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ARTICLE

# From AutoCAD to 3ds Max: An automated approach for animating heavy lifting studies

Zhen Lei, Hosein Taghaddos, SangHyeok Han, Ahmed Bouferguène, Mohamed Al-Hussein, and Ulrich Hermann

**Abstract:** Modular construction is a dominant manufacturing method for industrial construction in Alberta, Canada. Modularization requires large-capacity mobile cranes to lift heavy modules, such as piperack modules. The current practice utilizes AutoCAD to generate heavy lift studies for modular onsite installations. Heavy lift studies consist of 2D and 3D simulations of the lifting scenarios, along with the corresponding calculations (e.g., lifting capacity checking, ground bearing pressure checking). These static simulations provide snapshots of mobile cranes at pick and set configurations, but they do not represent the movements between the two configurations. For better communication among site engineers and crews, current static heavy lift studies need to be improved by animating the entire lifting process. 3ds Max is an animation tool that can visualize the lifting process, but the tedious and manual process of preparing the animation restricts efficiency and productivity. This research thus introduces a newly developed animation system that automates the transfer of heavy lift studies from AutoCAD into Autodesk 3ds Max animation. Also in this research, the kinetics of mobile cranes are studied and generic crane movements are defined. Using MAXScript, a script is written to link the crane and project database for automatic generating of animations. This research aims to provide the construction industry with a generic method for automating the animation process for heavy lifts based on AutoCAD and 3ds Max systems.

*Key words:* animation, automation, mobile crane, heavy lift, 3ds Max.

**Résumé :** La construction modulaire est le procédé le plus utilisé sur les chantiers de construction industriels en Alberta, au Canada. Ce type de construction requiert des grues mobiles puissantes capables de soulever des modules lourds, tels que des modules de ponts de tuyauterie. On utilise couramment AutoCAD pour réaliser des études de levage de charges lourdes sur les installations modulaires présentes sur des sites de construction. Ces études consistent en des simulations 2D et 3D de scénarios de levage et en les calculs correspondants (p. ex. vérifications de la capacité de levage et de la pression au sol). Ces simulations statiques fournissent des « instantanés » des grues mobiles dans leur configuration lors du levage et du dépôt du module transporté, mais elles ne représentent pas les mouvements entre les deux configurations. Pour que les ingénieurs et employés du site communiquent mieux entre eux, il est nécessaire d'améliorer les études statiques actuelles portant sur le levage de charges lourdes en réalisant l'animation de l'ensemble du processus de levage. Le logiciel 3ds Max est un outil d'animation qui permet de visualiser le processus de levage, mais le travail de préparation de l'animation, manuel et fastidieux, réduit le rendement et la productivité. La présente étude présente donc un système d'animation récemment élaboré qui convertit automatiquement les études de levage de charges lourdes réalisées sous AutoCAD en des animations dans le logiciel Autodesk 3ds Max. L'étude s'intéresse également à la cinétique des grues mobiles et décrit les mouvements généraux de ces dernières. À l'aide du langage MAXScript, un script est rédigé afin de relier la grue modélisée à la base de données du projet et générer automatiquement les animations de cette dernière. Ainsi, la présente étude a pour but de fournir au secteur de la construction une méthode générique d'automatisation du processus d'animation des opérations de levage de charges lourdes à l'aide des environnements AutoCAD et 3ds Max. [Traduit par la Rédaction]

*Mots-clés :* animation, automatisation, grue mobile, levage de charges lourdes, 3ds Max.

## Introduction and background

The construction industry in Alberta, Canada is propelled by the province's rich oil sands reserves. The Albertan oil sands entice organizations to invest within the province, resulting in a major influx of industrial projects. The increasing scale of industrial projects compounds the challenge of delivering these projects in an efficient and productive manner. As a construction method that eliminates waste and improves productivity, modular construction has been widely adopted in Canada for heavy industrial projects. The modular method involves small components, so-called *modules*, which are prefabricated and assembled off site to be shipped on site for installation by mobile cranes; (see Fig. 1 for a mobile crane lifting a piperack module on a heavy industrial construction site). Due to on-site congestion and the sheer size of mobile cranes, lift studies must be conducted before the actual lifting. During this analysis, the clearance and lifting capacity of the mobile cranes must be verified. Other factors, such as the ground bearing pressure (GBP) and rigging–reeving capacity, should also be taken into consideration in the analysis. Due to the complexity of these analyses, practitioners and researchers have endeavored to develop systems and algorithms that can ac-

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**Fig. 1.** Module lifting by a mobile crane at an industrial site.


celerate the planning process. Overall, current research in crane-related fields can be categorized as follows: (*i*) approaches by which to rapidly and accurately select crane types based on limited known information (Hanna and Lotfallah 1999; Hasan et al. 2013; Olearczyk et al. 2014; Wu et al. 2011); (*ii*) approaches to select and optimize crane locations for heavy lifts (Huang et al. 2011; Safouhi et al. 2011; Lien and Cheng 2014); (*iii*) planning of crane motions using robotic techniques (AlBahnassi and Hammad 2012; Zhang and Hammad 2012; Lei et al. 2013*a*, 2013*b*; Lin et al. 2014); (*iv*) simulation and modelling of the crane lifting process (Al-Hussein et al. 2006; Tantisevi and Akinci 2009; Lin et al. 2012; Juang et al. 2013; Taghaddos et al. 2014); and (*v*) improving crane lift safety by applying state-of-the-art technologies (Lee et al. 2009, 2012; Cheng and Teizer 2012; Hwang 2012; Li and Liu 2012). Crane lift path planning, as a sub-task of heavy lift study, aims to provide feasible paths for crane lifting; collision detection is also often involved in this type of analysis. Crane lift path planning and computer-aided heavy lift studies can be dated back to the early 1990s with the emergence of powerful computers. Hornaday et al. (1993) introduced a computer-aided heavy lift study tool which has been used for analysis of vessel lifting; in their work, the manually drafted drawings are replaced using the AutoCAD system and a simulation system called HeLPS. Following this effort, researchers have begun to borrow the idea of path planning from robotics. One of the widely used concepts from robotics is the Configuration-Space (C-Space) approach (Lozano-Pérez 1983). Numerous projects can be found in the crane lift field that have utilized the C-Space approach to find proper lifting paths for cranes (Reddy and Varghese 2002; Sivakumar et al. 2003; Ali et al. 2005; Kang and Miranda 2006; Chang et al. 2012). The core idea underlying implementation of C-Space is to build a virtual space based on the existing environment and geometric shape of the lifted object, and search the lifting path in the C-Space using various searching methods. Some of the searching methods include genetic algorithm (GA) (Ali et al. 2005), heuristic search methods (hill climbing and A*) (Sivakumar et al. 2003), rapidly exploring random trees (RRTs) (Lin et al. 2014), and probabilistic road map (PRM) (Chang et al. 2012). As well, in the previously mentioned studies, mobile cranes are treated as robotic manipulators with certain degrees-of-freedom (DOFs). For instance, in a recent study, a total of seven DOFs, which define the types of movement performed, were identified for a mobile crane (Lin et al. 2014).

In the current heavy construction industry, the common approach to heavy lift studies is to plan and design the lifts using database technology (Hasan et al. 2010; Hermann et al. 2010), and then plot the designed results using AutoCAD. A heavy lift study drawing is produced by an engineer. The current 2D or 3D lift study only provides "snapshots" of the crane lifting process at its pick and set location, while overlooking the dynamic process of movement between the pick and set locations. In some cases, the mobile crane passes clearance checking at both locations, but fails during the moving process. This shortcoming results in the unpredictability of operations for site engineers. Furthermore, 2D and 3D lift studies are not straightforward; as a result, those who need to review the studies sometimes have difficulty understanding the analyses. These deficiencies may lead to miscommunication and may consequently result in low productivity and potential safety issues in the lifting process. Many researchers thus use visualization tools to analyze heavy lifts (Wu et al. 2011; Lin et al. 2012, 2014). However, a challenge that exists in the process of making lifting animations is the significant human component involved. Taking 3ds Max for example, a crane AutoCAD model imported to 3ds Max needs to be further modified to make animations; *bones,* an entity in 3ds Max, need to be added to the crane components to operate the crane model in a 3D environment. In addition, the process of manually preparing the lifting process is tedious and any error may result in rework. Considering the needs of the industry and the challenges faced in current practice, this paper aims to provide an automated approach for animating heavy lifts using 3ds Max. A mechanism is introduced to transfer the AutoCAD-based heavy lift study to 3ds Max and automatically generate the lift animations. The developed system can automatically generate detailed lift animations that detect potential collisions and analyze critical lifts in a short period of time. An actual industrial project is used to test and validate the designed system.

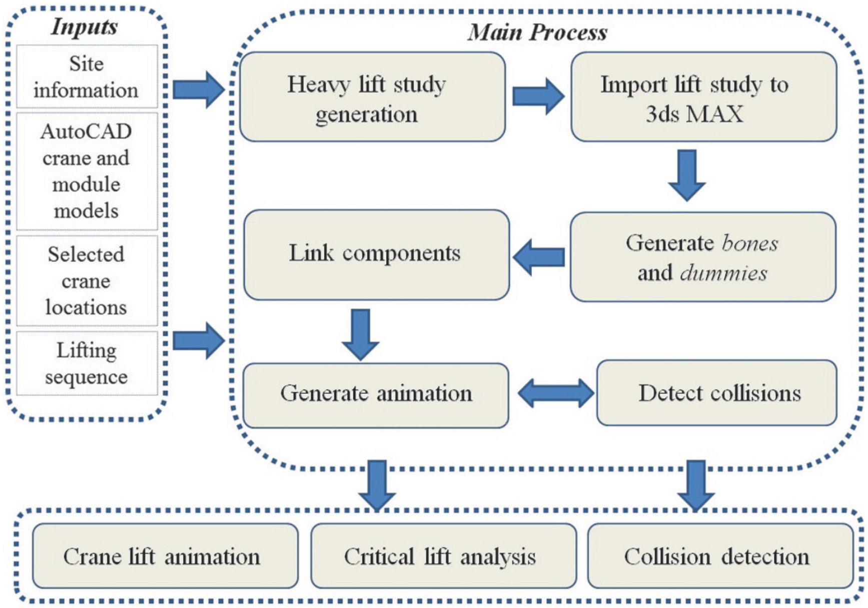
## Proposed methodology

The proposed methodology is shown in Fig. 2. The inputs of the designed process consist of the following: (*i*) site information, including the coordinates of the site boundaries and module information (e.g., weight, set location, pick location, dimensions, etc.); (*ii*) AutoCAD crane and module models; (*iii*) the selected crane locations based on the crane's lifting capacity and boom–tailswing–superlift clearance (see Hermann et al. 2010 for the details of selecting and positioning crane locations in heavy industrial projects); and (*iv*) the lifting sequence for the modules to be lifted. At PCL Industrial Management Inc., a central server database is used to store the required information, and an AutoCAD library contains models of both mobile cranes and modules. Some systems have been developed previously to deal with crane location selection, crane path checking, and lifting sequence planning. All these systems are connected to the central server database at PCL, including 3ds Max, which reads the required information such as crane locations and lifting sequence. In the main process of the proposed methodology, the heavy lift study is generated in the AutoCAD system by automatically retrieving information from the database and AutoCAD library. The generated lift study is then imported into the 3ds Max system. A customized add-on using MAXScript is developed in 3ds Max that automatically makes adjustments for the imported CAD models for the purpose of generating animations. The outputs of the system consist of the following: (*i*) time-dependent crane lift animation; (*ii*) critical lift analysis in congested areas; and (*iii*) potential collision detection of heavy lifts.

### Mobile crane modelling and kinematics

To animate the mobile crane lifting process, the kinematics need to be studied to define the different crane movements. In general, there are two types of mobile crane lifting processes:

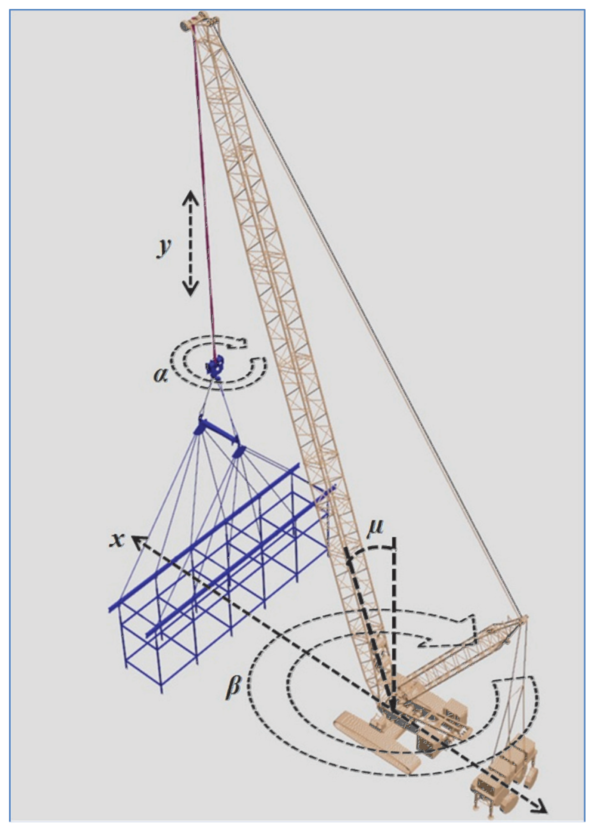
**Fig. 2.** Proposed methodology.




*pick-and-swing lifting* and *crane walking lifting*. In pick-and-swing lifting, the mobile crane performs the lift at one fixed location, and only a picking-swinging-dropping process is involved. However, crane walking lifting allows the mobile crane to walk a certain distance with the load to reach the module's set position, which is a common lifting approach for congested areas. In mechanical engineering, degree-of-freedom (DOF) is a concept that is used to define the configuration of a machine or a robot. In previous crane-related research, DOFs have also been used to define the configurations of cranes in a 3D environment. In this research, a mobile crane's DOFs for both pick-and-swing lifting and crane walking lifting are categorized into types (see Fig. 3 for an illustrative example of a crawler crane with its DOFs): (*i*) $x$: straight-line walking following the crane track direction on the ground elevation; (*ii*) $y$: hoisting up and down with the lifted module; (*iii*) $\alpha$: clockwise and counter-clockwise rotation of the hook block (the lifted module rotates accordingly); (*iv*) $\beta$: rotation of the crane's upper components, including the crane derricks (mast), tailswing–superlift counterweight, main boom, hook block and hoist lines, riggings, and the lifted object (i.e., module); and (*v*) $\mu$: booming up and down with the hoist line length fixed. The configuration of a mobile crane can thus be formulized as eq. (1).

$$C = [x, y, \alpha, \beta, \mu] \tag{1}$$

**Fig. 3.** Degrees-of-freedom (DOFs) of a crawler crane.




## Detailed algorithms for mobile crane movements

Although various lifting processes exist, the main lifting process can be summarized as shown in Fig. 4. The mobile crane starts at its pick configuration and lifts the module from its pick elevation ($E_{\text{pick}}$) up to the module's set elevation ($E_{\text{set}}$). In this interest of safety, an elevation buffer ($B_{\text{elevation}}$), usually 10 ft, is added to the set elevation, satisfying eq. (2).

$$E_{\text{lift-up}} = E_{\text{set}} + B_{\text{elevation}} \tag{2}$$

where $E_{\text{lift-up}}$ is the lift-up elevation to which the module should be lifted at its pick position.

Once the module is lifted up to $E_{\text{lift-up}}$, the module is then rotated to be perpendicular to the boom's vertical projection. The DOF used in this rotation is $\alpha$ in eq. (1).

Given a rectangular cuboid module to be lifted, which is the most common shape of piperack as shown in the plan view in Fig. 5, the first motion that needs to be performed once the module reaches the lift-up elevation is usually a rotation around the line connecting the tip of the boom to the object (assumed to be the local $z$-axis), the angle of which is $\theta_{\text{rot}}$. The purpose of this rotation is to orient the cuboid payload so that its length is perpendicular to the vertical plane containing the boom. Of course, rotations of the modules may also be required as part of crane lifting path planning to avoid obstacles in the site. According to

**Fig. 4.** Flowchart of mobile crane lifting process.

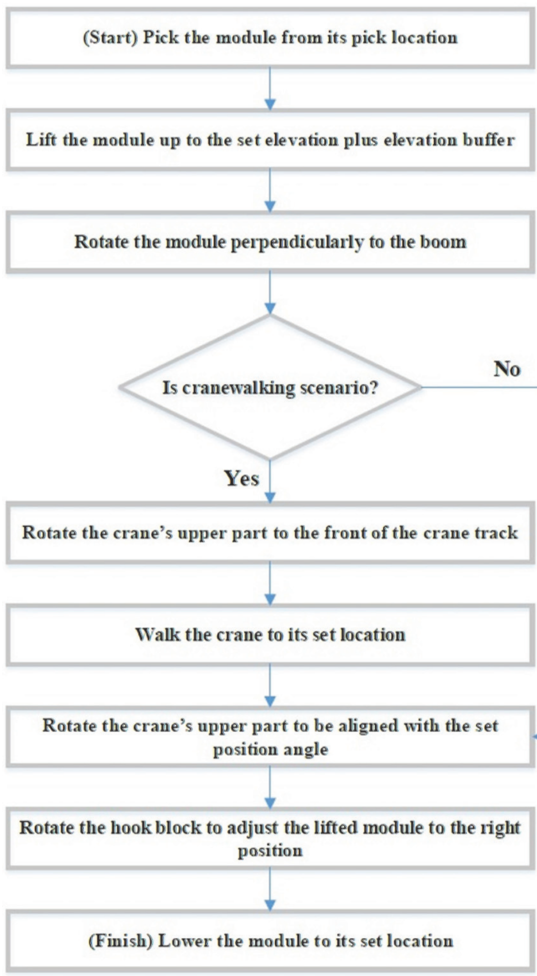



**Fig. 5.** Pick position adjustment.

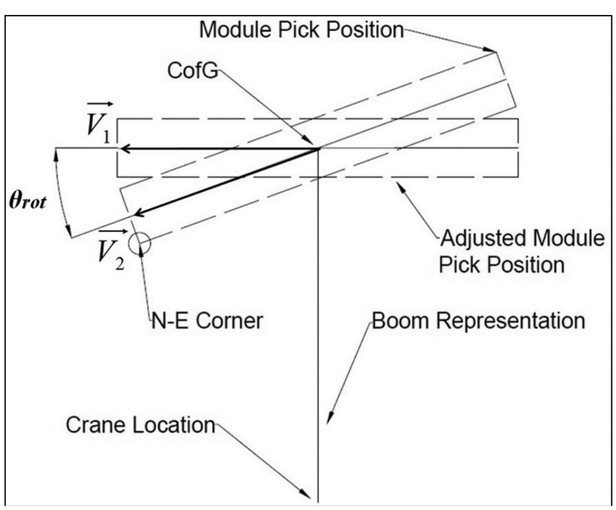



Fig. 5, the module's rotation angle, $\theta_{\text{rot}}$, is determined by means of two vectors — $\vec{v}_1 = (v_{1,x}, v_{1,y}, v_{1,z})$, defining the initial orientation, and $\vec{v}_2 = (v_{2,x}, v_{2,y}, v_{2,z})$, defining the final orientation. These two vectors are selected in the alignment of one of the principal axes of inertia that is perpendicular to the rotation axis. The rotation axis (local *z*-axis) is orthogonal to the plane defined by vectors $\vec{v}_1$ and $\vec{v}_2$. Therefore, the angle, $\theta_{\text{rot}}$, can be determined using the dot

**Fig. 6.** Pick-to-set rotation.

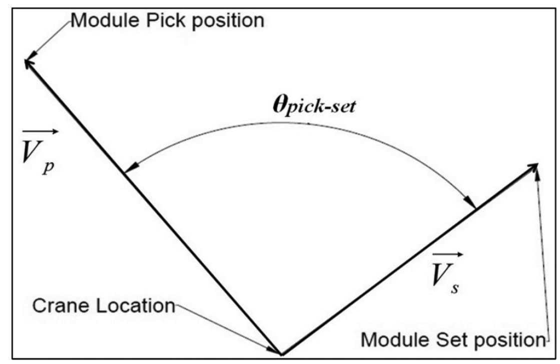
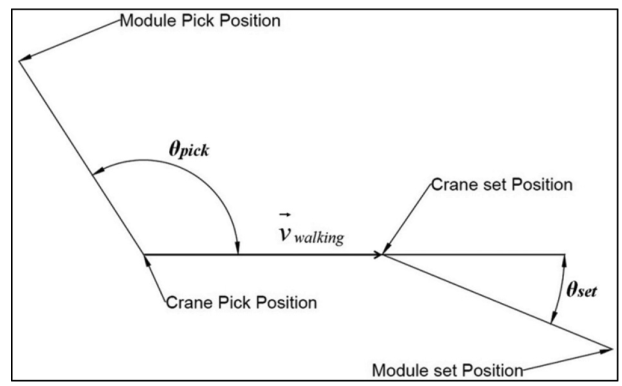



**Fig. 7.** Crane walking model.




product of these vectors and the sign of the projection of the cross product onto the *z*-axis.

$$\theta_{\text{rot}} = \text{sgn}(v_{1,x}, v_{2,y} - v_{1,y}v_{2,x})\cos^{-1}\left(\frac{\vec{v}_1 \bullet \vec{v}_2}{\|\vec{v}_1\|\,\|\vec{v}_2\|}\right) \tag{3}$$

As mentioned above, the mobile crane's movements can be categorized as either pick-and-swing lifting or crane walking lifting. In the crane walking lifting case, the module is typically placed in front of the crane body; however, in some rare cases (e.g., locations in congested sites that provide limited boom clearance), the boom does not necessarily align with the crane moving direction (see "Case 3 — Crane crab walking" for an example of such a case). In this case, the crane needs to walk with the lifted object from a location from where it is able to pick the payload to a point from which it is able to deliver the payload to its set point. In the pick-and-swing lifting case, the walking process is irrelevant, and hence ignored.

For the pick-and-swing lifting case, the mobile crane performs the lift without walking. The crane's movement involves swinging the lifted module from its pick position to its set position. The generic case (i.e., not taking into account the *z*-coordinate), for pick-and-swing lifting is illustrated in Fig. 6. The boom swings from the module pick location to the module set location — the rotation denoted as $\theta_{\text{pick-set}}$ in Fig. 6. The swinging corresponds to $\beta$ among the crane's DOFs in eq. (1). In application, the rotating direction can vary depending on the program used (e.g., in 3ds Max rotation in the counter-clockwise direction is considered by default to be positive). To determine the swing angle, $\beta_{\text{pick-set}}$, we use eq. (3), which is developed for the pick point adjustment in which the initial and final orientation vectors $\vec{v}_1$ and $\vec{v}_2$ are replaced by $\vec{v}_{\text{p}}$ and $\vec{v}_{\text{s}}$ (Fig. 6). Figure 7 shows a symbolic model of the mobile crane walking from a plan view. It is assumed that the

**Fig. 8.** Crawler crane blocks.

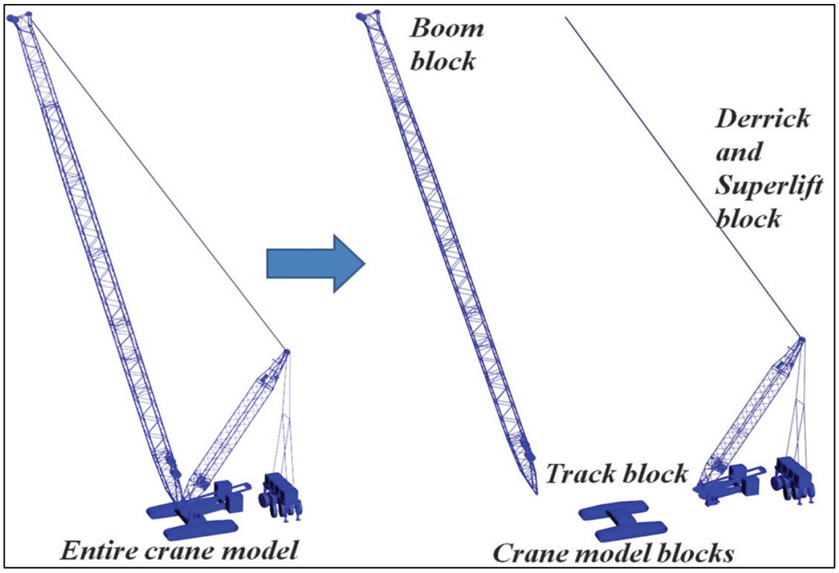
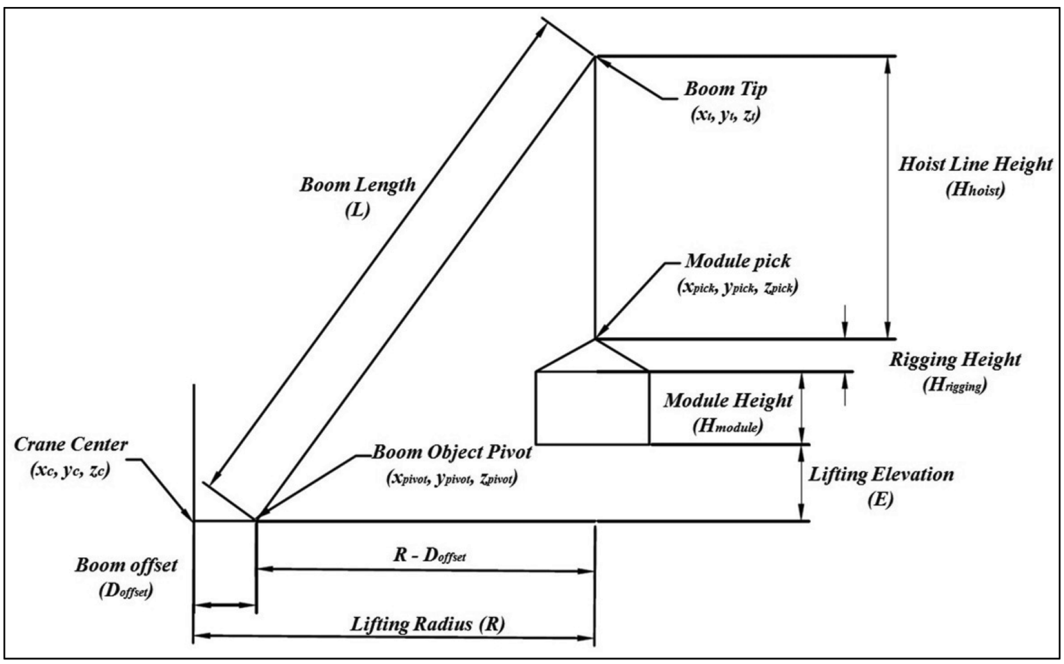



**Fig. 9.** Boom tip coordinates calculation.




lifted module hangs in front of the crane body during the walking process (rotation $\theta_{\text{pick}}$). The vector, $\vec{v}_{\text{walking}}$, expresses the process of walking from the crane's pick position to the crane's set position. The boom's position, it should be noted, needs to be re-adjusted at the crane's set location (rotation $\theta_{\text{set}}$). For the calculations of $\theta_{\text{pick}}$ and $\theta_{\text{set}}$, refer to Fig. 7 and the algorithm used to calculate $\theta_{\text{pick-set}}$.

## Algorithm implementation and programming

The heavy lift study is drafted in the AutoCAD system, which contains the 3D models of the mobile crane, rigging, and module. These models can be created using the concept of *blocks* in AutoCAD, which can be recognized by 3ds Max (Fig. 8 shows an example of different blocks of a mobile crane). The challenge in using these models in 3ds Max is the absence of a bone system that can be used to "operate" the mobile crane for animation purposes. A bone system is a jointed, hierarchical linkage of bone objects that can be used to animate other objects or hierarchies (Autodesk Inc. 2014). Implementation of the above algorithms thus follows two steps: (*i*) automatically setting up the bones and links; and (*ii*) animating the mobile crane movement based on the above mentioned algorithms. We represent the first step as the function *.CreateBones()*, and the second step as the function, *.CreateAnimation()*. These two functions are programmed in MAXScript, a scripting platform that allows users to implement customized 3ds Max functions.

There are three bones that need to be added to the imported CAD model in 3ds Max: (*i*) the boom bone, (*ii*) the crane body bone, and (*iii*) the tailswing–superlift bone. The code for creating the boom bone in MAXScript is provided below (the crane body and tailswing–superlift bones can be added using similar code):

```
BoomObject = execute ("$" + BoomName + "")
BoomBoneCreation()
```

**Fig. 10.** Crane component hierarchy.

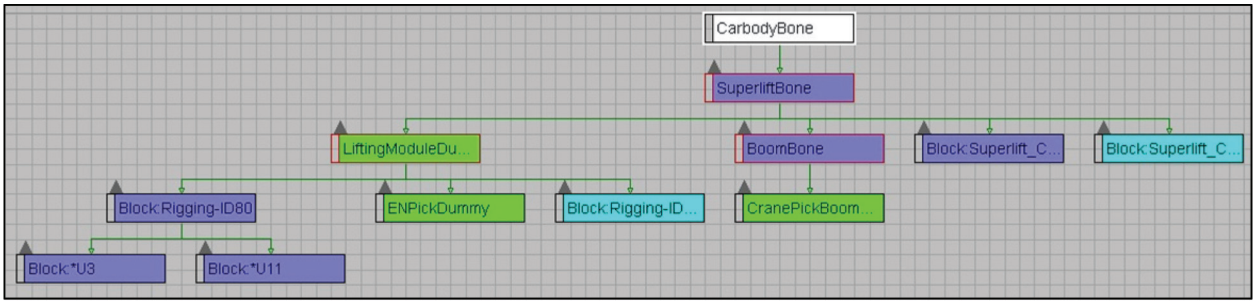
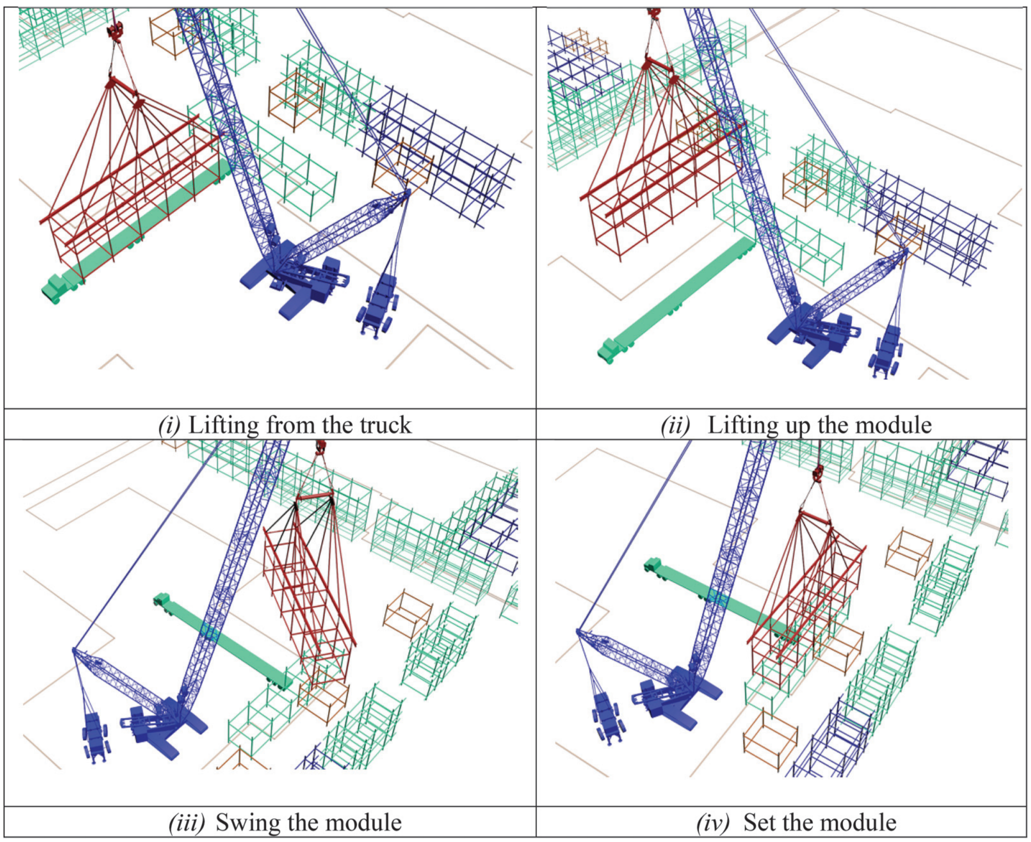



**Fig. 11.** Pick-and-swing lifting case.



*(i)* Lifting from the truck; *(ii)* Lifting up the module; *(iii)* Swing the module; *(iv)* Set the module

```
BoomBone = bonesys.createBone BoomObject.pivot CranePick-
BoomTipPos ZAxis
BoomBone.name = "BoomBone"
mySkin = Skin()
addmodifier BoomObject mySkin
max modify mode
modpanel.setCurrentObject mySkin
SkinOps.addBone mySkin $BoomBone 1
```

where BoomBoneCreation() calculates the coordinates of the crane boom tip, shown in Fig. 9, satisfying eq. (4).

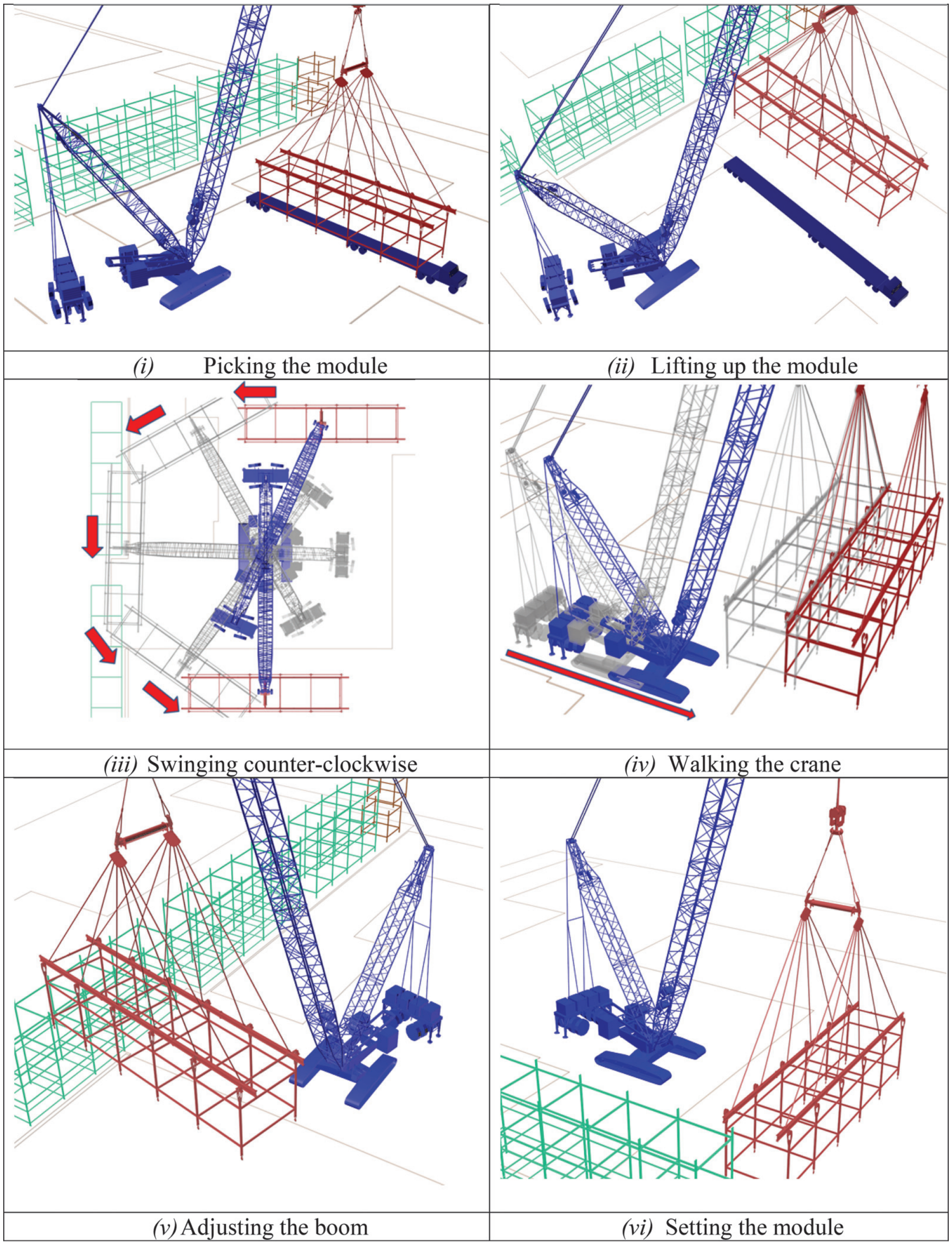
$$\text{(4)}\qquad \text{Boomtip} = \Big\{(x_t, y_t, z_t)|x_t = x_{\text{pick}}, y_t = y_{\text{pick}}, z_t = \sqrt{L^2 - \left[(x_{\text{pick}} - x_{\text{pivot}})^2 + (y_{\text{pick}} - y_{\text{pivot}})^2\right]^{1/2}}$$

where Boomtip represents the coordinates ($x_t$, $y_t$, $z_t$) of the boom tip in a 3D environment; ($x_{\text{pick}}$, $y_{\text{pick}}$, $z_{\text{pick}}$) are the coordinates of the hook block at the pick position; and ($x_{\text{pivot}}$, $y_{\text{pivot}}$, $z_{\text{pivot}}$) are the coordinates of the boom pivot at the pick position.

*Dummies*, which are used for position tracking, also need to be incorporated into the CAD model. In particular, (*i*) a hook block *dummy* can be added to the hook block to track the position of the lifted module during crane movements; and (*ii*) a boom tip *dummy* is used for positioning the boom at the appropriate angle. The hook block dummy and the boom tip dummy can be used to locate the *hose* component. (A *hose* component is used in 3ds Max to replace the crane's hoist line as an adjustable sling.) The added components need to be linked according to a defined hierarchy to function simultaneously (see Fig. 10 for a sample). The generic code for adding the dummy and hose is as follows:

```
— Add dummy
LiftingObjectDummy = Dummy()
LiftingObjectDummy.boxsize = [10,10,10]
LiftingObjectDummy.pos = ModulePickPos
```

**Fig. 12.** Crane walking lifting case.




```
LiftingObjectDummy.pos.z = ModulePickPos.z + L3 + RiggingHeight
LiftingObjectDummy.name = "LiftingModuleDummy"
— Add hose
SlingHose = hose ()
SlingHose.End_Placement_Method = 2
SlingHose.pos = $LiftingModuleDummy.pos
SlingHose.Hose_Height = $CranePickBoomTipDummy.pos.z-$LiftingModuleDummy.pos.z
SlingHose.Round_Hose_Diameter = 1
SlingHose.Top_Tension = 0
SlingHose.Bottom_Tension = 0
```

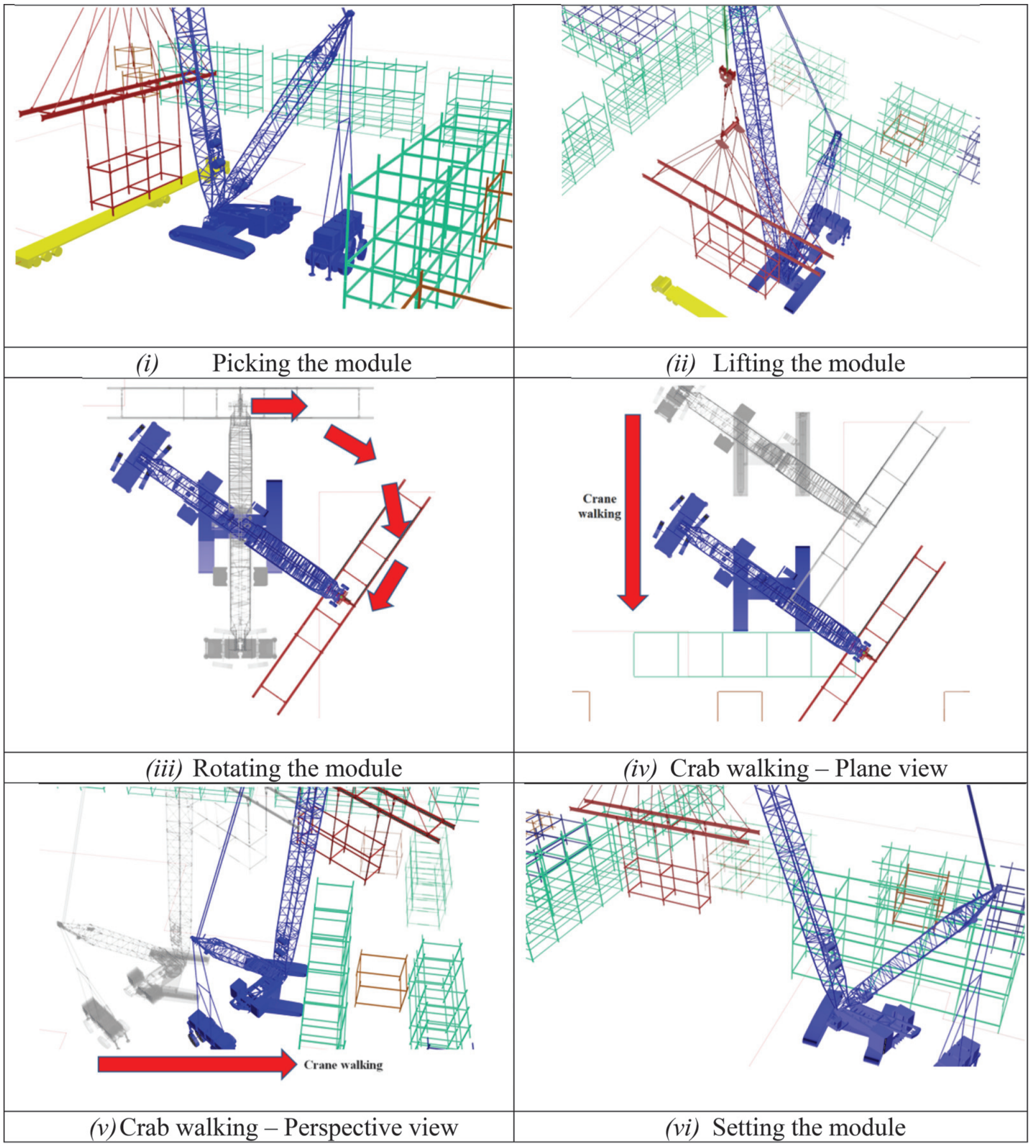
The animation process follows the procedures defined in Fig. 4. We assume that each crane movement takes 20 frames on the timeline; however, the user can adjust the time consumed by different movements by assigning the corresponding speeds provided by the crane manufacturer. A sample code by which to animate crane walking is as follows:

```
animate on — walk the crane
(
at time 120 ($CarbodyBone.pos = $CarbodyBone.pos)
at time 150 ($CarbodyBone.pos = CraneSetPos)
)
```

## Implementation and case studies

The designed system has been applied to an actual industrial project, located in Fort McMurray, Alberta, Canada. This project

**Fig. 13.** Crane crab walking scenario.




consists of a total of 210 prefabricated modules, and the mobile crane primarily used in this project is a Demag CC2800 (crane capacity rating 660 t) attached with Superlift equipment. The Demag CC2800 has a superlift radius of 49.2 ft (15 m) and a weight of 661 487 lb (300 metric tons). For operations with this crane, the designed system is capable of animating time-dependent lift studies generated in AutoCAD by professional engineers. In this paper, three cases from the project will be elaborated on: one focusing on pick-and-swing lifting, a second analyzing the crane walking scenario, and the third case illustrating the anomalous scenario in which a typical *crane walking* cannot be allowed due to site obstacles.

### Case 1 – pick-and-swing lifting

Case 1 shows a module lift scenario using the pick-and-swing lifting process. The piperack module weighs 286 044 lb (129 747 kg) with a length of 118.51 ft (36.12 m), a width of 19.68 ft (6.00 m), and a height of 30.51 ft (9.30 m). The lift study shows that the mobile crane uses 69.4% of its lifting capacity at both the pick and set locations. Figure 11 shows the lifting process animation automatically generated in 3ds Max. During the animation, the mobile crane stays at one specific location to perform the lift without walking.

### Case 2 – crane walking lifting

Case 2 presents a crane walking lifting scenario, in which the module weighs 349 667 lb (158 606 kg), with a length of 98.42 ft (30.00 m), a width of 23.78 ft (7.25 m), and a height of 22.14 ft (6.75 m). Due to site congestion from existing obstacles, the crane must pick the module (using 73.6% of its lifting capacity), swing the module to the crane's front, and walk with the module to its set location where the mobile crane takes 80.7% of its full lifting capacity. Figure 12 shows the details of each step of the crane walking lifting process.

### Case 3 – crane crab walking

In most cases, the module hangs in front of the walking mobile crane, as shown in Fig. 12. However, in some extreme cases, due to the presence of an obstacle in the walking path, the mobile crane must hang the lifted module at an offset angle to its walking direction, i.e., *crab walking* (Fig. 13). In Fig. 13(*iv*) and Fig. 13(*v*), the mobile crane walks with the load suspended at an offset angle to the walking direction (i.e., the module is not oriented perpendicular to the mobile crane during its walk). In this case, the obstacle in the walking path that necessitates crab walking is the stacked piperack modules in front of the mobile crane in Fig. 13(*v*).

**Conclusions and future research**

This paper has proposed a generic method to automate the mobile crane animation process that considers two types of crane motions: pick-and-swing lifting and crane walking lifting. In the former situation, the mobile crane performs the lifting without walking the crane, while, in the latter situation, the mobile crane must walk to complete the lift. Five DOFs are defined for a typical crawler crane that can be used to control the crane's movements in a 3D environment. By programming the proposed crane movement logic using MAXScript, provided in the 3ds Max system, the animation process for the mobile crane movements can be automated. The designed system has been integrated with PCL Industrial Management Inc.'s server database where the crane and project information is stored. The contribution of this research is to provide a solution for automating the animation process for heavy lifting; meanwhile, a standard lifting procedure applicable to other users and other types of projects has also been defined. The 3ds Max codes and logic provided in this paper can also provide general guidance to practitioners seeking to develop their own animation systems. Based on this research, the authors plan to develop a game engine mobile crane operator. Using this operator, practitioners will be able to simulate the lifting process by controlling the crane model in a 3D environment. The application of this future research will assist with detecting potential safety issues involved in the lifting process, and will as with training of crane operators.

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