Dynamic Space Conflict Modeling for Construction Operations

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Abstract –

Site planning is critical for efficient and safe construction operations. Current industry practice primarily relies on highly experienced planers and their personal judgment to anticipate and prevent space conflicts during construction operation. Inaccurate and unreliable site space planning not only leads to major loss of time and cost, but also negatively impact safety performance. Recent research has introduced new planning methods during the pre-construction phase to enhance site safety and productivity. This paper proposes a site spatial planning solution called Dynamic Space Conflict Modeling (DSCM), which can model dynamic field operations on a construction job site in a 3D model format based on the space demand of each activity and each resource. DSCM provides a process in which schedulers use time, crew information, and space demand of resources as inputs and capture the live space conflict as the output.

Keywords –

Dynamic Planning; Space Demand; Space Conflict; Safety; Productivity

1 Introduction

Successful delivery of a construction project rely heavily on effective project planning[1]. It is vital to plan the work flow considering various constraints such as time and space to maximize performance and reliability of construction processes[2]. Nonetheless, site space is usually not considered explicitly as a resource like material, equipment, labor, time, and money. Not surprisingly, site space is one of the most overlooked resources in planning[3].

Site congestion can significantly impacts productivity and safety performance, and past research estimated an efficiency loss of up to 65% [3]. This is especially the case for labor productivity since 50% to 60% of the total project cost devotes to labor cost on large construction projects[4]. In addition, numerous past research has confirmed that site congestion and stacking of trades is one of the leading contributors to safety accidents.

Current industry practice primarily relies on a planner's experience and personal judgment to have a feel about site space, visualize it in a 2D drawing format, anticipate conflicts, evaluate the impact on project performance, and resolve these conflicts proactively[1][6]. Due to the highly dynamic and complex nature of construction field operation, this informal and subjective approach in managing space can result in inaccurate and unreliable site planning that further leads to poor productivity and safety performance [7].

With the new advancements in modeling techniques (e.g. 3D, 4D modeling, and building information modeling), sensing (e.g. range camera and laser scanner), and spatial computational methods, site spatial planning is evolving from a 2D format and a manual procedure to a virtual 3D modeling approach with automated data processing that minimizes manual data entry. Virtual construction environment continuously capturing as-built or future site conditions in a digital format enables planners to better visualize and explore dynamic site space for planning purposes[6][6]. It has a great potential to minimize subjectivity in the current planning practice and improve the accuracy and timeliness of recognizing and avoiding conflicts**Error! Reference source not found.**[8].

A key element of this virtual space planning approach is to capture the space demand of construction activities and detect potential conflicts among them, which is the objective of this study. The following section provides a review of relevant past studies. A 3D site planning solution, Dynamic Space Conflict Modeling (DSCM), is then proposed. The proposed method is demonstrated in a prototype sytem.

2 Literature Review

Construction projects consist of a large number of activities and the interactions among the activities are highly dynamic and constantly changing[9]. Traditional planning methods consider space resource implicitly in a 2D drawing format, which is less efficient and accurate to capture the intricacies and dynamics of site conditions[3]. Recent research in the area of construction space planning benefits from the advancement in computer graphics, simulation, and artificial intelligence[10].

2.1 Dynamic Layout Planning

Recognizing and analyzing space demand of construction activities is critical in site space planning. Each activity on the site needs to have a specific amount of space in order to be executed with acceptable safety and productivity performance.

Dynamic site planning uses the project schedule to generate a logical sequence of layouts spanning the entire construction duration. As the condition of the site varies over time and project progresses, schedule can be adjusted to overcome any space availability issue[3]. How to update schedule dynamically to accommodate space demand is the subject of many studies. One of the solutions, MovePlan, assists users to plan the location and handling of resources on site with a 2D graphical user interface [3]. When the user interactively moves resources around until a satisfactory layout is obtained, MovePlan automatically updates the layout plan of the project. [3]This dynamic site planning approach allows users to model approximate site space needs during project scheduling and to create layouts for different stages of construction.

Thabet and Beliveau developed a work-space model that uses a numerical index to measure the degree of congestion at different locations of the site[11][11]. This index is calculated as the ratio of space demand to available space on the construction site. This model helps the planners to identify, prioritize, and response to space conflicts of the project.

Riley and Sanvido presented another work-space model that identifies the space needs of the activities by defining twelve construction-activity space use patterns[12]. This method is applicable to repetitive construction operations, such as multistory building construction. The typical pattern of space demand for each activity and potential interface problems can be predicted using this model, thus supports the logical planning of productive work sequence.

Guo proposed a method which categorizes construction activities based on type and location of the activities along with the project timeline and existing demands to expose overlapping spaces and conflicts on the construction site [13]. This method attempted to automatically resolve conflicts using predefined resolution strategies[13].

2.2 4D Planning and Virtual Construction

4D modeling visualizes the construction process in a time-phased 3D format. 4D CAD enables the planners to analyze construction sequence before the actual start of construction[14]. It helps planners to identify performance issues and avoid conflicts which can save a considerable amount of time and money during the field operation[15]. 4D planning also enables location-based scheduling that integrates the work flow and its performing locations. The planning data can be merged with the spatial data of the project in one single 4D CAD model[2].

Another application in 4D planning is 4D WorkPlanner which aims at overcoming the weakness of the traditional Critical Path Method by representing the spatial requirements of activities and managing the spatial conflicts[16]. This method is able to analyze time-space conflicts and offer customized solutions to planners.

Finally, Virtual Construction Environment (VCE) empowers users to reconstruct a project in a 3D digital model and visualize many different aspects of the project, e.g. the facility, resources, space availability, and work sequence [1]. This environment can be thought of as a test bed for multiple purposes, such as planning and constructability review.

2.3 Spatial Optimization

Construction site layouts can be simulated and optimized with respect to cost and safety of the project. In this method, the user is able to evaluate the site layout efficiently and intelligently, thus save planning time and cost[10]. Dawood and Mallasi developed a method for optimizing temporary facilities of a project. In this method, different types of conflicts are categorized and the productivity rates of activities are assumed to vary from time to time due to uncertainty[17].

2.4 Space Demand

There are many factors affecting the work-space demand on a construction project. It is important to understand the demand and quantify it in the first place[11]. The space demand for each activity consists of the space that the activity occupies on the construction site plus its surrounding area (Equation 1)[11].

$$D_R = S_P + S_S \tag{1}$$
$$D_R = Resource\ space\ demand$$
$$S_P = Space\ needed\ for\ performance$$
$$S_S = Surrounding\ space\ for\ safety$$

The surrounding space is considered as a safety zone and is necessary for the safe movement of resources. This space must be added to the physical space needed for activity performance in order to form a safe and trustworthy space demand[11]. It should be noted that not all types of resources have the same demand:

1. Space demand for equipment and labor resources must consider the mobility and volume of these resources as well as their quantity (Equation 2).
2. Equipment and labor need larger space than material resource does due to performance and safety considerations.
3. The space demand of material is determined based on the physical area that the material occupies on the site (Equation 3)[11].

The physical performance space can be estimated from the facility 3D model as well as scheduling data such as the size of a crew, while the volume of surrounding safety area can be estimated based on past project experience.

$$D_{L\,\&\,E} = \sum Q\ \times (S_P + S_S) \tag{2}$$
$$D_M = \sum (Q \times S_P) + S_S \tag{3}$$
$$D_{L\,\&\,E} = Labor\ \&\ equiment\ space\ Demand$$
$$D_M = Material\ space\ demand$$
$$Q = Quantity\ of\ resources$$

3 Dynamic Space Conflict Modeling

Most of existing research recognizes and analyzes space demand and space conflict on the construction site and assist the user in taking corrective actions. However, although most of them make the planner aware of the existing conflicts, there is no tool that assists the planner in updating the activity space requirements dynamically while visualizing the conflicts. The proposed method, Dynamic Space Conflict Modeling (DSCM), strives to offer a space planning method which visualizes dynamic space conflicts among activities. Meanwhile, the user has the ability to change the characteristics of each activity such as crew size and space demand per crew member dynamically, compare the results to the original plan, and make optimal decision.

The initial input for the proposed method is the project schedule. The planner needs to plan construction activities and resources (e.g. crew, equipment, and material) as usual before using the DSCM model. The activity data is later used as inputs for visualizing and evaluating space demand and space conflicts. The following section defines the method used in quantifying space conflicts.

3.1 Space Conflict

Space conflict between the activities and resources causes a large amount of problems in different aspects of the project like constructability, safety and productivity. space conflicts with different forms can create various problems in the project life cycle and multiple types of space conflict can exist between two overlapping resources on the jobsite [16]. Space conflict has a close correlation with space demand in the project. As discussed in the literature review, once the space demand for each resource and each activity are determined, different types of space conflicts among resources must be defined so that conflicts and their potential impact can be quantified.

3.1.1 Type A

In this type of conflict, no resource has conflicts with other resources. As shown in Figure 1, solid lines represent the physical performance space and dotted lines represent surrounding area. When this type occurs, the activities can be executed as planned safely.

3.1.2 Type B

In the space conflict Type B, the surrounding area of resource *I* has conflicts with the surrounding area of resource *II*. The risk of implementation of activities with this conflict type is moderate in regards to safety.

3.1.3 Type C

In this type, the surrounding space of resource *II* has conflicts with the physical space of resource *I*. However, the physical spaces of two resources does not have conflicts. The risk of implementing the activities while the resources have conflict Type C is higher than Type B.

3.1.4 Type D

In this type, the physical spaces of both resources have conflicts with each other. The risk of implementing the activities with this type of conflict is high and the planner should adjust the project schedule accordingly.

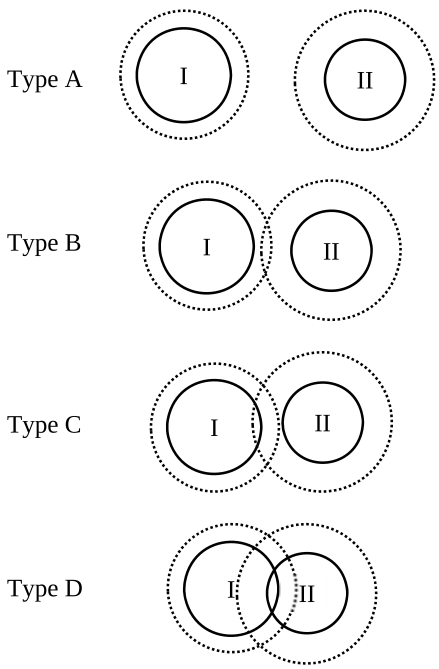

Figure 1. Various types of space conflicts.

3.2 Model Definition

The proposed DSCM model evaluates and visualizes space conflicts among resources. It captures space demand of each resource in each activity and visualizes space conflicts with adjacent resources. In addition to the project schedule, the inputs to this model also include resource type, space demand per unit of resource, and resource quantity. Once all inputs are defined, the model calculates the physical performance and surrounding space demand for each resource based on the resource type. In the next step, the conflicts between the space demand of a resource and its adjacent resources are calculated. The immediate output of the model is the visualization of space conflicts. Additionally, the model defines an index based on the spatial information of the conflicts. Space Conflict Index (SCI) calculates the proportion of space conflicts to the space demand of a resource. SCI assists the planner in making decisions about the feasibility of performing an activity based on the existing conflicts and desired safety and productivity performance.

$$SCI = \frac{Space\ Conflict}{Space\ Demand} \tag{4}$$

However, as different types of conflicts can occur among the resources, different types of SCI can be identified:

1. The space conflict between physical space of resource *A* and physical space of other adjacent resources divided by physical space of resource *A*.
2. The space conflict between physical space of resource *A* and surrounding space of other adjacent resources divided by physical space of resource *A*.
3. The space conflict between surrounding space of resource *A* and physical space of other adjacent resources divided by surrounding space of resource *A*.
4. The space conflict between surrounding space of resource *A* and surrounding space of other adjacent resources divided by surrounding space of resource *A*.

SCI represents how much is the proportion of space conflicts to space demand of each resource. Depending on the desired performance, the user must specify the maximum allowed SCI threshold for each resource and each type of SCI in order to detect space conflicts. This threshold value can be determined by the planner and based on historical experience.

As illustrated in Figure 2, when a SCI value is larger than the allowed threshold, the model will flag the conflicts for the planner to take corrective action, such as adjusting activity start time, sequence, and/or crew mix to avoid conflicts.

4 Prototype Implementation

DSCM requires a graphical environment in which planners can update resources, activities, and space demands. Rhinoceros is a 3D CAD application that is used as the platform for the implementation of the DSCM method. BIM facility models can be imported to or exported from Rhinoceros easily using Industry Foundation Classes (IFC) file format. Rhinoceros allows users to update and interact with the 3D model using a visual programming language named Grasshopper, as illustrated in Figure 3[18]. The abilities of visual programming helps the users with limited programming knowledge to develop interactive and dynamic models which could be later updated easily.

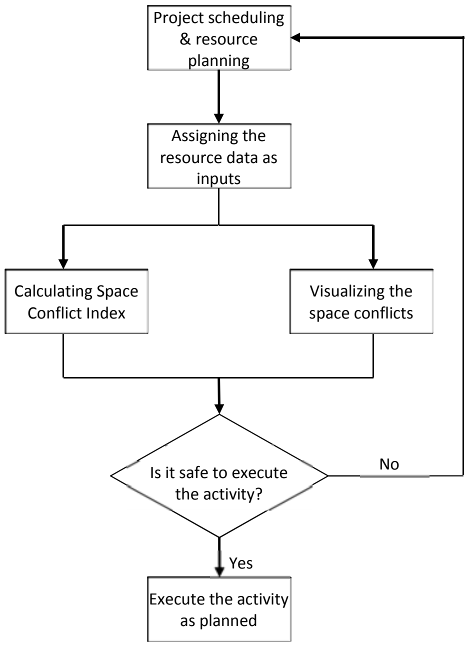

Figure 2. Dynamic Space Conflict Model

For demonstration purpose, the proposed method is implemented on a basic 3D model of a construction site in Rhinoceros 3D and programmed using Grasshopper as described below.

The first step for using the proposed model is to enter the inputs for the resources that will be evaluated, as shown in Figure 4. The initial inputs for each resource are:

1. A base or anchor point on the construction site 3D model that all of the space conflicts can be visualized based on that point.
2. Resource type which identifies the relationship between the physical and surrounding space as discussed before.
3. Space demand of each resource per unit. This input is demonstrated based on the nature of each resource and the planner's knowledge.
4. Quantity of each resource which is already allocated based on the project schedule.
5. The last input is the surrounding factor, which is a floating number between 0 and 1. It identifies the surrounding area devoted to each resource for safety and will be added to the physical space required by each resource and considering the type of each resource.

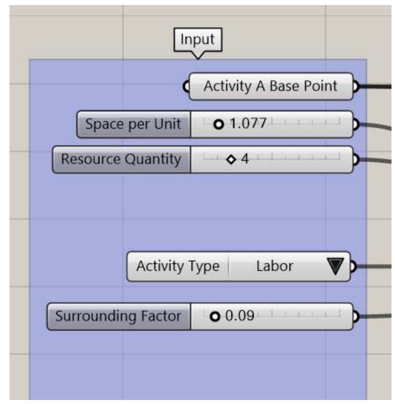

Figure 4. The inputs for one resource in DSCM model.

Once all of the inputs have been recorded, the DSCM model will calculate and visualize the space conflict among resources. At any time the planner updates the input data, the space conflict will be regenerated based on the new input data. Changing these values will trigger the change of space conflict visualization dynamically.

In Figure 5, each red point demonstrates the base point for each resource which is identified by the planner and the area highlighted in green shows the space conflict between the physical space of one resource and surrounding area of the other resource. Similarly, in Figure 6, the area highlighted in green shows the space conflict between physical spaces of two resources.

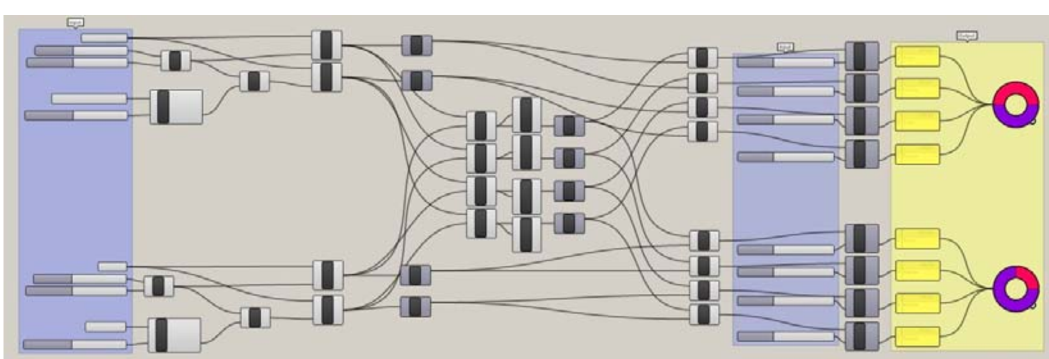

Figure 3. Implementation of DSCM using visual programming language

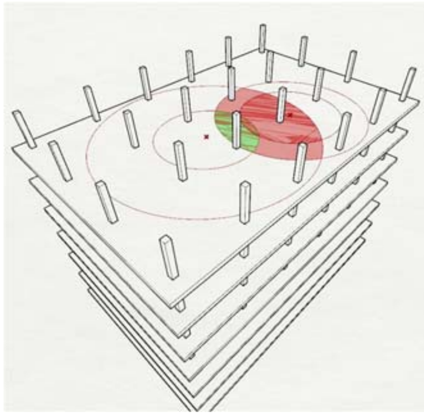

Figure 5. The existing amount of space conflict between the physical space of one resource and surrounding area of the other resource.

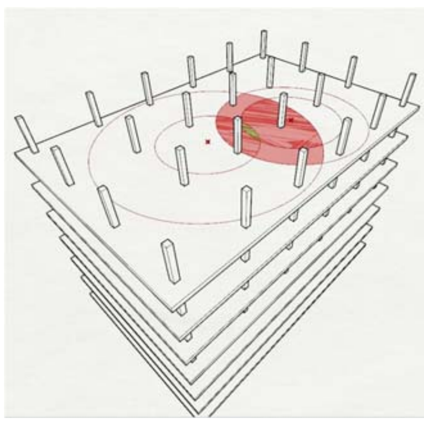

Figure 6. The existing amount of space conflict between physical spaces of two resources.

For automatic space conflict identification, the planner must predefine a maximum allowed value for each 4 types of SCI described in “Model Definition” (see Figure 7). With these threshold values, the DSCM model will first calculate the amount of visualized conflicts and the proportion of existing space conflicts to the space demand (SCI) for all 4 types of SCI, and then compare the existing SCIs to the planner’s maximum allowed value. The results will be either “true” or “false” format (see Figure 8). The value “true” indicates that the existing SCI value is less than the maximum allowed value and the resource passes that particular type of SCI test. The value “false” indicate that the existing SCI value is more than the maximum allowed value and the resource fails that particular SCI test. The results of failed and passed SCI tests for each resource then will be presented in a pie chart, as shown in Figure 8. This index makes the planners aware of the existing space conflicts and helps them in determining resolutions. Also, with this index, the planners can make decision whether or not to perform the activity based on the existing condition of the resources and the present space conflicts.

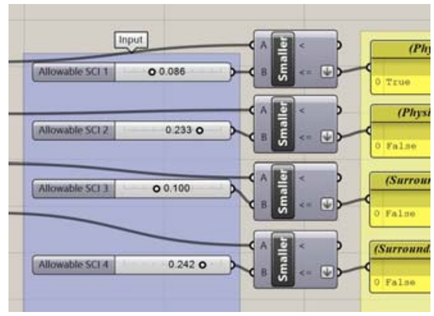

Figure 7. The maximum allowable amount for different types of SCI for a resource.

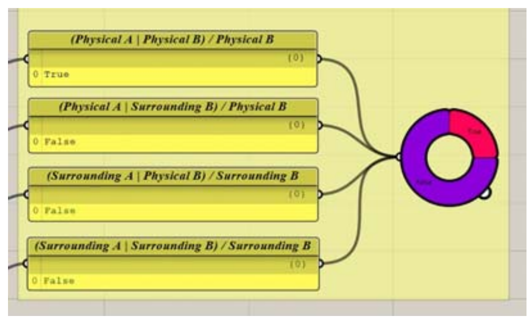

Figure 8. The results of comparing different types of existing and allowable SCIs for each resource.

5 Conclusion

Site space planning is one of the most important areas of construction planning which is inadequately considered by planners. A significant amount of time and cost can be saved with an accurate and reliable site space plan. Existing applications and methods focus on space demand modeling and conflict recognition. However, there is no tool that generates and visualizes the space conflict dynamically. DSCM proposed in this study assists planners in modeling space demand and identifying space conflicts among resources on the construction site. This method visualizes the space conflicts and calculates the amount of conflicts at the same time. With an allowable amount of space conflict defined, the model can compare the conflicts with the allowable threshold and warn the planner any future space conflict that affects productivity and safety performance of the work. The advantage of this model over the existing models is the ability to capture the interactive and live space conflicts in different areas of the project using the resource information as the input. In this model, the planners are able to observe the changes happening to the space conflicts of the project by changing the resource input and also observe the changes in the visualized 3D model at the same time. Traditional methods allow the planner to either observe the changes visually or mathematically.

For future research, the proposed method have several limitations which need to be addressed. The current implementation lacks automation, for example the planner needs to manually transfer scheduling data and evaluate resources individually. Another improvement is to measure space conflict in 3D format so that more type of conflicts (e.g. overhead work) can be analyzed. Finally, our recent work is focused on quantifying the impact of space conflicts on productivity and safety thus minimizing the subjectivity involved in decision making.

References

[1] Waly A.F. and Thabet W.Y. A virtual construction environment for preconstruction planning. *Automation in Construction*, 12(2): 139-154, 2003.

[2] Jongeling R. and Olofsson T. A method for planning of work-flow by combined use of location-based scheduling and 4D CAD. *Automation in Construction*, 16(2): 189-198, 2007.

[3] Tommelein I.D. and Zouein P.P. Interactive dynamic layout planning. *Journal of Construction Engineering and Management*, 119(2): 266-287, 1993.

[4] Elbeltagi E. *Construction site layout planning: Identifying, sizing and locating temporary facilities on construction sites*, volume 1(1). Lap Lambert Academic Publishing, Saarbrücken, Germany, 2014.

[5] Elbeltagi E., Hegazy T. and Eldosouky A. Dynamic layout of construction temporary facilities considering safety. *Journal of Construction Engineering and Management*, 130(4): 534-541, 2004.

[6] Liu C.W. and Kang S.C. A Video-Enabled Dynamic Site Planner. *Computing in Civil and Building Engineering*, 1562-1569, 2014.

[7] Riley D.R. and Sanvido V.E. Space planning method for multistory building construction. *Journal of Construction Engineering and Management*, 123(2): 171-180, 1997.

[8] Lai K.C. and Kang S.C. Collision detection strategies for virtual construction simulation, *Automation in Construction*, 18(6): 724-736, 2008.

[9] Gore S., Song L. and Eldin N. Photo-modeling for construction site space planning. In *Proceedings of Construction Research Congress 2012*, pages 1350-1359, West Lafayette, IN, 2012.

[10] Tawfik, H. and Fernando, T. A simulation environment for construction site planning. In *Proceedings of Fifth International Conference on Information Visualization*, pages 199-204, London, United Kindom, 2001.

[11] Thabet W.Y. and Beliveau Y.J. Modeling work space to schedule repetitive floors in multistory buildings. *Journal of Construction Engineering and Management*, 120(1): 96-116, 1994.

[12] Riley D.R. and Sanvido V.E. Patterns of Construction-space use in multistory buildings. *Journal of Construction Engineering and Management*, 121(4): 464-473, 1995.

[13] Guo S.J. Identification and resolution of work space conflicts in building construction. *Journal of Construction Engineering and Management*, 128(4): 287-295, 2002.

[14] Mallasi Z. and Dawood N. Registering space requirements of construction operations using site-PECASO model. In *Proceedings of Distributing Knowledge In Building, CIB W78 International Conference*, Aarhus School of Architecture, Denmark, 2002.

[15] Heesom D. and Mahdjoubi L. Trends of 4D CAD applications for construction planning. *Construction Management and Economics*, 22(2): 171-182, 2004.

[16] Akinci B. and Fischer M. 4-D workplanner: A prototype system for automated generation of construction spaces and analysis of time-space conflicts. *Computing in Civil and Building Engineering*, 740-747, 2000.

[17] Dawood N. and Mallasi Z. Construction workspace planning: assignment and analysis utilizing 4D visualization technologies. *Computer‐Aided Civil and Infrastructure Engineering*, 21(7): 498-513, 2006.

[18] Robert McNeel & Associates. Grasshopper 3D. On-line: http://www.grasshopper3d.com, Accessed: 10/03/2016