An Automated Approach to Construction Site Layout Generation

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Knowledge of the status of site spaces is critical to generating effective and reliable site layout plans. Previous approaches to site layout planning advocate generating layouts based on the planned project schedule which do not reflect the actual status of the project in terms of activities, resources and associated spaces. As such, this questions the reliability of the generated site layouts. This study presents the development of an automated component level system that is capable of generating optimized site layouts using radio frequency identification (RFID) technology for tracking the context of site resources and spaces in real-time. The prototype implementation applies to cost controlling and management in terms of automating the generation of context-adaptive site layout models. Conclusions are drawn on the industrial application and functionality of the developed system.

Key Words: Automatic Construction Site Layout, Building Information Model, RFID-RTLS System, Genetic Algorithm

Introduction

Effective layout of resources and activities is critical to the success of construction projects. Project managers require updated information about the status and availability of site spaces, prior to positioning resources on the job site. The status of site spaces changes throughout the construction phase as a result of the dynamic nature of site operations which can be attributed to factors such as the actual progress of site activities, the rate of consumption of associated resources, possible relocation of resources and material delivery times (Zouein & Tommelein, 1999). As such, developing a reliable and functional site layout plan will require project managers to spend significant amount of time monitoring and tracking construction site spaces to determine their availability (Navon & Sacks, 2007). This could be particularly difficult in an environment as dynamic as the construction site and particularly when the project site is large and congested. Awareness of the context of site spaces is therefore crucial for generating reliable site layout plans.

Over the years, there have being a number of studies exploring the potential of different computational techniques such as Genetic Algorithm (GA) (Mazinani et al., 2013), Ant colony algorithm (Lam et al., 2007) and Particle Bee Algorithm (Lien & Cheng, 2012) for generating construction site layout plans. While these studies focused on improving the intelligence of site layout planning, there still remains the issue of how to effectively track the status of site spaces and resources in relation to the construction progress. Emerging wireless sensing technologies have shown potential for improving spatial awareness and the context of construction site resources (Teizer et al. 2008; Song et al., 2006). Specifically, radio frequency identification real-time location sensing (RFID-RTLS) systems can provide the location of resources with spatially mapped site spaces (Torrent & Caldas, 2009). Arguably, there are tremendous opportunities for enabling an adaptive interaction between the site and project facilities, in terms of generating a reliable and automated site layout plan, when spatially mapped site spaces are monitored with technologies that have real time location sensing capabilities. Such opportunities include being able to observe and control issues that encumber schedule integrity immediately they occur rather than detecting such in an 'unreal' time, when they may have impacted productivity markedly. In line with this, evidence from past studies has consistently shown that, for performance optimization reasons, it is expedient that site spaces and resources are consistently monitored, are adaptive to varying contexts and are managed effectively (Lindkvist, 2008).

Thus, the objective of this study is to develop an automated site layout modelling system that relies on bi-directional data integration platform – between computational data in design models and actual construction data. Construction data are automatically captured through Radio Frequency Identification (RFID) system with real-time location sensing capability to track construction resources and generate site plans through a supporting application, plugged into design models, for optimized actuation. This paper begins by describing the RFID-RTLS system, the problem formulation and the role of (GA) as the optimization tool. The development of the automated site layout modelling system is introduced. The potential of the developed system is illustrated using a case study of a campus apartment building in Kalamazoo, Michigan. The benefits and limitations of the developed system are presented in the concluding section of the paper.

Research Method

This research primes progress monitoring and control on design data in project model (BIM), and uses Genetic Algorithms (GAs), as function optimizers, to determine resource locations.

RFID-RTLS system

The RFID-RTLS system (shown in Figure 1) consists of master and slave readers, location engine software and battery-powered tags which are usually attached to assets and personnel being tracked. Location information is relayed to the master and slave reader through the tags within a predetermined cycle time. Also, tag detection fields are created through the slave and master readers which are positioned at the boundaries of areas of interest: slaves determine the range of the tags and relay the data reposed in the tags to the master reader. From here, the data are relayed to the location engine software which had been installed in the associated computer system with a goal to determine the location of the RFID-RTLS tags based on time-of-arrival (TOA) of radio frequency signal from the tags to the reader. The distance between tags and readers, positioned at known reference locations, are determined by cycle times of the signal travelling between the two entities. As RFID tags' locations can be visualized via the location engine's graphical user interface, the real-time location sensing component of the system enables tracking tagged components (e.g. staging, storage and other areas for placing temporary facilities) within spatially mapped areas on the construction site.

Problem Formulation

Based on a review of existing work and discussions with project managers, the following factors were identified as necessary for computing site layout model and associated costs:

- *Frequency of trips between facilities and resource pairs,* which refers to the interaction and relationship between assigned pairs of resources and temporary facilities during construction (Cheung et al., 2002). This factor can be measured as the number of trips per period of interest, such as day or week, made by work personnel within project facilities or other forms of resource components between storage and point of use.
- *Distances between available locations on job site,* which are measured as the rectangular distance between the centre points of prescribed locations using the travel path of resource movement (Zhang & Wang, 2008)
- *Transportation cost between the facilities within a site,* which represents the cost of moving construction resources between mapped facilities within a construction site (Ahuja et al., 2000).
- *Shifting cost of facilities between locations,* calculated on the basis of travel variability between facilities and point of use (El-Rayes & Said, 2009). Except in a stage without precedence, changes may be required to the location of facilities as construction processes progress. The shifting cost represents the cost of removing and transporting a facility from its previous to a new location.
- *Setup Cost of Facilities at Specific Locations within a site,* calculated as the cost of installing site facilities on project site for the first time at any stage of the project (Zhang & Wang, 2008). When such facilities are moved to a different location, a shifting cost factor applies.

The Objective Function

The objectives of this site layout problem are to automatically generate site layout models as construction progress changes, and to minimize the total layout cost. The total site layout cost is defined as in Eq. (1):

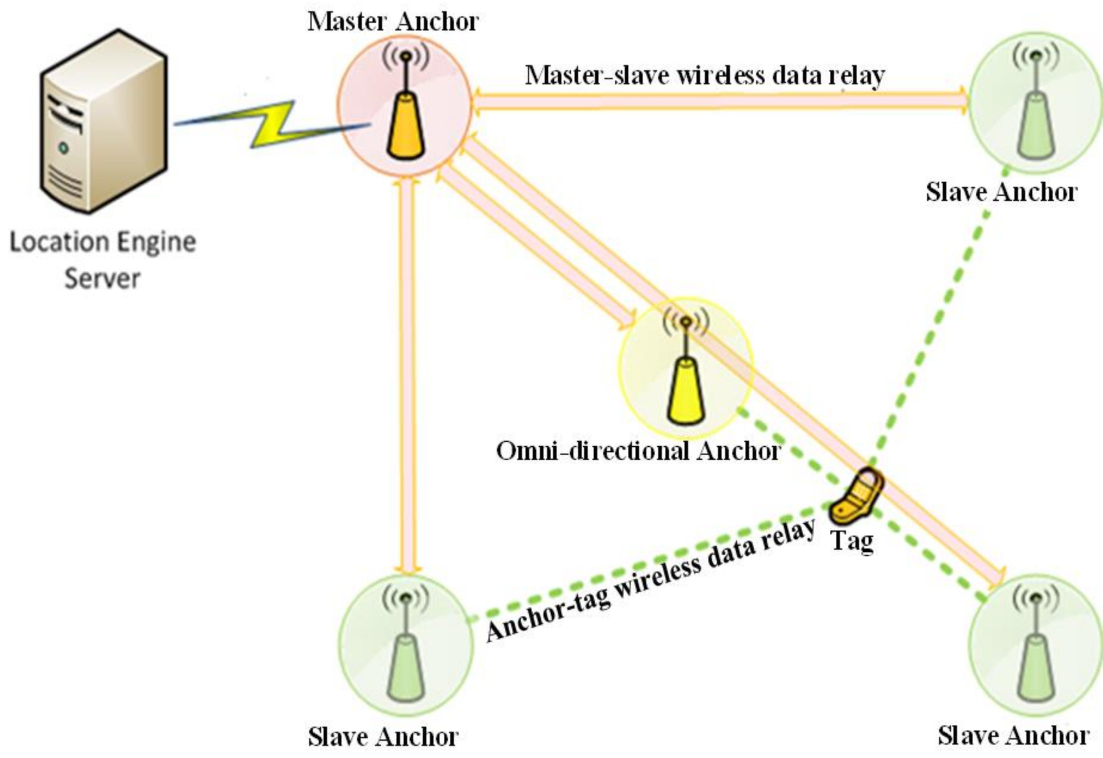


Figure 1: Component overview of the RFID-RTLS system

Minimize

$$\sum_{i=1}^{M}\sum_{k=1}^{M}\sum_{j=1}^{N}\sum_{l=1}^{N} F_{ik}d_{jl}\,C_{ik}X_{ij}X_{kl} + \sum_{i=1}^{M}\sum_{j=1}^{N} S_iX_{ij} + \sum_{i=1}^{M}\sum_{j=1}^{N}\sum_{l=1}^{N} A_{ijl}d_{jl}Y_{ijl} \qquad (1)$$

Where i and k are the i^{th} and k^{th} facilities, j and l are the j^{th} and l^{th} locations, M is the total number of possible facilities to install and N is the total number of locations available. F_{ik} is the frequency of trips matrix between facilities i and k, d_{jl} is the distance between location j and l. C_{ik} is the material transportation cost between facilities i and k. A_{ijl} is the shifting cost of facility i between location j and l, and S_i is the setup cost of facility i. X_{ij}, X_{kl} are the decision variables which indicates if-scenario when facilities i, k are installed in location j, l. Y_{ijl} is also decision variable that indicates moving facilities at a current construction stage.

These variables are subject to:

$$\sum_{i=1}^{M} X_{ij} \leq 1 \qquad (2)$$

Consequently, only 1 facility can be assigned to 1 location and vice versa.

$$\sum_{j=1}^{M} X_{kl} \leq 1 \qquad (3)$$

$$X, Y \in \{0, 1\} \qquad (4)$$

This equation sets the permutation matrices X and Y to binary numbers, indicating the facilities that belong to locations.

The objective function contains the product of two decision variables, and this makes the scenario of its use a non-linear optimization problem. However, by using exact methods and the following genetic algorithm approach, such issues can be solved conveniently as a linear optimization problem.

Genetic Algorithm

GA is a search optimization method that is suitable for permutation while optimising solutions to site layout planning problems. The flexibility of GA makes it suitable for coding in many types of objective functions; whether discrete, linear or non-linear. The underlying principle is that a GA deploys a population of solutions encoded as linear in binary form (i.e. 0s and 1s), and as integers or real numbers. For the site layout problem, GA uses a binary matrix, of which the components represent the values of the decision variable X_{ik}. Based on Equation 1, each possible solution (layout) is evaluated by an objective function to obtain the minimum cost option from an iterative population of possible total site layout cost scenarios. As each selected solution is taken from a new or a current population being iterated, all unselected solutions are reserved for the next randomized iteration. The rationale behind this is to trigger optimum outcomes in-between the iterations. At the end of the iterations, the system is able to produce the objective function that is best fitted for the project situation. The algorithm is designed to stop only when the optimum criteria are met e.g. a maximum iteration or a satisfactory fitness of the possible outcomes of the objective function.

Automated Site Layout System

The system architecture of the automated site layout system is shown in Figure 2. The system integrates Building Information Models (BIM), RFID-RTLS system, MySQL database and GA (implemented in Matlab software) using a middleware written in Visual Studio.Net (C#). The sequence of activities is described below:

a. Construction site boundaries and coordinates are initially prepared and created in the graphical user interface (GUI) of RFID-RTLS system.
b. Following this, the middleware collects location data of the tagged components from the RFID-RTLS system, computes the number and coordinates of possible available locations and stores them in the MySQL database.
c. Based on the coomputed data, frequency of trips matrix is developed in Excel and collected as an input to the GA by the Matlab code.
d. The project schedule is based on BIM data (using Autodesk Navisworks), and this includes the different phases with related tasks and activities. Within BIM, the middleware enables the user to insert facilities related to each task. The middleware also collects and stores the facilities information into the MySQL database.
e. Upon entry of the information into the database, the middleware triggers the GA Matlab code to generate site layouts. Subsequently, the GA Matlab code uses the information in MySQL database (i.e. number and coordinates of possible locations and the list of related facilities) to generate site layouts. The middleware is then able to capture site layouts adaptively, displaying them using the RFID-RTLS system GUI.

At the beginning of each project phase, sequence (b)-(e) above is repeated.

Case Study

This case study illustrates a laboratory scale implementation of the automated site layout generation system on the Western View Apartment project at Western Michigan University. The total area of the project site is 136,800ft^2 (15,200 m^2). From this, we targeted the parking lot which has a total area of 59,535ft^2 (6,615 m^2). The schedule of the project was generated using Autodesk Navisworks.

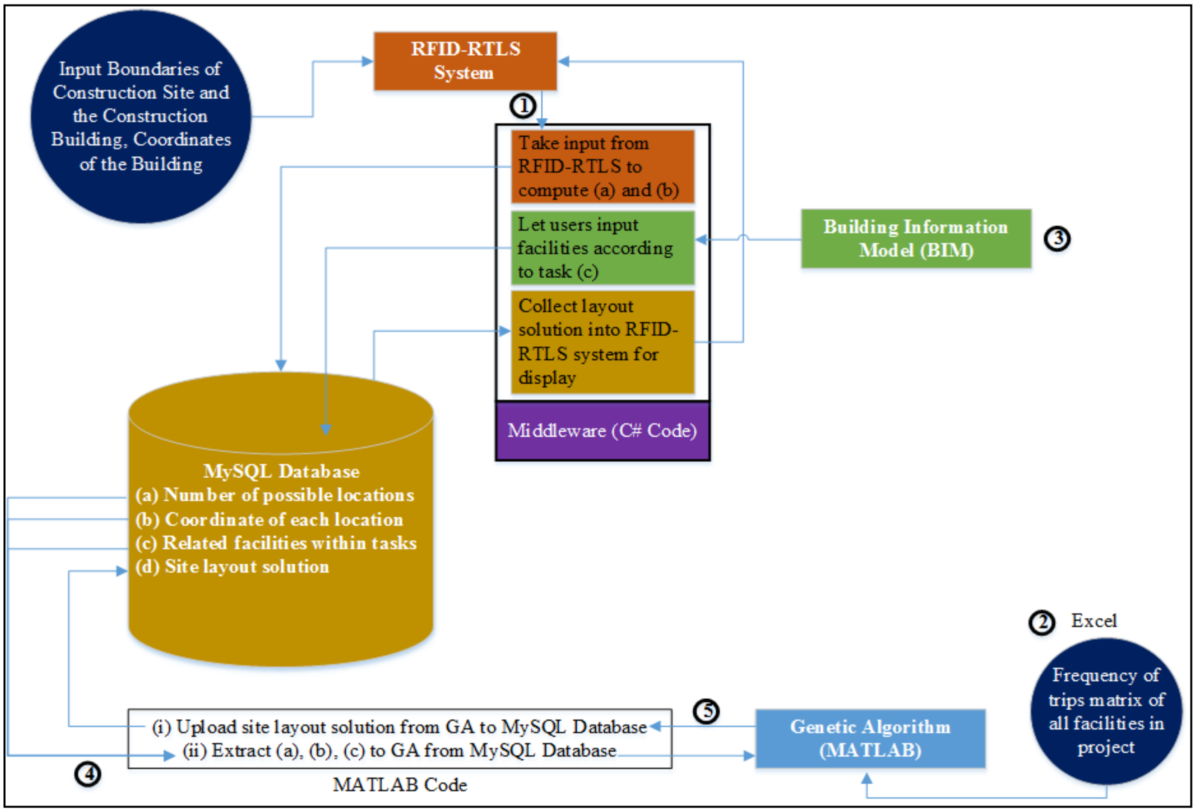


Figure 2: System Architecture for Automated Site Generation System

Results

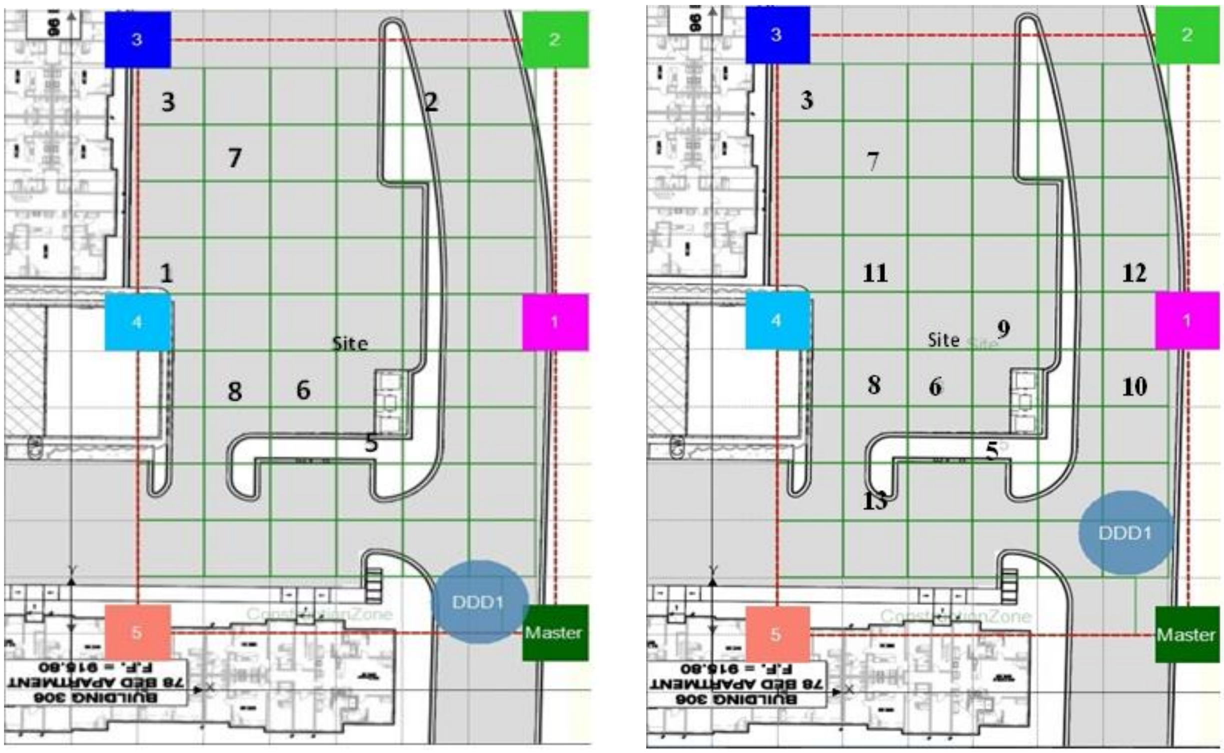
According to the project schedule, at the beginning of Stage 1, a total of 8 facilities were setup. The list of facilities is shown in Table 2. Also, the list of facilities in each stage is shown in Table 3. As shown in Table 1, GA generated a site layout with total cost of $1392.9; representing layout and setup costs of $157.9 and $1235 respectively. There was no shifting cost of temporary facilities in Stage 1 since the Stage has no preceding stage. Thus, layout of the temporary facilities was produced and input into RFID-RTLS system without considering variability of locations prior to this stage. *(b)*

Figure 3(a) and (b) shows the layouts for phase 1 and 2 on the graphical user interface (GUI) of the RFID-RTLS system. The total cost of site layout of Stage 2 is $982.4 (Table 1). This includes layout cost, setup cost and shifting cost, calculated as $128.4, $700 and $154, respectively. Setup cost represents the cost of setting up facilities 9 to 13 since they are the new items in Stage 2. Where a facility which is not in use in a Stage is to be moved, the removal cost will be added to the shifting cost. The same procedures in Stages 1 and 2 are applied to Stage 3.

Table 1

Total cost of each site layout generation

Phase	**Layout Cost ($)**	**Setup cost ($)**	**Shifting Cost ($)**	**Total cost ($)**
1	157.9	1235	---	1392.9
2	128.4	700	154	982.4
3	155.9	685	836	1676.9



(a) *(b)*

Figure 3: Sample Site layout of Phase 1 (a) and Phase 2 (b) in the RFID-RTLS system GUI

According to the project schedule, Facility 13 was not moved since the associated task started in Stage 2 and but was carried over to Stage 3. BIM triggered GA for site layout generation for the Stage. As shown in Table 1, the total cost of site layout generation in Stage 3 is $1676.9. The corresponding layout, setup and shifting cost are $155.9, $685 and $836, respectively. The setup cost includes the cost of setting up facilities 14 to 18 and the cost of shifting or moving facilities 3 to 12. Thus, the total cost depends on the number of facilities associated with each phase and the number of facilities that are shifted. From a practical point of view, while most of the facilities are initially set up, it is important to avoid moving the facilities between stages so as to minimize the total layout cost. However, the objective of this case study is to demonstrate the capability of the automated site layout system in generating layouts based on the project schedule and space availability. The system provides this, considering optimal layout solutions which are primed on minimal total cost for resource transportation, facility setup and shifting. The system also enables visualizing the generated layout through the RFID-RTLS system GUI.

Table 2

List of facilities involved throughout the project life

ID	Name
1	Concrete Element storage area
2	Rebar bending yard
3	Carpentry workshop
4	Molding board storage area
5	Storage Container
6	Material delivery storage area
7	Mechanical equipment storage
8	Raw material container
9	Material hoist
10	Brick Yard
11	Electrical equipment storage area
12	Insulation material area
13	Drywall sheet storage
14	Concrete pour equipment
15	Paint storage
16	Finishing equipment storage
17	Carpet/interior material storage
18	Cleaning equipment

Table 3

List of temporary facilities involved in each construction stage

	Stage 1	Stage 2	Stage 3
Temporary Facilities	1	3	13
	2	4	14
	3	5	15
	4	6	16
	5	7	17
	6	8	18
	7	9	
	8	10	
		11	
		12	
		13	

Conclusion

This study aims to develop an automated component level system that is capable of generating optimized site layouts in real time. The developed system uses computational algorithms and was able to automatically track temporary facilities and model available site spaces in relation to optimum cost outcomes. It relies on the adaptivity of parametric design model as it interacts with GA and RFID-RTLS system. As illustrated through execution Stages 1 to 3 of the case study, the optimized outcomes were able to actuate medium level control measures, particularly actions leading to optimized cost management. Moreover, in all cases, the automated cost estimation for each of the cases of variability was context-adaptive and reflects the current situations in the site layout models. Despite the fact that the developed system provides an effective and reliable means for tracking site spaces and resources for automated site layout generation, there are some limitations in their application. Since the system utilizes RFID-RTLS system, its application is currently limited to tracking components, labor and equipment. Furthermore, for full implementation of the developed system, there is need to investigate the optimum placement of the readers for effective location data capture. The placement of the readers will obviously depend on the congestion level of the site and the location of resources of interest. These readers are likely to obstruct the movement of resources on the job site.

In spite of the limitations of this system, it has succeeded in adding to growing research on the applications of RFID for construction control and optimization, GA and context-adaptive platforms for construction process simulation. The contributions have been primed on the use of real time location sensing capability of an RFID system, and the integrative ability of BIM to retain design data adaptively. In-between these two, GA has been used to automate the actuation of optimized outcomes. Furthermore, the proposed system helps project managers to optimize site layout planning in terms of costs and space.

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