Application of an interrelated UAS - BIM system for construction progress monitoring, inspection and project management[1]

Shahab Moeini, Azzeddine Oudjehane, Tareq Baker, Wade Hawkins

Southern Alberta Institute of Technology
Calgary, Alberta, Canada

ABSTRACT

Construction progress monitoring and constant comparison between “AS Planned” and the actual state of the project “as-built” is a critical task for construction project managers to keep projects on track. Currently, progress and inspection reports are based on manual input and observation of each and every phase of the construction projects. Such processes are costly and time consuming.

Unlike the traditional method for project control, integrating advanced technologies such Building Information Modeling (BIM), Unmanned Autonomous Systems (UAS) and real-time cloud based data modeling and analysis, enable real time project control, monitoring and inspection,

Advanced BIM encompasses project As-Planned information such as design, specification, cost, and schedule which enables CPMs to have an accurate comparison between as As-Planned and the UAS based As-Built states of the project. This paper describes

- The current state for building information modelling and unmanned aerial system in construction projects
- A strategy for the application and integration of BIM and UAS throughout progress monitoring of the construction of a recreational facility.
- The challenges and opportunities for full automation and data analytics towards real time project control and monitoring of Construction projects.

INTRODUCTION

In the knowledge era and time of Artificial Intelligence (AI) the world is changing much faster than ever before. In a time of disruptive technologies, and rapid social, political

[1] *Second Editions are previously published papers that have continued relevance in today’s project management world, or which were originally published in conference proceedings or in a language other than English. Original publication acknowledged; authors retain copyright. This paper was originally presented at the 4th Annual University of Maryland PM Symposium in May 2017. It is republished here with the permission of the authors and conference organizers.*

and environmental changes, it is the moral obligation of each and every industry to transform (WEF, 2016). While this transformation will have positive impacts on construction cost, schedule, productivity, efficiency and environmental, the construction industry has remains one of the least efficient industries with an unimpressive track record in the world.

Even though other industry sectors have embraced fundamental changes over the last few decades, and have gained the benefits of advanced technological achievements, process and product innovations, the construction sector has been hesitant to fully embrace the latest technological opportunities, which has thus far resulted in stagnation of productivity in major global construction projects.

Technological advancement and market maturity of digitalization such as 3D scanning and virtual reality, in addition to Building Information Modelling (BIM), Unmanned Aerial and Ground systems (UAS and UGS), autonomous machineries and equipment and advanced building materials has provided a potential for fundamental changes to boost construction sector productivity and efficiency. While new technologies and innovation have emerged to some extent on the enterprise or company level, the rate of innovation and overall productivity in construction sector has remained nearly flat for the last 50 years (Beck, 2016).

According the World Economic Forum report in 2016, the unimpressive record of the construction industry is mainly caused by:

- *Lack of innovation and delayed adaptation*
- *Informal process or insufficient rigour and consistency in process execution*
- *Insufficient knowledge transfer from project to project*
- *Weak project monitoring*
- *Little collaboration with supplier*
- *Conservative company culture*
- *Little cross functional cooperation*
- *Shortage of young talent and people development*

Despite all the above mentioned issues and dominant conservative culture in construction sectors, few construction companies have adopted a progressive and innovative approach to pioneer the integration of advanced technologies such as BIM and UAS. This research and its outcomes herein have been the result of a collaborative approach between progressive construction industry partner/owners and academic Scholars/practitioners to: a) study the integration of the advanced BIM UAV based data into the progress reporting, technical inspection and safety analysis of the construction sites, b) demonstrate the advantages of implementing of the integrated strategy and c) identify the technical barrier to advanced technologies such as UAS in the construction sector.

WHAT IS THE STATE OF THE ART?

BIM as an integrated design and construction process is being increasingly incorporated into the construction sector as a tool for advanced design and to provide higher quality, and interactive project plan to improve construction project management (CPM) productivity (Eastman, 2008). The advanced BIM (3D & 4D) and high computerization level of construction interactive virtual modeling and simulation enabling CPMs to accurately generate project schedule, cost loaded schedule (CLS), and progress reporting plan (Abourizk, 2010). This high level automation process from design to management will reduce the overall cost of the project by reduced requests for information (RFI) and change orders which will results in improved return of investment, Earned Value (EV), and minimized the project cost/schedule contingencies (Barlish & Sullivan, 2012). The integration of BIM in early phases of construction projects also reduce the design conflict, improve communication between project participants, and helps to identify possible, technical, non-technical and managerial issues through the visualization of time- control model (virtual reality) of the project (Arain & Burkle, 2011; Feng et al. 2010).

Even though BIM is mostly being used during the design phase, construction projects would benefit from the interactive updated BIM model during the implementation phase. To do so the project progress information have to be: a) captured constantly with the same patterns by the use of UASs and UGSs, b) the captured data be integrated into the BIM model and rendered accordingly to provide the simulation of the future steps based on the as-built data, planned and Actual value through the construction project (Moeini, 2016; Ghanem & Abdelrazig, 2006).

Earned Value Management (EVM) as a cost component adds the fifth dimension (5D) to the BIM system to study and analyze whether the budget and schedule objectives are and will be preserved before the construction starts and during each phases of project. The implementation of effective and efficient EVM though BIM also requires constant update of the project data extradited from the advanced project progress reports. However, obtaining true values for tasks' completion rate is difficult (Fleming & Koppelman, 1997) and requires advanced situational and progress reporting and up-to-date information regarding as-built state which has to be attained frequently and compared to the as-planned state. To do so integration of new data acquisition methods and modeling techniques such as UAS, UGS, remote sensing and AI rather than traditional methods (Arian & Moeini, 2016) is necessary.

Application of UAVS, UGS, and remote sensing enables the CPMs to go beyond the labour-and time intensive traditional process of as-build reporting which is usually based on 2D plans. The collected as-built information acquired by High Definition (HD) cameras, laser scanning and photogrammetric point clouds as a modern approach can be used to provide the necessary information for as-built demonstration in the BIM (Ham et al., 2016; Maalek, et al., 2015; (Karsch et al., 2014; Golparvar-Fard et al., 2012)

UASs and UGSs autonomous flight planning capability enable the CPM to predefined mission planning (knows flight pass in UAS) through the project and took the required measurements for collision avoidance during each pre-planned flight. The work of Freimuth and König (2015) explained the automated calculation of the UAS mission planning using a BIM by defining the secure distance to all objects during the operation of the autonomous systems to a) improve the safety of the operation and b) plan the UAS operation based on the latest up-dated BIM.

The work of Tuttas et al (2015) illustrates the photogrammetric point clouds which are generate based on the captured data by UAVS through the projects can be used for the project progress monitoring (as-built) as well as detection of temporary objects (e.g. cranes) for future mission planning of the UASs. Integration of as-built information (captured by UASS and UGSs) into the BIM enables the CPM to make well-informed decisions, improve the efficiency of project team to improve communication, coordination among project participants and eventually improve the project success and productivity rate (Arain & Moeini 2016).

INTEGRATED BIM – UAS SYSTEM

The strategy behind integrating building information and modelling and unmanned aerial systems aims to firstly build the capacity for real time automated visualization of project progress. The integrated BIM-UAS system is in fact a “big data” collection with data analytics.

Before developing an integrated BIM-UAS system, it is necessary to identify separately how the building information modeling and the UAS (drones) can be strategized separately within construction projects.

For construction projects where BIM 3D is used, the 3 D building information model provides data and information of the ‘As planned or as designed” project. As shown below, the BIM model as part of the integrated design process enables the creation of the 3D model benchmark information data.

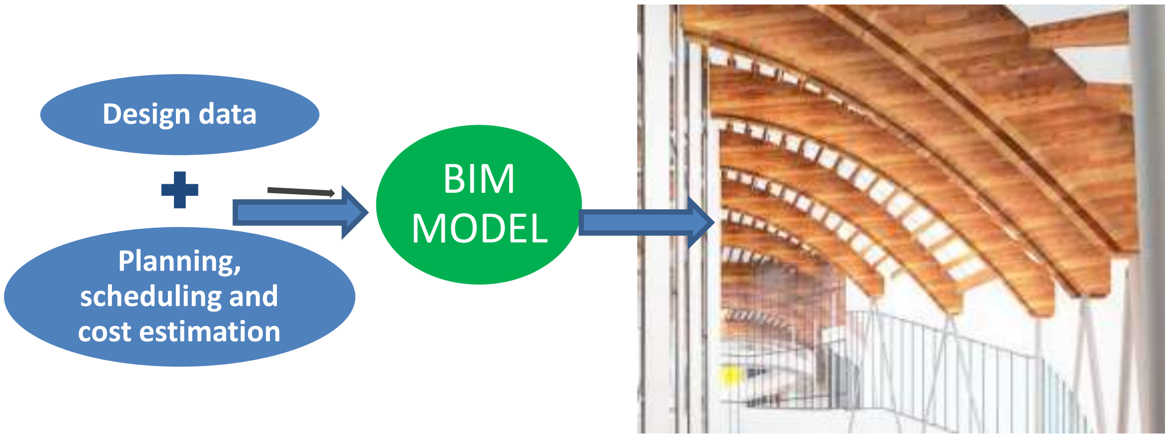

Figure 1. The building information modeling data generation

In the implementation of unmanned aerial systems for monitoring, the drones are used to capture data of the constriction progress. In this context, the project site is scanned by the use of UAS at a pre-determined frequency (monthly or semi-monthly) for the of the construction. The frequency can thus be directed on the basis of the project control requirement. The collected data is then processed before data analytics derive a cloud model representative of the "as built" model as shown below.

Figure 2. The cloud point generation using unmanned aerial systems

Lastly, the integrated BIM-UAS process is the ultimate post processing of input data from: a/ the BIM model and b/ the cloud model post processed from the drone input information.

The framework for an integrated BIM-UAS process as shown below, allows for the integration of site-wide survey-grade imagery, which are overlaid with BIM design data.

The integrated BIM-UAS mode serves for project control by comparing the As-built" and "as designed model. Algorithms and further data processing of the integrated model should allow the generation of project control metrics and KPIs such as earned value or cost variance.

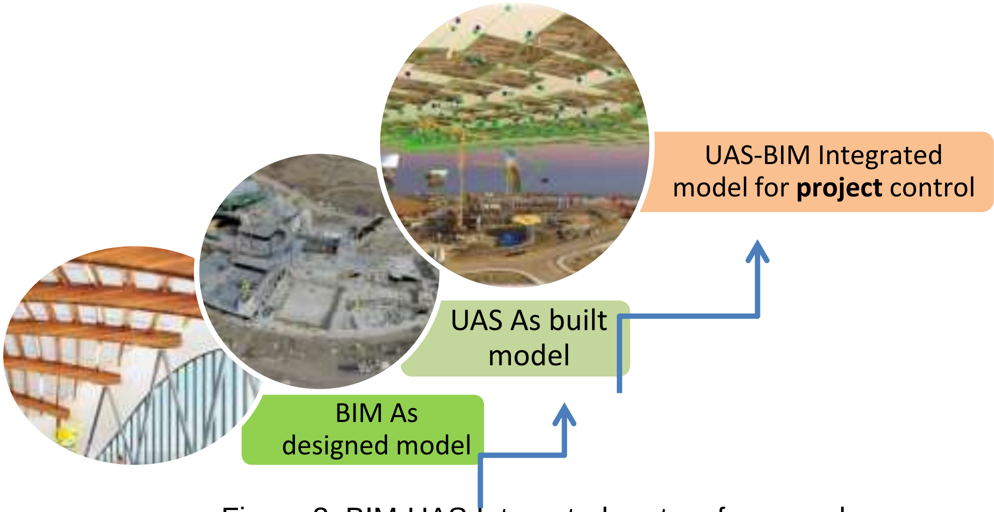

Figure 3. BIM-UAS Integrated system framework

TESTING THE UAS BIM SYSTEM

Unmanned Aerial and Ground Systems which provide the capability of low altitude aerial photogrammetry and gourd based imagery can provide a unique advantage to improve the project progress reporting and quality in construction sites. The UAV and UGV technology has become the center of attention of some construction companies industry and expands the practical application scope. The capability of the Unmanned Aerial Vehicle (UAV) system to capture low altitude aerial (airborne) photogrammetry on urban project site and the suitability of the captured images to make 3D model of project progress has made UAVs one of the most influential tools for construction project management. Three dimensional simulation of the project site in addition to the virtual reality resulted from the overlapping of the as-planned and as-built data enable the research team to visually analyses the project progress in the first few months of operation.

To firstly validate the implementation of UAVs in construction project monitoring, testing was conducted on a selected project. The project is a recreation facility located within the inner city of Calgary (A Alberta, Canada). Natural Park, tucked between an existing hill landscape and highest natural elevation and a reconstructed wetland.

Figure 4. The Rocky Ridge Facility in Calgary (The City of Calgary)

As shown above in the design picture. The project site is approximately 284,000 square feet building is designed to complement the surrounding landscape. The roof component of the structure is quite unique making it the largest wooden glulam supported roof in North America. The highway and residential neighborhood located in the southern part of the project site was one of the main risks associated with safe operation of UAVs. This UAV operation was the first official and legal UAV flight with the city boundary under Special Flight Operation Certificate (SFOC) issued by transport Canada.

The construction site was monitored by the use of UAVs and the required photogrammetric data was captured since very early stage of the project on every three weeks bases. The captured combining nadir and oblique airborne (UAV) images of the project site were used to generate a georeferenced 3D cloud point and orthomosaic for further analysis.

The UAV acquisition is associated to an acquisition with several UAV systems mainly DJI products and adherence to the regulation for UAV flights in Canada, which are among others:

- Maximal flight height of 400 Feet
- Flight was conducted within visual line of sight
- No flights was conducted over the main highway on the southern part of the site
- No flights was conducted during working hours
- No flight was conducted below -5 degree centigrade

A monthly frequency of site monitoring was implemented throughout the 2 year duration of the project. For executing each monthly flight in the project site the DJI Flight Planner and DJI mission planner apps were used. At beginning of the project the Industry Foundation Classes (IFC) process was used to avoid obstacle as explained by Freimuth and König (2015). Obstacle avoidance sensors were later integrated into the UAS platforms which enabled the team to move beyond the Industry IFC limitation and lengthy process of mission planning to avoid obstacles. The adoption of avoidance sensors into the drone system has reduced the UAS flight planning based on obstacle avoidance, data capturing time and also improve the flight operational safety.

The geometries of the building and site layout elements, which lay in the neighborhood of the take-off and surveying position, are extracted as bounding boxes. Using the bounding boxes and the data of the surveying job, grid points are generated. These grid points are the main basis to calculate the optimal waypoint between the take-off and surveying position. The results are stored as flight mission and should be evaluated by simulating the flight of the UAV in an interactive viewer component of the Survey Planner application.

The wide angel cameras used in UAVS increase the base-height ratio (distance on the ground between the centers of overlapping photos, divided by aircraft altitude) and improve the accuracy of height measurement with the wide angle of view from the longitudinal direction. The lateral direction increases the surface width covered in the captured images and improve the efficiency of the flight and reduce the quantity of the control points in the project site (Feifeia et al, 2012).The image below is an illustration of the as bult images acquired during a flight over the construction site.

Figure 5. UAS as built construction site image

The captured photos were imported into Pix4D, a photogrammetry software. The software was used to generate 3D point cloud model from the captured photos. The geolocation and camera orientation of each picture and camera specifications was used to calibrate the photos inside the software. The image below shows the calibrated camera positions in green and the initial camera positions (GPS coordinates) in blue. Depending on the number of images used the time to generate the 3D point cloud model varies. On average it took 48 hours to generate a model as shown in the images below.

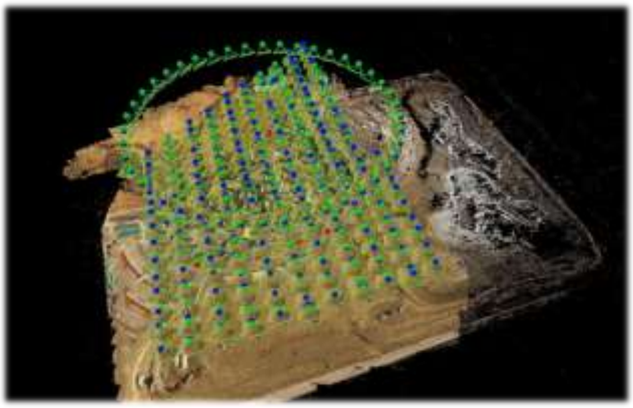

Figure 6. UAS point cloud generated model

Finally, the as-built Point Cloud model was manually overlaid over the BIM Model using Autodesk Naviswork, a 5D BIM simulation and analysis software. The point cloud and BIM models were compared visually. The latter visual matching between the as bult and as planned models is currently the last step of data processing visualisation to allow a benchmark comparison between project up to date status and initial planned data.

OPPORTUNITIES AND CURRENT LIMITATIONS

Cost overruns and delays occur in construction projects often when the realities of the physical world are out of alignment with the plans of the digital world. The BIM-UAS integrated model and system bridges the gap between the project planned features and the completed project features. The integration of site-wide survey-grade imagery, perfectly overlaid with BIM design data is so far the closest project control and monitoring could get to enable real time visualization of progress.

The proof of concept for the integrated BIM-UAS system was successfully demonstrated with the recreational facility construction project. Indeed, photogrammetry can be used to generate a relatively accurate 3D Cloud Point Models that can be used over existing 3D design models to enable construction monitoring.

The data analysis and processing of the terabytes of collected data in various forms, although lengthy has provided accurate comparison between the point cloud models and the BIM 3 D model. The benefits and opportunities have been well demonstrated within the framework of the construction project t currently being monitored.

Limitations however persist as the data generated is currently qualitative with a visualization of the project progress. For the purpose of validating the BIM-UAS model, in absence of any software capable of aligning the BIM model and the point cloud model, the integration followed a manual step by step process of data processing and post processing. Notably, the next step would consist in automating the data analytics.to produce quantitative and measurable data for project control and performance monitoring.

In order to optimize the BIM- UAS integrated system for project monitoring and inspection, the next development steps have to target:

- achieving an automation of the integrated BIM-UAS system to generate a real time visual of the 3D geometries over the UAS scanned model.

- a real time data processing that extracts the key project control metrics to enable project managers with the capacity to reduce risks while increasing project productivity. Linking schedule BIM model (4D) and adding project cost BIM (5D), should enable that functionality.

ACKNOWLEDGMENTS

We would like to acknowledge PCL Inc. for the support of this applied research project. The following undergraduate students from the BSc. in Construction Project Management at SAIT: Miguel Garcia and Dominic Aello.

REFERENCES

Arain, F. and Moeini, S, 2016, Leveraging on Unmanned Aerial Vehicle (UAV) for effective emergency response and disaster management, in Proceedings of the Project Management Symposium at U of MD College Park Maryland,, 2016 ISSN 2374-9377 retrieved February 2017 from ,http://pmsymposium.umd.edu/blog/speaker/shahab-moeini/

Dillow, C 2016, The Construction Industry Is in Love with Drones, Fortune Tech, September 2016, retrievedFebruary 2017, http://fortune.com/2016/09/13/commercial-drone-construction-industry/

Engeelbrat, D.C. 1965, Augmenting human intellect: experiments, concepts and possibilities, in Advanced Research Projects Agency and National Aeronautics and Space Agency 1968, 395-410.

Kymmell, W. K. 2008, Building Information Modeling: Planning and Managing Construction Projects with 4D CAD and Simulations, McGraw Hill Series, New York, 2008

Higgins C. 2015, Is Disruptive Innovation possible in the construction industry?, retrieved February 2017 from http://themidnightlunch.com/disruptive-innovation-construction-industry/

Oudjehane A. 2014, Value analysis in green building construction, at the Value Analysis Symposium in Montreal 2014

Rokooei S., 2015, Building Information Modeling in Project Management: Necessities, Challenges and Outcomes, in Procedia - Social and Behavioral Sciences 210 (2015) 87 – 95

The City of Calgary, Rocky Ridge Recreation Facility, images retrieved February 2017, https://www.google.ca/search?q=rocky+ridge+calgary&source=lnms&tbm=isch&sa=X&ved=0ahUKEwiE_9TfqJDSAhVKVWMKHWfqDP8Q_AUICSgC&biw=1163&bih=494#imgrc=RD0C8WKQLmILPM:

The Kore Company ,2016, 10 Construction Trends Shaping the Industry in 2016 and Beyond, For Construction Pros Magazine, January 2016,

Tuttas, S., Braun, A., Borrmann, A. and Stilla, U., 2014a. Comparison of photogrammetric point clouds with BIM building elements for construction progress monitoring. Int. Arch. Photogramm. Remote Sens. Spatial Inf. Sci. XL-3, pp. 341–345.

Tuttas, S., Braun, A., Borrmann, A. and Stilla, U., 2014b. Konzept zur automatischen Baufortschrittskontrolle durch Integration eines Building Information Models und photogrammetrisch erzeugten Punktwolken. In: E. Seyfert, E. Gülch, C. Heipke, J. Schiewe and M. Sester (eds), Gemeinsame Tagung 2014 der DGfK, der DGPF, der GfGI und des GiN, pp. 363–372.

Freimuth, H. and König, M., 2015. Generation of waypoints for UAV-assisted progress monitoring and acceptance of construction work. In: CONVR2015.

Tuttas, S., Braun, A., Borrmann, A. and Stilla, U., 2015. Validation of BIM components by photogrammetric point clouds for construction site monitoring. ISPRS Ann. Photogramm. Remote Sens. Spatial Inf. Sci. II-3/W4, pp. 231–237.

Maalek, R., Lichti, D. D. and Ruwanpura, J., 2015. Robust classification and segmentation of planar and linear features for construction site progress monitoring and structural dimension compliance control. ISPRS Ann. Photogramm. Remote Sens. Spatial Inf. Sci.II-3/W5, pp. 129–136.

Ham, Y., Han, K., Lin, J. and Golparvar-Fard, M., 2016. Visual monitoring of civil infrastructure systems via camera-equipped unmanned aerial vehicles (UAVs): a review of related works. Visualization in Engineering.

Karsch, K., Golparvar-Fard, M. and Forsyth, D., 2014. ConstructAide: analyzing and visualizing construction sites through photographs and building models. ACM Trans. Graph.

Golparvar-Fard, M., Peña Mora, F. and Savarese, S., 2012. Automated progress monitoring using unordered daily construction photographs and IFC-based building information models. Journal of Computing in Civil Engineering.

G. Ghanem, and Y. A. Abdelrazig, "A framework for real-time construction project progress tracking. Earth and Space," in *Earth and Space 2006—10th Biennial International Conference on Engineering, Construction, and Operations in Challenging Environments, March 5, 2006-March 8, 2006, League City/Houston, TX, United States*, pp. 1–8, American Society of Civil Engineers, 2006.

Q. W. Fleming and J. M. Koppelman, "Earned value project management," *Cost Engineering*, vol. 39, no. 2, pp. 13–15, 1997.

F. M. Arain and M. Burkle, "Learning construction project management in the virtual world: leveraging on second life," *Electronic Journal of Information Technology in Construction*, vol. 16, pp. 243–258, 2011.

K. Barlish and K. Sullivan, "How to measure the benefits of BIM—a case study approach," *Automation in Construction*, vol. 24, pp. 149–159, 2012.

S. Abourizk, "Role of simulation in construction engineering and management," *Journal of Construction Engineering and Management*, vol. 136, no. 10, pp. 1140–1153, 2010.

C. M. Eastman, *BIMHandbook: A Guide to Building Information Modeling for Owners, Managers, Designers, Engineers and Contractors*, Wiley, 2008.

The City of Calgary, Rocky Ridge Recreation Facility, images retrieved February 2017, https://www.google.ca/search?q=rocky+ridge+calgary&source=lnms&tbm=isch&sa=X&ved=0ahUKEwiE_9TfqJDSAhVKVWMKHWfqDP8Q_AUICSgC&biw=1163&bih=494#imgrc=RD0C8WKQLmILPM

About the Authors

Shahab Moeini

Alberta, Canada

Shahab Moeini is currently completing a doctorate degree in Business Administration with a focus on organizational management with the University of Liverpool in the UK. He holds a Master of Science in Geospatial Science from the University of Salzburg and a Bachelor of Science in Natural Resource Engineering (Water Resources) from the Azad University in Iran.

Shahab started his professional career as an emergency construction manager and worked six years as a manager in charge of rehabilitation and reconstruction of municipal infrastructure after natural disasters or conflicts. He then worked 10 years as a water resources and soil engineer in water infrastructure project management before joining international organizations as a water and habitat engineer, leading projects in conflict and post-conflict zones throughout Africa, Asia, and the Middle East. In addition to his work as an instructor, Shahab is also the director of a Canadian-based consulting firm, providing project management and strategic advice to international organizations.

Dr. Azzeddine Oudehane

Southern Alberta Institute of Technology
Calgary, Alberta, Canada

Dr. Azzeddine Oudjehane joined SAIT to teach in and the BSc Construction Project Management in 2012 and develop applied and scholarly research opportunities meeting the needs of the construction industry in Alberta. With over 20 years of experience leading multi-disciplinary projects in R&D, business innovation and market development and performance evaluation, Dr. Oudjehane working with various stakeholders from government and industry. He is also Principal of AZZO Consulting. He holds graduate degrees in both Applied Science and Business Administration.

With over 50 publications and presentations at international conferences, Dr. Oudjehane serves in various journal review committees and has chaired sessions at conferences. In 2014, Azzeddine was elected to the Board of Directors of the Alberta Chapter for Canada Green Building Council, where he leads the Green School

Initiative. Over the past year, he has given talks and presentations on sustainability and innovation in construction project management.

Dr. Tariq Baker

Alberta, Canada

Tareq Baker holds a PhD in Environmental Design from the University of Calgary and a Master of Building Science from the University of Southern California. During his PhD, his research evaluated the performance of the mechanical system in a LEED Platinum building, while his master's degree research focused on developing software for visualizing building performance data.

Dr. Baker's has worked as an architectural engineer, project manager, mechanical engineer design assistant, building information modelling (BIM) specialist and building energy simulation researcher. Through his work and research experience, Tareq developed a strong passion for green building technologies, construction project management and BIM. His current research focuses mainly on the use of BIM in construction project management and the integration of BIM in evaluating building performance.

Wade Hawkins

Alberta, Canada

Wade Hawkins holds a Geographic Information System Professional (GISP) designation from the GIS Certification Institute (GISCI) and received his Bachelor of Science (Geography) and Certificate in Geographic Information Systems and Remote Sensing from the University of Winnipeg.

Wade is a faculty member in the Southern Alberta Institute of Technology (SAIT) Bachelor of Applied Technology Geographic Information Systems (BGIS) program. He has been responsible for teaching and curricula development. He has taught introductory and advanced courses in Geomatics technology such as Geographic Information Systems (GIS), Global Navigation Satellite Systems (GNSS), Remote Sensing, Programming and Project Management. In addition, he manages over 50 student capstone projects per year, is responsible for ongoing curriculum development and program renewal, manages software licensing and server infrastructure, and participates in Unmanned Aerial Systems (UAS) research activities.