Proceedings of the 2016 Winter Simulation Conference
T. M. K. Roeder, P. I. Frazier, R. Szechtman, E. Zhou, T. Huschka, and S. E. Chick, eds.

ANALYSIS TOOLS FOR STORMWATER CONTROLS ON CONSTRUCTION SITES

Jintaek Ock
Raja R. A. Issa
Ian Flood

Rinker School of Construction Management
University of Florida
Box 115703
Gainesville, FL 32611-5703, USA

ABSTRACT

Stormwater discharges from construction activities can have significant impact on water quality by contributing sediments and pollutants to waterbodies. The National Pollutant Discharge Elimination System (NPDES) for most States and the Construction General Permit (CGP) for a few states in the U.S. require the development and implementation of Storm Water Pollution Prevention Plan (SWPPP) and Best Management Practices (BMPs), which should contain storm water collection and discharge points, and drainage patterns across construction projects. Generally, erosion and sedimentation from disturbed construction sites need to be controled before and after construction. This regulatory compliance frequently results in schedule delays or decreased productivity at the beginning of construction process and violations or failure to implement stormwater management on construction sites increases construction costs. Therefore, an appropriate SWPPP needs to be developed at the planning phase. This study explores the feasibility of utilizing BIM tools for SWPPP and BMPs developments.

1 INTRODUCTION

Stormwater runoff from soil erosion at construction sites can have significant impact on water quality by contributing pollutants and sediments to waterbodies. Polluted stormwater and sedimentation can harm and destroy aquatic habitat by carrying chemical contaminants and by increasing turbidity. In order to control and manage stormwater runoff from active construction sites, the implementation of Best Management Practices (BMPs) is required. It includes controls of soil erosion and sedimentation, management of stormwater runoff direction, elimination of chemical waste, and designing adequate capacity detention basin. Basically, a well-designed detention basin at construction site has the capability of reducing soil and sedimentation discharge as well as holding stormwater runoff during peak flow. Therefore, an appropriate detention basin design can be most effective way to mitigate environmental impact from stormwater runoff at construction sites.

In the U.S., construction sites that disturb one or more acre are regulated under the National Pollutant Discharge Elimination (NPDES) program; or, the Construction General Permit (CGP) is applied in few states. The development and implementation of a Stormwater Pollution Prevention Plan (SWPPP) and BMPs are required under environmental regulations.

These regulatory compliances frequently result in schedule delays or decreased productivity at the beginning of construction process. Moreover, violations or failure to implement stormwater management at construction sites will increase construction costs through penalties. The major type of construction stormwater management failure is related to the lack of BMPs and scientific data (Kaufman 2000, Alsharif 2010).

As a result, creating SWPPP and implementing BMPs at construction sites are fundamental process for contractors and engineers. The conventional procedure of implementing BMPs in the construction planning phase requires conducting field surveys to collect size and grading information for planning sites. In addition, expertise knowledge is frequently required for the development of SWPPP and BMPs. This conventional process is usually accompanied by additional cost and schedule delaying.

Recently as the area of Building Information Modeling (BIM) has expanded rapidly, interactive design and analysis process is widely accepted in real practices. More specifically, BIM stores and provides the geometric information of buildings and sites that can be used in other tools (Eastman et al. 2011). In addition, the capability and accuracy of BIM based simulation and analysis functions have significantly improved. Consequently, multiple design options can be quickly evaluated using BIM integrated analysis tools, such as geospatial and stormwater analysis, to acquire a solution that balances environmental impact and cost effectiveness.

With consideration of these benefits of BIM, this study investigates the feasibility of utilizing BIM tools for SWPPP and BMPs development to facilitate stormwater management on construction sites. More specifically, widely used BMPs at construction sites such as erosion and sediment control, are considered in this study.

2 METHODOLOGY

The primary purpose of this study is to evaluate the feasibility of BIM based BMPs (erosion and sediment control) analysis in the construction site design phase. Due to their seamless interoperability feature and data transfer functions, Autodesk design tools, including Revit 2016 and 3D Civil CAD 2016, and Autodesk Storm and Sanitary Analysis 2016 (hereafter: SSA) tool are used to evaluate the hydrologic runoff characteristics and water quality model with adequate detention pond design at the construction site. Specifically, SSA allows users to easily consider stormwater BMPs into the project design, and design changes in SSA can be synchronized with the design model in Civil 3D.

Another benefit of using SSA in this study is that representative hydrologic (e.g. US EPA SWMM, Rational Method, SCS TR-20 and 55) and hydraulic calculation methods (Steady Flow, Kinematic Wave, and Hydrodynamic) are integrated into this tool. These embedded features can facilitate to analyze the effects of stormwater runoff at disturbed construction site on soil erosion and sedimentation. Moreover, due to the reliability and accuracy of SSA application, it is widely used in industry section (Olson et al. 2010, Kim et al. 2015).

With consideration of these unique SSA features, the SSA simulation process using BIM application is reviewed in this study. As an initial step, a virtual project site is created by using Revit and Civil 3D with identical topographic information to compare interoperability with SSA.

The size of the project construction site is about 3.8 acre (15,444 m2) and the building site is about 0.8 acre (3,264 m2) presenting the impervious area including building and parking space for commercial building construction. The grading of site (contour) is added up to 1 m on the West side and 1.5 m on the East side as shown in Figure 1. And, it is assumed that the topsoil (top layer of soil) of the project site is removed during construction. This assumption generates a maximum soil erosion rate during the rain events.

One of the main function of SSA is to analyze the detention pond performance which is one of the most used implementation methods of BMPs. In addition to designing the detention pond to collect runoff from construction sites, controlling water quality and the occurrence of overflow from construction sites are important in stormwater management.

In this study, the location, size and capacity of the detention pond at the modelled site is evaluated. Also, the analysis method of water quantity and quality based on 10 year-24h rain event data is proposed. Since this study aims to investigate how BIM is used in the development of stormwater management on

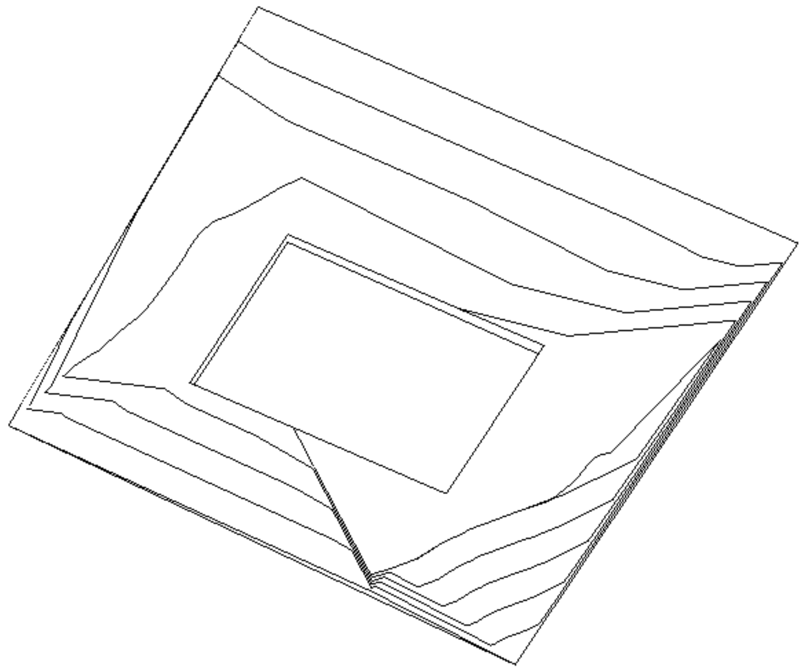

Figure 1: Modeled projected and building site.

construction sites, the fundamental BMP for the construction period, such as detention basin, is presented in this study. The other BMP techniques such as chemical stabilization of soil erosion or installation of a dam are not considered in this study.

The created project site using Revit is exported to AutoCAD file type (.dwg) and it is imported to SSA. On the other hand, the project site model created from Civil 3D is directly imported into SSA. The hydrology method for SSA analysis in this study is set as SCS TR-20 because TR-20 is able to generate pond storage indication while TR-55 only estimates pond effects in calculation. And, the time of concentration (TOC) method is set as SCS TR-55 with the minimum allowable TOC set as 5 minutes as shown in Figure 2.

The additional analysis setting for SCR TR-55 TOC is added as a Manning's roughness of 0.11 for commercial construction sites and the location of the project site, Alachua County, Florida. The Manning's roughness numbers are obtained from SSA with tabulated value depending on ground and usage, and it was applied to sub-basins properties.

For optimal temporary detention pond location during construction, four different locations within the projected site are selected as shown in Figure 3. After running the analysis, the yielded maximum runoff volumes for four locations (D1, D2, D3, and D4) are used to choose the best location and storage for temporary detention pond design. Moreover, the additional features such as predicting water quantity and quality using SSA are evaluated.

3 RESULTS

The stormwater analysis for a construction site is conducted using BIM tools, Autodesk Revit, Civil 3D, and Autodesk SSA. The virtual construction site (3.8 acre of projected area; 0.8 acre of building area) is modeled using Autodesk Revit and Civil 3D with same topographic configurations. The unpaved slopes of 1 m height on the West and 1.5 m height on the East area around the building are added to create flow paths. The model created from Revit needs to be exported as a .dwg file type for importing to SSA tools. But, the project site model from Civil 3D can be directly imported to SSA without any conversion process.

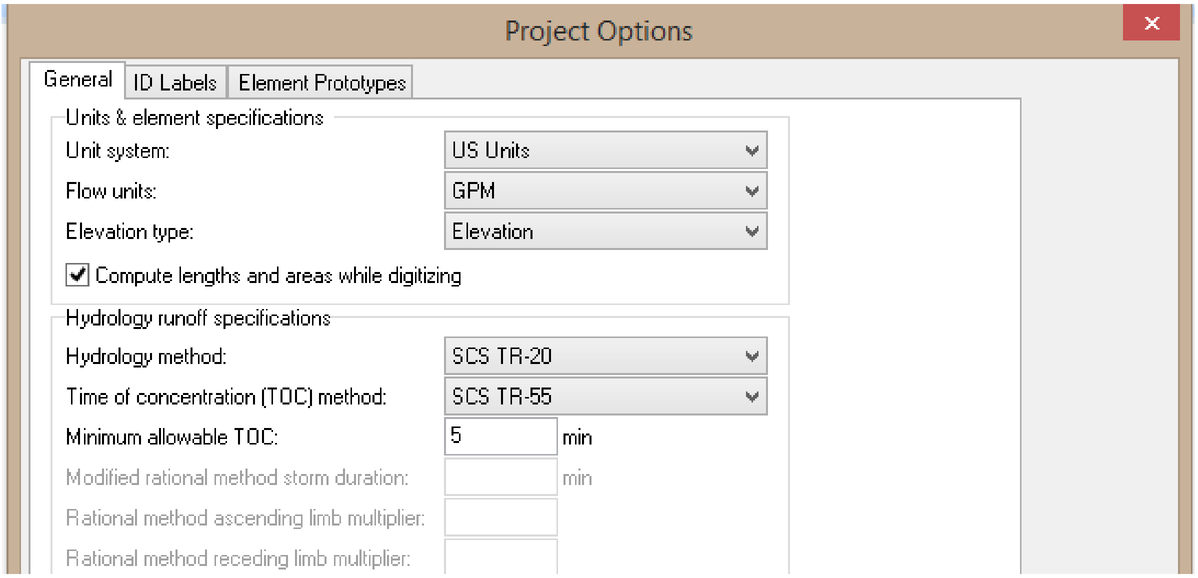

Figure 2: SSA Project settings for proposed construction site.

Then, slope analysis is conducted using Civil 3D to identify runoff flow paths. The slope analysis function, which is required for performing stormwater runoff analysis in SSA, is not integrated into Revit; therefore, additional analysis for the slope and contour of created project site model from Revit is required to be imported to Civil 3D. Basically, since SSA is developed as add-on application for Civil 3D, data transfer from Revit to SSA is still limited. For example, the elevation data, water flow path, pipe network and soil type information are inappropriately transferred to SSA.

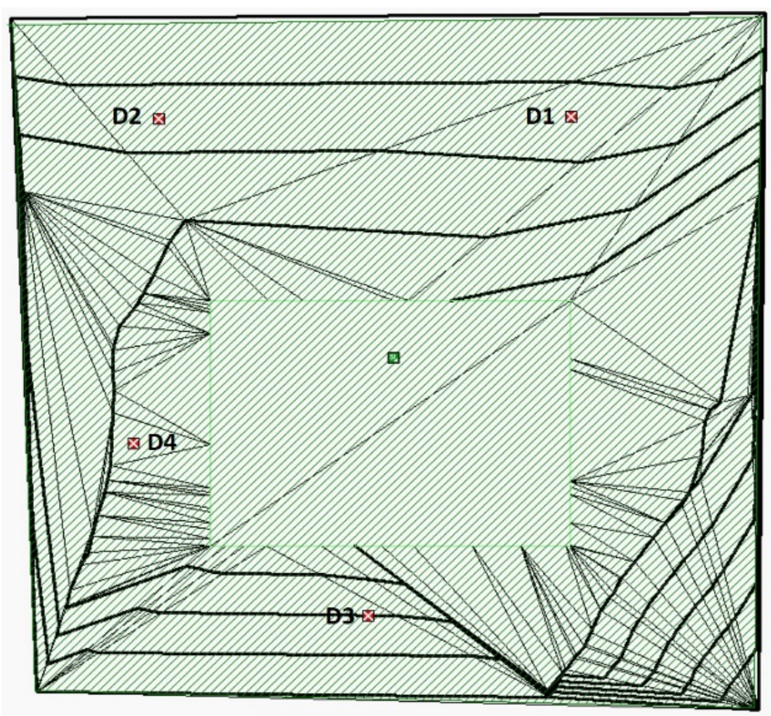

Figure 3: Four different planned locations for the detention pond.

In addition, accurate geometric information is not transferred to SSA tools. The area of the designed model from Revit and Civil 3D (3.8 acre) is imported into SSA presenting a bigger (20.3 acre) area. But, the hill height percentage and 3D model is properly imported. Only the numerical value of area is improperly transferred to SSA. The area of the imported model can be manually modified in SSA.

Four possible locations for temporary detention ponds are selected based on the criteria shown in Table 1. Theoretically, since D4 is located at a high slope level, runoff will not be collected in this spot. Rather, the stormwater at this spot will flow to the lower level. The reason for selecting this spot is to examine whether the runoff analysis can run accurately depending on the slope level in SSA. Consequently, three locations except for D4 are considered as actual detention pond locations for evaluation.

Table 1: Different criteria for different detention pond location.

Detention Pond Location	Criteria
D1	Lowest slope leveled spot; Closest to highest spot on East south hill
D2	Lowest slope leveled spot; Farthest to highest spot on East South hill
D3	Low slope leveled spot; located between two hills
D4	High slope level spot; selected to compare runoff to other locations (D1, D2, and D3)

The rain event parameter is input using a 10-year intensity storm for Alachua County, FL, with a total rainfall amount of 7.00 using a Florida DOT 1-hr storm distribution. The analysis duration is set at 1 year, from 6/1/2014 to 6/1/2015.

The analysis using the 10-year storm event data generated a maximum runoff volume for all four targeted locations. The results can be exported to a spreadsheet format as shown in Table 2.

The analysis results show that the D1 location has the most amount of runoff volume. And as expected, peak runoff at D4 is consistently recorded as the lowest amount of volume. Consequently, it can be inferred that the different slope levels are appropriately applied by the SSA tool.

According to the analysis results, D1 is best spot for a temporary detention pond at the proposed construction site. By choosing the D1 location, the risk of overflow occurrence can be minimized because the other three locations have lower peak runoff amounts. Also, the slope level of D1 is the lowest resulting in the most stormwater runoff that can be collected at this location.

Although the time-based analysis of the peak runoff for four locations generates consistent results, the functions for determining size and capacity of detention pond is not included in SSA. Therefore, supplementary analysis method will be required for optimal detention pond design.

For water quality analysis, SSA provides the analysis features for pollutants transportation. The basic properties of expected pollutants need to be manually added. Rain concentration, I&I (Inflow & Infiltration) and Groundwater concentration has to be manually monitored to run analysis as shown in Figure 4. For users' convenience, the range of water quality characteristics for urban runoff is provided from SSA.

Table 2: Peak runoff and TOC for four different planned location.

SN	Element	Area (acres)	Total Precipitation (inches)	Total Runoff (inches)	Peak Runoff (cfs)	TOC (days hh:mm:ss)
1	D1	3.80	6.97	3.80	38.01	0 00:05:38
2	D2	3.80	6.97	3.80	32.86	0 00:05:31
3	D3	3.80	6.97	3.80	34.52	0 00:05:36
4	D4	3.80	6.97	3.80	18.33	0 00:03:27

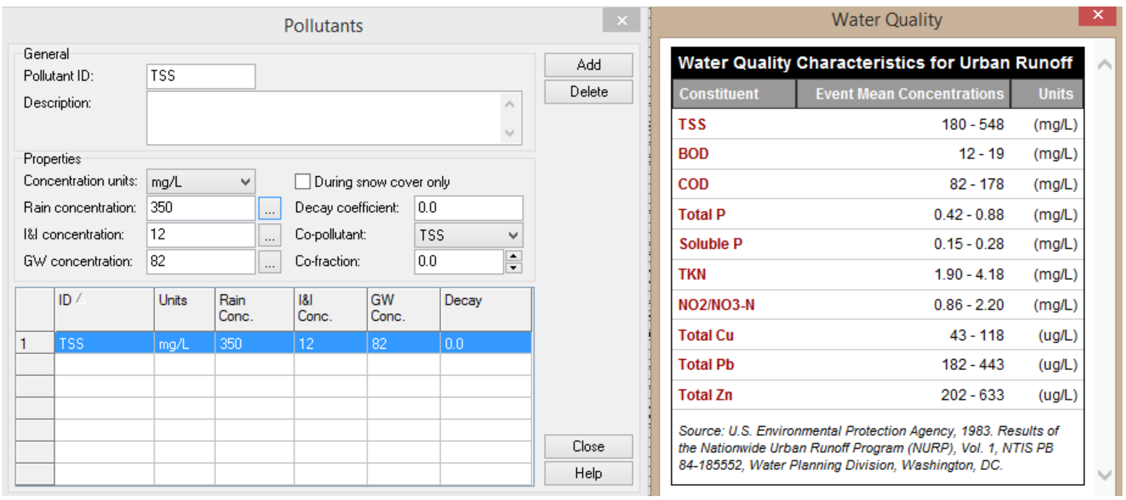

Figure 4: Addition of pollution characteristics in SSA.

In this study, to track Total Suspended Solid (TSS) pollutants, TSS rain concentration of 200 mg/L, I&I concentration of 120 mg/L, and GW concentration of 80 mg/L are added to analysis; and the result shows that maximum TSS concentration at D1 location 285 mg/L. The analysis is based on assumption that the building area is just excavated and not paved yet. It means that all the projected area is unpaved. This assumption causes an increase in the maximum TSS at the D1 location.

Another advanced feature for water quality analysis is to "Pollutants Land Types". This advanced feature enables the estimation of mean and maximum pollutants concentration at a specific point. This feature is a coefficient based calculation method. The coefficient values depending on land use categories are provided; however, the coefficients are used for post construction sites. Therefore, this feature is not considered in this study.

4 CONCLUSIONS

This study aims to investigate the feasibility of BIM based analysis tools for stormwater management practices at construction sites. More specifically, one of the most used BMPs, detention pond design aspect is evaluated using Autodesk Revit, Civil 3D, and SSA.

The model created using Revit was successfully imported into Civil 3D and SSA with showing big discrepancy of topographic information. About 3.8 acre of the projected area was created in Revit and Civil 3D; but, the imported file indicated an area of 20.8 acre. The area size can be manually corrected by the user. Also, slope analysis of the created project site model is required before importing to SSA. Through this analysis, the project site model can be updated with information on slope, contour, and water flow path. This analysis is not available in Revit and the SSA tool.

Four planned locations for temporary detention ponds were analyzed using SSA. And it generated reliable results. Depending on the distance between planned location and adjacent high levelled hill, different peak runoffs for each location was identified. In order to check the capability of the slope characteristics consideration, one location was selected at the highest levelled spot expecting to generate the lowest amount of peak runoff. The analysis results yielded the lowest runoff value in this location, and it can be inferred that slope characteristics are properly applied in the SSA tool.

For water quality estimation, SSA provides the feature of pollutants' concentration analysis. Users can add multiple pollutants' characteristics, rain, I&I, and GW concentration. These data are usually required for U.S. Environmental Protection Agency (EPA) monitoring regulation. Using monitored data, expected pollutants' concentration at specific point can be analyzed.

Overall, the procedure of site design and analysis using Autodesk BIM tools does not have a lot of interoperability issues except for inappropriate topographic information transfer, and the significant factors such as slope elevation and rain event are properly applied by the analysis algorithm. The most considerable benefit of BIM tools for the development of SWPPP and BMPs at construction sites is that contractors or designers can easily analyze runoff at projected sites. In addition, BIM tools expedite the evaluation of possible BMPs performances.

Since the SSA tool is basically integrated with Civil 3D, the SSA tool provides more effective synchronized functions with Civil 3D than Revit. For example, when geometric information is changed to increase certain BMP performance characteristics in SSA, the changed information is synchronized with the model in Civil 3D without any manual intervention. However, this function is not yet available in Revit.

Although there are some advantages from using BIM tools for the development of stormwater management practices in construction sites, there are also some limitations including:

1. The SSA tool was originally developed for post-constructed civil infrastructures. Consequently, specific functions for BMPs in construction sites were not yet available. For example, the evaluation process for determining the optimized size and capacity of the detention pond is not available. The proposed procedure for identifying the optimal location of the detention pond in this study is interpreted through the comparison of the peak runoff flow for all planned spots.
2. Only the methods of temporary detention pond design and water quality prediction were evaluated in this study. In real conditions, many BMPs (e.g. topsoil stockpile protection, sediment traps, grassed swale, and dam) are utilized with detention ponds. The additional evaluation for the combined effects of other BMPs on the detention pond is required.
3. Specific products, Autodesk tools were used in this study. The interoperability of other tools was not investigated in this study.
4. The analysis results from this study are validated with a very limited case study. Two case studies (Olson et al. 2010, Kim et al. 2015) used the SSA tool for urban scaled stormwater runoff evaluation. The evaluated site for both cases was a mixed land type (e.g. developed and wetland). Also, both cases included the evaluation of stormwater runoff through an installed pipe network system. The results in this study need to be validated later with actual data sites on temporary detention pond design from actual construction.

This study shows the workflow for identifying an optimal detention pond location on a construction site using Autodesk BIM tools. Although the analysis method for storage and capacity for temporary detention ponds at a construction site is not available using the SSA tool, the design criteria for a temporary detention pond can be roughly estimated with long term rainfall simulation (e.g 100-yr).

Overall, the analysis processes for stormwater management at an active construction site using current specific BIM tools (Autodesk products) have some issue related to transferring topographic data; they can be simply corrected by a manual process. Another issue is that required slope analysis is not included in SSA and consequently additional analysis using Civil 3D is required. If Revit is used to model the construction site plan, the created model has to be exported in .dwg format to be able to import it into Civil 3D for slope analysis. Lastly, identifying the size and capacity of a detention pond using SSA is limited; thus, a supplementary analysis method should be integrated with SSA for full consideration of temporary detention pond design at construction sites.

REFERENCES

Alsharif, K. 2010. "Construction and Stormwater Pollution: Policy, Violations, and Penalties." *Land Use Policy* 27(2): 612-616.

Eastman, C., P. Teicholz, R. Sacks, and K. Liston. 2011. *BIM Handbook: A Guide to Building Information Modeling for Owners, Managers, Designers, Engineers and Contractors*. Wiley.

Kaufman, M. M. 2000. "Erosion Control at Construction Sites: The Science–Policy Gap." *Environmental Management* 26(1): 89-97.

Kim, R., S. Park, and H. Lee. 2015. "The Application Evaluation of Autodesk Storm and Sanitary Analysis for the Low Impact Development Design in the Park Area." *International Journal of Multimedia and Ubiquitous Engineering* 10(10): 167-176.

Olson, T., L. Linton, and C. Maeder. 2010. "Automation Innovations in Stormwater Modeling Case Study: City of Ramsey, Minnesota, Surface Water Management Plan." *Watershed Management* 2010**:** 552-562.

AUTHOR BIOGRAPHIES

JINTAEK OCK is a Ph.D. candidate in the Rinker School of Construction Management at the University of Florida. His research interests are building information modeling (BIM), environmental performance analysis and energy simulation. He holds a Master's degree in building construction. His email address is okjihad@ufl.edu.

RAJA RAYMOND ISSA is a Holland Professor and Director of the Center for Advanced Construction Information Modeling in the Rinker School of Construction Management at the University of Florida. He has over 30 years of industry and academic experience in computer science and construction engineering and management. He received a B.S., M.S. and Ph.D. in Civil Engineering from Mississippi State University and a JD from the University of Memphis where he also did post-graduate work in computer science. His areas of research include construction law, information systems and advanced construction information modeling. His email is raymond-issa@ufl.edu.

IAN FLOOD is Holland Professor in the Rinker School of Construction Management at the University of Florida. He received his Ph.D. from the University of Manchester, UK, on parallel computing techniques applied to the simulation of construction processes. He has published over 140 refereed articles on the subjects of simulation modeling and intelligent computing applied to civil engineering. His email is flood@ufl.edu.