



## **CALCULATION OF THE CONSTRUCTION SITES' OCCUPANCY RATE USING CHONOGRAPHIC MODELING**

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**Abstract:** Trying to prevent stagnation and regressing productivity in the construction industry is as complex as trying to measure and identify the factors that influence it. The introduction of Building Information Modeling (BIM) has impacted the visualization and flow of information, and forced the industry to review its management practices, methods and techniques. BIM was originally intended for the design prospect. When applied to construction and operation phases, producing 4D simulations requires significant revisions to the model and project schedules, particularly to characterize the spatial nature of projects. This is due to several factors, including the limitations of scheduling techniques. These techniques model either a bar chart diagram that hardly represents time-space constraints, or a linear diagram scheduling method that is not suitable for model building projects. It is hard to show the work sequence, circulation and supply flow between different sites on a construction project. The efficiency of Lean Manufacturing has attracted the construction industry's attention, mainly to stabilize workflow with TAKT-Time planning. The Last Planner system has been developed to create more realistic schedules. Based on Lean Construction, the Last Planner involves those in charge of carrying out the work. In order to develop better-adapted and more flexible models, Chronographic Modeling, based on spatial modeling concepts, aims to represent construction site flow and operations properly. Based on this model, the current paper proposes a new operation process to facilitate 4D simulation. This process classifies and characterizes the types of project stages, operations, flow, and spaces. Construction stages are divided according to the construction phases, namely: i) Space creation, ii) Systems, iii) Space division, iv) Finishing work, and v) Closing of space. The operation process and flow includes repetitive, unique, and spontaneous tasks, which are classified as either exclusive or inclusive. Space occupations are specified as spatial, linear or isolated, and zones are divided into floors, sectors and exteriors. The model also considers the size and continuity of the teams as well as the occupancy rate of the site. Application of the model on a case study demonstrates its adaptability to 4D simulations.

**Keywords:** Occupancy rate, BIM, 4D Simulation, Chronographic Modeling; Construction management; Space planning, resource management.

## **1 BACKGROUND**

Measuring and quantifying productivity on construction sites is never a simple task, and researchers have explored these factors through detailed analysis (Park, Thomas, and Tucker 2005) and mathematical models (Li and Liu 2012; Nazarko and Chodakowska 2015; Vogl and Abdel-Wahab 2015). The goal was to help construction managers determine the factors that influence site productivity (Valverde-Gascuena et al. 2011) and/or improve it using simulation methods (Hammad et al. 2012). Considering the nature of a construction site and the involvement of large numbers of stakeholders, including subcontractors, measuring and improving productivity became a complex task.

Advances in Lean Construction (Koskela 1992; Ballard and Howell 1994) have led to the development of management systems that contribute to improved productivity on construction sites. First, the Last Planner System (Ballard 2000) aims to improve the accuracy of deadlines by involving those responsible for the execution of the work in the planning and coordination. The TAKT-Time planning (Frandsen, Berghede, and Tommelein 2014; Frandsen and Tommelein 2014; Frandsen, Berghede, and Tommelein 2013) helps to stabilize the work flow. The introduction of BIM forced the industry to review its management practices, methods and techniques. Originally conceived for the design prospect, BIM processes are not yet well suited to construction and operation phases. To produce a 4D simulation, they require significant revisions the project schedule. This is due to several factors, including the limitations of scheduling techniques and the difficulty of representing the spatial nature of the projects. In fact, these techniques- Last Planner System, TAKT-time and the 4D simulation- model either a bar chart diagram with precedence constraints that hardly represent time-space constraints, or a linear diagram scheduling method that does not suit model-building projects. It is difficult to show the work sequence, circulation and supply flow between the different sites on a construction project.

Based on the concept of Space Planning (Riley and Sanvido 1995, 1997), Chronographic Modeling (Francis 2004, 2013, 2016) allows the creation of compatible tabular and graphical schedule modeling that considers all the production elements, including work, resources and spaces, as well as the construction processes, especially on-site operations, supplies, and flow.

In concordance with the Last Planner System, TAKT-time planning and Chronographic Modeling, this research studies the spatiotemporal evolution and occupancy rates of the construction site. The methodology uses Chronographic Modeling to perform a spatiotemporal analysis of the construction schedule. It also considers the space occupied by the construction processes and products, as well as material and labor circulation.

This modeling provides a dynamic representation of the occupancy rate. It will assist the project managers and offer them a graphical tool to help level the site production and monitor the evolution of the occupancy rate. The study focuses on the problems of over- and under-occupation of available space, which negatively affects the productivity and total duration of the project. The objective is to optimize site management for building projects based on the dynamic evolution of the building occupancy rate.

## **2 SPATIOTEMPORAL EVOLUTION OF CONSTRUCTION SITES**

The occupation of spaces is characterized by two (2) criteria. The first is the location of occupation in the area; whether the work is on the ground, the walls or the ceiling. The second is the type of occupation; whether the work occupies the space in area, or in a linear or punctual manner. The combination of these two (2) criteria provides the nine (9) types of space occupancy shown in Figure 1.

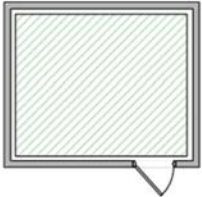



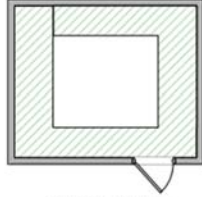

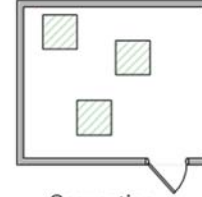
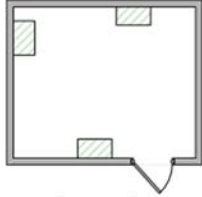
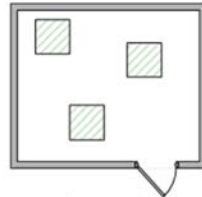
	Ground	Wall	Ceiling
Surface	 <p>Occupation = Work area</p>	 <p>Occupation = Wall length X work width</p>	 <p>Occupation = Ceiling's work area</p>
Linear	 <p>Occupation = work length X work width</p>	 <p>Occupation = Wall length X work width</p>	 <p>Occupation = work length X work width</p>
Ponctual	 <p>Occupation = sum of all ponctual surfaces</p>	 <p>Occupation = sum of all ponctual surfaces</p>	 <p>Occupation = sum of all ponctual surfaces</p>

Figure 1. Different types of space occupancy

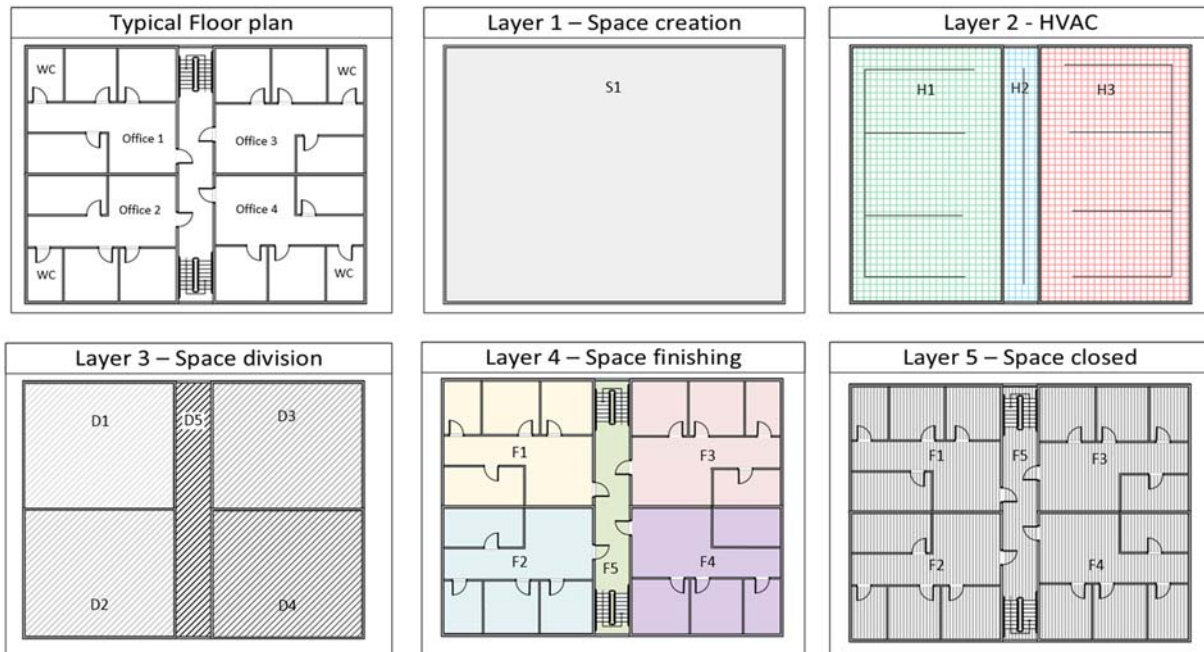


Figure 2. Space planning 5-layers system

The proper functioning of the proposed procedure relies on the ability of managers to clearly define the different sectors and their evolution over time. A 5-layer system was therefore developed, allowing the sectors to be classified according to the main phases of construction, namely: i) Space creation, ii) Systems, iii) Space division, iv) Finishing work, and v) Closing of space. A sixth layer could be added to demonstrate the Building Envelope. For each layer, sectors are divided in a way that will facilitate a TAKT planning. Figure 2 shows the floor plan of a building project in which the division of each layer in the sector is illustrated.

Regarding the standard phases of construction operations, Figure 3 shows the evolution of space use. Figure 3.a shows the first layer representing the sector in which the erection of structure will take place (sector S1). Once sector S1 is liberated, Layer 2 could take place, allowing the start of the system layer for mechanical (ventilation) work in sectors H1, H2 and H3 (Figure 3.b). Once the ventilation work in sector H1 is completed, Layer 3 is applied, thus adding sectors D1 and D2, so the division work can start (Figure 3.c). The succession of layers continues until the application of the fifth layer, which indicates the completion of all work in one sector (view Figures 3.d and 3.e).

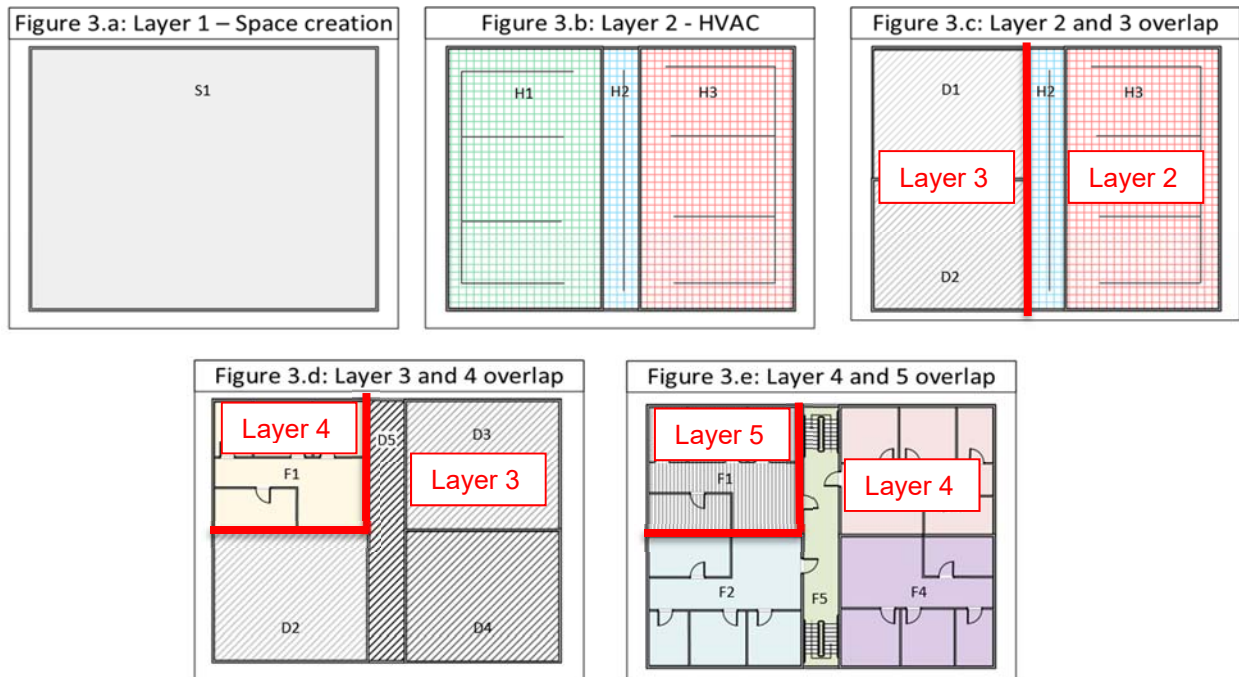


Figure 3. Space planning by layer

With this strategy, the different layers representing the main construction phases are overlapped for optimal site management. The occupancy rate of a given period is calculated by adding the sectors of all the layers used in this period (Francis and Morin-Pepin, 2017). The evolution of the occupied spaces over time is then evaluated. The generated Chronographic schedule demonstrates the dynamic evolution of the work, layers and sectors in addition to the occupancy rate over time. The schedule presented in Figure 4 shows this evolution.

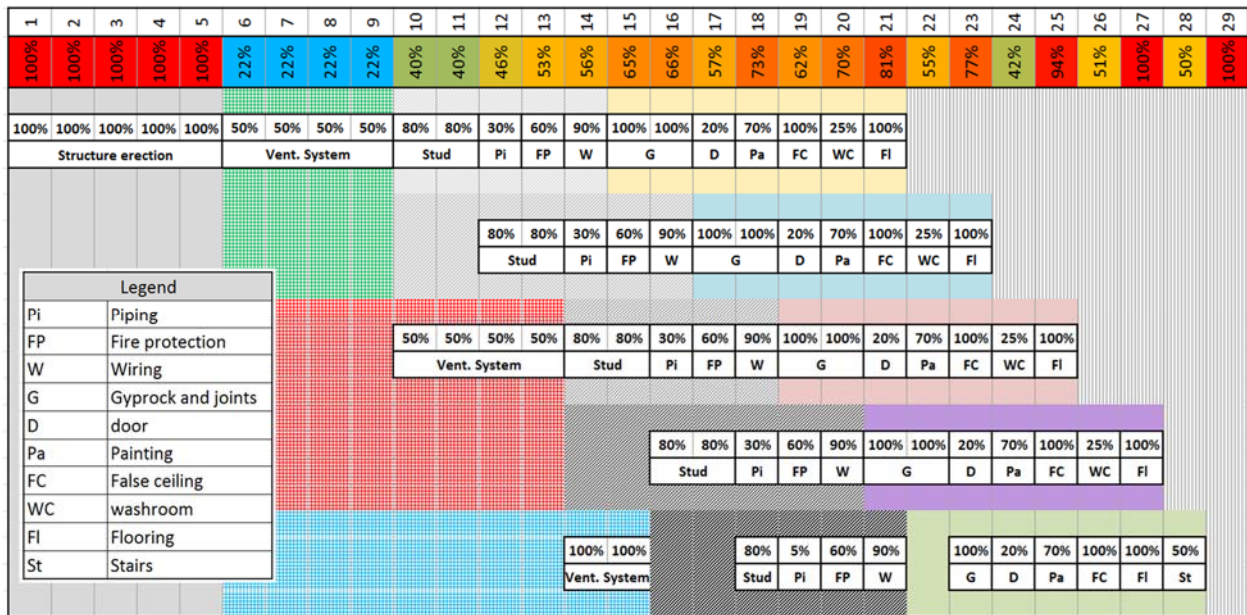


Figure 4. Chronographical modeling of the schedule

### 3 EXCLUSIVE VS. INCLUSIVE OCCUPATION AND THE CALCULATION OF THE DYNAMIC OCCUPATION RATE

Although some work may only partially occupy a sector, the nature of this work may require the use of the entire available space. An example would be concrete demolition work; the generated silica often requires restricted access to the entire sector. Pouring a concrete slab also is also a limiting factor, as the curing time often requires restricted access to the area for a period following the concrete pouring.

These constraints impose a distinction between the inclusive or exclusive use of the area. Indicating that work is inclusive means that other work of a different nature can be performed simultaneously in the same sector, if there is enough space. In contrast, exclusive work indicates that no other work can be performed simultaneously.

The calculation process is shown in figure 5. All the production elements, including work, resources, and spaces, and the construction processes, especially on-site operations, supplies, and flow must be considered in the occupancy rate calculation. Many factors like temporary installations and intermediate stocks will increase the site occupancy rate without increasing the production. The duration of the project will be extended unnecessarily, also increasing the indirect costs of the project. We must also consider that not all sectors have the same importance; for instance, a corridor or central room will have a greater impact on traffic. Thus, given that each sector has a different area and relative importance, each sector must have proportionate weight in the calculation of the overall occupancy rate for a given period.

The use of experience, statistics and databases is therefore very useful, and it is necessary to combine the subcontractor's expertise with new planning techniques such as the Last Planner and the Space planning.

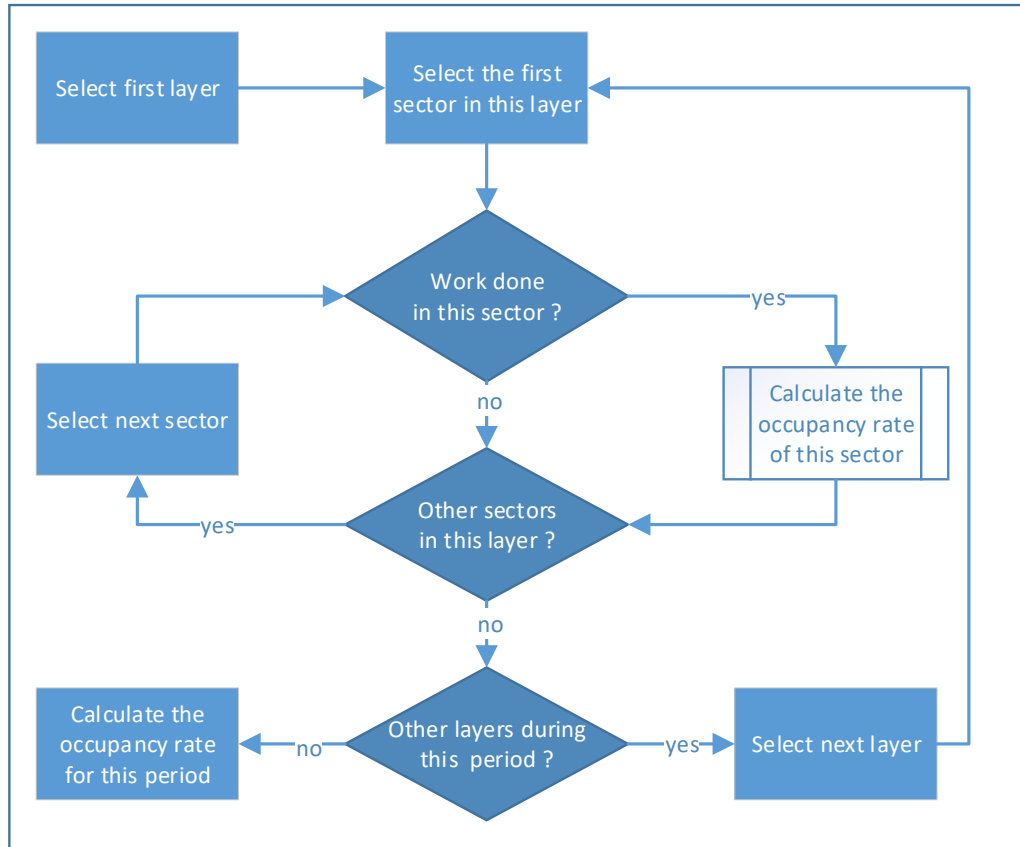


Figure 5. Calculation of the occupancy rate for a period

#### 4 CONCLUSION

Improving productivity is a major issue in the construction industry. Neglect of aspects related to site management is one of the most important factors impacting productivity losses. Ideally, during the scheduling process, the manager should promote an optimal use of the site space. He must consider the construction processes, temporary facility, labor, tools and equipment, construction materials flow and waste management. Current scheduling methods do not take most of these constraints in to consideration, creating non-optimal scheduling. This failure during planning causes problems of overuse or underutilization of the available space, directly affecting the duration of the project, independently of whether the activity is on the critical path or not. A partial solution is the study of the dynamic evolution of occupancy rate during schedule design. This makes it possible to perform schedule leveling, improving the use of the available space on the site, limiting the loss of time related to the building site congestion and the unnecessary movement of workers, materials, tools of machinery and waste.

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