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An Architecture for Reviewing Conducted Collaborative Operational Strategies and Exploring Alternatives in Virtual Environments: the Case of Asphalt Compaction

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ABSTRACT

This paper proposes a generalized architecture that suggests an approach to extend utilization of Virtual Environments (VEs) in Civil Engineering. The architecture allows to combine [a] approaches to visualize previously conducted construction activities that involved multiple construction machines and [b] methods that support demonstrating and evaluating alternative operational strategies. The proposed architecture was tested by developing and applying a specialized VE oriented to review asphalt compaction operational strategies and explore alternatives. To allow assessing the continuity and consistency of both real and demonstrated activities we outlined a set of special indicators characterize compaction processes. The VEs developed according to the proposed architecture ultimately aim to support communication and reflection amidst construction professionals who possess different sets of knowledge and experience. The VE-induced interactions are expected to stimulate knowledge integration, collaborative sense making, learning, and process improvement.

INTRODUCTION: VIRTUAL ENVIRONMENTS IN CIVIL ENGINEERING

Virtual environments (VEs) are commonly perceived as a means to enhance the innovative potential of companies. Such environments allow to involve multiple people with different knowledge and experience in the innovation process and can help with capturing suggested ideas (Watts et al., 1998). Also, because the immersive interfaces of VEs can naturally support situated learning (Dede, 2009), virtual environments can effectively support education and knowledge transfer tasks. The recognition of the VE benefits resulted in the fact that the development and utilization of such environments is one of the research trends in the construction domain (Balaguer and Abderrahim, 2008).

Typically, VEs in the construction domain are tailored towards a specific purpose. Such a purpose could be to support education, for example in construction safety (Son et al., 2011), train equipment operators, analyze conducted, or simulate alternative construction activities. According to these demands, nowadays multiple VEs for the construction industry are offered by both industry (e.g. CAE Mining simulator:

www.cae.com/cae-terra-simulator/) and the academia (see for instance Velez et al. (2013)). However, as VEs are normally oriented to support only one of the listed purposes, they lack the ability to be effectively used for other objectives. This leads to the risk that the potential of virtual environments in civil engineering is not fully exploited.

This study suggests an architecture that allows to fuse several functions of VEs in order to extend utilization of virtual environments in construction domain. We suggest to incorporate best practices related to visualizing earlier conducted construction activities (such as AsphaltOpen (Miller et al., 2011)) and allowing equipment operators to show rather than to explain how they would proceed in the given conditions (Vasenev et al., 2013a). Specifically, we propose to utilize VEs to support the review of previously performed construction activities and at the same time provide users with an opportunity to experiment on alternative working strategies. The proposed scenario of utilizing VEs aims to support discussions between construction professionals, who possess different knowledge and experience, and ultimately aims to advance on-site collaborative working practices.

The next section will present the proposed generalized system architecture that suggests a way to combine VEs with data processing and visualization elements in order to provide opportunities for reviewing earlier conducted collaborative working strategies and demonstrating alternatives. Afterwards, an application of the architecture for the case of asphalt compaction processes will be described. Finally, initial tests of the specially developed VE and the indicators that describe operators' behavior are shortly presented.

ARCHITECTURE OF THE PROPOSED VIRTUAL ENVIRONMENT

To suggest a way to combine possibilities to visualize previously conducted construction activities with opportunities to try and evaluate alternative operational strategies we developed a generalized architecture shown in Figure 1. The architecture incorporates elements related to (1) collecting data during real projects, (2) processing the data, (3) demonstrating the conducted operations on site in a VE together with documenting alternative working strategies, and (4) visualizing indicators related to both conducted earlier in reality and demonstrated within the VE working strategies.

Specifically, sensor readings from different types of sensors collected during real construction operations form the input data streams. These incoming streams, such as temperature from the linescanner and GNSS(Global Navigation Satellite System) data, are pre-processed and aligned. For instance, the collected GNSS data might need to be transformed from global (WGS84) to local coordinates or freed from outliers using automatic (Bijleveld et al., 2011) or human-centered (Vasenev et al., 2013b) approaches.

The fused data streams can then be visualized within a specialized VE. Such VEs should support different types of the user's engagement who can (1) review construction activities and in addition (2) take control of a virtual machine (such as an asphalt roller) and experiment with alternative working strategies. For instance, the user can show the direction that the equipment should move by pointing a pen on an interactive whiteboard, or by using other HCI (human-computer interaction) devices.

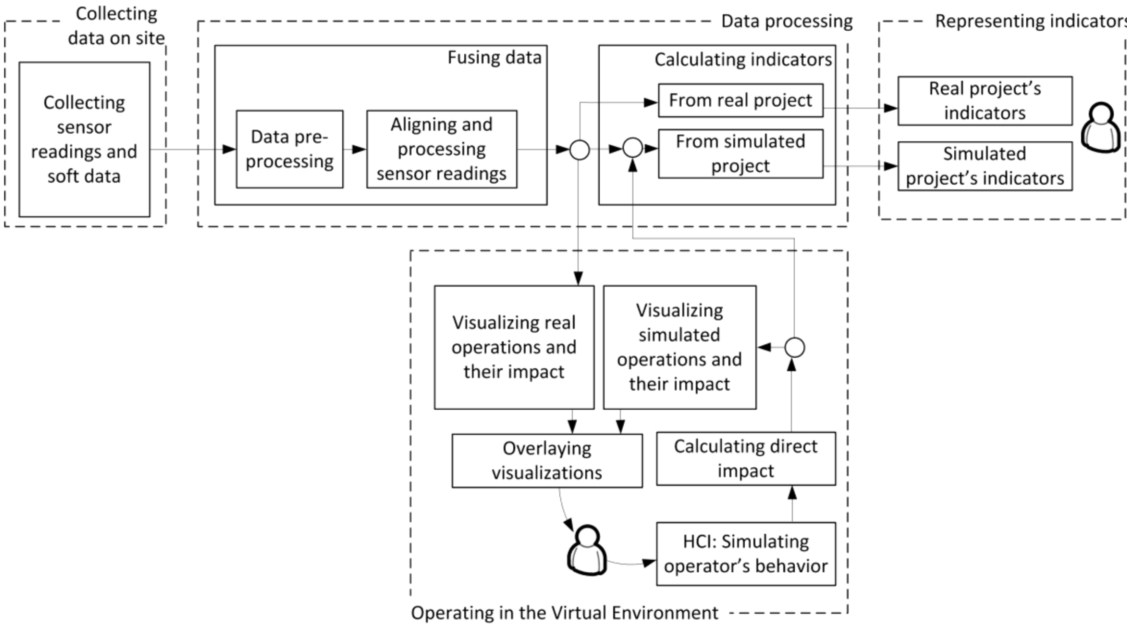


Figure 1. A generalized architecture to review conducted and analyze alternative working strategies

After the demonstration of the alternative working strategy is complete, the demonstrated strategy can be compared to the one that was employed during the real construction project. This comparison can be performed based on a set indicators that characterize working strategies in terms of the continuity and the consistency. Such indicators are specific for different types of construction activities.

The following sections will demonstrate the applicability of the architecture for a particular type of construction activities: asphalt compaction. For this purpose, we will propose a specialized set of indicators. Then, a specialized VE will be introduced.

INDICATORS TO CHARACTERIZE THE COMPACTION PROCESS

Asphalt compaction activities require that multiple specialized machines work in a coordinated manner in order to construct high-quality and long-lasting asphalt layers. Several features characterize asphalt compaction:

- Multiple compactors roll over the asphalt mat deployed by the paver,
- The adequate compaction (amount of roller passes) should be conducted when the asphalt temperature is within specific limits,
- The cooling of the asphalt layer during compaction operations and discrepancies in the paving process demand operators to continuously make decisions about which part of the asphalt mat to compact next.

According to specifications of the process, roller operators have to continuously move their machines in relation to their previous movements, movements of other machines, and in correspondence to the impact that machines earlier made on the paved layer. These characteristics can be quantified to describe the machine movements.

In order to construct a set of indicators that describe behavior of on operator in context we presumed that his decisions are operationalized as machine movements. The machine movements result in some individual (direct) impact made to the constructed entity. The type of the made impact depends on the type of a particular machine. In case of paving machines, it is a newly spread asphalt layer, while for rollers the impact is the compaction effort delivered to the asphalt layer. Summarized outcomes of individual impacts contribute to – and in fact form – the outcome of the construction project. For asphalt paving the desired outcome is an evenly spread and uniformly compacted asphalt layer.

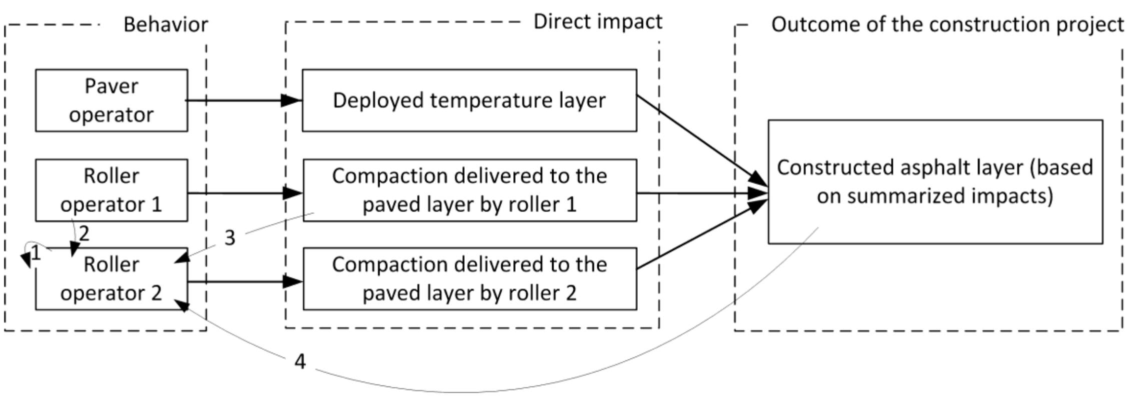


Figure 2. Indicators to describe operational behavior during compaction processes as activities are related to (1) the self-behavior; (2) behavior of other machine operators; (3) direct impact made by the same or other construction machines; and (4) the summarized impact made by two or more machines.

According to these considerations, several types of indicators are needed to meaningfully "quantify" the operational behavior during compaction processes. The developed structure of the indicators characterize the following (Figure 2):

1. Individual behavior in relation to previously implemented operational decisions of the same operator, e.g. operationalized as changes in the equipment's speed or distances between reversing movement directions,
2. Individual behavior in relation to behavior of other operators, such as typical distances between rollers or distances between the paver and a roller,
3. Individual behavior linked to the direct impact of one particular construction equipment, e.g. when (and how) the first or last pass is normally performed in relation to the temperature of the asphalt layer (in this condition the layer seen as the direct impact made by the paver operator),

4. Individual behavior related to the outcome of the construction project (or the sum of direct impacts of at least two project participants). For instance, last roller can consider when to conducts his last passes over specific locations on asphalt mat, based on the current temperature of the asphalt layer and how many passes the previous roller has already performed.

The described structure of indicators allows to consider the operational behavior in relation to different conditions and therefore coherently describes the behavior in context. The calculated indicators can then serve as a ground to compare conducted during the real-world projects compaction strategies with their alternatives shown within a specialized VE. The next section describes how such comparisons can be performed using a specialized VE developed according to the proposed architecture.

PaVE: DEVELOPING AND TESTING

To illustrate the applicability of the proposed architecture for the case of asphalt compaction we developed and tested specialized Paving site Virtual Environment (PaVE). During the development we followed the iterative procedure proposed by (Hartmann et al., 2009) and conducted several meetings with paving experts to demonstrate the current progress and receive feedbacks on computation and visualization methods.

As a core of the specialized virtual environment we utilized the jMonkey 3.0 game engine. This engine, solely written in Java and coupled with an IDE, proved to be a suitable solution to rapidly develop sophisticated VEs. The engine's flexibility allowed us to promptly implement specialized visualization techniques, such as specialized grid-based textures to provide visual cues for considering relative distances between different construction machines.

To demonstrate the functionality of the environment we reconstructed an asphalt paving project that took place near the city Apeldoorn in The Netherlands on July 2010. During the day-long working shift the paving team formed by one paver and two rollers constructed two asphalt layers one above the another. An undesirable event took place during the construction of the first layer – the paver stopped for a long period of time. To mitigate the negative interruption of the construction process, roller operators continued compacting the deployed asphalt mat, conducting more passes than desirable. This relatively typical situation was selected as a demonstrator case. To represent the case we calculated all machine movements during the project and their impacts. However, the following description of the case will concentrate only on two machines: the paver and the first rollers.

In particular, we visualized within PaVE movements of the machines, asphalt temperature distribution after the paver and the compaction effort performed by the first roller in the fleet (Figure 3). Then, we asked an asphalt paving specialist to demonstrate an alternative compaction strategy for the first roller operator by "controlling" the virtual roller within the VE. In order to illuminate the difference between the documented and the demonstrated operator's behaviors we slightly increased the speed of the virtual roller. After the user demonstrated an alternative compaction strategy, we computed indicators of the first and second types (described within a set of indicators above) for both real and the demonstrated construction activities.

The calculated indicators formed two groups that characterized movements of the real roller that took place during the construction project (Figure 4a) and movements of the virtual roller that were demonstrated in the VE (Figure 4b). Each group included two types of indicators: lengths of rolling in a single direction (the indicator of the first type) and changes of distances between the roller and the paver (as the second type of indicators). Green zones in Figure 4 highlight periods of time that the user was controlling the roller in PaVE, as well as the corresponding time periods related to the real movements on site.

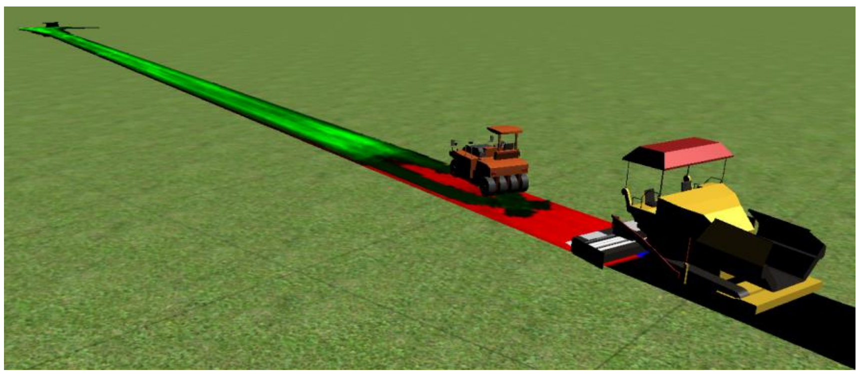
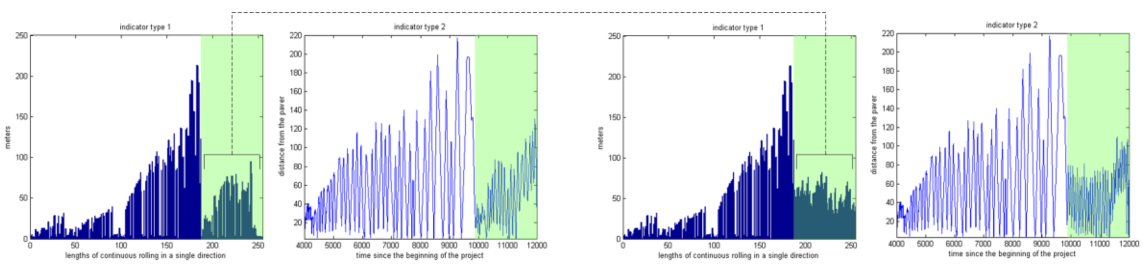


Figure 3. An asphalt paving project reconstructed in PaVE



a. b.

Figure 4. Indicators that characterize the roller's behavior based on: a. roller's movements during real world project; b. movements within the PaVE

Pairwise comparisons of similar indicators allow demonstrating differences between particular characteristics of the compaction strategies. As first graphs of both groups indicate, the user who controlled the virtual roller conducted rolling in a more consistent manner than it was performed in reality – the distances between changing rolling direction were similar to each other. Likewise, according to the second indicator type, the user kept distances between the roller and the paver within a more consistent zone that was not continuously increasing, in contrast to what happened in reality. These findings as well as the indicators themselves were then discussed with the user .

DISCUSSION

As shown, the developed VE provides an opportunity to review operational decisions of equipment operators instantiated as equipment movements, and also to explore alternative (or demonstrate preferable) strategies. At the same time, the indicators provided a solid ground for the rapid assessment of the continuity of operations conducted by a particular machine both in relation to its previous movements as well as to the movements of another machines. To this extent, the environment together with the indicators illustrate the applicability of the proposed architecture to utilize VEs to review earlier conducted and explore alternative operational strategies.

In addition to having the illustrative capacity, we consider the developed VE together with the specialized indicators as a potentially useful tool for assessing, generating, and adopting knowledge possessed by different construction professionals. In particular, the developed environment expected to be suitable to support scenario-based education to train roller operators on how to mitigate unforeseen events, such as equipment breakdowns or delays in the asphalt mixture delivery. For this purpose, construction teams can access the continuity of the construction process in context and develop preferred schemes of their collaborative activities.

Though within the scope of this paper the developed set of indicators was represented as a means to compare previously conducted machine movements with those demonstrated within the VE, the structure of indicators can also support systematical analysis of operators' working patterns across different projects. The demonstrated indicators (or any other subset of indicators that constitute the structure described above) are oriented to provide coherent descriptions of operators' behavior. Such description can be of interest to equipment operators, paving specialists, or apprentices who will become operators in the future.

Meanwhile, though the specialized virtual environment was developed in close collaboration with practitioners, having additional tests of the VE and discussions about the indicators with paving experts is desired. Those discussions might in particular give additional insights about how specific indicators can be meaningfully interpreted or improved.

CONCLUSIONS AND FUTURE WORK

This paper proposed a generalized architecture that suggests how to extend the opportunities for utilizing VEs in Civil Engineering by fusing methods to review conducted operational strategies while providing opportunities to explore alternatives. To illustrate the architecture we developed a specialized VE for the case of asphalt paving. The VE was then tested and the indicators calculated for the conducted and alternative compaction strategies were discussed with paving specialists.

Overall, we see the suggested architecture as a step towards understanding and improving on-site collaborative working strategies related not only to paving but also other construction activities. Ultimately, the solutions developed according to the proposed approach are expected to stimulate knowledge integration, collaborative sense making, learning, and process improvements.

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