.net

DESIGN AND ENGINEERING – MATERIAL ORDER

Lars Andersen[1]

ABSTRACT

The problem to be addressed in this paper is how to develop the creative forces of collaboration combined with an effective decision making system. The purpose of the research is to improve the new forms of complex and specialized design and engineering processes. Research method is a combination of formative process research, process tracking, and phenomenological analysis. Research case is the construction of a hospital. Construction in oil industry (offshore) and shipbuilding are supporting cases. The empirical study confirms that increased collaboration and interaction in a context of concurrent and integrated design and engineering triggers both value-creation and value-capture, and also that there is a great potential for further development of the process. However, the collaboration based on reciprocal dialogues and the spirit of the partners' independence and equality also leads to deterioration of the logical order of the traditional decision-making process, which triggers reduced process control and design errors. A proposition in this paper is that a satisfactory illumination of the problem to be addressed requires an expansion of the existing lean discourse: The paper first discusses language action theory and the eighth flow approach in a broader theoretical and epistemological context. It then discusses how modern organizational system theory and a material order approach might represent a contribution to this expansion.

KEYWORDS

Design, complexity, collaboration, communication, materiality

INTRODUCTION

The traditional design process is sequential-linear (Bølviken et al. 2010) with a corresponding decision-making system: The architects first make their drawings and decision premises for the Structural Consultants (SC) which calculate statistics, capacity etc. for the building and make drawings for the concrete work. Architects design further on the carpentry drawings, which in turn together with the SC drawings, constitutes the decision premises and basis for the drawing of the technical disciplines. The empirical study support (see also Andersen 2016) that this decision-making system is based on an underlying material-technology order of dependency. This order (rationale) for the

[1] Dr. Philos. Mag.art. PhD. NTNU – Norwegian University of Science and Technology. Trondheim. Norway. +047 92885305. Lars.Andersen@samfunn.ntnu.no

decision-making system in traditional design has, however, to a high degree been an implicit assumption. However, the new empirical development makes it possible to reveal this order and to make it explicit. It makes a reconstruction of the order and its suppositions possible, but now in the new context of integrated concurrent design and engineering and autonomous experts and their reciprocal communications and dialogues. The reconstruction provides for both a basis for fulfilling the potential for increased creative interaction and a decision-making system that triggers increased process control and reduced design errors.

The first part of the paper uses three empirical cases to discuss the practical problems of how to organize for increased creative force and efficient decision making in the design process. The middle part of the paper discusses the theoretical approaches that illuminate the problem to be addressed: First, it discusses language-action theory and the eighth flow approach in an extended theoretical context that highlights the epistemological suppositions regarding holism and individualization. Then follows a presentation of modern (sociological) organizational system theory that strengthens our notions of autonomous (autopoietic) specialized disciplines that are both "closed" to each other and that must at the same time communicate and interact as a community. The paper’s final section presents a theoretical proposal based on phenomenological analysis where both the creative processes between specialists and an efficient decision-making system are derived from analyses of the material-technological order of dependencies in building processes, as reflected in the logic of materialized models and drawings in design. The paper outlines, finally and in accordance with the purpose of the research, some implications of the material-order approach for the organizational layout of the design process.

THE EMPIRICAL CASES: COMPLEXITY AND POTENTIAL

The main empirical case involves the construction of a hospital. There are two support cases based on cross-sectional studies from the stationary manufacturing industry. The study of the hospital project was funded by contractors, consulting firms, and the builder. Support cases are from an ongoing project, "INPRO," funded by the Norwegian Research Council (2014–2017). The research method in the hospital project was formative research (observations, interviews, and workshops) and process tracking: deficiencies in the work substrates (drawings, work plans etc.) of the physical construction was traced to the engineering and design phases, and deficiencies in the engineering to the design phase. The data was subject to a phenomenological analysis. The research method in the support cases was based on interviews.

In **case 1**, the hospital project used Integrated Concurrent Engineering (ICE) and Virtual Design and Construction (Chachere, 2009) with collocation. In the ICE session (both formal and informal), the activities were parallel and integrated and participants constructed their object areas using meaning-centered communication (Clegg and Baily, 2008; Luhmann, 2002; Andersen 2016), in which the participants reciprocate and through iterations build on each other's ideas, adding meaning on meaning. Meaning-centered communication is fundamentally unpredictable; participants understand their own contribution by virtue of what the other answers (Luhmann 2002). The participants have mutually enclosed knowledge domains (distributed knowledge), but are at the same time communicating to create common emergent meaning corresponding to the joint product of the process.

Some of the discipline participants organized themselves at **discipline** level (cf. SC, Electrical Consultant (EC) etc.) using their own separate meeting arenas, but it was large variations between companies; and general ambiguities about how the disciplines systematically could reinforce and use their resources in the project. The communication in the meetings where the discipline discussed their tasks in the different multidisciplinary teams had anyway elements of meaning-centered communication and emergent processes.

The organization of the design process was essentially **interdisciplinary**. The project was divided into parallel working, multidisciplinary teams organized according to different thematic parts of the building based on clusters of interconnected, determining functions: entrance hall, auditorium, operating rooms, etc.). The specialists communicated in the multidisciplinary teams in the interdisciplinary interfaces with limited access to each other's knowledge. What is happening between the disciplines, however, cannot be understood solely by a notion of interface. The processes in each multidisciplinary team take the character of a separate, closed, emerging community creating its own unique and unified object.

The multi-disciplinary teams were coordinated on the **project** level by a core group. Also, work at this level takes the character of something substantively and as more than a coordination of the multidisciplinary thematic groups.

The study showed an interdependence between the emergent processes at each level: creative expertise at the discipline level is, for example, a prerequisite for creativity in interdisciplinary dialogues and vice versa. In accordance with ICE was the communication form in the hospital case marked by equal dialogues and roles in decision making: all subjects and disciplines counted on an equal footing both at the multidisciplinary level and at the project level.

Case 2 deals with the design process for the construction of oil rigs. The company wanted to concentrate the work of the disciplines into multidisciplinary teams and intensive interactive processes. The new way of working thus began with a phase of system design going through the entirety of a single rig construction. Then, inspired by the development methodologies of Scrum and Agile, the company developed a method in which a multidisciplinary team sequentially works through modules extended to physical subareas of the rig construction. The areas of the rig as a whole was not processed in parallel and integrated. This implied that the project level was not included as a simultaneous and dynamic element in the process. The organization with a single team that worked through the whole construction created a great demand for generalist skills. **Case 3** deals with the processes of a design unit in a shipyard, originally organized top down and with a process in which the disciplines followed in a sequential, linear order. Then the unit changed to a flat structure with a multidisciplinary team organization - with each team working with one project. The new culture was based on dialogic and open processes with emphasis on integrated joint expertise, generalist competence, and knowledge sharing.

Out of the three cases, it is Case 1 that has the most developed and complex process with a parallel and open interplay between all three levels: discipline, multidiscipline, and on the level coordinating the multidisciplinary teams: the project level (compact complexity). On the multidiscipline level, the joint product is an evident object (the restaurant, the auditorium, etc.). The project level gets the architect's purpose to appear based on what we in the continuation shall call structural material. One can assume that the most intensive form with the highest innovative force takes place when all three levels concurrently and in mutual interplay produce emergent contributions.

In Case 1 during the building process, defects in the work substratum (drawing, models and plans) were revealed, and also how the emphasis on dialogue between equal participants resulted in a vacuum in the common decision making process (Andersen, 2016). The pattern of the defects made it possible to track the causes of the errors back to the vagueness and lack of order in the decision-making structure (and tendencies to a decision vacuum) in the design and engineering phases (a split turnkey contract used in the project helped to highlight the matter).

THEORETICAL APPROACHES

LANGUAGE ACTION THEORY – ORGANIC KNOWLEDGE AND HOLISM

Language Action Theory is especially used in connection with the Last Planner System (Ballard, 2000). The theory focuses on how people in organizations work through speech acts. Speech acts bring into focus “assertions, assessments, requests, promises, and declarations" (Parrish, 2014: 1169) and how those as performative utterances "do things" in the real world (Austin). In the Language Action Theory, the coordination of actions takes place primarily in the language in use. Accordingly, organizations ought to be organized around members’ conversations and those conversations’ ability to create binding unity and harmonized actions. In this theory it is the pragmatic relationship in language that is in focus; that is, the relationship between the subject and the utterance.

The Language Action Theory may be interpreted according to Wittgenstein’s (1881–1951) language games, and the tradition as continued in socio-cultural learning theory (Wygotsky, 1978), including Community of Practice (CoP: Lave and Wenger, 1991). Each CoP grows out of specific practices, such as the work communities for machine repairmen, web designers, etc. The CoP approach is also used in the analysis of modern specialized and knowledge-intensive organizations (Carlile, 2004). The organization or project is determined as a community of practice with a unified and integrated knowledge and competence base. This kind of process may be further interpreted by the theory of organic organizations; see for example Burns and Stalker (1961). An organic organization adapts to changing and unpredictable internal tasks in accordance with unpredictable external environments. Organic organization requires employees with broad expertise; the employees are generalists and can work with a wide range of challenges, working in a flat organization with teams of changing compositions, etc. It can be contrasted with a mechanistic organization (Parrish, 2014: 1169), based on comprehensive, specialized work; but in a fixed form and where each specialist's expertise is isolated from the others and tied down to a specialized domain. Language Action Theory is here interpreted in light of an organic holistic tradition where generalist skills (whole) are developed across and above the specialist expertise (parts). Cf. Cases 2 and 3 in the empirical section

THE EIGHT FLOW AND INDIVIDUALIZED KNOWLEDGE

"Individualized" approaches emphasize a conceptual strategy that highlights the individual's and single parts' autonomy in an organization or a project. The theoretical contribution of the eighth flow (Pasquire and Court, 2013) is about human understanding and a corresponding expansion of Lean Construction discourse about physical flows (Koskela, 2000). The eighth flow assumes that knowledge is distributed and that individual people have their unique perspectives, experiences, and understandings related to the network of flows (Pasquire and Court, 2013: 5). According to the eighth flow, the individual´s performance of work is situational and requires the independent use of knowledge, including insight into the relationships of work - or in other words, it requires understanding. The subjects may increasingly create a common understanding through planning processes that integrate distributed knowledge. The assumption of the eighth flow about distributed knowledge focuses on language's semantic side; the relationship between the term (utterances) and what is termed.

The theory Communities of Knowing (CoK: Boland and Tenkasi, 1995) is about communication between separate, different, and knowledge-intensive communities. The knowledge of each community is based on verbalized and explicit cognitive knowledge (as opposed to CoP). Each CoK, has a "paradigmatic" foundation and a shared pre-understanding that gives members a common frame of reference. In highly complex and specialized organizations, such as a modern construction project, each discipline is a CoK. CoK theory distinguishes between perspective-making, perspective-taking, and perspective-presentation (Litchfield and Genty, 2010). Each community creates (strong) perspectives through increased access to narratives and the systematic development of the base of experience (empirical experiments). Perspective-taking is all about taking the perspective of others to see the situation from the other´s point of view as when one discipline takes the perspective of the other. The disciplines' perspective-making, perspective-presentation, and perspective-taking are prerequisites for interdisciplinary communication and dialogue.

In the eighth flow and CoK, individuals and disciplines are independent entities with mutually "closed" (specialized) experiences and knowledge bases. What is common between the units is, however, insufficiently determined. What, for example, providing different individuals a unified outer experience so they can build something common in real external production (construction, models, etc.) - beyond a cognitive plan level? And how is it that the seven "physical" flows are connected with the common reality "out there"? Both the eighth flow and CoK examine the language's semantic dimension without further determining the outer world as the signs and knowledge refer to. Both are limited to linguistic theory and semiotics (Saussure 1974) where the reality outside language melts in the air.

MODERN "ORGANIZATIONAL SYSTEM THEORY"

This theory (Luhmann, 2000) is intended to transcend the dichotomy between holistic and individualistic (atomistic) theories. An organization's members' mental "systems" differ from the organization as a social communication system (ibid). Individuals have freedom and can (as mental systems) connect to and from each communication system. The communication system is differentiated into autonomous part-systems by function- or system differentiation. The systems are operationally closed and autopoietic in the sense that each system creates and recreates itself out of its own elements and its own internal logic (ibid). When the systems communicate, they do partially penetrate each other (interpenetration) – as when disciplines interact. To organize each system involves developing general decision-making premises, such as conditional- and target-programs, communication routes, and permanent membership (individuals), which stabilize and make the autopoiesis of each system possible. Systems theory helps us to determine autopoietic "parts" – the individual disciplines in a design process can develop their own programs (plans) and strong perspectives that they can use in the interdisciplinary dialogues on the thematic level or the dialogues concerning the joint project program. According to systems theory, there is a communication network that keeps the part-systems together through "mutual adjustment". The theory, however, also creates an opening for determining an independent autopoietic communication system with its own content at the interfaces where the disciplines meet and cooperate.

The "organizational system theory" grasps essential features of the empirical process described on the basis of Case 1 in the empirical section; cf. the observation of closed, autopoietic, emergent, and emerging processes in communication arenas at all levels: the discipline level, multi-disciplinary level, and "project level". The content of, for instance, the core group´s work could not be described simply as handling interfaces, as coordination, network formation, etc., but must be determined as a separate emergent communication system with its own content sui generis. But at this point, we also meet the limitations of the theory: First, that all systems are equal corresponding to an polycentric decision-making system. Second, that the theory is a communication theory about the emergence of new levels of order of **social meaning.** Similar to the previous theories, this theory is a "social relational" theory. Husserl, the founder of phenomenology, developed another theoretical base that presupposes that the outer material and technological object-world allow for the human subjects to come into contact with each other. The Corresponding phenomenological method involves analysis of intentionally mediated deep structures in the outer phenomenon world (Zahavi, 2003). Regarding the need to anchor the theories on a metaphysical level, see Koskela and Kagioglou 2006.

THE MATERIAL -TECHNOLOGICAL ORDER

The classical phenomenology implies a change of scene in the sense that we must anchor organizational and project theory at a material-technical order and material dependencies.

This order offers an answer to the question of how individuals' contributions are interrelated and how the system contributions are included in one another in practical life. What is it specifically that gets contributions from the amount of specialists, functions and subfunctions, to be interconnected and united in practice in the outer empirical world?

If we focus on the entrance of the hospital, its lighting fixtures are hung in special places to provide the desired illuminations, the reception is positioned to "communicate" with the front door and further into the building, etc. The single functions are included in a social context to make sense to the user of the building. However, the functions of meaning **do not** float in the air, but are functions of different types of materials. The partial functions are arranged in material causal-chains which lead to features and user-functions: "here it is good lighting", "this room was cool in the summer heat - good ventilation!" The ventilation system is positioned at a place separated from the electrical system. The social context can be extended through user-functions over into a material context - and further into a deeper material order: when user-functions should be arranged, this happens using what I propose to denote **structuring material**: lighting, ventilation, piping, etc. are fastened, build into or lay down in the floor, walls, and ceiling (Andersen 2016). This is the building's "skeleton", the constructional elements (concrete, wood, steel structures) which make it possible to give the other material and individual functions a fixed order, coherence and continuity in space and time. Structural material, logically and in time, precede the other material and functions. One cannot attach the ceiling in the cables. It is the unity of the two dimensions that coordinate each “side” of the process: the social and the material side. This unity makes the specialist´s contributions to something coherent.

It is, based on this approach, the structuring (formative) material that safeguards the "whole" in the process in outer reality, and it is this material that gives structure to the arrangement of the materials. It is first and foremost the architect's task, responsibility, and specialty to preserve and develop the appropriate linkages of meaning; user-values and the corresponding value creation of the building. As an extension of this, they also have a responsibility for the good order and coordination of the user-functions anchored in the physical material contribution of other disciplines.

It is further the Structuring Consultants (SC), structural engineers (on site) and normally the concrete subjects and carpenters who are specialists in and have responsibility for structuring material (the building’s skeleton). When architects, SC etc. (what can be termed the “structuring subjects-axis” – or “structuring-axis”) take their role, they create by realizing the purpose and tasks of their own subject at the same time primarily coordinating guidelines for the other subjects like the technical subjects. All subjects have their specialist expertise; the structuring-axis from architect to SC and on to concrete work and carpentry have in addition a general structuring competence integrated into their own specialist expertise which is about to coordinate interfaces between structural-axis and other subjects (this competence is normally most explicitly developed by the architect subject).

The rest of the disciplines must not only take the other disciplines’ perspectives, but especially the perspective of the structuring-axis: they must e.g. familiarize themselves with the architect’s perspective as it concerns the material effects for the customer (user).

Structuring material makes up the concrete totality and is the entrance to the project perspective.

The transition from the disciplinary to the multidisciplinary level makes the logical order of the material evident: the team that create the common product or object (e.g., the restaurant) must first sketch or create the physical "skeleton", then the electricians hang up their part, plumbers append the piping, etc. The teams' products (restaurant, auditorium etc.) are also in the last instance linked together through structuring material. Also on a project level, the structuring material contributes so that the process can be understood as an autopoietic process similar to the creation of a unified and common product or object. The material order and the distinction between structuring and specific materials add a general basis for a more differentiated concept of “structured emergence,” “structured meaning-centered communication,” “structured collaboration,” and “structured decision making”.

ORGANIZATIONAL LAYOUT

The material-order approach (Andersen 2016) unites a strong dialogue orientation and an efficient decision-making system by using structured collaboration: questions concerning the interface between a structuring-axis (decision-axis) and other subjects belong in the last turn to the structuring-axis (decision-axis) specialty. These subjects are responsible for primary coordinating guidelines. If dialogues between disciplines on issues at the interface have not in itself led to agreement and decisions, then the decision-axis or the part of the axis involved decides based on its expertise. The principle is, however, "dialogue first”. Generally on the arenas in the project at the multidisciplinary and project level, representatives of the decision-axis are used as group leaders and coordinators, to draft plans, etc.

According to the material-order approach, there should be a separate organization on the discipline level (for each discipline), for each multidiscipline team, and on the project-level (core group) to generate their own programs (operational plans), develop internal and external communication channels, and stabilize their manning. Based on the organized discipline level the discipline-actors should develop **strong,** situation-specific, **discipline-perspectives** directed towards tasks at the multidisciplinary team level and correspondingly at the project level.

The main task for the decision-axis (e.g., in the core group) is to create social coherence and physical cohesion for the project by using the idea of structuring material (in accordance with a separate autopoietic system) by developing a plan. The plan must be developed in dialogue with representatives from each multidisciplinary team and each individual discipline so that all perspectives and interests are integrated in the plan. It is e.g., the architect’s task after the meeting in practice to further develop the idea of the building through the structuring material as an assumed autopoietic system - still in dialogue with the other disciplines or subjects. The task of the rest of the decision-axis is further realization of the system - in the end as a physical material building.

The principles of organizational layout outlined above are the same with regard to the various stages in the construction project. The material-technological order of dependencies in the physical building processes is e.g. reflected in the materialized models and drawings in engineering and in design.

CONCLUSION

Recent development in the implementation of design processes has made visible aspects of empirical reality that challenge basic assumptions of existing theory. In the paper, some actual theories has been divided into organic (holistic) and individualizing approaches. The organic theories illuminate processes related to the whole and community, while the individualizing theories address processes related to the autonomy of parts, individuals, disciplines, etc. The paper suggests a material-technological order approach that mediates between autonomous (autopoietic) parts and joint production kept together by forming and structuring material. The material order is the **possibility-condition** both for the development of competencies at the levels of discipline, project, and multidiscipline. It is at the same time possibility condition for an effective decision-making system which comes into force when the dialogical processes do not in themselves lead to consensus and agreed decisions. The material order approach is proposed as an expansion of the Lean Construction discourse. Future research of the material order approach will further examine the interactions between discipline, multidisciplinary, and project levels of design and engineering processes, using comparative empirical implementation studies. Future research will also examine contract strategies (including contract forms) in light of the approach.

REFERENCES

Andersen, L. (2016): *Organization of complex processes. Scientific theory and philosophical assumptions*. Fagbok Publishing House. Oslo. Norway.

Ballard, G. (2000): *The Last Planner System of Production Control.* The University of Birmingham. UK.

Bell, S.B. and Kozlowski, S.W.J. (2002): A typology of virtual teams: Implications for effective leadership. *Group and Organization Management. IBI. INFORM. G.Pg.14.*

Boland, J and Tenkasi, R.V. (1995): Perspective Making and Perspective Taking in Communities of Knowing. *Organization Science. 6(4): 350-372.*

Burns, T.R and GM. Stalker (1961): *The Management of Innovations.* Tavistock. London.

Bølviken, T., Gullbrekken, B., Nyseth, K. (2010): Collaboration design management. *Proceedings IGLC-18, July 2010, Technion, Haifa, Israel*

Chachere. J. (2009): Observation, Theory, and Simulation of Integrated Concurrent Engineering: Grounded Theoretical Factors that Enable Radical Project Acceleration. *Management Science 49 (9): 1180-1195.*

Carlile, P.R. (2004): Transferring, Translating, and Transforming: An Integrative

Frame-work for Managing Knowledge Across Boundaries. *Organization Science. Vol 15 (5): 555-568.*

Clegg, S.R. and Bailey, J.R. (2008): *International Encyclopedia of Organizaton Studies.* Los Angeles. Sage Publications.

Koskela, L. (2000): *An exploration towards a production theory and its application to construction.* University of Technology, Espoo. Finland.

Koskela, L. and Kagioglou, M. (2006): On the Metaphysics of Management. *IGLC-14. Santiago, Chile.*

Lave, J. & Wenger, S. (1991): *Situated Learning*. Cambridge University Press. UK.

Litchfield, R.C. and Gentry, R.J. (2010): Perspective-taking as an organizational capability. *Strategic Organization*. Sage Pub. University of Florida.

Luhmann, N. (2000). *Organization and Decision-making.* Wiesenbaden: Westd. Verlag.

Mintzberg, H. (2009): *Structure in Fives. Designing Effective Organisations.* Prentice Hall/International. London.

Parrish, K. (2014): Towards a Language-Action Paradigm: Experiences of a Trade Contractor. *Proceedings IGLC-22, June. Oslo. Norway.*

Pasquire, C. and Court, P. (2013): The 8th flow – common understanding. *Proceedings of the Annual Conference of IGLC.* San Diego. USA.

Saussure, F. (1974): *Course in General Linguistics*. London. Fontana

Wygotsky, L. 1978: *Mind in Society. The Development of Higher Psychological Processes.* Harvard University Press. Cambridge.

Zahavi, D. (2003): *Husserl´s Phenomenology*. Stanford University Press. California.