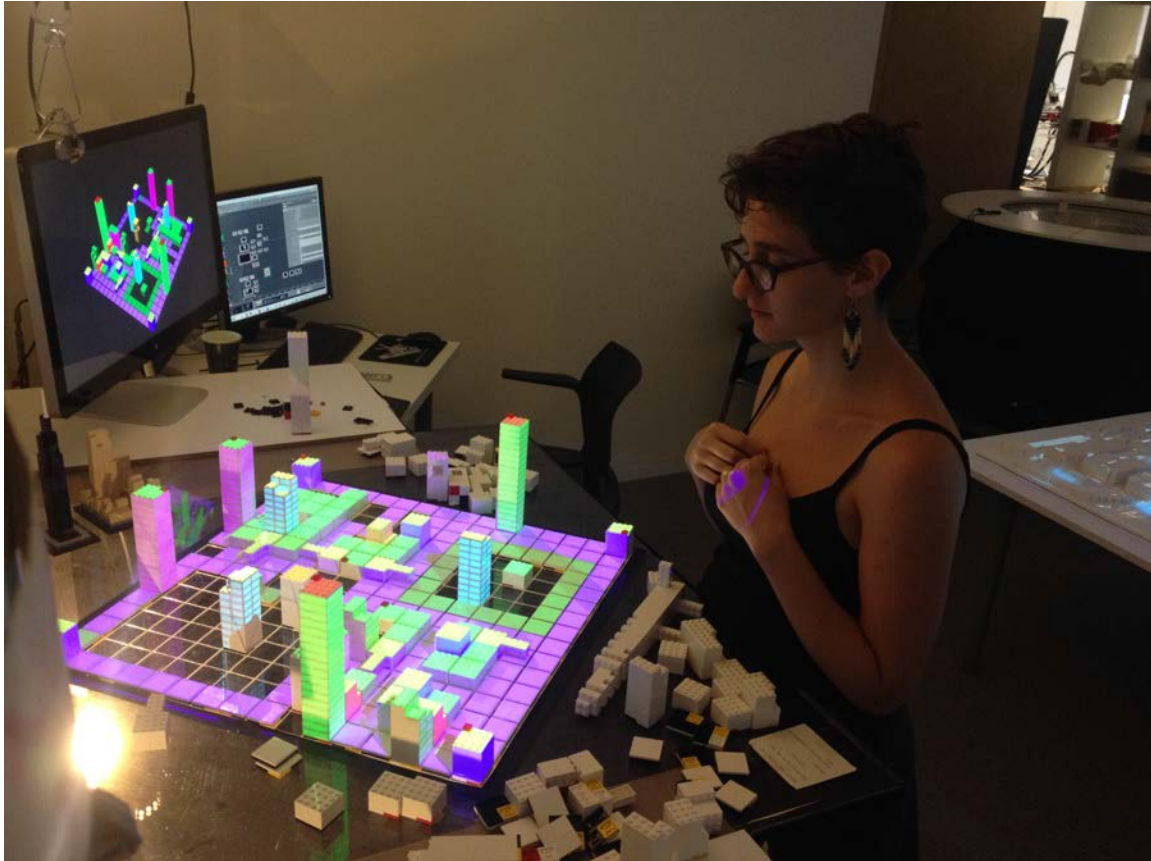# System for Real-time Digital Reconstruction and 3D Projection-Mapping of Arbitrarily Many Tagged Physical Objects

Technology Description
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Presented by:

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I. Description of the Invention

In illustrative implementations of this invention, a system
- (a) detects arbitrarily many uniquely tagged physical objects in real time as they are moved by a user;
- (b) performs real-time digital reconstruction of objects' configuration including form, position, ID, and any metadata;
- (c) performs real-time analysis of the objects' configuration; and
- (d) performs real-time visualization of analysis via display screen(s) and projection mapping of visual content onto objects.

For example, in a prototype, a system detects, digitally reconstructs and projects light onto more than 1,000 separate physical objects in real time. However, in illustrative implementations, the number of objects is easily scaled to much larger numbers while still requiring only modest computational resources.

This ability to process (i.e., detect, digitally reconstruct and project light onto) an extremely large number of separate physical objects in real time is facilitated by a novel feature of this invention: a human user can place the physical objects in a spatial region, but the placement of the physical objects in the spatial region is constrained, such that only certain positions of the physical objects in the spatial region are allowed, and such that the physical objects cannot be placed in other positions in the spatial region.

For example, in a prototype, a human user places the physical objects into indentations in a table. The indentations form a grid on the table. The indentations constrain the position of the physical objects on the table. The fact that the allowed locations of the physical objects on the table are limited to a set of specified positions in a physical grid simplifies detection and digital reconstruction of the objects and also simplifies projection of light onto the physical objects.

Processes are performed in real-time (faster than human reaction time) to give human users instantaneous feedback from the system. As such, components of the system are configured to overcome latency issues that have, up to now, prevented real-time reconstruction of arbitrarily many uniquely tagged 3D objects.

The system includes a kit of tagged 3D objects, a table that constrains the placement of 3D objects into a scene, one or more sensors for scanning the scene, one or more computers, one or more display screens, and one or more projectors for projecting light patterns onto the scene. The projected light patterns, via projection mapping, augment the 3D physical scene with information and analytics unique to the user's configuration of the objects.
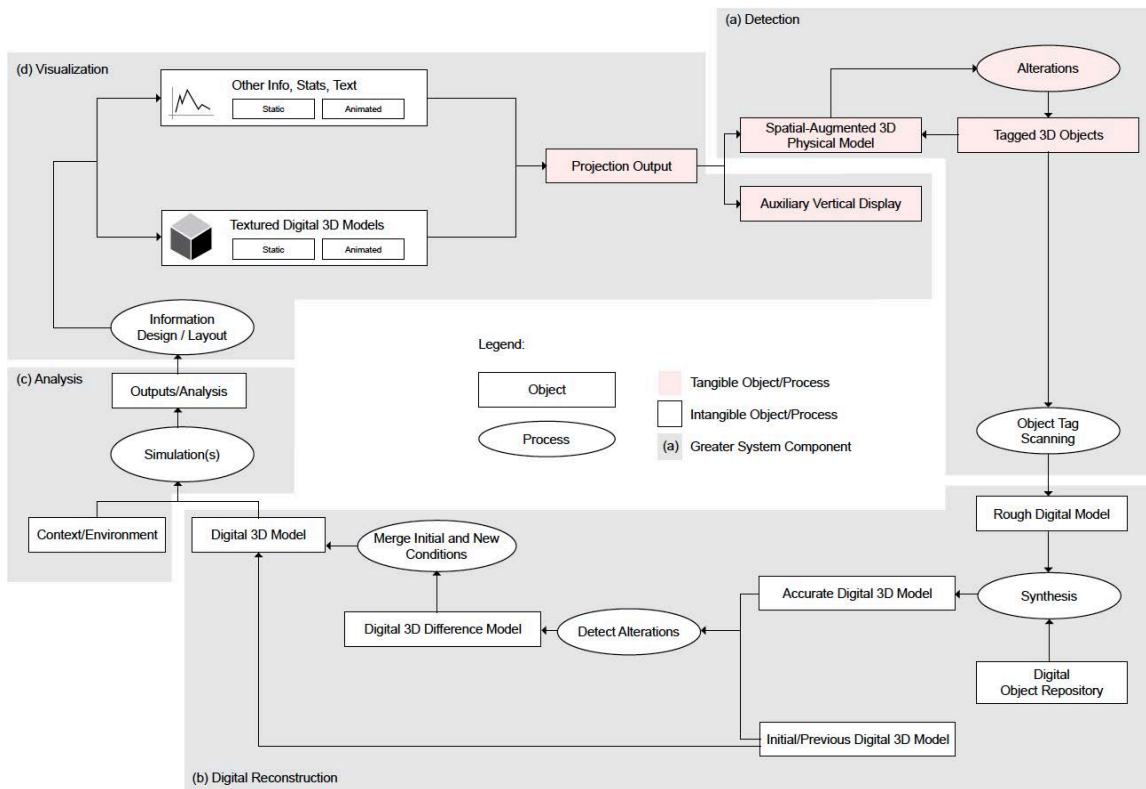
Figure 1:

Figure 1 is a diagram that shows steps in a method of detecting, digitally reconstructing and projecting light onto physical objects, in an illustrative implementation of this invention. In the example shown in Figure 1, a human user interfaces with the system by changing the configuration of "tagged 3D objects" within a "spatial-augmented 3D physical model." A specially designed table surface constrains the placement of objects and defines the boundaries of the physical model. Specifically, a user places, moves, or removes a tagged 3D object within object-shaped depressions. Illustrative implementations have designed such object-shaped depressions as an NxN rectilinear grid placed upon a clear acrylic surface (Figure 3a). Unique patterns placed upon the bottom of objects are visible from the underside of the table. A sensor continuously scans the state of this NxN grid from below the table (Figure 5a). A computer takes the sensor feed as an input and performs an algorithm that determines the pattern (or non-pattern) at each grid cell, and from that pattern determines the location, ID, and rotation of each object present on the table (Figure 6a). Since location and rotation are constrained by the table, the algorithm requires fewer calculations and latency is very low.

A computer merges the location, rotation, and ID data with a "digital object repository" that uses IDs to link data. The repository contains additional information about object form and any other metadata important to associate with that object. In an illustrative example, the repository was populated with building metadata including land use, building use, population density, square feet, and materiality (Figure 6b). A computer

then performs another algorithm that takes the finished digital reconstruction as an input and generates secondary analysis of the model. In an illustrative example, the unique attributes of each object, representing a building, are used to compute an evaluation of walkability (Figure 6c).   A computer also performs an algorithm that packages the digital 3D model, its meta-data, and any analysis into integrated visualizations for export to display screens or projectors. The user may use the visualizations to influence their next interaction with the system, thus completing a real-time feedback loop.
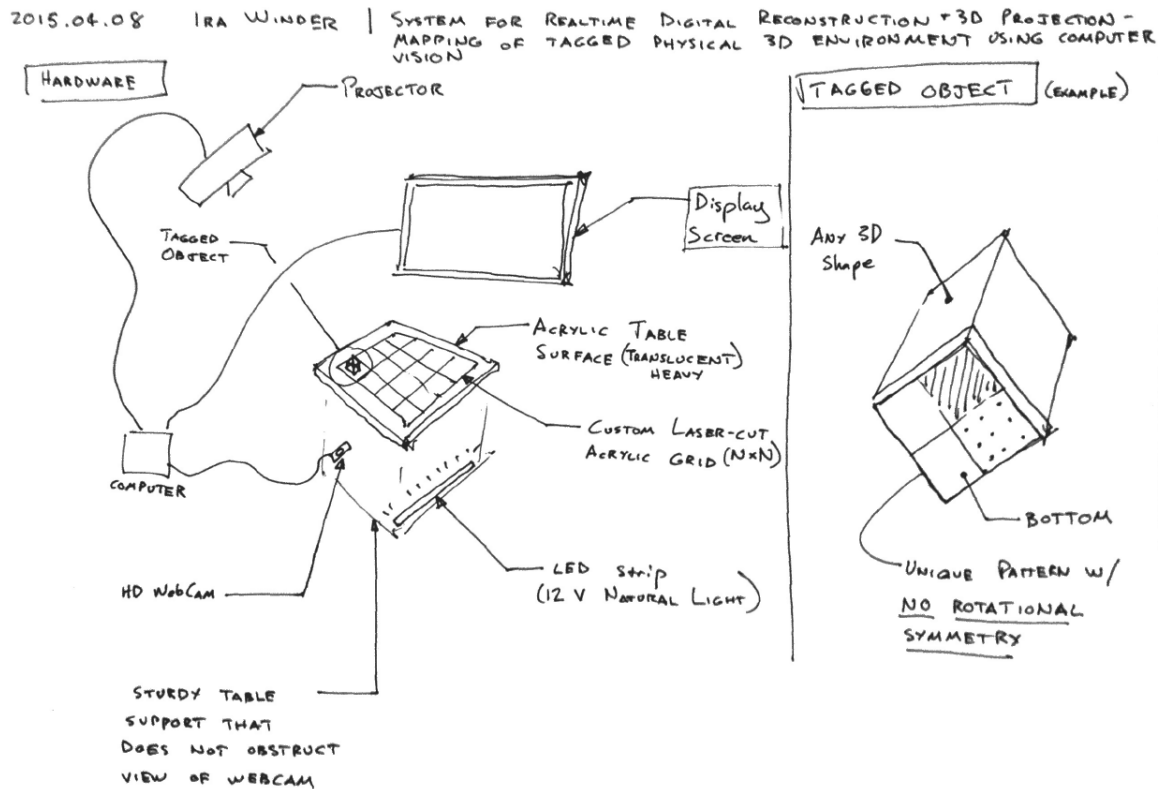

Figure 2: Hardware Components

Figure 2 is a diagram showing hardware components of the system. In the example shown in Figure 2, the system comprises a gridded table surface (Figures 3a and 3b), 3D tagged objects (Figures 4a and 4b), projector(s), computer(s), sensor(s), and display(s).

The gridded table surface constrains the location and rotation of detectable 3D objects. Shallow depressions in the grid define constraints for piece placement.
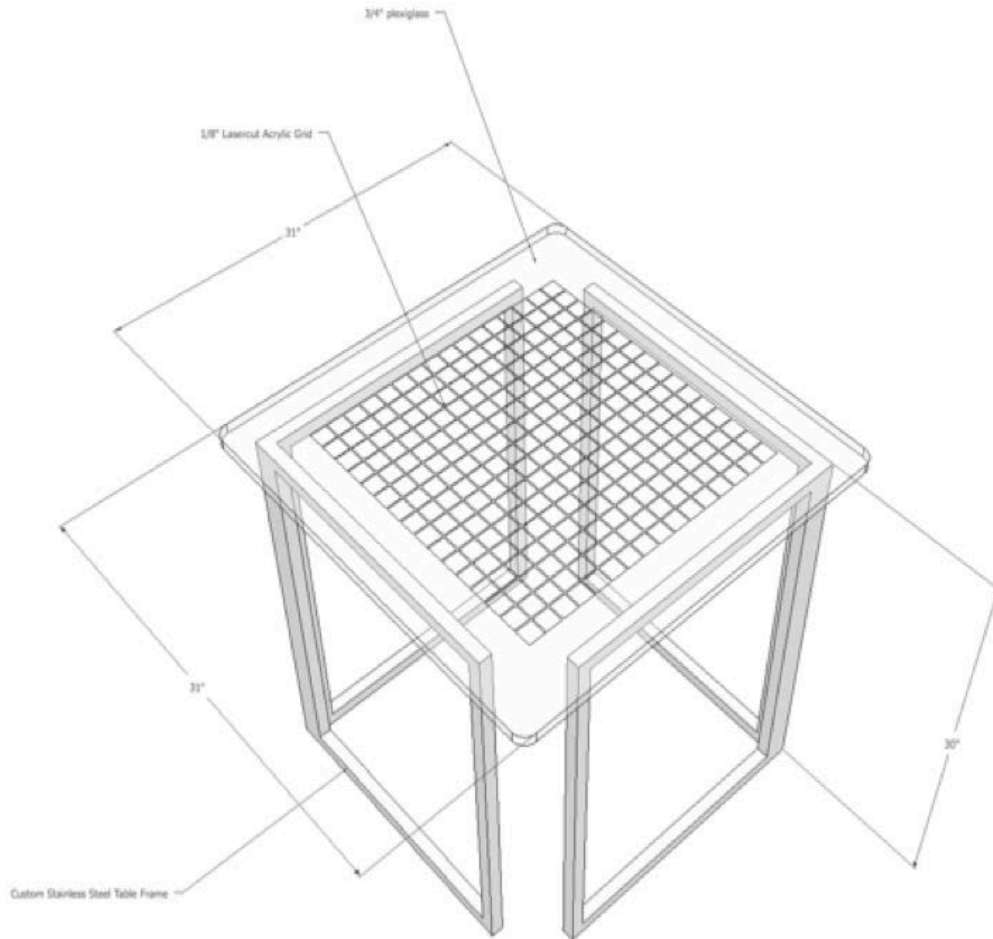

Figure 3a: Table configuration with transparent acrylic surface, acrylic grid, and stainless steel frame designed to not obstruct view to grid from sensor
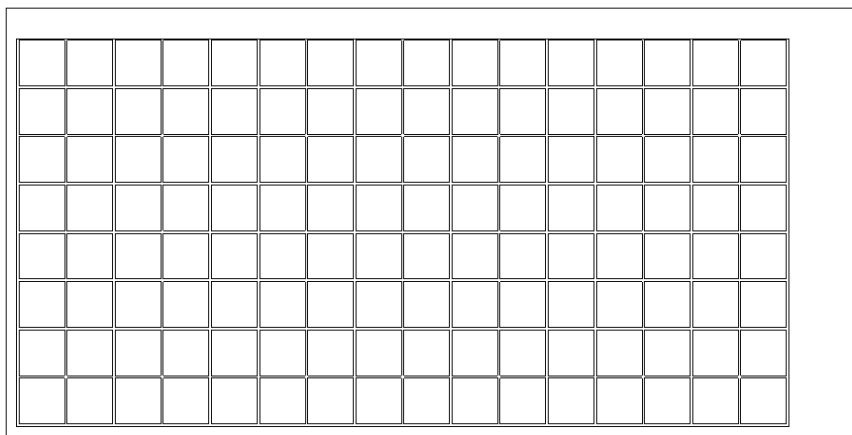
Figure 3b: Template for laser-cutting a 16x8 grid template out of 1/32'' thick acrylic sheet

Tagged objects (or "pieces") are custom-built to fit into the table grid. Objects may be any form of solid white or off-white material ideal for rendering projected light. Unique tags are placed in a discrete place on the object, for instance the bottom or inside of the object. Tags communicate two key pieces of information: piece ID and rotation. In the proof of concept, tags are custom 4-digit color codes placed on the bottom of each piece (Figure 4a).
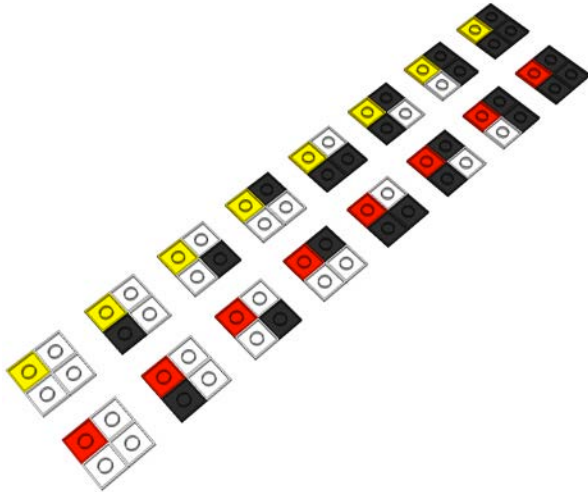
*Figure 4a: Example of 16 unique color tags with both ID and rotation information*

Figure 4b: Example of unique tags attached to bottom of tangible-interactive building objects

In proofs-of-concept, a computer performs a custom computer vision algorithm that takes a webcam feed as input and detects the position, ID, and rotation of each piece in the grid. A natural-light LED strip adjacent to the webcam provides ample photons for the sensor and minimizes light noise. Though a webcam works well, other means of optical sensing may be applied (infrared, for instance), or even a table surface with integrated electronic sensing.

The location of projector(s), table, and sensor(s) are immobilized and secured relative to each other. The system works best in low-light conditions where projection mapping is easily visible. The projector is placed high enough so that its cone of projection covers the entirety of the table, but not much more.

Optional display screen(s) present real-time 3D renderings and analysis of the physical environment.

One or more computers communicate (by one or more wired or wireless communication links) with other hardware components, such as projector(s), sensor(s), and display screen(s). The one or more computers control, or interface with, these other components.
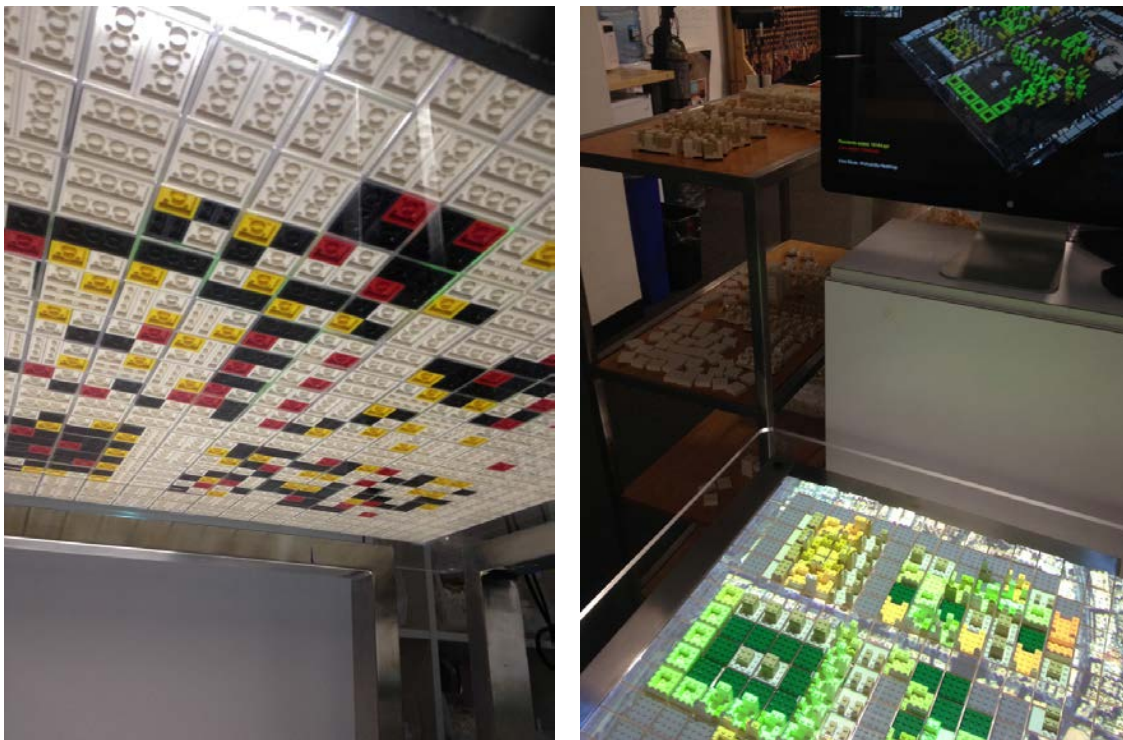
Figure 5a (left): View of tagged objects from underside of clear acrylic table. Figure 5b (right) view of system performing with realtime object detection, digital reconstruction, analysis, and visualization via both projection-mapping and on-screen display. The content shows how a given urban configuration performs in terms of walkability.
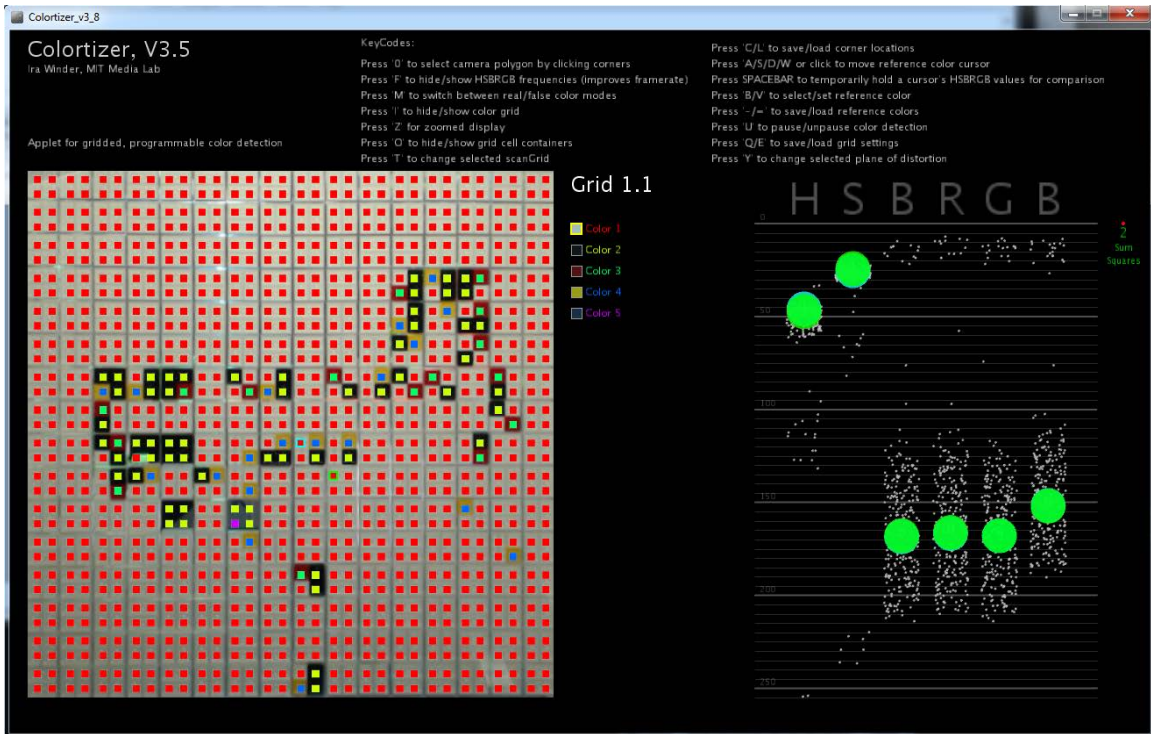
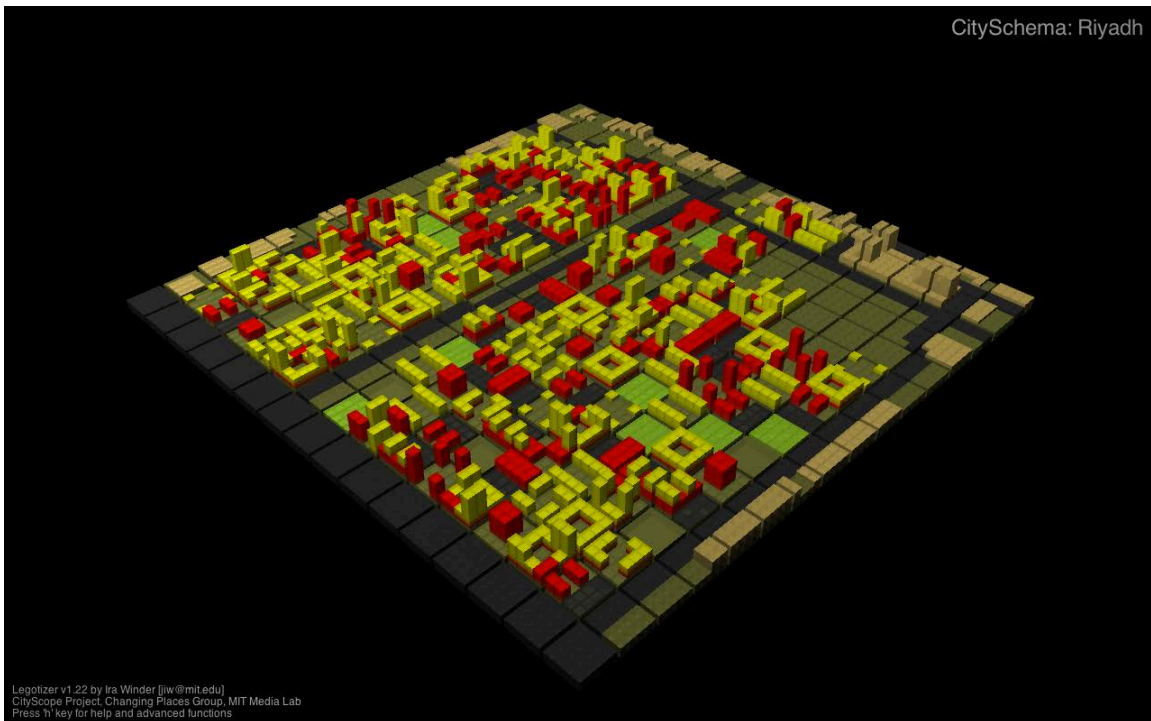*Figure 6a: Object Detection calculates Location, ID, and Rotation of objects based upon sensor input.*

Figure 6b: Digital Reconstruction populates a model with inputs from object detection algorithm
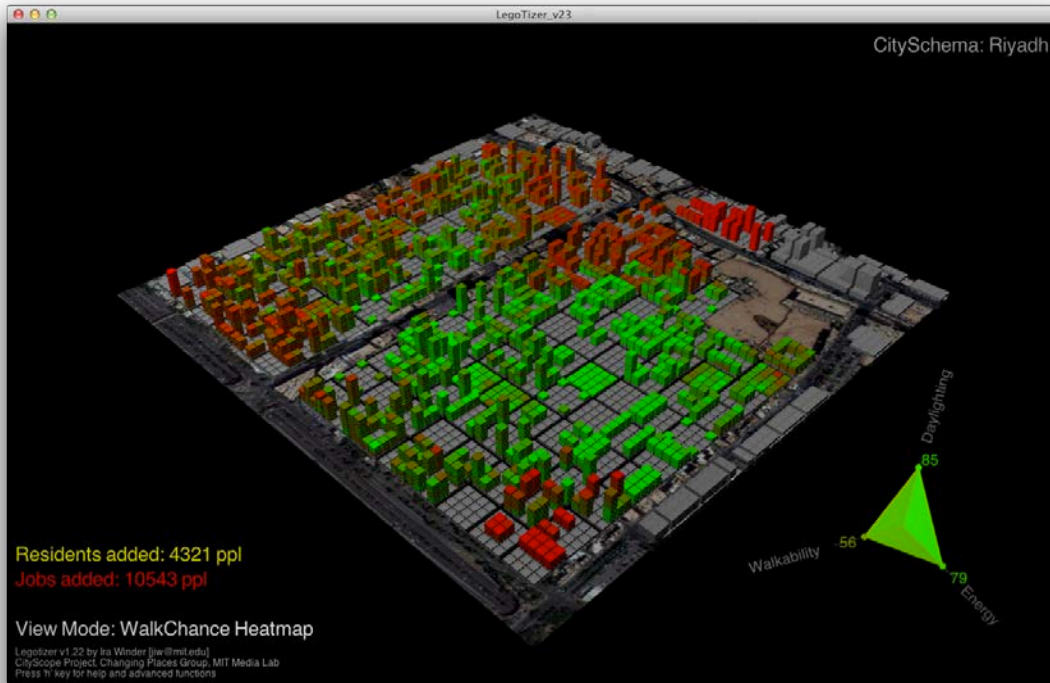
Figure 6c: Analysis&Visualization performed before output is sent to screen or projector.
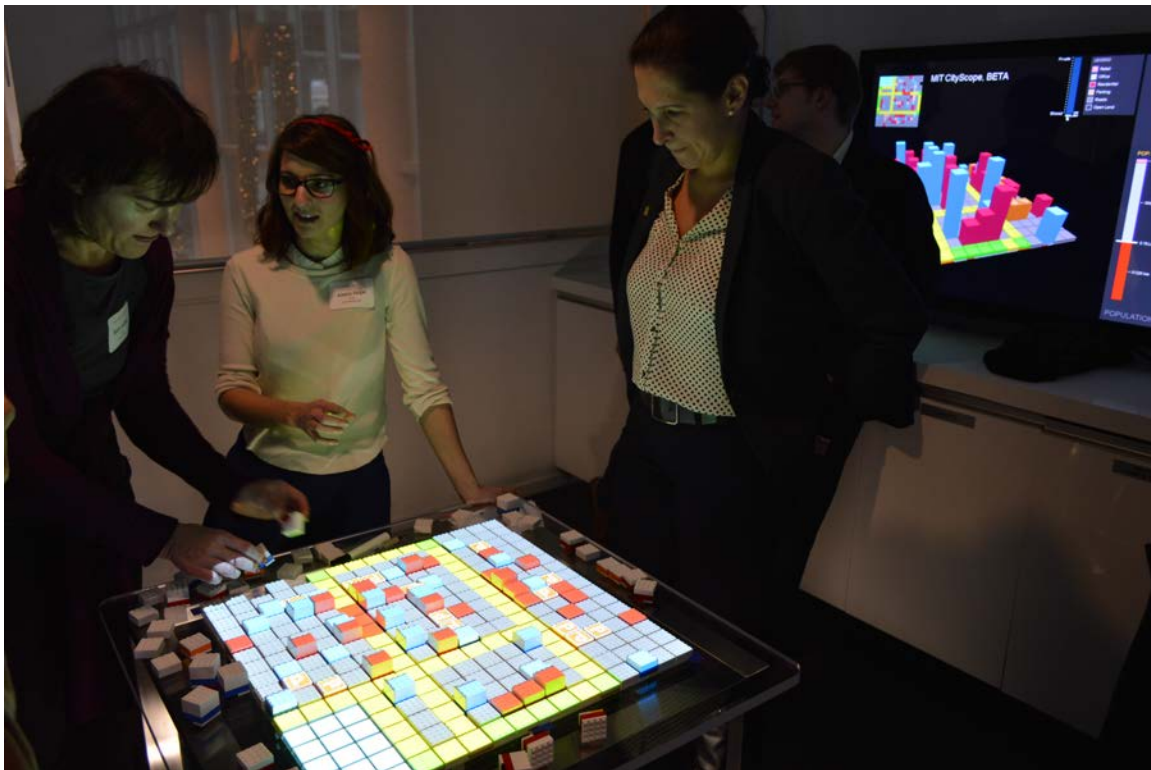

Figure 7: Use scenario in which system dynamically simulates and displays traffic congestion as a function of building placement.

As used herein, "including" means including without limitation. As used herein, the terms "a" and "an", when modifying a noun, do not imply that only one of the noun exists. As used herein, the term "or" is inclusive, not exclusive. For example A or B is true if A is true, or B is true, or both A or B are true. As used herein, "for example", "e.g." and "such as" refer to non-limiting examples that are not exclusive examples.

Conclusion

The above description (including any attached drawings and figures) describes exemplary implementations of the invention. However, the invention may be implemented in other ways. The methods and apparatus which are described above are merely illustrative applications of the principles of the invention. Numerous modifications may be made by those skilled in the art without departing from the scope of the invention. Also, this invention includes without limitation each combination, subcombination, and permutation of one or more of the abovementioned implementations, embodiments and features.