Analysing Construction Cost Estimation Factors as a Map

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Introduction

In a construction project, the cost estimation process is usually performed based on parameters such as project size, type of project, material costs, duration, and ground conditions (Oberlender and Trost, 2019). The relationship between these parameters is mostly defined and modelled by a human expert such as a project manager or builder and this can create inconsistencies in estimation (Agyekum, 2019). Hence, it is important that these factors and the relationships between them are properly addressed in an applied model to create an accurate cost estimation proposal (Elfaki et al., 2014). To achieve this, different intelligent construction cost estimation techniques can be applied. For example, An et al., (2007) used Support Vector Machines (SVMs) to assess the quality of conceptual cost estimates. They examined different factors such as availability of data, quality of drawings and the estimator's experience to evaluate the quality of the cost model. A genetic algorithm was utilised by Ghoddousi et al., (2013) for project scheduling. The model used time, cost and allocated resource to identify the starting point of each project activity. Ko et al., (2017) employed Artificial Neural Networks (ANNs) to analyse the cost and duration for the road construction project.

These methods have two main common characteristics. First, they usually employ attribute data in a non-geographic space to define the relationship between the parameters. Second, the use of the methods requires the expertise of the human professional (Elfaki et al., 2014; Ko et al., 2017). This paper presents a new method that uses Geographic Information System (GIS)-based spatialisation (Fabrikant and Skupin, 2005; Moore and Bricker, 2015) that allows us to integrate, visualise and evaluate the relationship between the parameters, e.g. time, cost and physical conditions in a three-dimensional map-like space. In contrast to conventional GIS-based methods (Reshma,2017; Zhang 2020) that typically use spatial data to create 3D views or to integrate data from different sources, the proposed method applies non-spatial data to formulate the relationship between construction cost parameters within a unified data structure, namely a map. This allows the relevant stakeholders, e.g. property owners, lenders, or builders, to readily, consistently, and accurately share the construction project information.

Method

Project factors

In a construction project, cost estimators apply different factors such as duration, cost and completion week to itemise each stage of construction (Table 1).

Project stage	Completion week	Duration	Difficulty	Cost A	Cost B	Predecessor
Clearing of the site	Week 2	2 weeks	2	5%	6%	……..
Base stage	Week 8	6 weeks	3	15%	13%	Activity 1
Frame stage	Week 15	7 weeks	4	20%	23%	Activity 2
Lockup stage	Week 18	4 weeks	4	20%	22%	Activity 3
Fixing stage	Week 22	6 weeks	5	30%	27%	Activity 4
Practical completion stage	Week 24	2 weeks	3	10%	9%	Activity 5

Table 1. Six different stages for a house-construction project.

The aim of the proposed model is to compare two cost lists, Cost A and Cost B, in terms of the construction factors and identify the best cost estimation plan. The algorithm is implemented using Repast, a Java-based Toolkit on an Intel CPU at 1.70 GHz and 4 GB of memory. ArcGIS 10.5 is also used to represent the 2D and 3D views of the generated maps.

Creation of the 2D spatialised map

In the proposed method, the task duration and due date values from Table 1 were used as coordinates to convert and transfer them into a two-dimensional space as a point. As the number of stages are limited and the relationship between them is sequential, the model of Gantt chart was applied for time mapping. In this case, the x-axis and y-axis are the corresponding duration and completion week of each stage, respectively. Thus, each stage is represented by a point specified by $S_n(x_n,y_n)$ in which x_n and y_n are a function of the duration and completion week of each stage, respectively. In the next step, the method employs a Voronoi diagram to divide the 2D space (that is represented as a grid of regularly-sized cells, the points of which are specified by $P(x_p,y_p)$) into a set of regions. The method employs the metric below to create Voronoi polygons.

$$d_{Sp} = {}^{1}/_{TD}\sqrt{\left(x_n - x_p\right)^2 + \left(y_n - y_p\right)^2}, \qquad (1)$$

Where TD is the duration, x_n and y_n are the coordinates of each stage in the 2D space and x_p and y_p represent the coordinate of each point P in the 2D space. $S_n(x_n,y_n)$ at each stage are denoted with single points in Figure 1. $P(x_p,y_p)$ are the points determined by cells in Figure 1, and d_{Sp} is the weighted distance.

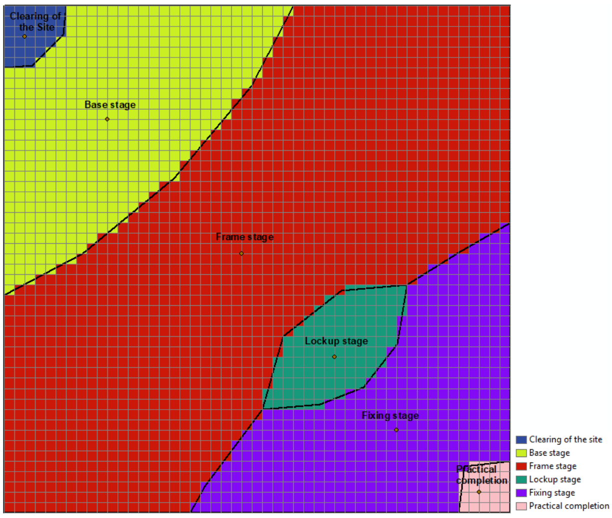


Figure 1: The weighted Voronoi polygons in the 2D space.

The algorithm uses the minimum weighted distance for each point P to allocate that point to one of the stage points S_n, thus segmenting the 2D map. In Figure 1, each region corresponds to one stage of the project, the area of each polygon in proportion to the stage duration.

Construction of the topographic map

There is a strong relationship between cost, duration and project conditions such as difficulty (Bromilow et al., 1988). This relationship is typically defined based on an exponential function (Edum-Fotwe, 2003). The model used in this study employs a sigmoidal shape (Wolfram, 2015), to transfer the cost and difficulty factors from Table I to add a “height” dimension to the 2D space. Equation (2) was used to perform this transformation (Moore and Bricker, 2015) and is used to calculate the height for every *P* within a stage region, based on its distance from stage point S_n.

$$igmoid\,(d_{Sp}) = \left({}^{1}\!/_{1 + e^{-norm\,(d_{Sp})}} \right) \times C_n \quad (2)$$

Where *C* is the condition project of each stage, and in this case, it represents the difficulty at each stage number (*n*). The normalised distance is depicted as $norm(d_{Sp})$ and ranges between -5 and 5 within each stage region. The output of the model is a topographic map where each hill represents the difficulty of each construction stage (Figure 2).

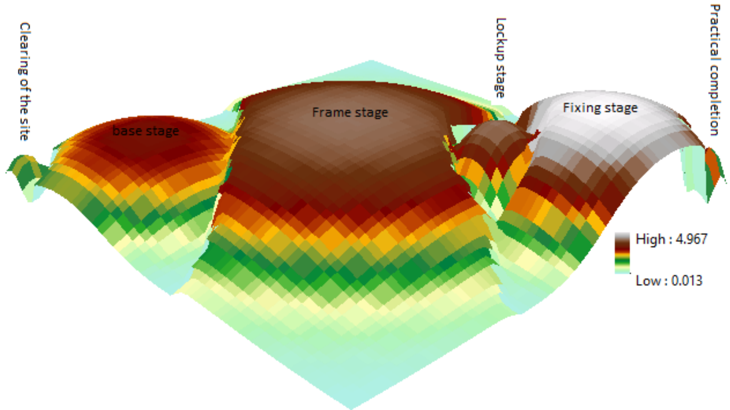
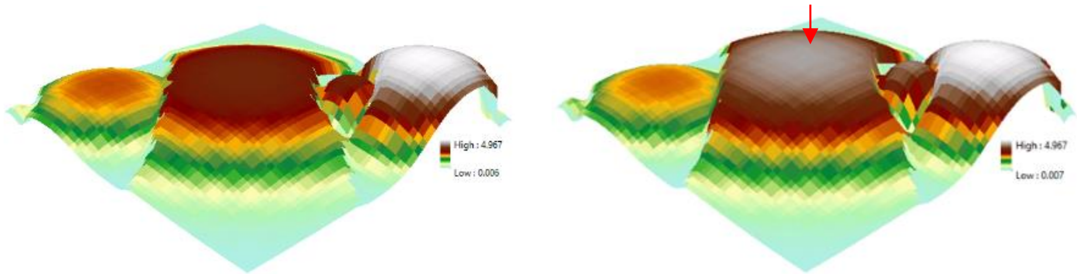


Figure 2: The difficulty map for each stage.

Equation (2) is then applied to create two 3D maps based on Cost A and Cost B. In this event, *C* values are specified based on the Cost A and B lists. Figure 3 displays these two maps in a 3D topographic spatialisation. A visual assessment of the 3D maps based on elevation values shows that the elevations of the 3D Cost B map are similar to the corresponding points in the difficulty map (red arrows on Figure 2 and Figure 3(b) for the Frame stage). In contrast, this elevation difference is evidently different for the 3D Cost A map. This means that there is no balance between the difficulty and the allocated cost for the Frame stage in Cost A, whereas there is a balance in Cost B.



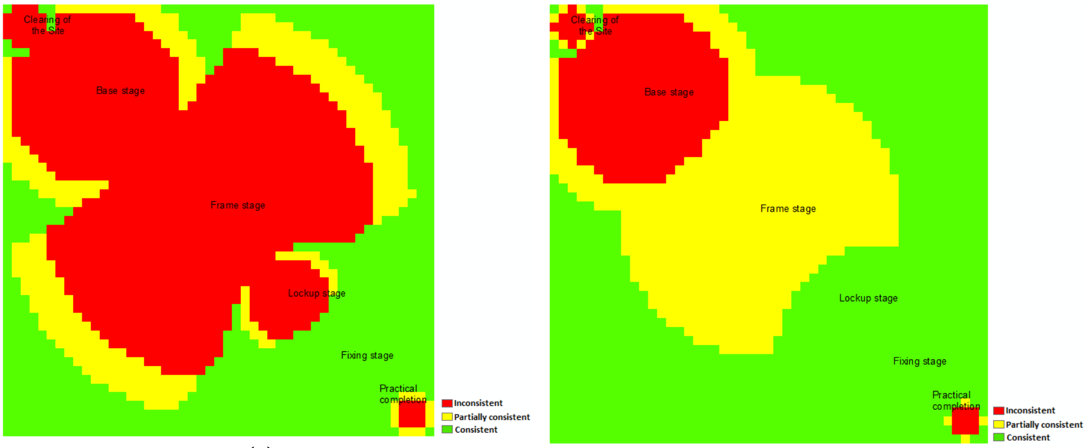
(a) (b)

Figure 3: (a) and (b) are the 3D views of the Cost A map and Cost B map, respectively,

A visual assessment of the 3D maps based on elevation values shows that there is no balance between the difficulty and the allocated cost for the Frame stage in Cost A, whereas there is a balance in Cost B (red arrows on Figure 2 and Figure 3(b) for the Frame stage).

Production of the consistency map

In this step, the difference between the difficulty map and the Cost A map was used to generate a consistency map A (Figure 4a). In the same way, the Cost B map and the difficulty map are applied to create the consistency map B shown in Figure 4b.



(a) (b)

Figure 4: (a) and (b) display the consistency maps for Cost A and Cost B in the 2D abstract space, respectively.

A visual assessment of these two maps demonstrates that the Cost B scheme is more accurate than the Cost A scheme in terms of the allocated time and difficulty of each stage. Table 2 lists the area of each cost group from Figure 4a and Figure 4b. As shown, there is a sharp difference between the inconsistent areas on the two maps.

Proposal	Consistent	Partially consistent	Inconsistent
Cost A	866	390	1145
Cost B	1202	858	341

Table 2: The area of each cost category

Discussion and Conclusion

The cost estimation process is an important stage in a construction project and it involves different parameters that need to be simultaneously analysed to provide an accurate cost estimate. This paper highlights a new method that allows us to map the relationship between different non-spatial factors in the cost estimation model and to spatially display this information as maps in 2D and 3D map-like spatialisations. The generated maps are then used to quantify the relationship between parameters and further create inconsistency maps, which can then be used to better estimate the project cost for each stage, and to provide a more consistent and reliable method of cost estimation for relevant stakeholders. Moreover, the use of the applied method allows us to identify unbalanced project stages in terms of the project factors and to update any initial balanced cost lists. The results demonstrate the high potential of the proposed method to estimate the cost for a house-construction project and can be scaled up for use on more complex construction projects. The implementation of a more complex scenario and the integration of other factors would be interesting for further research.

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