Formwork application optimization by using augmented reality

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Abstract. By using the PLM (Product Lifecycle Management) principle on the formwork case study, after determining the functions and the technical solutions, the application must be made as optimum as possible in order to assure productivity and provide the necessary information as quick as possible. The concept is to create a complex management for the formwork based on augmented reality. By taking into account the development rate of the information, augmented reality is tending to be one of the widest (in term of domain) visualization instrument. Also used in the construction domain, augmented reality can be applied also for the case of formwork design and management. The application of the solution will be retrieved in the construction of the product, its transportation and deposit. The usage of this concept will help reduce, even eliminate human or technical errors and can offer a precise state of a specific required formwork from the stock.

1. Formwork
1.1. Introduction
One of the main problems in the formwork domain is management. The paper deals with the storage and inventory aspects of this field.
The aim is to obtain a stock – pile that offers the possibility to select a certain formwork, to obtain all the necessary information regarding the desired product (location on site/ in the deposit, number of panels available, state: clean or prepared for cleaning), to transport it and to prepare the falsework for delivery on site. Also, for the construction of a certain element, after the selection of the panels, one can virtually assemble the modules to create the pouring form and to design the mounting stages that the site worker must execute. By using the A.R. you can simulate the position and correct the errors that can appear, in this way at the building yard the assembling process will ensue normally. In order to group the formwork panels we first need to determine the selection method. Taking into account the existing formwork panels (suppliers), the principle selection factors are:
- shape
- dimensions
- assembling method
- material.

1.2. Formwork shape/form
In the construction domain, buildings are erected not only in the traditional shapes and forms. Architects exceeded this barrier and different regular and irregular shaped institutions can be seen all over the world. By putting together all the two – dimensional and 3D forms, it results that for each concrete building a specific casting mould was used (whether it is a known shape or not). Figure 1 is an exemplification of such buildings.
By analyzing the previous affinity diagram and the canonical form of the functions that determine the buildings’ shape we can use the unique representation and use that formula in order to obtain the necessary formwork.

**Figure 1.** Different shaped buildings [16]
Because every complex shape is formed of simple parts, for the modular panels it is essential to define the line’s origin, radius, second and third point (if necessary). By knowing all these, one can easily determine the canonical form of the geometric figure. Hence, each modular component can be reduced to a curve or segment (the case when the segments’ ends represent the radius of the circumscribed circle).

After assembling the parts the desired formwork can be used for pouring. Such an example is represented in Figure 2, where a cylinder wall is exploded into different modular parts – formwork panels. For each modular panel we define the radius, length and corresponding height (function of the supplier) and we can obtain the different curved panels that we need.

When the height of the panels is not enough one can easily combine the existing modules and reach the desired dimensions by maintaining the curved shape constant to the upper and lower panels.

For a proper storage of the modular panels we can simply write the radius dimension first, the length, the height and if necessary the coordinates of another point of the panel (the origin will be considered the left hand lower corner of the panel of the pouring position) and generate a simple bar code.

For example, for a middle panel from the cylindrical formwork column we will introduce as input data the radius R, L, H, and then 0, 0, H and L,0, H. If the panel has 2.5m radius, with a height of 5m and 1.8 m long, then the bar code would be:

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2.5-1.8-5-0,0,5-1.8,0,5
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![Figure 2. Cylinder wall – formwork components](image)

On line bar code reader can easily determine the code numbers (the type code used initially was Code –
and we can simply determine the necessary parameters as follows:

\[ \text{radius} \quad \text{length} \quad \text{height} \quad \text{first point coordinates} \quad \text{second point coordinate} \]

\[ 2.5 \quad 1.8 \quad 5 \quad 0.0,5 \quad 1.8,0,5 \]

1.3. Formwork dimensions

Function of the supplier that we work with, we can easily define the available dimensions of the straight and circular panels.

In order to have the desired productivity other aspects regarding the product are mandatory (pressure resistance, material, connection type, estimated assembly time).

As a case study, we selected 9 formwork suppliers to work with, known world-wide, in order to exemplify the storage functionality.

Table 1 is a classification of each supplier according to their existing products.

| Characteristic | Supplier |
|----------------|----------|
| Pressure\(^a\) | Neru     | RMD     | Ulma   | Doka   | Noe    | Meva   | Hunebeck | Peri   |
|                | <50-70   | <60     | <60-80 | <60    | <60    | <60    | <60     | <60     |
| Min. radius\(^b\) | 2.5     | 2.5    | 2.25/1.125/2 | 3.5    | 2.75   | 2.5    | 4       | 1       |
| Height\(^b\)   | 2.5/3/3.5 | 3/1.5 | 3/2/1.5 | 0.7/1.2/2.4/3/3.6 | 3/1.5/0.75 | 3/1.5 | 1.5/2/3 | 0.6/1.2/1.8 | 2.4/3/3.6 |
| Length\(^b\)   | 2.5/3/3.5 | 3/1.5 | 3/2/1.5 | 0.7/1.2/2.4/3/3.6 | 3/1.5/0.75 | 3/1.5 | 1.5/2/3 | 0.6/1.2/1.8 | 2.4/3/3.6 |
| Connection type | ‘u’ clamp | trapeze key bolt options/multi clamp | tapped vice | double vice and tapped vice | tapped vice | rigid clamp,clippers | bolt clamp, wailing clamp, tapped vice | tapped vice |
| Material        | plywood + plywood + plywood + plywood + plywood + plywood + plywood + plywood |
|                 | + steel + aluminium + Steel/ aluminium + steel + steel + steel |

\(^a\) unit measure ‘kN/m\(^2\).

\(^b\) unit measure ‘m’.

Taking into account that all buildings elements are modular ones (foundation elements: sleeves, foundation girders, columns, walls, girders, beams), the modules are realized in order to assure the pouring height and width as optimum as possible. Hence it results an order/variation of all the subsets formworks that fulfill the requirements

1.4. Formwork assembling methods

Function of the producer, there are different type of clamps that connect the panels together.
1.5. **Formwork material**

Now-a-days there are 5 known materials: timber, steel, aluminum, composite and fabric. In the following figure (Figure 5) one can see the different shapes and materials that the formwork has.

![Figure 4. Formwork coupling](image)

![Figure 5. Formwork material [17]](image)

1.6. **Formwork selection**

A “Lean construction” represents [1] an improved system that eliminates all the “waste” factors from the planning and execution domain. For the case of formwork storage, the following aspects need to be evaluated: transportation time, unnecessary movement, inventory, rework, maintenance planning.
The formwork (as stated before) is one of the important aspects concerning productivity and on site scheduling.

Figure 6. Selection algorithm

Taking into account the discussed selection parameters, an algorithm was conducted in order to determine the necessary type of formwork.
The applied algorithm is a decision tree type. The idea is to determine the “leaf” element (the main selection aspects) and to obtain a method for a decision making. Because many consumers (from the construction execution field) do not analyse the selection process thorough, problems can appear during the pouring process concerning the quality of the resulted element (e.g.: porous surfaces, reworks, formwork failure) or additional costs (auxiliary tie-rods for extra resistance, rent payments for unnecessary formwork panels) that can easily be avoided.

The simple path that we must work on is:

select shape -> material -> dimensions -> number of modules + type -> assembly method

In order to have the expected results, for each decision leaf time is of the essence. Hence for each branch other subdivisions must be created, obtaining Figure 6.

After having the necessary components established, by scanning a bar code of those specific modules and auxiliary items, we can see in the inventory management program if that type of form is on stock, the number of pieces available or its current position, days of usage or time till it is storage back. The bar code is available for each shape – dimension – supplier – material.

Having all the data known we can assemble the mounting kit. The obtained group will now have a new code that will assure a correct mounting on site. Also by using Augmented Reality we can visualize if the selected panels assemble in the correct manner.

2. Augmented reality

The concept of augmented reality is a tool that can easily guide and minimize errors before executing works. This technique blends in a 3D space both the elements of the real world and virtual one creating a simulation of what the virtual product could look like in a certain (real) environment.

In the construction domain because of the new technologies and materials the traditional ways of execution and design have also changed. Augmented reality offers the possibility to answer all the questions regarding the site – design correlations such as: position on the terrain, possible excavations, execution works or even dimensioning precision. Recent studies [2] show that the main construction domain of focus for the Augmented Reality applications is the building sector followed by infrastructures and highways. The purpose of using such technology can be diverse [2]. From the monetarization one to error detection, model evaluation, update and validation to infrastructure tasks [3] such as: site dimensioning, excavations, geometry, supervision, planning or control [4].

The usage of Augmented Reality systems could be classified as stationary or mobile. The table below shows the tendency for each construction domain mentioned above taking into account the latest researches.

| Table 2. Construction domain leaning |
|--------------------------------------|
| **Construction domain** | **Article** | **Purpose** | **Usage type** |
| Buildings | “Management of building supported on virtual interactive models” [5] | Offers and idea about the stages of the construction in a 4D application (function of time) | mobile |
| Infrastructure | “Potential of Mobile Augmented Reality for Infrastructure Field Tasks” [6] | Offers real time information about the site characteristics (network, tunnels, water drainage) | mobile |
| | “Development of methodology and virtual system for optimized simulation of road design data” [7] | Simulates road design taking into account the natural real environment | stationary |
| Highway | “Evaluation of image-based modelling and laser scanning accuracy for emerging automated performance monitoring” [8] | An A.R. system that can recognize images for design input data | mobile + stationary |
For our case study we used a combined system: mobile + stationary. By using a camera (mobile system) we can scan the QR code from the formwork 2D drawing and see the step by step assembly. By the help of the stationary device (the A.R. program) we can see on the laptop the steps a worker has to perform in order to put together the modular components.

The case study represents a concrete wall having the dimensions \(L \times H \times g\): 4.5m x 3.4m x 0.5m. By applying the selection chart we determined the optimum modular panels to work with. Figure 7 is a representation of the panel position.

The panels type 1 have the dimensions \(L \times H\): 0.9 m x 2.7 m, panel 2: \(L \times H\): 0.9 m x 0.9 m and panel no. 3 \(L \times H\): 2.7 m x 0.75 m.

When reading the technical documentation and drawings, by using the QR code, the assembling steps will ensure the correct position and mounting of the three panel types.
Figure 8 is the execution plan of the wall formwork.

In order to apply the A.R. after designing the form in Catia v5, we transformed the product and its parts into a simplified format called .wrl (virtual reality modeling language). Using this format, we could...
virtually see the assembling steps.
In order to execute this mounting operation 17 steps need to be performed:

panel 1 -> panel 2 -> clamps -> panel 3 -> clamps -> panel 4 -> clamps -> panel 5 -> clamps ->
step 1  step 2  step 3  step 4  step 5  step 6  step 7  step 8  step 9

panel 6 -> clamps -> panel 7 -> clamps -> panel 8 -> clamps -> tie-rods -> concrete pouring
step 10  step 11  step 12  step 13  step 14  step 15  step 16  step 17

Also, for the clamps and tie-rods another code can be defined in order to see the section and the
responding position. Figure 10 and figure 11 represent a detailed representation of the two
components.

![Figure 10. Formwork clamp 2D and 3d detail](image)

Concerning the tie-rods, they connect the two panels that form the formwork.

![Figure 11. Formwork tie-rod position](image)

3. Conclusions
The storage assures the proper selection of the necessary form and offers the proper information about
the components.
The usage of Augmented Reality not only helps avoiding errors but also increases labor productivity. By selecting the optimum solution for the panel, the 3D visualization helps the workers assemble the formwork precise and correct.

References
[1] Ansah R, Sorooshian S, Mustafa S 2015 Lean Construction Techniques A Framework towards Elimination of Waste in Construction Industry Proceeding of the 2015 International Conference on Operations Excellence and Service Engineering (IEOM 2015) Orlando Florida USA
[2] Rankohi S, Waugh L 2013 Review and analysis of augmented reality literature for construction Visualization in Engineering p 1-9
[3] Behzadan A H, Dong S and Kamat V R 2015 Augmented reality visualization: A review of civil infrastructure system applications Advance Engineering Informatics 29 252-267D
[4] Sahin, Togay A 2016 Augmented reality applications in product design process Global Journal on humanities and Social Sciences 3 115-125
[5] Sampaio A, Gomes A R and Santos J P 2012 Management of building supported on virtual interactive models Journal of Information Technology in Construction 17 121-133
[6] A. Hammad, J. Garrett, H. Karimi 2002 Potential of Mobile Augmented Reality for Infrastructure Field Tasks Applications of Advanced Technologies in Transportation 425-432
[7] Kang L S, Moon S H, Dawood N and Kang M S 2010 Development of methodology and virtual system for optimized simulation of road design data Journal of Automation in Construction 19 1000–1015
[8] Golparvar-Fard M, Bohnb J, Teizerb T et al. 2011 Evaluation of image-based modeling and laser scanning accuracy for emerging automated performance monitoring Journal of Automation in Construction 20 1143–1155
[9] Chi H-L, Kang S-C and Wang X 2013 Research trends and opportunities of augmented reality applications in architecture, engineering and construction Automation in Construction 33 116-122
[10] Akhavian R and Behzadan A H 2012 An integrated data collection and analysis framework for remote monitoring and planning of construction operations Advance Engineering Informatics 26 issue 4 749-761
[11] Behzadan A H, Dong S and Kamat V R 2015 Augmented reality visualization: A review of civil infrastructure system applications Advance Engineering Informatics 29 252-267
[12] Agarwal S 2016 Review on application of augmented reality in civil engineering International Conference on Interdisciplinary Research in Engineering and Technology
[13] Chien-Ho K and Jiun-De K 2015 Making formwork construction lean Journal of Civil Engineering and Management 21 issue 4 444 – 458
[14] Abdelhamid T S, El-Gafy M and Mitropoulos P 2009 Selection of Roof Casting Formwork Systems for the Bird Island Project: Case Study Practice Periodical on Structural Design and Construction 14 issue 4
[15] Schall G, Mendez E et.al 2009 Handheld Augmented Reality for underground infrastructure visualization Personal and Ubiquitous Computing 13 issue 4 281-291
[16] Images Figure 1 available at: http://www.architecturaldigest.com/; http://dels.nas.edu/; http://www.designboom.com/ sq.wikipedia.org; http://design-milk.com/
[17] Images Figure 5 available at: http://studio-tm.com/; http://www.tradekorea.com/;
[18] Formwork suppliers’ sites available at: http://www.peri.com/en/; www.huennebeck.ro; www.mevaformwork.com; www.noe.de/en/homepage.html; www.doka.com/en/; www.ulmaconstruction.com/en/formwork; www.neru.com.tr/en/index.php; www.mesaimalat.com/