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(I) WHY PERT & GANTT DO NOT WORK IN BUILDING PROJECTS?

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Process engineering applied to building projects has not developed its own methodology for project management, so it has been using generic project management tools, based on PERT and GANTT, under the paradigms Critical Path Method or Critical Chain. Both PERT and GANTT do not consider some variables that are relevant in the specific environment of a construction site, such as: location, repetitive activities, productivity, continuity of work for external crews, material transformation, space clashes, etc. This article analyzes: 1) The theoretical foundations of generic project management tools based on activities management, 2) The significant variables in both production and project management paradigms, 3) The new paradigm and conceptual tools developed over the last 20 years in the Lean Construction community of knowledge. The findings of this research will help construction managers and superintendents, explaining why the standard tools they are using are not enough to manage their regular work, and proposing a more adequate set of tools and systems to plan and control production activities on site.

Keywords: Lean Construction; Scientific Paradigm; PERT; GANTT; CPM; Collective Intelligence.

(I) ¿PORQUÉ PERT & GANTT NO FUNCIONA EN PROYECTOS DE EDIFICACIÓN?

La ingeniería de procesos aplicada a proyectos de edificación no ha desarrollado una metodología propia para la gestión de proyectos, por lo que ha venido utilizando herramientas genéricas de gestión de proyectos, basadas en PERT y GANTT, bajo los paradigmas Critical Path Method o Critical Chain. Tanto PERT como GANTT no consideran algunas variables que son relevantes en el entorno específico de una obra de construcción, tales como: ubicación, actividades repetitivas, productividad, continuidad de trabajo para cuadrillas externas, transformación de materiales, choques de espacio, etc. Este artículo analiza: 1) Los fundamentos teóricos de las herramientas genéricas de gestión de proyectos basadas en la gestión de actividades, 2) Las variables significativas en los paradigmas tanto de producción como de gestión de proyectos, 3) El nuevo paradigma y las herramientas conceptuales desarrolladas en los últimos 20 años en la comunidad de conocimiento Lean Construction. Los hallazgos de esta investigación ayudarán a los gerentes y superintendentes de construcción, explicando por qué las herramientas estándar que utilizan no son suficientes para administrar su trabajo regular y proponiendo un conjunto de herramientas y sistemas más adecuado para planificar y controlar las actividades de producción en el sitio.

Palabras clave: Construcción Lean; Paradigma científico; PERT; GANTT; CPM; Inteligencia colectiva.

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1. Introduction

The typical representation for a project schedule is some kind of combination of CPM-PERT graph with a GANTT bar sheet, depending on whether you want to highlight the functional relationship between activities or their reflection in a calendar (Goldratt, 2017). Many projects can be planned and controlled with these tools. However, the experience in construction is that these project management tools require a considerable amount of time and effort to be updated, which leads to the abandonment of planning; many times, with the bad conscience for the Project Manager that is not being diligent enough in his role, and should devote more time to plan and control on a scientific and methodical basis.

Decades before Project Management and CPM-PERT tools were developed, building industry achieved remarkable milestones in speed, efficiency and quality, with the construction of skyscrapers in Chicago and New York, 1900 – 1930. For the construction of the Empire State Building, a conceptual tool from industrial production management was used: Line of Balance, which allowed the organization of the logistics of the work applying Just in Time criteria and analysis of the flow of operations, as it was a production assembly line (Ghosh & Robson, 2015). Line of Balance has recently seen a new rebirth in building industry, under the names of Location Based Scheduling LBS and TaktTime Planning TTP (Frandson et al., 2015).

The available scientific literature has mainly focused on documenting experiences of application of these systems, and comparing the results achieved. This article adopts a theoretical approach, analyzing the underlying paradigm in each case: the relevant variables that each conceptual tool considers, and a comparison of these variables with those that a building environment needs to considered.

This article proposes that building management needs the conceptual tools used in both project and production management, but also other conceptual tools specific for construction projects. Proposes also the *Train of Trades* as the Layout Plan that best suites the organization of the work in a construction project.

2. Methodology

The methodology of this study is based in the internal and theoretical analysis of the subjacent paradigms of Production Management and Project Management, isolating the relevant variables that underpin a scientific paradigm. This methodology was so far applied to the Theory of Human Action in Organizations (Pérez López & Polo, 1991). In this study, this method is applied for the first time to Project, Production and Building Management.

3. State of the Art

A paradigm is *a philosophical and theoretical framework of a scientific school or discipline within which theories, laws, and generalizations and the experiments performed in support of them are formulated* (Merriam-Webster Dictionary 2022). See below the actual paradigms of Project Management, Production Management and Building Management.

3.1. **Project Management Paradigm**

Project Management has established itself as a scientific discipline thanks to the periodic publication since 1987 of the PMBOK Guide, *A Guide to the Project Management Body of Knowledge*, by the Project Management Institute (USA), which is in its 7th edition in 2021. The PMBOK can thus be considered the dominant and accepted Paradigm of project management, because it is a mature fruit of consensus among scientists and practitioners of that discipline. Project is defined as *temporary endeavor undertaken to create a unique product, service or result* (Project Management Institute, 2021). This definition be considered as consolidated, because it has not changed since the first edition of the PMBOK: for 35 years, the entire scientific community has peacefully accepted that definition as *paradigmatic* of what a project is.

Traditionally, the PMBOK has also defined the *significant variables* of its paradigm, calling them *Knowledge Areas* and *Process Groups*. There are 10 *Areas* (Integration, Scope, Schedule, Cost, Quality, Resource, Communications, Risk, Procurement and Stakeholder Engagement) and 5 *Process Groups* (Initiating, Planning, Executing, Monitoring and Closing). Meaning that, in a project, if one attends to each of these variables in a systematic and differentiated way, will be considering everything necessary to explain the reality and phenomena involved.

For example, the Area of Project Cost Management describes the processes involved in initiating, planning, estimating, budgeting, controlling, and closing costs, for the project to be completed within the approved budget. And so, for each of the 10 areas, each of the 5 processes is applied. Which gives a total of 15 significant variables in the general paradigm of Project Management.

Not all projects require those 15 variables. If a project is executed by a single person, the variable *Communications* = 0, and that of *Human Resources* is very easy to manage; if the project is not important or critical for the activity of the company, the variable *Risk* can also be considered non-significant.

Similarly, some project circumstances or characteristics will lead to a variable having a large weight compared to the others in a given project: if the delivery date is already practically expired, the *Planning* variable may be irrelevant compared to the *Execution* variable; if the success of the project is vital for the survival of the company, *Risk* management could be the most determinant.

In the 2021 edition, the PMBOK introduces some structural changes, to take into account the contributions of Agile Management and Lean, moving from a prescriptive, process-oriented standard towards principle-based format ((Project Management Institute, 2021). Thus, it replaces the traditional 10 Knowledge Areas described until 2017 by 8 *Performance Domains.* However, for the purposes of this study, it does not introduce changes in the significant variables of the Project Management paradigm.

3.2. **Construction Projects paradigm**

The Project Management paradigm has proven to be applicable to all types of projects, from software development to weddings organization. The management of construction projects has some specific characteristics, and so the PMI recognized in 2000 by developing the *Construction Extension to the PMBOK*, which in 2016 published its third and currently last edition.

In that *Construction Extension*,

a) The 10 Areas of Knowledge of generic Project Management are maintained with small modifications, and another 2 specific Areas are added for Construction Projects: one that encompasses 4 areas: Health, Security, Safety and Environment, called HSSE; and another of Finance management. An annex for a Claims management area is also incorporated.

b) The 5 generic process groups of the PMBOK remain unchanged.

In summary, just as in generic project management 15 relevant variables can be considered, while in the case of construction projects this number can be extended to 17.

However, when facing a type of activity in which many of these 17 variables are not significant, a simple project should be considered. But if we are facing a type of activity in which more significant variables in addition to those 17 are considered, variables that cannot be ignored to explain the reality, something more complex than a project should be considered.

3.3. **Production or Project Environment**

It is relevant to highlight that a project pursues a *unique result*. It does not contemplate the production of more than one unit of product, service or result. That is the fundamental difference between a Project environment and a Production environment, since, in a Production environment, the number of units produced is always higher than one.

This leads to the appearance of three new factors, which in Projects it is not necessary to consider:

- *repetition of activities*;

- the emergence of the concept of productivity or *performance*: units produced per unit of time;

- the emphasis on *flow* rather than only on *activities*.

These three factors are relevant when constructing a building, where operators can spend weeks repeating the same activities every day throughout the various areas of the building, with related exigences for crew continuity and productivity. These relevant factors are considered by the Production Management paradigm, which is explained below.

3.4. **Production Management Paradigm**

Production management or industrial organization, as a scientific discipline, was born in the 1910s (Taylor, 1911), and develops Gantt bar charts (Clark, 1923) and production flow control systems, such as Line of Balance LoB. In parallel, the introduction of the Assembly Line Layout initially developed for car assembly (Ford & Crowther, 1922), was developed and generalized to a wide variety of industries, which lead to the mass industrial production of affordable, low cost goods.

Industrial production has been classically defined as the *result obtained from a set of people, materials and machinery organized under some form of direction* (Muther, 1955).

The organization of production is the way in which the relationships and flow of these four relevant variables are organized: materials, people, machinery and information. The *information* is necessary to give stop and start-up orders, coordinate the input / output of materials, and generally to organize the supply chain.

The *Material* is the basic element in a production environment (Muther, 1955), and all the production process is organized around it. In all cases, production requires the material to flow along a set of processes, in each of them, one of the following three things happen to it: 1. Change its shape (manufacturing), 2. Change its characteristics (treatment), or 3. Be added to a previous material (assembly). In the production process of a building things are somewhat different.

As for the *People*, in Production this variable is not the same as that of Human Resources in the Project paradigm: it would be considered even if all people were replaced by autonomous robots, which would move throughout the processes.

Finally, note that for most goods production industries, all the activities take place within or around a workshop building. In this case, the Production organization uses Plant Layout as its basic infrastructure.

Plant Layout involves the physical management of industrial elements. This arrangement includes all the spaces necessary for the movement of material, storage, indirect workers and all other activities or services, such as work equipment and workshop staff.

There are mainly four types of Layout Plan: fixed position, assembly line, process and combination (Muther, 1955), (Cuatrecasas, 2017). The first two are described below, due to their conceptual relationship with the Layout Plant that will be proposed for Building Management.

3.5. **Fixed Position Layout**

The main element remains in a fixed place, and all tools, machinery, men and other pieces of material moves around it. All work is done with the main component parked in one position. This is how prototypes are built, or all those things that are produced in small series, especially if they are large. It is also the typical organization of artisanal production. See Figure 1.

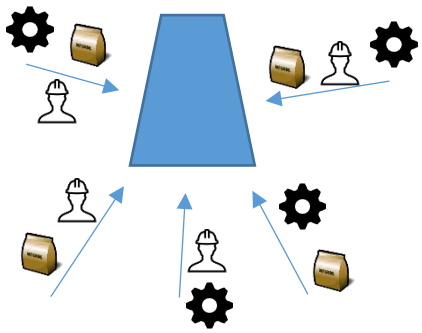

Figure 1: Fixed Position Layout

3.6. **Assembly Line Layout**

The main element moves, but not people or machines, which are in a fixed position; the material to be added reaches the predetermined positions to the extent necessary to feed the line. The main element is transformed as it progresses. See Figure 2.

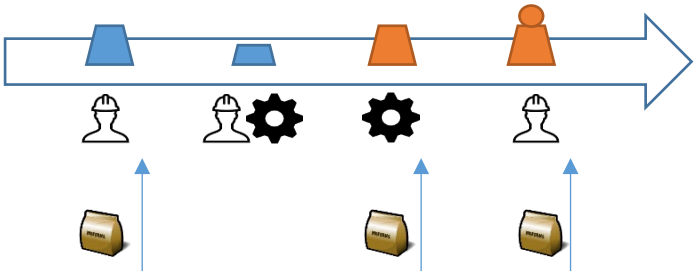

Figure 2: Assembly Line Layout

The first approach to line distribution works in batches, because operations are not balanced. However, as operations and process times are ordered, there is a tendency to balance the flow and to have a real chain or conveyor belt, where the main element moves at a constant speed, and no intermediate work in progress is stocked.

3.7. Underlaying Paradigm of Layout Plant

The improvements introduced throughout the twentieth century in the Assembly Line (Just in Time, Total Quality Management, Theory of Constraints, Lean Management, SixSigma, SMED, etc.) have focused on the way materials come to the chain (kanban), the size of the series or batches, the speed in the change of tools, how to control quality, flow balancing, how to govern constraints, etc. But they have not changed the underlying paradigm of line production, which is still the one implanted by the Ford Motor Company in its first assembly plants: the main component moves, men and machines are fixed, and the material comes.

Line Layout often involves the division of labor and specialization. Together with the saving of time and energy that the elimination of transport entails, the performance of operations, especially in assembly tasks, is multiplied by factors ranging from 3 to 6 with respect to the same production when carried out by hand (Ford & Crowther, 1922).

In general, a process is industrial or industrialized when it is as close as possible to the Line Layout; and it remains artisanal if you work by Fixed Position.

4. Insufficiency of Project and Product management paradigms in Building

Engineers in charge of planning and controlling the execution of a building have been commonly used generic project management tools: PERT / CPM graphs and GANTT charts (Lowe et al., 2012). These are the tools that are advised and explained in the textbooks that are studied in engineering schools or in postgraduate courses in Construction.

Despite the fact that these techniques are available, and despite there are many software packages that facilitate their use at a very affordable cost, in a large majority of projects they are used only for initial planning, being abandoned throughout the execution (Koskela et al., 2014).

It is commonly accepted that a building is a *project*. Construction companies and site managers regularly use principles, tools and concepts taken from project management (PERT arrows or precedence graphs, Critical Path or Critical Chain method, GANTT bar graphs, etc.) to plan their operations, manage resources and forecast delivery dates.

And certainly, the entire building, once produced and finished, does fit the definition of a project according to the PMBOK. A temporary effort has been made, and a single material product has been finished.

However, the construction process that has led to this product is not made of *subprojects*, but of *production processes*. This is deduced analyzing some variables that are totally relevant in the construction of buildings, which appear in production environments but are not contemplated in the project management paradigm:

1. *Repetition*. In project management, *repetitive activities* are not considered. But, in a building, the same workers perform the same activities continuously, using the same materials and tools, moving from one work area to another. It is not necessary that the building is reducible to equal modules, such as an apartment block. Even when all the spaces are different, and therefore so is the production, the operator wants to execute the same operations in all of them, and wants to achieve the same productivity.

2. The *transformation of material* is another relevant variable in the construction of buildings, and we can find it in the form of manufacturing (raising a brick wall), or treatment (concrete setting), or assembly (placement of false ceiling). But neither the material nor its transformations are variables considered in the general paradigm of project management.

3. The *productivity* of tasks is a determining variable in the construction of a building, but it is not in project management. The PMBOK also does not consider productivity as a specific management area, since n = 1.

4. *Work area*. In a building, the spatial working area is a very determining variable, and in fact planning and control systems based on the area are used very successfully, both in linear projects (basically civil works: roads, tunnels, bridges, etc.) and in building projects (Location Based Scheduling). But generic project management tools and software packages does not consider the management of the space where the activities take place.

5. *Time*. As a consequence of the variables Repetition and Productivity, the *time* factor has a different meaning in Production than in Projects. In a project environment, Time is understood as Milestone or *calendar date*: the project must be finished on that date, and there are various conceptual tools to manage it: partial milestones, time buffers, gaps, critical path, etc.

In Production, Time is not a calendar date, but the *Duration* of the process. Calendar time is something external to the production process. The organizer of the production is not so much concerned with finishing before or after a date, but using as few hours as possible. Because shortening the duration of a process means, in general terms, making production cheaper.

Certainly, in both cases, the time-calendar is determined by the time-duration of the processes, but in Projects the time factor is usually more critical, and hence one of the dominant paradigms is precisely called the Critical Path Method, which tries to protect the committed delivery date. On the other hand, in Production many times the fulfillment of committed delivery dates causes disorder and inefficiencies.

In conclusion, if the work is to erect a building, its conceptualization as a *project* leads to an *incomplete abstraction of reality* (Pérez López, 1991), because this approach has left out several relevant variables, such as those that have been identified above: Repetition, Material, Productivity and Area, in addition to applying a different meaning to the Time factor. Factors that do consider the general paradigm of Production.

Therefore, a first deduction is that the construction of a building must be managed as a *Production environment*, rather than as a *Project environment*.

This first conclusion advances a possible explanation of why project management tools have so little success in building, or can represent a great effort for a poor result. Planning with Gantt bar graphs or with PERT graphs or precedence, under the paradigm of the Critical Path or the Critical Chain, so useful for many types of projects, are incomplete or inadequate tools when it comes to organizing the production of a building: they do not consider the spatial variable or the repetition of activities, neither in its graphic representation nor in its internal logic. And fundamentally, they put the emphasis on the activities and not on the flow and continuity of the people's work.

A Builder works with flows of people, materials and machinery, to achieve a physical result. That's what defines a production environment, not a project environment.

A Building Management requires some more significant variables, and therefore it is necessary to develop an even more complete paradigm than that of Production. Below the study of the Plant Layout in a construction site is addressed.

5. Proposal of Layout Plan for Building: the Train of Trades

Traditionally, the production of a building has been considered as an example of **distribution by fixed position** (Muther, 1954), since a main characteristic of the building is usually its immobility.

The classic texts of organization of industrial production usually bring that example in their first chapters, but after that they absolutely ignore the production of buildings and focus on other industries. So, the distribution by fixed position is the one applied in the absence of any other type of organization of production. It is, par excellence, the organization of artisanal processes. Certainly, a small building can also be produced like this.

This paper proposes that the appropriate Layout Plant for the production of a building is not the Fixed Position, but the *Train of Trades*, which in the first approximation can be seen as a combination of layout by Fixed Position and layout by Assembly Line. This *Train of Trades* is organized according to both the Activities and the Spaces the crews have to occupy successively, and therefore makes a scheduling by Areas or Location Based Scheduling (Kenley & Sepannen, 2006), which is based on the following premises:

- The Team1 of operators who are going to execute an Activity1, together with their materials and tools, occupy an AreaA during the time assigned to work in it.

- No other team works in that AreaA in the meantime, to avoid collisions.

- When Team1 finishes, goes on to run that same Activity1 in another AreaB.

- Team2 can then enter Area A to execute Activity2. and so on.

This Location Based Scheduling combines the three productive elements (people, machines and materials) with a different Layout Plant, which considers that *the Manufacturing Plant itself is moving*, along with the materials, personnel and machines. See Figure 4:

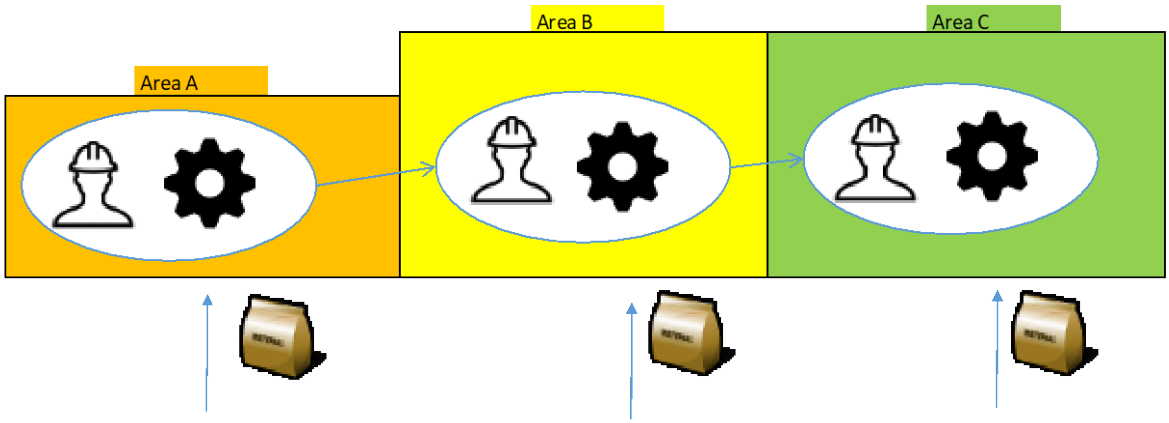

Figure 4: Train of Trades Layout

In this layout, operators and machines move from one area to another, as they create it, or finish their work in that area; and the materials come directly to the area, ideally *just in time* to be assembled.

This Layout Plant is something new, as far as organizational theory is concerned. It is not contemplated in the production organization manuals, which always start from a fixed and already built industrial warehouse, which houses the production process. Nor is it contemplated in the manuals of construction management, which have not contemplated the Plant Layout of the industrial processes.

Now a new relevant variable has appeared, necessary in Building but not present in Projects or Production: the *Area, Location* or physical space where the activities take place. A theory of Building Production that considers the Location will be more complete than one that does not. An activity planning methodology that plans according to the location occupied by each crew will be more complete than others that only focus on what can be done before, after or at the same time (Critical Path Method); or even considering the limitation of resources (Critical Chain).

When studying the Paradigm of Production Management, the basic element in a production environment is the *material*, to which three things can happen fundamentally: to be manufactured, treated or assembled.

In Building the basic element is not the *material*, but the *Space*, which is first *created* (slabs, walls, ceilings), then *equipped* (electricity, pipes, systems, etc.) and finally *covered* (floor coverings, walls, ceiling, facades, carpets, paintings, etc.).

In that Space, certainly the material will suffer the same operations seen in Production: it can be *manufactured* in the space creation phase (concrete pouring, erection of brick walls, etc.), *assembled* in the equipment phase (assembly of MEP networks) and *treated* in the coating phase (painting).

That Location is successively occupied by the various wagons of the Train of Trades. And the art in the organization of production is how to get a stable flow throughout the Locations. All the wagons of the train have to travel at the same speed.

In a production line, the emphasis is not on activities, as is done in project management, but on flow. All the activities are organized to achieve a flow of materials as stable as possible (Ohno & Bodek, 2019). But the flow in building management is not a flow of materials, but a

flow of trades along the locations. In the graphical expression of Location Based Scheduling, the lines of every crew have to be parallel, applying TaktTime System (Frandson et al., 2015), (Kenley & Seppänen, 2006). See Figure 5.

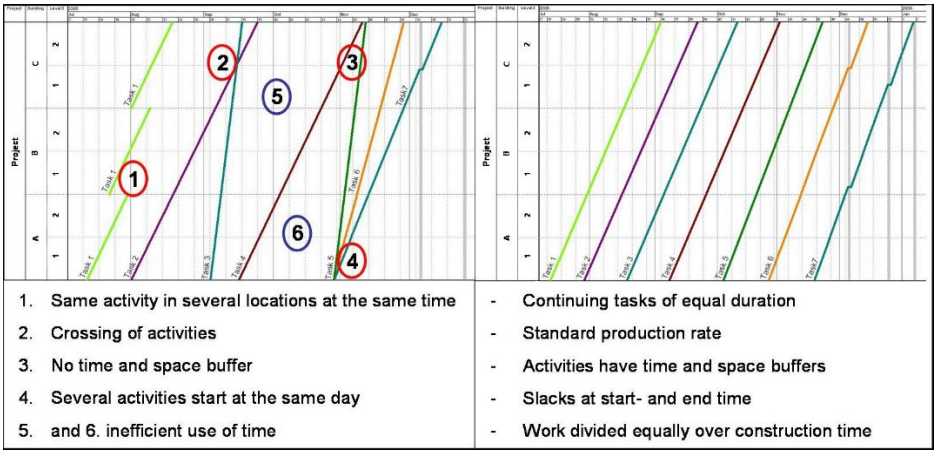

Figure 5. Location Based Scheduling

6. Conclusions

This paper has presented a proposal of Layout Plan for buildings: a *Train of Trades* which suits the organization of the work in a construction project. This proposal can help contractors, site engineers, superintendents and production assistants to improve their job:

- CPM - PERT - GANTT are valid only when the number of locations in the construction site is very small, or the continuity of the work of your crews are not required.

- The combination of FlowLine schedules and Location Based Scheduling with TaktTime Planning contains the most complete production theory for building projects, until now.

- The general theories of Project and Production Management are incomplete to explain the construction reality, for they omit the relevant variable Location.

However, for those Architects / Engineers working in Design phase only; or Owners making an investment, then a building should be considered as a project and Project Management paradigm is the best approach.

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