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The time dimension in site layout planning

Mohsen Andayesh *, Farnaz Sadeghpour

Department of Civil Engineering, University of Calgary, 2500 University Drive NW, Calgary, Alberta T2N 1N4, Canada

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ABSTRACT

With regard to incorporation of the time factor, site layout models are traditionally grouped into two categories of *static* models (with no considerations of the changes over time), and *dynamic* models (reflecting the changes on the construction sites). This paper demonstrates that there are in fact fundamental differences in the assumptions and the final outcome of models that are currently all categorized under dynamic site layout planning models, and proposes that these should in fact be divided into two groups of *phased* and *dynamic* models. The paper provides a comparative analysis of the three approaches of *static*, *phased* and *dynamic* site layout planning. The strengths, limitations, and differences in the final results of the three approaches are demonstrated through numerical examples. Finally, existing methods for the 2D representation of dynamic site layouts are compared, and an improved algorithm is provided to represent dynamic site layouts in minimum number of overlap-free drawings.

1. Introduction

Different objects such as tower cranes, batch plants, management offices, material storage areas, and workshops are required on the site to support construction activities. These objects are often allocated space on a first-come first served basis — e.g., the objects take the best available location at the time of their arrival on the site. In the long run, this may decrease the efficiency of site operations. Studies have shown that front-end planning of the layout of the construction site can contribute to a decrease in the cost of material handling and workflows between objects, and to an increase in the safety and productivity of projects [1,2]. Determining the optimum location of objects on the construction site is referred to as site layout planning [1,3]. Site layout planning has attracted the attention of researchers in the past three decades, and several models have been developed for the optimization of construction site layouts. The common objective of these models is to determine the optimum location of objects in the available space on the site, while considering the workflows between objects. Although all models share this general objective, they have adopted different approaches in the way they define and address the problem. Due to the complex nature of construction sites, a large number of parameters are involved in modeling site layout planning. This paper focuses solely on one of the main parameters, namely the “time factor”.

The “time factor” determines how changes that occur on the site during the course of project are reflected in the site layout model. As the project progresses, the construction activities change, and accordingly the supporting objects associated with these activities are subject to change as well. This dynamic nature of construction sites defines one of the main challenges in site layout planning, namely the incorporation of the time factor in the optimization of layouts. The incorporation of time factor changes the construction site layout problem from a 2D or 3D optimization problem – i.e. one that only includes physical dimensions – into a 4D optimization problem, by adding the time dimension to the physical dimensions. In other words, unlike floor planning, construction site layout planning is not simply a space optimization problem, rather an optimization of space over time.

In the past few decades, different approaches have been used for representing the time factor in site layout planning, and the research has evolved over time. Inspired by plant layout planning (e.g.[4]), the first generation of site layout models ignored the changes that occur on construction sites, and generated a single layout for the entire duration of the project. These models are referred to as *static* models. In later studies, the importance of incorporating the time factor in site layout models and reflecting the changes on the construction site was recognized. The next generation of site layout models considered the time factor and incorporated the changes that occur on the site over the course of time in the optimization of layouts. In existing literature, any consideration of time factor in site layout models has been referred to as “dynamic” layout planning. However, as this paper will demonstrate, there are major differences between these models, and grouping them collectively under the same term is inaccurate and ignores the differences between them.

In this paper, a distinction is made between two approaches that consider the time factor in the optimization process. These two approaches differ significantly from each other, and can consequently lead to very different solutions. The paper first provides a comparative

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* Corresponding author. Tel.: +1 403 210 6929; fax: +1 403 282 7026.
E-mail addresses: m.andayesh@ucalgary.ca (M. Andayesh), f.sadeghpour@ucalgary.ca (F. Sadeghpour).

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analysis of the different approaches for modeling the time factor in site layout models. The impact of the time factor on the generated layout is then demonstrated through numerical examples. In the final section, the paper focuses on visual representation of a dynamic site layout in 2D space of paper documents. Two existing representation methods from literature are compared, and an improved method is proposed for representing a dynamic site layout in a way that facilitates the on-site communication of information related to site layout planning.

2. Approaches to representing the time dimension in site layout planning

The role of construction objects such as equipment, material, workspaces and temporary facilities is to support construction activities. The time and duration for which the objects stay on the site depend on the activities that they are associated with [5]. As the project progresses and construction activities change, the required objects, and accordingly, the space required on the site to accommodate them, are subject to change. Different approaches have been used in literature to represent these changes in site layout planning. As mentioned above, these approaches were generally identified either as static, when they don't reflect changes, or as dynamic, when they reflect changes over time. However, close examination of models previously identified as dynamic reveals that they can in fact be grouped under two separate approaches: one of which is *phased*, while the other is actually *dynamic*. This section provides a comparative analysis of the main underlying assumptions that differentiate between *static*, *phased*, and *dynamic* approaches for representing the time factor in site layout planning through an illustrative case.

2.1. Static approach

In the static approach, it is assumed that all objects are required for the entire duration of the project, and hence, do not allow two objects to use the same space on the site [1–3,6–30]. In this approach, the optimum location for each object is searched regardless of its duration of existence on the site. The advantage of this assumption is that it simplifies the search process. The static approach can be considered suitable and sufficient for short-term projects with a large available site space, where there are few changes that occur on the site and the available space is abundant. However, for more complex projects with longer durations, where numerous objects arrive and leave the site over the course of construction, the *static* approach will be limiting. Since the changes in site space requirements are not reflected in the *static* approach, the reuse of the space that was previously occupied by other objects is not considered [31,32]. As a result, the *static* approach does not provide a realistic representation of space requirements, and consequently, does not lead to an efficient use of space.

2.1.1. Case example

To illustrate the importance of incorporating changes in the space requirements over the duration of a project, consider the following example. Assume a construction project with 800 m^2 of available site space and nine (9) objects. The objects have different sizes and are required on site for different periods of the construction project, as shown in Fig. 1. In the reality of construction sites, objects can be assigned to any available space when they arrive to the site. For instance, the Batch Plant (object C) in this example requires 120 m^2 on the site between months 5 and 12. This object can be assigned to any available space at month 5 including the space that was occupied by the Geotechnical Lab (object A) during months 1 through 4. Similarly, the space occupied by the Batch Plant (C) can be reused for objects that enter the site after month 12 (i.e. Carpentry Shop (E) and Landscape Shop (I)). However, since the changes in space requirements are ignored in the *static* approach, in fact it does not allow the reuse of site space. The Geotechnical Lab (object A) and the Batch Plant (object C) in this example would not be allowed to use the same space in the *static* approach, even though in reality they do not exist on the site at the same time.

The space requirements for accommodating the objects on the site over the course of a project can be presented using a space histogram [33] (Fig. 2). The area under the histogram curve reflects the time–space requirement for the project; i.e. the total amount of space required to accommodate all the objects over the course of project. The time–space requirement of a project can be determined as follows:

$$\text{Time–Space Requirement} = \sum A_i \times T_i \tag{1}$$

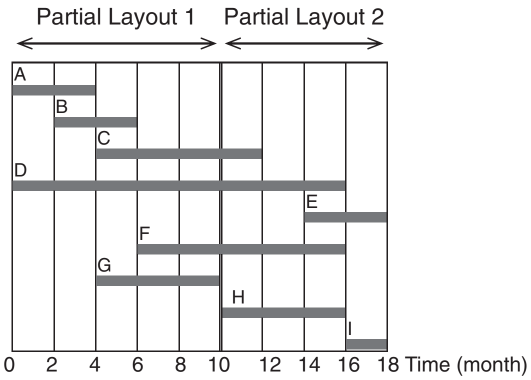
where A_i is the footprint area for object i, and T_i is the duration that object i exists on the site. Since changes are not considered in the *static* approach, it is as if it is assumed all objects that exist on the site for the entire duration of the project. This assumption means that in the static approach, the space required to accommodate objects at any given time is equal to the sum of the footprints of all the objects (900 m^2 in this example). Accordingly, the time–space histogram will be a straight line, indicating that space requirements do not change over time in the static approach (see Fig. 2). The total required time–space (i.e. space required over the duration of the project) for the example illustrated in Fig. 1 in the *static* scenario can be calculated using Eq. (1):

$$\begin{aligned}&\text{Time–Space Requirement}_{\text{static}}\\ &\quad = (100 + 90 + 120 + 110 + 80 + 70 + 130 + 120 + 80) \times 18\\ &\quad = (900) \times 18 = 16{,}200 \quad \text{month-m}^2.\end{aligned}$$

The unit month-m^2 is used to refer to the space needed over a specific period of time (m^2 over time) to distinguish it from the footprint of objects (m^2). The total time–space available for this

ID	Name	Size (m^2)	Duration (month)	Time-Space month-m^2
A	Geotechnical Lab	100	4	400
B	Rebar Shop	90	4	360
C	Batch Plant	120	8	960
D	Offices	110	16	1760
E	Carpentry Shop	80	4	320
F	Storage	70	10	700
G	Gravel Depot	130	6	780
H	Brick Depot	120	6	720
I	Landscape Shop	80	2	160

(a)



(b)

Fig. 1. Case example; a. Construction objects properties, b. Construction objects schedule.