AS SEQUENCES FLOW: PROPOSAL OF ORGANIZATIONAL RULES FOR 'LEAN CONSTRUCTION' MANAGEMENT

Saverio Mecca[1]

ABSTRACT

The reliability of building processes is related not only to the level of performance required but also to their organizational structure. Conditions of turbulence in which constructors operate on site closely interact with the performance of the construction process and particularly with the risk of non-conformance of a building to the performances required. Interaction is characterised by the stability of the organisational structure or its capacity to adapt to environmental variability.

A technical risk organisational factor analysis in construction processes can lead construction management to design organisational structures capable of reacting to environmental conditions in which "on site" production operations develop, and also able to increase the reliability of the building process. Working on organisational interfaces can lead not only to changes in detail design, but also in performances required to each operator, in order to obtain higher efficiency levels.

Based on case studies conducted on sequential organisational structures of the building process, a set of organisational rules is proposed for implementation in experimental "lean construction" processes. Organisational rules based on risk organisational factors analysis can lead to the designing of a "lean" organizational structure of construction processes.

KEY WORDS

Construction, organisational design, sequential process, uncertainty

[1] Associate Professor of Construction Management at the University of Calabria, Dipartimento di Strutture, Facoltà di Ingegneria, Arcavacata di Rende (CS), Italy, lucat@fu.penteres.it

INTRODUCTION

A construction process is naturally uncertain, unrepeatable and nomadic, as Koskela (1992) listed. Its characteristics are "one-of-a-kind nature of projects, site production, and temporary organizations"; it also is extremely complex from an organisational and technical point of view in its variability and in the intensity of the relationships between the operators and their materials. It is characterised by a weak knowledge of the cause and effect relations of construction phenomena and their defects. Operators in the construction industry work in a turbulent environment, which is made worse by the lack of relevant information and its unreliability. A natural management style based on weak planning and reactiveness—or *tayloristic* project management—are both inappropriate and inadequate to successfully manage construction processes

This endemic uncertainty tends to conflict with the objectives of effectiveness and efficiency, unless new organizational strategies are developed. On one hand, these must be capable, of reducing uncertainty through quality planning and "robust" design (Andery et al. 1998). On the other, to monitor their own activities and co-ordinate with other participants in the realisation of a "project", through the increased ability of the operators to react to unforeseen contingencies; and according to concurrent engineering and partnering principles and practices (Austin et al. 1994, Hall 1991)

The analysis of uncertainties and organisational risks determined by the relation between operators and their assigned tasks can be one of the principal actions to be taken in order to increase effectiveness and efficiency.

In organisation studies it is assumed that businesses are efficient if differentiated and graded according to knowledge of the area concerned.

The "Contingency Theory" model (Lawrence and Lorsch 1967) considers the environment not as a global entity, but subdivided and segmented into sectors typified by a differing degree of uncertainty. It delineates the planning of the organisational structure as a process of progressive definition of environmental differentiation requirements, of models of influence between functional subsystems and between organisational levels and of integration and conflict solving mechanisms. The model proposed by these authors places the plan at the centre, not only because of its technical performances, but above all for its capacity to integrate and structure human and social, as well as technical and temporal relations: the same planning procedure makes up the first integration mechanism.

Organisational strategies (Thompson 1967) for construction are definable in relation to diverse levels of knowledge, temporarily acquired, of the environment and of the project. Moreover, the organisational strategy of each operator is defined as a function of the available information and therefore depends on the collocation, role, competence and responsibilities of the operator within the construction process.

In construction management, if we assume the condition of uncertainty to be decisive, we need a new paradigm based on principles of Lean Construction and on organisational theories, like the "Contingency Theory". These allow a wider understanding of the behaviour of

organisations and their planning methods of flows and operations based on transparency, participation and diffused risk management.

INTERFACES AND INTERDEPENDENCES

According to Koskela (1992) production planning does not consist only of conversion process scheduling, but mostly of flow planning; working on flow improvements means working on organisational structure, on boundaries of responsibilities, or rather on technical and organisational interfaces between operators and between conversion processes.

According to Thompson (1967) one of the most relevant management tasks consists in the identification, analysis, planning, communication and control of technical and organisational interfaces.

Through analysing the technical and organisational interfaces. of a production process we may identify (Thompson 1967) three forms of interdependence among parts:

- **generic interdependence or pooled interdependence.** In interfaces characterised by generic interdependence there is co-ordination by standardisation.
- **sequential interdependence,** when the interdependence assumes a more direct form, both parts contribute to the system as a whole (generic interdependence), but there is also a direct interdependence between the two parts in an order that can be specified. In interfaces characterised by sequential interdependence there is co-ordination by planning.
- **reciprocal interdependence,** when we have a situation where the outputs of each part become inputs of the other parts; the activity of each part is directly linked to that of the other. In this relationship the other two types of relation are also present, but the particular and qualifying aspect is the reciprocity with which the behaviour of one part places a constraint, an element of uncertainty, on the behaviour of the others. In interfaces with reciprocal interdependence there is co-ordination by mutual adaptation, which can be a cause/condition of technical and organisational failure.

The three interdependence relationships respectively present increasing difficulties of coordination (Simon 1969), as they contain an increasing degree of complexity, constraints and uncertainty.

On a traditional construction process the aggregation of tasks, activities and responsibilities prevailingly generates relations of reciprocal interdependence, but tayloristic project management or CPM scheduling do not consider interdependence relationships and consequently do not manage them.

We can assume a more functional organisational structure, in which the organisational interfaces are characterised by sequential rather than reciprocal interdependence, which allows for the co-ordination of construction process by planning (time, cost, and quality) as the basis for increasing effectiveness and efficiency in construction processes.

SEQUENTIAL ORGANISATIONAL STRUCTURE FOR CONSTRUCTION PROCESSES

Since the 1960s some French firms specialised in individual homes production, JLM, Bruno Petit, etc., (Roland 1987) have applied organisational structures based on teams of operators able to perform a wide and complete set of building operations in conditions of continuity.

On the basis of this experience, during the '80s in France, Plan Construction promoted experimental operations of "démarche séquentielle" (Bobroff 1987, Flouzat 1987, Martin 1991, Mecca 1996). Analyzing on the field these experiences, we may define a "sequential" organizational structure, which can be a way for implementing Lean Production principles in construction processes (table 1).

Table 1: Main information on experimental project by SOCAE Atlantique at Foncastel, Bordeaux, France, 1991-1992 (Mecca 1995)

Client:	Office Départemental d'HLM (*social housing*) de la Gironde
Design:	J. P. Soulard, Architecte DPLG
Main Contractor:	SOCAE ATLANTIQUE
On site:	J. L. Aubert, Maitre d'oeuvre, G. Cremon, Conducteur d'oeuvre, M. Tesseire, Chef de Chantier
Budget (four buildings):	35.580.000,00 FF TTC
N° flats:	4 x 25 = 100
Parking:	4 x 20 = 80
useful surface:	4 x 1.735 = 6940 m^2
cost/m^2:	5126,80 FF TTC / m^2
Mean flat surface:	69,4 m^2
cost/flat:	355.800,00 FF TTC

SEQUENTIAL MODEL

The sequential model is a partial application of concurrent engineering and partnering concepts and practices (Austin 1994, Hall 1991). The model is called sequential because is characterised by a careful analysis of the organisational and technical interfaces and the interdependence links that derive from them.

The elements that characterize a sequential organisation are:

- organizational risk management of interfaces between building process operators;
- flow control of the process on the interfaces between the sequences;
- formal phase of preparation of the site activities, time and adequate resources.

The objectives of each sequence constitute a horizon for the operator not only for reasonable expectations of efficiency and coordination with other interdependent operators but above all for the monitoring and self-monitoring of the standard of results.

The sequence becomes the reference for identifying the overall specifics of the final and intermediate performances. The most important part sequence determination work consists in specification analysis for the interfaces and in identifying the appropriate intermediate specifications and responsibilities for each operator.

DEFINING A SEQUENCE

A sequence is a set of building operations fully carried out in a continuous way by only one Group or firm and without other operators working at the same time in the same place. The rules to create a sequential organisation can be as follows:

- each building phase or sequence should construct a coherent and autonomous subsystem of the construction process as regards both time and space. This allows operators in charge of its realisation to carry out all the tasks allocated to them in an autonomous and continuous way, without reciprocal interdependence from other operators. That is, without the need for other sequence operators to intervene on the same part of the construction site during the execution of a given phase;
- each sequence should allow the Group of operators in charge of its realisation the chance to work fully and continuously, without any time-wasting;
- each sequence should be carried out by one firm only or, if not possible, by a very close-knit group, to avoid the creation within each sequence of reciprocal interdependencies generating the organisational malfunctioning typical of construction sites.
- in the interfaces between the different sequences there should be room for the control of sequence completion. This intermediate control phase, effective only in conditions of sequential interdependence, represents the central element in the model of conflict-solving between operators, and it is in conformity with the ISO 9000 norms.

IDENTIFYING RISK TASKS

The boundaries of each elementary task are determined by competence, know-how, by used instrument, or changes in materials or space. Organization problems, the faults in quality and efficiency most of the time arise at the end of tasks, in the handing over of competence and responsibility. Each of these tasks is linked to a technical and practical competence, to an instrument or material; in this way an analysis of the changes of competence, instruments and materials can be developed.

A risk task is one whose position and/or realisation implies the risk of producing a fault in quality or in time co-ordination with other connected technical and organisational tasks. If the tasks involved in the production process of a construction site are systematically analysed, using these organisational parameters, we can identify those passage points, those technical-organisational interfaces which generate reciprocal interdependencies, and so define an organisational structure that minimises their number and effect on the efficiency of the process.

The list of tasks is a complete list of the tasks to be carried out and co-ordinated according to the technical and temporal construction programme.

REDUCING RISK ORGANISATIONAL FACTORS

The transfer and regrouping of tasks are aimed at eliminating risk points, reducing the number of operators and limiting the number of sequences, being based as far as possible on already tested practises. Each transfer or regrouping must be relevant to:

- reducing the risk of failures in quality, and consequently in time and cost;
- assuring technical and informational conditions for continuity;
- motivating and training operators.

The transfer of tasks consists in giving a task usually assigned to an operator skilled in a particular trade to a sequential operative, who is qualified in another trade. In most cases the transfer of tasks leads to reduction in the variety of operators and contributes to limiting the number of sequences. In some cases the transfer of tasks confirms an already tested practice. For instance, the installing of fixtures by the person who puts up partition walls, etc. In other cases it requires an organisational innovation that tends to eliminate an organisational interface, implying a risk because of irresolvable reciprocal interdependence, which can not be removed through technical innovation. (table 2)

Table 2: Comparing the traditional structure and sequential structure of the experimental project by SOCAE Atlantique at Foncastel, Bordeaux, France, 1991-1992 (Mecca 1995)

Traditional Structure		**Sequential structure**	
Subcontractor 1	Earth moving	SEQUENCE 0	Planning, motivation and training
Subcontractor 2	Gros Oeuvre	SEQUENCE 1	Gros Oeuvre
Subcontractor 3	Carpentry	SEQUENCE 2	Water and air outlets and safety
Subcontractor 4	Roof	SEQUENCE 3	Vertical technical columns
Subcontractor 5	Water proofing	SEQUENCE 4	Partitions
Subcontractor 6	Mechanical services	SEQUENCE 5	Technical plants
Subcontractor 7	Mechanical Ventilation	SEQUENCE 6	Painting and finishing
Subcontractor 8	Electrical services	SEQUENCE 7	Setting up and starting up machinery
Subcontractor 9	Gypsum internal walls		
Subcontractor 10	Windows	OUTSEQUENCE A	Finishing of facade
Subcontractor 11	Doors	OUTSEQUENCE B	Waterproofing
Subcontractor 12	Rolling gates	OUTSEQUENCE C	Elevators
Subcontractor 13	Suspended ceilings	OUTSEQUENCE D	VRD
Subcontractor 14	External finishes		
Subcontractor 15	Painting		
Subcontractor 16	Internal walls and floors finishes		
Subcontractor 17	Railings and ironwork		
Subcontractor 18	Elevators		
Subcontractor 19	VRD		
Subcontractor 20	External works		

The content of transferred tasks can be the employment of materials, the use of products provided by traditional trades, or both at the same time.

The regrouping of tasks means moving the carrying out of a task by the operator, who is usually responsible for it and inserting it in a sequence carried out by an operative belonging to a different trade. We have, therefore, the transfer of a task backwards or forwards in time without changing the actual operator but inserting him/her in another work context.

The sequential organisation of a construction site, given the same materials and products, leads to an increase in the reliability of the construction process due to, for instance, the use of a more efficient conflict solving model and a heightened motivation of the work force.

PARTICIPATING IN PLANNING

Action aimed at reducing and eliminating the critical points allows a progressive definition of a basic organisation structure and an operative programme (main integration mechanism). The splitting into subsystems linked by sequential interdependence - in other words the number, content and rhythm of the sequences - with a progressive deepening and checking at each developmental phase of the project (sketches, scheme design, detail design, production drawings, etc.).

The participation of the operators responsible for the sequences in the drafting of the plan and schedule, as far as the parts they are competent for and the technical and organisational interfaces are concerned, can assure: feasibility of the general program and of the sequence programmes, responsible autonomy, participation, and the motivation necessary for the assumption of joint responsibility in achieving the final result (figure 1).

This planning procedure requires operators be involved as early as possible, since the planning of the organisational structure already begins with the first sketches and the global project.

The same procedures, if started only in the execution phase of the project or during the preparation phase of the construction site, in practice cannot be applied or will not give such effective results, because it will be bogged down by the irreversible elements contained in the project decisions.

The plan becomes the main tool for communication between construction operators, the basis for detection of weak points and for determining task transfer or regrouping and to whom. The task list allows a different WBS whose second level is the sequential breakdown, the main breakdown of flow construction process (time, cost and value).

This phase indicates how the "zero" sequence of building site preparation is aimed at:

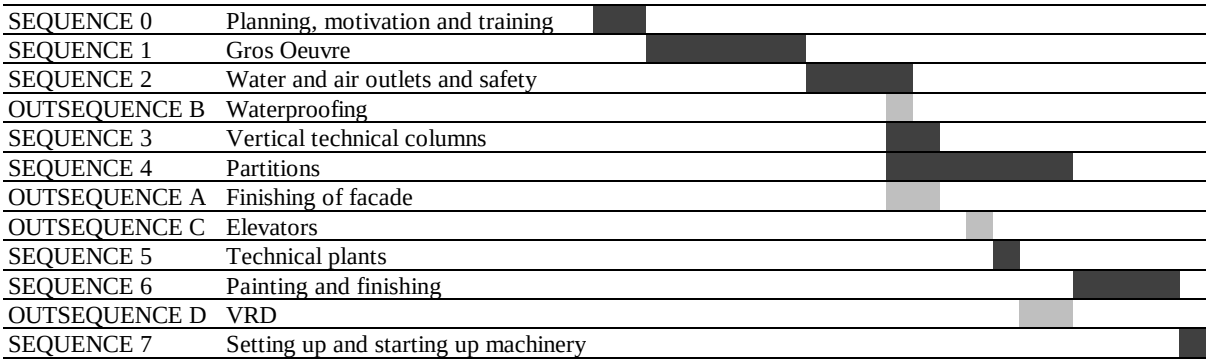
- careful examination of the project, programme of sequences, technical and organisational interfaces conducted under the guidance of work management with the site labourers;
- contextual verification of its workability and its possible modification to adapt it to the technical specifications of the operators' competence;
- organization of scheduling with attention given to the harmonisation of production rhythms;
- formal acceptance of the building programme and the working programme on the part of all the involved operators involved in the building site process.

The rhythms of the sequences have to be harmonised and verified in the identified place units, to avoid operational overlapping and the physical over-staffing of operators, causes of safety risks and risk of poor quality.

The structure of the program has to be analogous both in the division and hierarchy of the sequential organization and in the place units. A first level of sequential program allows the verification of the linking up of the sequences according to the defined place units. It has to be integrated with specific sub-programs of each sequence and identified place units.

The two ladders of program definition correspond to the organizational planning procedure that we initially delineated and they increase its reliability. Uncertainty estimation by means of traditional reticular probabilistic programming techniques, apart from not modifying its efficiency appreciably, certainly reduces its communicability to building site operators.

Harmonization of sequence rhythm and therefore of production flow is necessary for general balance and the full employment of the men. It depends directly on the specific groups or units of production. Acceleration phenomena occurred to accelerate certain sequences that disturbed the preceding sequences. They were generally caused by an underestimation of the efficiency of grouping tasks in terms of time savings (a phenomenon observed, for example, in the sequences of plant installation overlapping with finishing sequences) and solvable by reducing the number of groups allocated to the plants.



Sequence		**start**	**end**	**duration**
SEQUENCE 0	planning, information, motivation and training	1.10	25.10	19
SEQUENCE 1	“gros oeuvre”	26.10	21.1	62
SEQUENCE 2	out of rain and wind	15.1	11.3	40
OUT SEQ. B	water and damp proofing	5.3	11.3	5
SEQUENCE 3	main mechanical and electrical services	5.3	29.3	19
SEQUENCE 4	internal walls	5.3	7.6	69
OUT SEQ. A	external wall finishes	5.3	25.3	15
OUT SEQ. C	elevators	1.4	17.4	13
SEQUENCE 5	mechanical and electrical services	8.4	23.4	12
SEQUENCE 6	painting and internal finishes	10.6	29.7	36
OUT SEQ. D	connecting mains services	14.5	10.6	20
SEQUENCE 7	setting up and starting up machinery	23.7	5.8	10

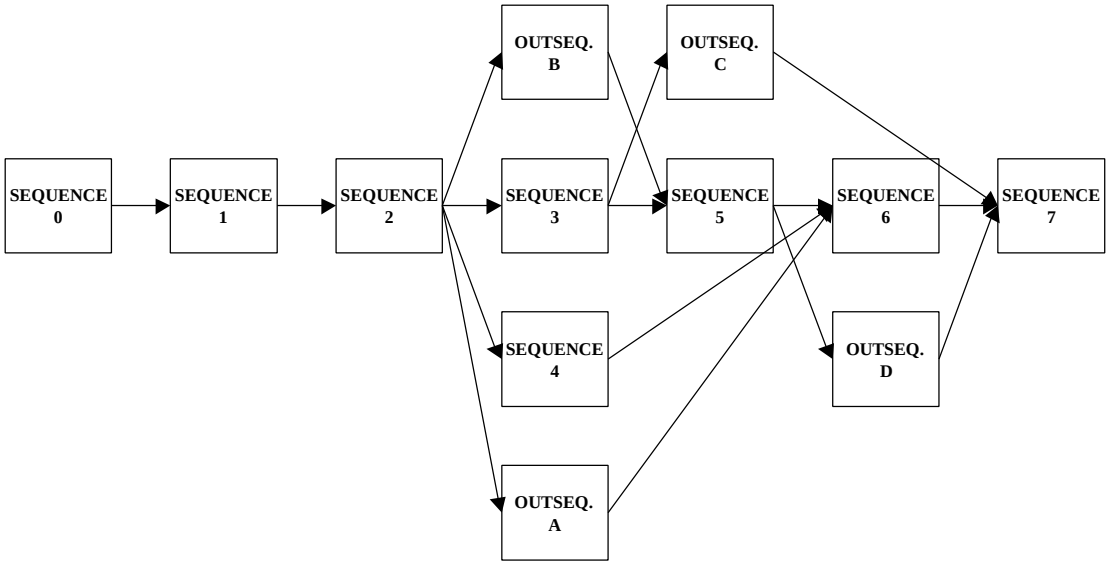


Figure 1: Scheduling of sequences (flow process) of the experimental project by SOCAE Atlantique at Foncastel, Bordeaux, France, 1991-1992 (Mecca 1995)

CONTROLLING WORK FLOW

The intermediate phases of control and acceptance are an "external control" across the construction process and located at the end of a sequence. The function is to increase the reliability of the process of checking and correcting "failures", not just economic and temporal, but technical, above all.

The human and social element is particularly important in this intermediate control procedure. The work team responsible for a sequence must formally hand over the completed work to the team responsible for the next sequence. As though they were handing it over to a customer in the presence of all the control technicians, with effective consequences as regards motivation and self monitoring.

Environmental disturbance and its effects on the building process are reduced if the capacity of response to unforeseen difficulties is the responsibility of all the operators involved whatever their status.

The management of the plan in the building site phases is simplified if:

- plan has foreseen "frictional" times between one sequence and another for the correction of technical and temporal failures;
- rhythm of effecting the sequences is piloted so that the continuity conditions of the use of resources are maintained;
- instruments of motivation and self-control are exploited along with participation in the process, such as operator training, their active involvement in preparation of the building site and in particular the ascertainment of sequence completion, that is one specificity of the sequential process.

In order that these control operations are effective the following conditions need to be assured:

- they must be transparently defined during the zero phase;
- people in charge of carrying out the work of the interfaced sequences, work managers, the director of the building site, a representative of the insurance company must all be present;
- people in charge of the subsequent sequences carefully verify how the work is consigned to them, clarify on the spot requests for changes and completion, and successively accept consignment of the previous sequence;
- people in charge of the completed sequences undertake all the changes and additions that are retained necessary on the basis of the planning documents before the start of the second programme of the successive sequence.

OPERATOR TRAINING

The preparation period of the building site is the ideal period for the training of operators who will have to carry out new tasks for traditional trades; training can continue during work on the site, but is more effective if begun in sequence zero. Several specific surveys have revealed the interest shown by building operators for processes that enrich and widen their competence and improve working conditions. On sequential building sites there has been an evolution of skills in this direction, whether or not the operators had specific training for the process.

During the development of the building site the control of completion can sustain a parallel checking of quality control, productivity and exploitation of the operators' professional competence.

SEQUENTIAL ORGANISATION AND QUALITY MANAGEMENT UNDER ISO 9000

The sequential organisation of the process of production on a construction site is able to reduce the risks of quality failure stemming from conflicts between operators, from an inadequate planning and from insufficient transparency of the process.

Entailed in the planning and running of a sequential construction site are: the overall package of risk analysis, prevention through the rationalisation of critical interfaces, preparation, orchestration, checking, documentation, and information. These mean, in effect, the setting up of continuous checks of the process from its initial conception to the handing over of the finished work.

The coming together, before the beginning of the work, of all operators interested in defining the technical and organisational solutions to problems on the project interface, ensure a better, more coherent way of working to real resources and an anticipation and simulation of the real construction site.

Three instruments in particular in the execution phase of the work allow us to consider this process similar to the process of Total Quality Management or, anyway, capable of ensuring that the site is well-run and that the quality of the work is satisfactory:

- prevision of a mobilisation phase or the concerted preparation of the site, times and adequate resources;
- analyze and reduction of critical interfaces within the carefully detailed preparation of the execution carried out in the so called "zero sequence";
- control of sequence completion located on the interfaces between one sequence and another.

CONCLUSION

This paper is a contribution to those who are working on ways for implementing principles of Lean Construction. Starting from the experiences we have analysed we may detect some innovative elements:

- separation in two hierarchical levels of organisational structure: a level consisting of the whole of complex building (sequential) phases and a second level made up of each sequence (building phase);
- analogous separation in two levels of the "integration mechanisms", that is operative and control plans;
- specific organizational action and control on the interfaces between the sequences;
- specific organizational setting of sequence corresponds to a responsibility and autonomy of the operator within the basic programme;
- scheduling of the process as the result of a settlement, an orchestration between operators, which can produce an identification with a system of objectives and sub-objectives in line with the structure of responsibilities and controls;
- operators become responsible for their own results and for the overall project through a formal acceptance;
- specific training of operators to allow task transfers.

In particular, the organisational and not simply technical hierarchy allows operators to pursue a condition of "limited rationality". Identifying operative sequences and interfaces as the basis of an organisational structure means defining sub-objectives made up of specific techniques, which provide clear boundaries for the actions and responsibilities of operators.

REFERENCES

Andery, P., Carvalho, A. N., and Helman, H. (1998). "Looking for what could be wrong: an approach to lean thinking." *Proc. 6th Ann. Conf. Intl. Group for Lean Constr.*, IGLC-6, 13-15 August held in Guaruja, Brazil.

Austin, S., Baldwin, A., and Newton, A. (1994). "Manipulating the flow of design information to improve the programming of building design." *Construction Management and Economics*, 12, 445-455.

Bobroff, J. and Campagnac, E. (1987). *La démarche séquentielle de la SGE-BTP. Quels atouts pour les travailleurs et les P.M.E.* Title in French, in English: The sequential

progress of SGE-BTP. Some tools for workers in small and medium firms. Plan Construction, Paris.

Campagnac, E., Bobroff, J., and Caro, C. (1990). *Approches de la productivité et methodes d'organisation dans les grandes entreprises de la construction.* Title in French, in English: Productivity approaches and methods in large construction firms. Plan Construction et Architecture, Paris.

ECOSIP (1993). *Pilotages de projet et entreprises*. Title in French, title in English Experiments of projects and firms, Economica, Paris

Flouzat, B. (1987). *Etude de cas d'experimentation de la démarche séquentielle et premières conclusions sur ses possibilités de généralisation*. Title in French, in English: Studies of experimental cases of sequential progress and first conclusions on its possible generalization. Study to the Direction de la Construction, Paris

Hall, D. (1991). "Concurrent Engineering: defining terms and techniques." *IEEE Spectrum*, July, 24-25.

Koskela, L. (1992). "Application of the New Production Philosophy to Construction." *Tech. Report 72*, CIFE, Stanford Univ., CA, September, 75 pp.

Lawrence, P.R. and Lorsch, J.W. (1967). *Organization and Environment. Managing Differentiation and Integration*, Div. of Research, Graduate School of Business Administration, Harward University, Boston

Martin, P. (1991). *Guide pratique pour l'organisation séquentielle des projets et des chantiers.* Title in French, in English: Practical guide to sequential organization of design and construction processes. Les Ed. de L'ENTREPRENEUR, Champigny-sur-Marne.

Mecca, S. and Torricelli, M.C. (1994). "Project Management and Quality Systems in Site Organisation of Building Project." *Proc. Joint Meeting W96 Arch. Mgmt. " W88 Quality Assurance Arch. Mgmt. Practice and Research"*, Florence, March, CIB, Rotterdam.

Mecca, S. and Naticchia B. (1995). *Costruire per Sequenze*. (In English: Building by sequences), Alinea, Firenze.

Mecca, S. (1996). "The role of Organisational Risk Analysis in improving Performances of a Building in relation to Probability of Conformity of Site Operations." *Proc. 3rd Int'l. Symp. CIB-ASTM-ISO-RILEM «Application of the Performance Concept in Building*, Tel-Aviv, Israel, December 9-12

Roland, O. and Colombard-Prout, M. (1987). *Vers l'industrialisation flexible? L'innovation technologique et organisationelle dans le secteur de la Maison Individuelle*. Title in French, in English: Towards flexible industrialization? Technological and organizational innovation in the single-family detached housing sector. CEBTP-Plan Construction et Architecture, Paris

Simon, H.G. (1969). *The Science of the Artificial*. MIT Press, Cambridge.

Thompson, J.D. (1967). *Organizations in action*. McGraw-Hill, New York.