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By

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# **The inspections of as-built construction records by 3D point clouds**

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## **Abstract**

This study establishes a method for recording and comparing the progress of an on-going construction site using 3D data retrieved by a 3D long-range laser scanner. For a comparison to scheduled categories, two point clouds reveal a construction condition of expanding, reducing, or changing status. The Boolean operations of point clouds provided a theoretical foundation for an algorithmic calculation of as-built construction process to display changes in details. We found that the as-built data were able to describe the building construction process based on what really occurs at a site, when 3D scans were made in stages or at various time intervals. Retrieved shapes were collected in a continuous manner or in a configuration as a whole. Once the clouds are retrieved and transferred into proper data format, the as-built schedule can be compared in a commercial available CAD platform to work with the environment currently used by most architecture or construction firms. An exemplification was made to a campus building construction site through the comparisons of data sets, as a proof in identifying the differences in phases, objects, volume, and details.

Keywords: 3D scan, 4D, architecture, building construction

## **Introduction**

VR or 3D modeling approaches are used to simulate tasks to facilitate better visualization of building construction [5,6,8]. However, making a digital representation of a construction site is a complicated task. Not only are some objects too minor to be represented, but also a great deal of the undefined data come from the construction process itself. 3D computer models are usually used to facilitate inspection of the design stage only, by showing related component definitions, such as walls, columns, openings, etc. in a built form. This type of representation may be sufficient to visualize a building in its final stage or be used as a basic guide for the construction process. However, an actual construction project is much more complicated than any visualization in terms of objects and their associated movements. Not only are the specified

activities on the construction schedule more numerous than the original design models can describe, but also the machinery, workers, materials, and all objects present but not included in the original 3D model are left to be noted only in a text or chart form, based largely on judgments derived from past experience.

Construction schedule records call for integrity in geometric as well as visual form. Geometric data are usually created in the design stage for analytic evaluation. In order to conduct a comparison between the design and construction stages, a common referencing base has to be set for both stages in a digital format. This way, questions arising about whether the finished parts of a building are the same as represented in the design can be verified in a more precise manner. A digital representation of a construction site may not have to start from the definition that originated in the design stage. Instead, a system that includes monitoring functions may be needed to represent the ongoing situation. The idea that the operation of large construction elements is too complicated to be simulated may not be true. The task of monitoring a construction process involving a large number of people and objects seems daunting, but a whole picture still needs to be available; otherwise there will always be many minor parts outside the main action that are not accounted for. That's why a construction monitoring system makes sense even for a project with large demands. Object identification and its match with schedule description would be even more helpful in achieving the goal of full digital representation of a construction process.

Construction site monitoring is an on-going process that records and monitors data for immediate and post-construction analysis [1-3,7]. The monitoring of a site and the correspondence of activities defined by a schedule require object identification and a thorough record of site occurrences. To achieve this goal, the function of 4D monitoring focuses on a pre-construction study for the better management of a site afterward [4]. During construction, object identification and comparison with scheduled activities are essential functions of site monitoring, and are usually conducted by supervisors as human-based tasks. This means site monitoring is an analogical process. Functions that could enable the digital identification of an object and the ability to check whether it is on schedule would be very helpful.

### **Purpose**

The purpose of this study is to record and compare the progress of an on-going construction site based on the geometric definition provided by 3D data. In order to fulfill the need of a thorough comparison between the design and construction stages, this study aims to record as much of the geometric information of the site as possible. A campus building site was tested.

A reversed description method is proposed to add the advantages of 4D technologies by recording site occurrences in geometric form and comparing them with the activities as planned on the schedule. The comparison is made as a reference base for evaluating actual progress. In contrast to 4D technology, which is based on data from the design stage, the application of a 3D scanner retrieves data on a construction site to facilitate an as-built description of models in a precise and reversed verification manner.

### **Systems**

The system consists of a long-range (50-100 meters) 3D laser scanner, Cyrax 2500 (see Fig. 1), that comes with software, Cyclone 3.1. The laser can create a matrix of point clouds of up to 999\*999 dots in width and height. A Class B laser is used and the distance is measured by the

differentiation of time the laser spot travels between the scanner and the target. Scans can be made individually or registered onto a large project by referring to tie-points. Each scan has a tolerance of 2mm / 50 meter. The system comes with a notebook computer, using a 1GHz CPU and 384 MB RAM, to handle the data received on site. Data operation was made on a desktop PC using a 2.8 GHz CPU and 1 GB RAM. PC and notebook are upgraded periodically.



Figure 1. Cyrax 2500 3D laser scan system and registration points

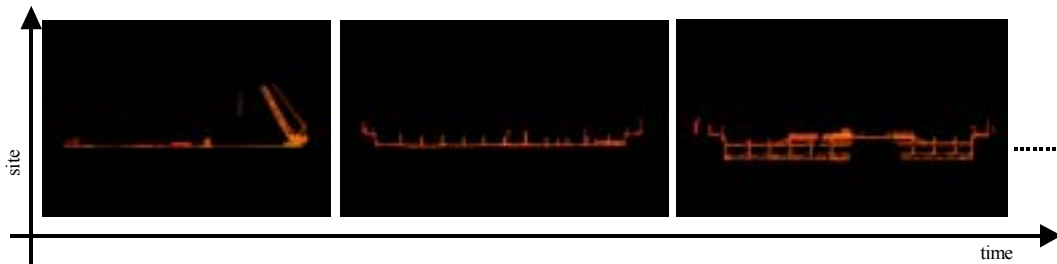


Figure 2. A point-cloud-based chronological record of a site excavation

Object representation comes from scanned data, in contrast to the traditional representation in schedule form that comes from a normal 3D modeling program. A comparison is made of a notation-based record of a site occurrence and the scan-data-based one. The differences come from the differentiation between 2D images and 3D objects. Fig 2. shows one section of a point-cloud-based chronological record of a site occurrence, including detailed description and referencing between stages of excavation.

### Scan-related activities

This study starts the site scan in a chronological manner along with a panoramic recording for the visual referencing of site occurrences. The data retrieved from the initial scan facilitates basic measurement and analysis activities in a visual or numeric manner. The scanned volumetric data also enable measurements to be made three dimensionally.

The application of 4D technology in construction site simulation, for the purposes of process evaluation and communication, has been under development for some time. The combined description of schedules and geometries of a particular scheduled event in a chronological manner helps to visualize the construction process. This kind of simulation is conducted at the design stage as a prediction of what will take place in the following construction process. For the representation of building parts in computer-generated models, the site occurrences are much more complicated than when using computer models made by geometric primitives (sphere,

cylinder, cube, cone, etc.) or their instances. The initiated construction sequence will not necessarily reflect in detail what the schedule has projected. As a result, problems occur in trying to match architectural components and construction events defined by a schedule. The simulation, which cannot draw a complete picture of an as-built situation of a site, may call for additional assistance in order to be used for evaluation purposes.

Two issues are raised:

1. The development of an as-built geometric description: Building renovation or additional construction needs as-built measurements to prepare correct construction drawings. A building may not have been built exactly as proposed in the design specifications. Deviations in location or height from the original design surely generate the need not only for the control of construction precision, but also for better prediction of the subsequent steps. How to retrieve an as-built geometric description is a concern.
2. The representation of an on-going construction process: 4D technology involves a geometric approach to relate object configuration to schedule, based on design and predefined computer-generated models of parts. A schedule represents an on-going construction process that should include all the activities associated with the changes in detailed object locations during a period of time. As site activities increase, object-based modeling not only is insufficient for a detailed description, but also is incapable of providing a reference base for chronological comparisons of any change in the location of a construction component.

### Site scan

Objects are accumulated as site construction progresses. A point-cloud-based chronological record represents the most fundamental and true record possible of site occurrences. It's like taking a 3D picture that includes all the objects of concern for any possible manner of identification (see Fig. 3). The traditional manner of recording can be replaced by geometry-based and depth-based measurements that are capable of providing dimension-related details.

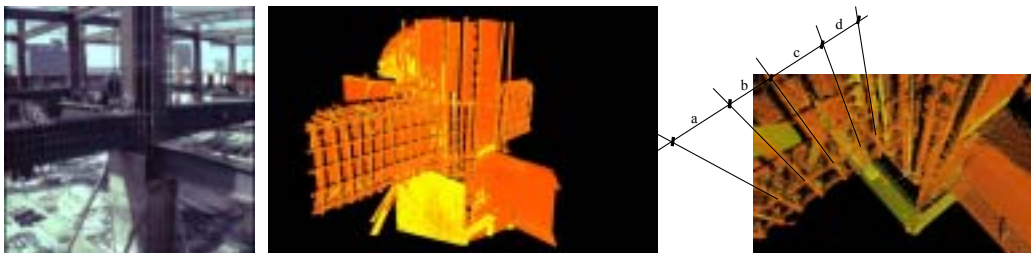


Figure 3. Column image and details in point cloud

An object can be scanned from different orientations and locations before being registered as a particular object. The density of dots may vary based on the desired spacing between dots. Multiple scans can simultaneously exist in the same or different sets of scanworlds. A scan that is made along with another scan within the same scanworld at the same orientation may have a higher density than the rest of the area so that more details can be retrieved from the part of concern.

Due to the unexpected blockage of other objects, scanworlds have to be integrated to complete an omni geometric view of a site. Some scanned data offer partially complete descriptions. Only when an object's movement or orientation changes so as to lead to more exposure to the receiving devices or applications can additional data be recorded and used to create a complete set. In a

chronological recording, each object may inherit a different level of data segmentation. Integrating the chronicle-based segmentation is a challenging task and is currently made by registration through referencing points.

### **Levels of object representation**

Why do we need a detailed geometric description of an object at a construction site, especially when the data retrieved can be very fragmented? The reason is a construction site is a very complicated scene; a detailed description of it can facilitate analysis without the risk of missing any valuable data. Furthermore, the fragmented nature of site information can now be redefined by registering the fragments together.

In facet, one of the problems to be solved by 4D technology is the effectiveness of digital representation of site occurrences. In general, comparisons are made between real objects in physical form and those objects in digital form. An object's digital representation is arrived at by scanning or computer modeling of real objects. Computer-generated models for design evaluation are usually created before construction begins. Objects initialized from scanned point clouds represent a physical form in a finished stage. Nevertheless, the intermediate stages between the design and construction stages can also be represented through scans of partially completed building parts and components allocated accordingly.

The manipulation of scanned geometric data is classified into two levels:

1. Level I – point clouds: Initial data retrieval is collected through 3D scans. Each point is initialized with x-, y-, and z-coordinates only. Points are either initialized with absolute coordinates or modified to show relative location. At this level of three-dimensional representation, measurements can be made to estimate the linear distance between two points or between a point and a plane. Data are in a generic form that opens up a referencing base for subsequent manipulation. It is suggested that at least one copy of raw scan data should be kept unchanged in terms of point coordinates, viewpoint, and the images associated with scan orientations.
2. Level II – object initialization: Structural detail, which represents the components and their mutual relationships, is created by fetching or matching points with geometries using mesh or various shapes of primitives. In contrast to one-dimensional representation, volumetric description enables calculations to be made of surface area and of object volume. Relative location between objects becomes more meaningful as the boundaries of objects are defined and can be manipulated afterward. In addition, the volumetric data are exported to domain-specific applications for further visualization or analysis.

### **Dimension-related geometric description**

The initial level of data manipulation emphasizes a preliminary use of scanned data and dimension-related checks based on geometric characteristics. Scanned data are used for analysis, measurement, recording, or visualization. Measured data are used for dimensioning, defining relative location, and recording geometric attributes. For example, a scan might record geometric information of a steel joint that can be used for further manipulation, such as spacing or form works. Related checks that could be derived from the scanned data include checks on spacing, size, number, and the relationship with adjacent components. The right image in Fig. 4 shows the distance between a binding steel bar and the outer surface of a column. Spacing is measured as a, b, c, and d. The spacing for concrete should be slightly smaller after the thickness of form is reduced.

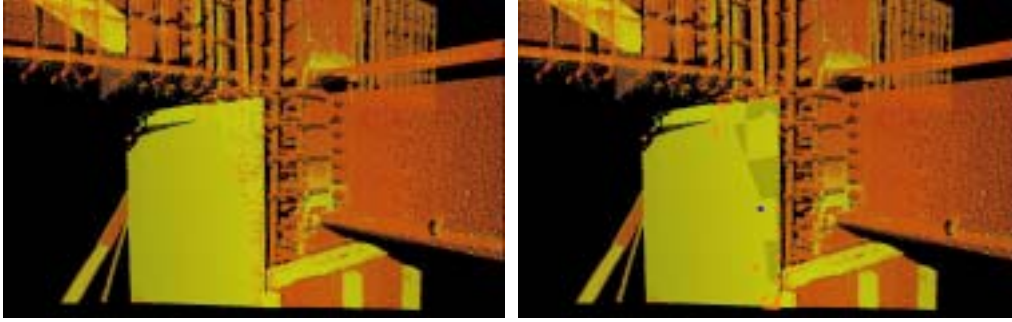


Figure 4. Tolerance causes differentiation and aggregation of component definition

When object initialization is conducted, tolerance causes the definition of objects in a differentiated or an aggregated manner. Some of this is a result of construction quality. In Fig. 4, two patched faces of a plywood concrete form show that this part of the point cloud is actually made of two regions with different levels of flatness. The surface of the SRC column may not be flat.

Dimension-related checks are made in terms of standard deviation, which mainly arises from stress-related (pressure, force, fire) deflection or poor construction quality. Geometry-related attributes of the scanned data are categorized based on their usage in one, two, and three dimensions, such as length, width, height, or their smoothness for finish works or bill of materials.

### **Point-cloud-based inspections**

Using point clouds as the main manner of representation for progress control has several advantages:

1. Point clouds represent a metaphor of “layers” which are translucent, so that offset parts or regions between two overlaid clouds in different colors can be identified.
2. the reasons for not translating point clouds into polygon models are threefold:
  - The surface cannot be seen through. Although a semi-transparent material can be assigned to allow a view of what is inside, the results are not satisfactory.
  - A polygon model represents a post-processing of point cloud data. The geometric characteristics of points can be altered by surface smoothness or point sampling processes. Although a polygon model enables point-to-face distance measurements, points are still need as the original reference.
  - The geometric information might be reduced in creating a polygon model, because point clouds might be incomplete due to on-site interferences caused by such features as landscapes or vehicles that trespass the scan region. Although the missing part can be interpolated from the surrounding surface curvature or be made by scans from other orientations, the same situation might occur again. The region with low point density may cause difficulty the construction of surface models. For most review situations, a partially complete point cloud is sufficient to show the configuration of an individual object or a group of objects.

### **Data format**

Both the 3D point cloud and mesh are stored in DXF, DWG, VRML, or browser-specific format that facilitate review in several environments:



1. scan-imbedded review: Since the 3D scanner provides the additional function of allowing changes in cloud attributes such as color, any two phases of clouds can be differentiated. In fact, most of the progress reviews for this study were made using clouds. The “overlap” function which was originally designed for defining the intersection area of two point clouds is now used to mark overlaying parts that occur simultaneously in two construction stages. When the overlaying parts are colored differently or one is represented in a mesh mode, the newly constructed parts are easily identified. The overlaid clouds become solid proof of construction work done compared to work scheduled.
2. Internet-enabled review: The 3D data sets are converted into VRML format, which makes review of the construction process available through existing Internet and company web pages (see Fig. 5). The VRML model can be manipulated at viewer’s end. The VRML format is able to be opened or imported by many 3D applications. Users are able to measure distances and perform operations such as editing or layering with AutoCAD, 3D Studio Max, TrueSpace, and Geometric Studio. Geometric Studio was originally designated for industrial design use. Its capability of patching point clouds to mesh and to polygonal surfaces is partnered with a cross section function to create contours for drawing-based documentation.

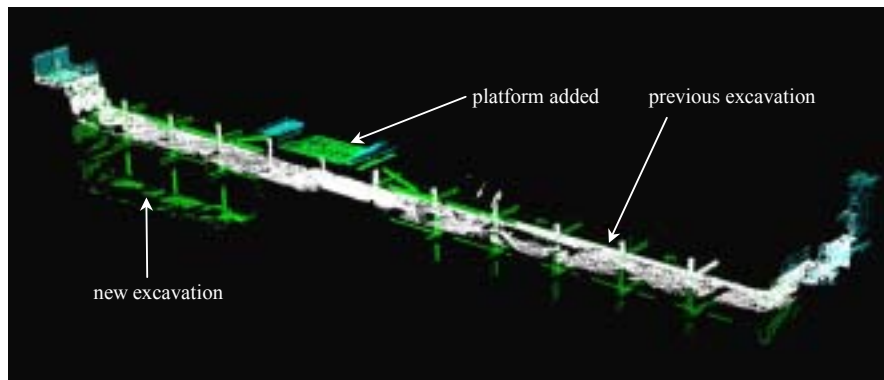


Figure 5. A VRML model

Data sets scanned on different days are registered together to reveal the differences in the construction process. Earlier point cloud scans are usually represented in mesh format. Scans made on later days are represented in point cloud form. In this way, a mesh and a point cloud can be placed together, with the parts of the point cloud not overlaid by mesh being readily identifiable as new construction elements. Components for this study were scanned and saved in VRML format, which facilitates a review using the Internet. In Fig. 5, horizontal H-beams are seen overlaid in corresponding locations within both mesh and point cloud. Later construction scanned in point cloud shows the addition of a working platform and an extended H-beam length that is measurable. The extension of beam length indicates the site was excavated deeper. The model can be rotated, zoomed in/out, or translated with corresponding plug-ins, such as Cosmo or Octree, enabling the creation of a browsing environment.

Displaying more than two sets on the same screen usually causes difficulties in identifying objects within a small computer screen. For this reason, other working environments such as Geometric Studio was used to differentiate data sets and assign “hide” or “show” as needed to clear up any visual interference. In contrast, color-keyed models in VRML model format meet the needs of visual inspection at the first place.

3. Traditional drawing environment review: Point clouds are converted to DXF format before being imported to AutoCAD. This application's drawing production environment takes the data of the point cloud and orients it to meet the orientation of the imbedded drawing world coordinate system (WCS) or user-defined coordinate system (UCS) to be overlaid with any relevant drawings (see Fig. 6). As a result, this simple "overlay" procedure creates a direct connection between a design and its actual construction at a certain stage. Not only is a traditional computer environment for drawing production now feasible for a new checking task, but also a draftsman can ensure quality control by just looking at the differences revealed by any misalignment of a projected point cloud and the lines in a drawing.

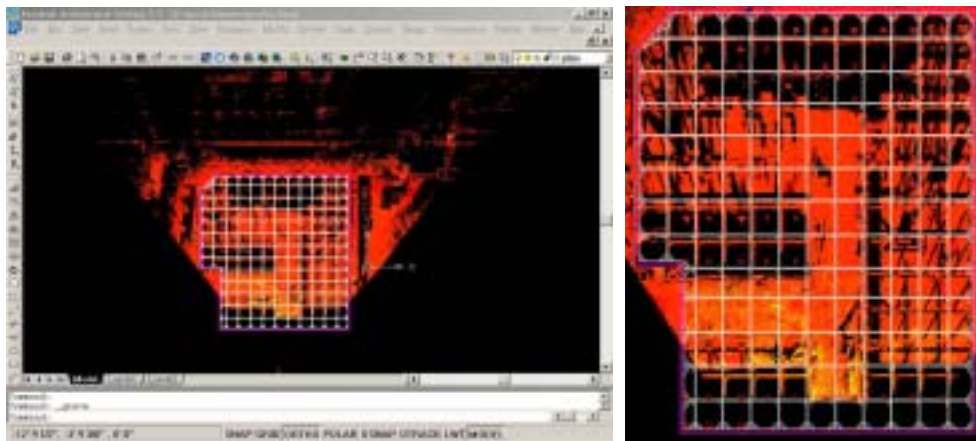


Figure 6. Overlaying point clouds with drawings



Figure 7. Referencing section through site

### Whole-site cross-section

A 3D scan is a good solution not only for reviewing an object as a whole from the outside, but also for providing a clear review of a cross-section of an entire site (see Fig. 7). The process does not have to be undertaken in a traditional manner, made by creating models and conducting software cuts. Most important of all, sections are made based on what really occurs at a site. The section is a good means of spatial representation suitable for construction quality control, such as for levels or clearance between slabs. The purposes of such a scan are to show:

- structural and compositional relationships: to reveal aggregation and segregation of building parts
- hidden components and spaces: to illustrate what might be left unseen from a viewing angle above ground

- part-whole generating process: to create a time-based transformation description of the occurrences at a site

### Data Comparison

Overlaid parts that are made of mesh and point clouds facilitate the following inspection-related tasks by providing a detailed visual description:

- description of newly modified components: in terms of parts, machinery and people
- dimension-related geometric description: in terms of dimension and volume. For example, by measuring the level difference between two stages of excavation, we can calculate soil volume in a higher accuracy, instead of replying approximate figures or on the number of dump trucks used.

#### Description of newly modified components – the Boolean operations of point clouds

For a comparison to scheduled categories, two point clouds can reveal a construction condition of either expanding, reducing, or changing status. The Boolean operations of point clouds provided a theoretical foundation for an algorithmic calculation of as-built construction process to display changes in details.

1. Expanding: This situation occurs at most construction stages when new parts are installed, such as main structures, enclosures, or flooring, as an indication of the level of completion of a building. In most cases the added components remain as parts of the cloud. Fig. 8 shows a new foundation frame has been built, structure columns have been erected, and B3 support structures have been removed between phases 1 and 2. Phase 1 represents an earlier status. The section shows the depth at which a laser beam can reach to the bottom has changed with the previous depth shown in light gray, and the new depth in a green-colored point cloud. A small program was written to subtract the overlaid points from a later scanned cloud to reveal the newly added parts.

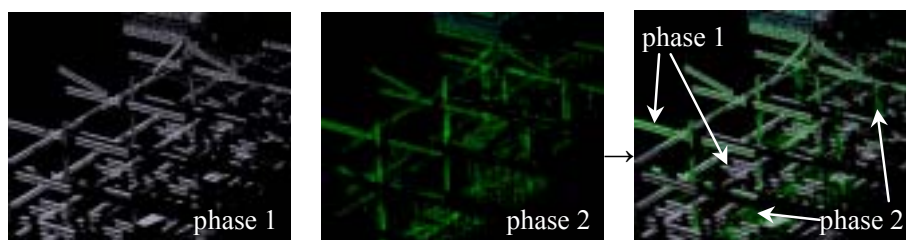


Figure 8. Structural members added

2. Reducing: This situation occurs when temporary structural supports are removed. An example could be excavation in which remaining soil volume is reduced, the bottom level is descended so that the void space is increased, and a retaining wall is built.
3. Changing shape: This situation occurs when changes are made to particular parts of a point cloud, rather than a constant increase or reduction in certain parts.
  - Reallocation of distributed subjects: Since a construction site is usually full of a variety of activities, the associated workers, machinery, and materials contribute to the whole geometric description of the construction process. Most of the machinery and materials are subject to being distributed and moved around. The reallocation of subjects characterizes the changed parts of the point cloud.

- Behavior-related operations: Taking excavation as an example, soil is on the one hand removed to a lower level, and on the other piled up temporarily. In this study, scans were made not only of the ground profile change at a certain time, but also at each minute for five minutes. The profile change is visualized for measurement as the change is related to the excavator's operations and the dump truck's location. See the description in the next section.

### Comparisons of data sets

Currently, only two data sets have been compared. The pair strategy is made based on time or major changes. Exemplifications are made to the comparisons based on phase, object, and volume.

1. Phase: Changes in phase are exemplified by a comparison before and after ground excavation (see Fig. 9). The photos to the left show the images of the check points of time when the site's point clouds are to be overlaid. The image to the right is the overlaid result in which phase 1 is at an earlier stage of excavation than phase 2. The two phases are illustrated in different colors to show that H-steels and a working platform have been added. By measuring the height, we can know the depth of excavation. The itemized identification of new components are categorized and recorded as well.
2. Object: Changes in object are observed by identification or comparison of retaining walls, structural members, and waste clean up and profile changes on the ground (see Figure 10-12).
  - Retaining walls (see Figure 10): During a site scan, the guiding path of a retaining wall was retrieved along with the allocation of machinery. This record is considered a representation of work flow that can be a reference for making comparisons to the construction schedule, as it provides data on the number and types of machines and their operation space (raising height, clear space), footprint area, allocation of supporting equipment (dump trucks, air compressors, generators, materials), and operators.
  - Structural members (see Figure 11): Installation of box columns is shown below. The itemization of newly added and categorized objects helps to create descriptions of relative location between columns and temporary support structures.
  - Waste clean up and profile changes on the ground (see Figure 12): Objects, buildings, or landscape within or around a site are shown. Geometric definition of the location or boundaries of preserved trees, a building's enclosure, level changes, and soil or landscape removal can be determined by referring to an earlier scan.

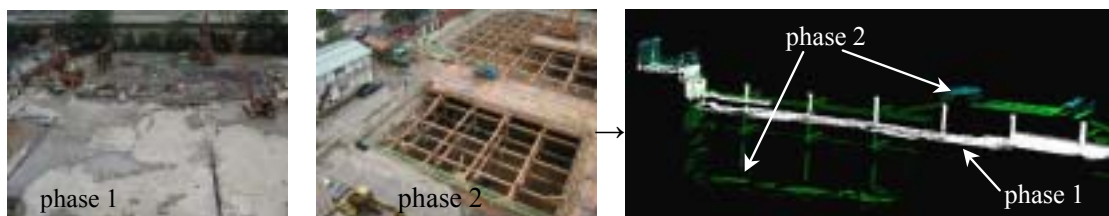


Figure 9. Comparison of phase changes



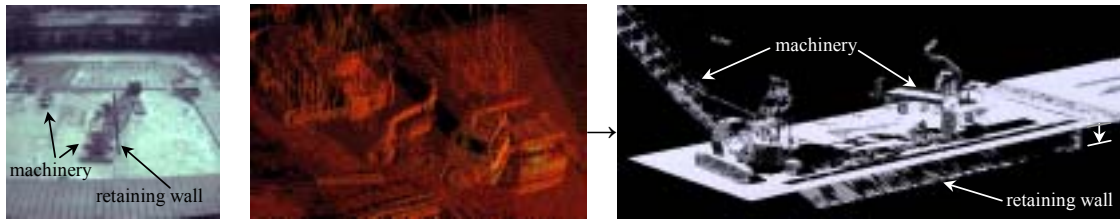


Figure 10. Excavation for retaining wall guiding rail

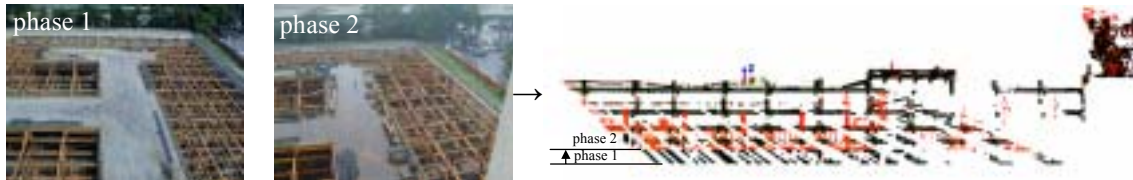


Figure 11. Structural members added

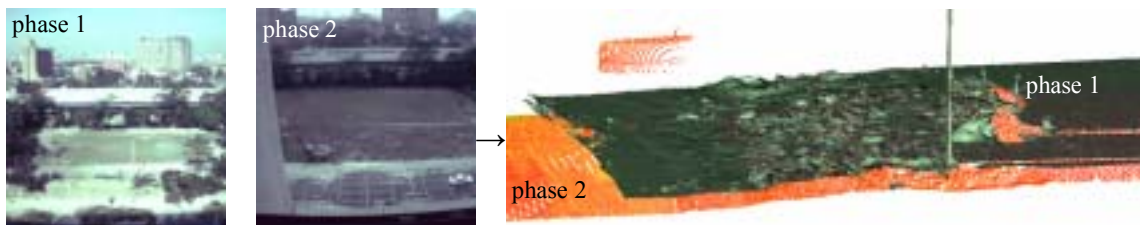


Figure 12. Changes in site profile

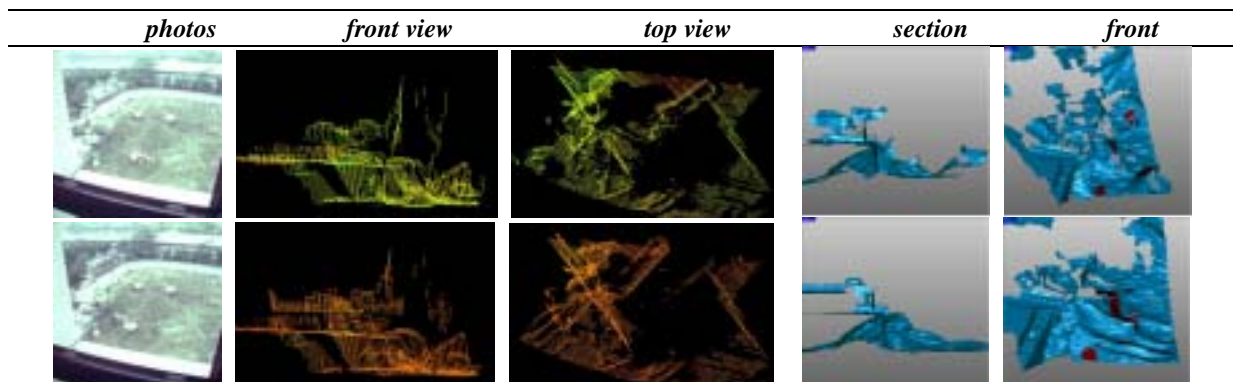


Figure 13. A chronological comparison of a site profile for 5 minutes

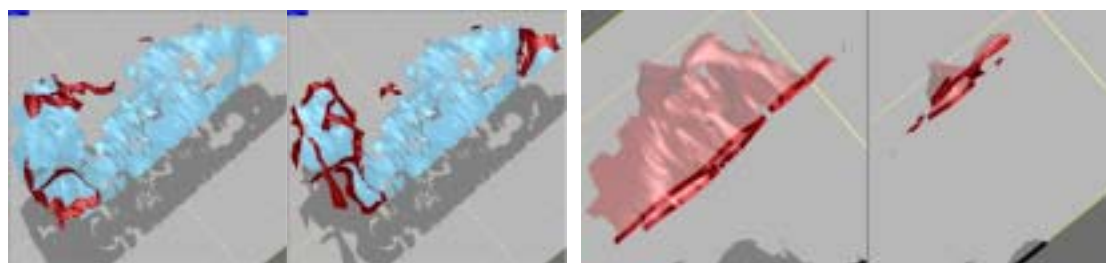


Figure 14. Two slice types of overlaid ground profiles (left: horizontal, right: vertical)

3. Volume (see Figure 13 & 14): A chronological comparison of a site profile for 5 minutes is made to a region of the construction site. Scanned soil profiles are overlaid to calculate the

volume of excavated soil.

A soil profile under the volumetric definition at various excavation intervals is shown in a process scan that was made in five continuous stages with about 1 minute in between (see Table 1). Each stage has a point cloud that shows the particular land configuration at that time point. The point data were then saved in .xyz format and transferred to other applications (for example, Geometric Studio, TrueSpace) for creating polygonal surfaces.

Table 1. Sequence of scans

sequence	time	date
1	10:52:46	
2	10:57:18	
3	10:58:26	May 14, 2002
4	10:59:32	
5	11:00:38	

The point cloud of each scan is presented in two orientations, which are used to compare the surface model generated by other application in terms of three orientations. Excavated ground is presented more explicitly with soil surface substantiated. Due to obstacle interference to the laser beam, part of the surface was left as a hole. Geometric Studio can fill such a hole based on the curvature around it. The parts of the surface in red (darker part) show where the locations of the holes are. Because the configuration of ground surface keeps changing within or between each scan, the polygonal surface is used to visualize the change in altitude.

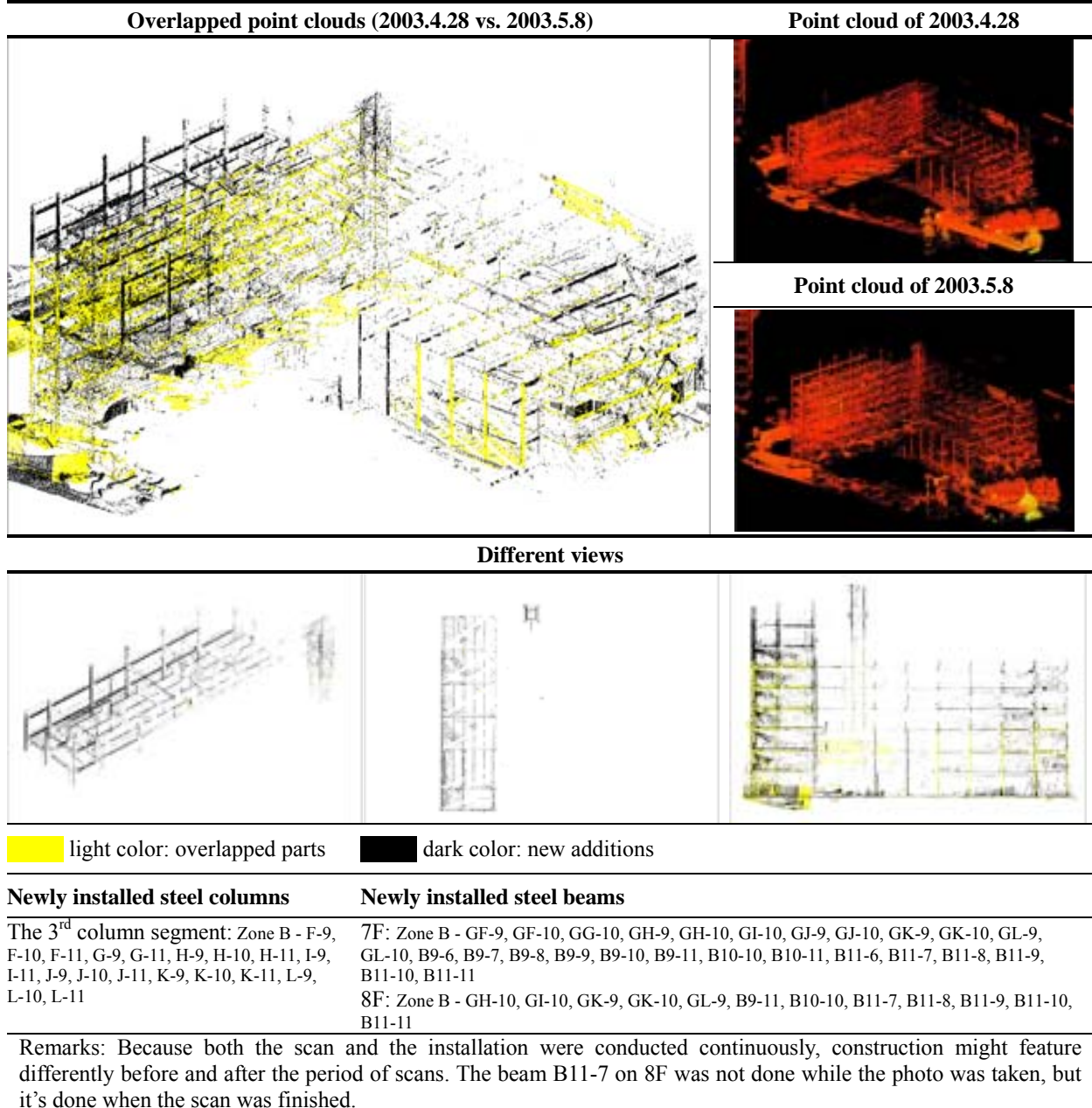
A similar operation was applied to overlaid clouds. Geometric Studio can wrap points with polygons by using their noise level to determine surface or volumetric types. A closer inspection of the polygon sets of each scan shows that minor differences do exist even within a one-minute period of time. When these clouds are presented together, polygons will be created with those points that are closely located. Because scans are made in rows and columns, if the distance between adjacent columns is relatively smaller than the distributed distance along the column, polygons will be made along the column. As the figure shows, edges will be seen when the polygons are viewed from the location straight above. The polygons, which represent the magnitude of displacement along the column direction, will be shown if the viewpoint is offset to the left or to the right. A combination of different shapes of polygons shows a change in ground profile within the scanned period of time in a planar manner of representation.

The region of tested ground is measured at about 7.25 meters in width and 14.67 meters in length. The ground profile is cut horizontally and longitudinally. The horizontal cut is ascended from a level of 45 at increments of 1 (the software's unit). The longitudinal cut is moved sidewise from a position of 63 at decrements of 3. Because this profile combines five scans, the final configuration is presented as a volume. The variation of height at each location can be seen as the thickness of the profile. Parts of the volume surface remain unclosed because those parts may have been produced when the laser beam was blocked by objects such as piled soil or machinery. The illustrated figures show the cut made before and after. Measurements show the maximum difference of level height for the ground profile is about 1.07 meters in about 5 minutes using three excavators.

4. Details: Overlapping comparison of point clouds for columns and beams was made. The progress in terms of times can be clearly presented by overlapping clouds. Fig. 15 shows the

difference between 2003.4.28 and 2003.5.8 which were represented by the two clouds on top right separately. The two clouds were overlapped and shown by indicating parts with light color and dark color after applying the intersection function of Cyclone 4.1. The part in light color represents the overlapped region which is also the existing construction. The part in dark color represents the un-overlapped region which is also the new construction made after the first scan. As shown in Fig. 15, the three small images are column segments, partial plan of the column segments, and the elevation of zone B and the section of zone A.

Figure 15. The assembly difference of beams and columns between 2003.4.28 and 2003.5.8



New constructions or differences can be seen from the overlapped clouds:

- Curtain walls facing central court: The overlapped parts in light color showed the four columns to the right were done before 2003.4.28. The columns in dark color to the left were new additions.
- The installation of the 5<sup>th</sup> column segment: The 5<sup>th</sup> segments of columns in zone B were close to be finished. Columns in zone A hadn't started yet.
- Tower crane: The height of tower crane was increased in order to install the 5<sup>th</sup> segments of columns.
- Steel beams: The beams of 7F and 8F on the 5<sup>th</sup> segments started assembling. Although the parts in zone A were farther and received less points, the 4<sup>th</sup> segment of steel columns were still identifiable. Some new beams were added to 4F. Beams on the 5F and 6F were new additions. Based on the cloud analysis and photo records, the steel beams on 5F and 6F were close to be finished.
- New installations: The diagonal supports in the 3F staircases of zone A were installed.

### Discussion

With the details shown, we found that point clouds were able to display construction progress without the presentation of the 3D models that are usually presented by 4D simulation. Based on the data comparison made in previous section, description of newly modified components and dimension-related geometric description were made possible through point cloud data format. The inspection of details was also made possible by overlapping comparison of point clouds to check the installations of columns and beams. The as-built progress in terms of times was presented with differences and locations shown where the new additions were. During the progress inspection, photos were used to help identification of objects. The new development of 3D laser scan has combine color attributes with point data of coordinates. The colored point clouds make the identification of activities more intuitive, not just visually but also physically. Once the clouds are retrieved and transferred into proper data format, the as-built schedule can be compared in a commercial available CAD platform. The cloud-to-cloud comparisons were made as well as cloud-to-model comparisons in which 3D models were used to display the progress differences in previous study. Both approaches were able to display the differences of as-built progress. The comparisons were made possible in AutoCAD and MicroStation in which the platforms were able to accept 3D models and point clouds and displayed them properly and visibly. However, not all the commercial platforms are feasible to accept both data formats. Since the point cloud format was frequently used in industrial design, one of the important issues in this interdisciplinary representation is to combine format from range data of point cloud and 3D (4D) modeling data. As tested of Common Point 4D, the format of point cloud has to be transferred into volumetric objects (in this case, TrueSpace was used) in order to be seen. The original point cloud in DXF format is simply a collection of x-, y-, and z-coordinates with no measurable size of each point is available. As a result, Common Point 4D did import the cloud and no point with size large enough to be seen clearly. The alternative representation made in TrueSpace could be seen when each point was enlarged by 0.1 m into a square by selecting import option and extruded 0.1 m into a cube afterward. The design of the program is different from the way an industrial design application handles point cloud. It's understandable that a program which was developed from design to predict construction problems may not fit in the application that goes reversely from as-built geometries to original design inspection.



## Conclusion

With the details shown, we found that point clouds were able to display construction progress without the presentation of the 3D models that are usually presented by 4D simulation. This study offers a method for representing a site under construction through data retrieved from a 3D scanner. As applied to a campus construction site, the data retrieved are point clouds that can be stored as records or can be initialized as geometric shapes afterward for the purpose of analysis and visualization. A site under construction can now be digitized. Traditional image records of a construction process are made by geometric representation. The digitized data provide a referencing base made after the design stage for verification.

With the application of 3D scanner site digitization, additional work such as construction information management has to be done. Site digitizing provides a dramatically different experience with geometric forms by using the application of new tools, data flow, and Internet communication. The schedule-based scan facilitates a detailed definition for partially completed construction work that adds flexibility to 4D technology and also provides as-built proof for geometric measurement and visualization.

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