Singapore Views: A Collaborative Interactive Visualisation and Analysis Framework for Urban Planning and Design

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I. Introduction

Cities are complex systems that comprise physical space (including infrastructure, environment, transportation, etc.), and individuals interacting with one another and the physical space. Architects, planners, and stakeholders aim to improve social and environmental well-beings in cities through urban planning and design. As cities are becoming increasingly complex and dynamic, planning and design methods are shifting from traditional static approaches to evidence-based analysis of big urban data. The emerging topic is highly interdisciplinary and involves not only traditional disciplines such as landscape, civil engineering, and transportation, but also contemporary research fields such as internet of things (IoT), big data analysis, and urban computing.

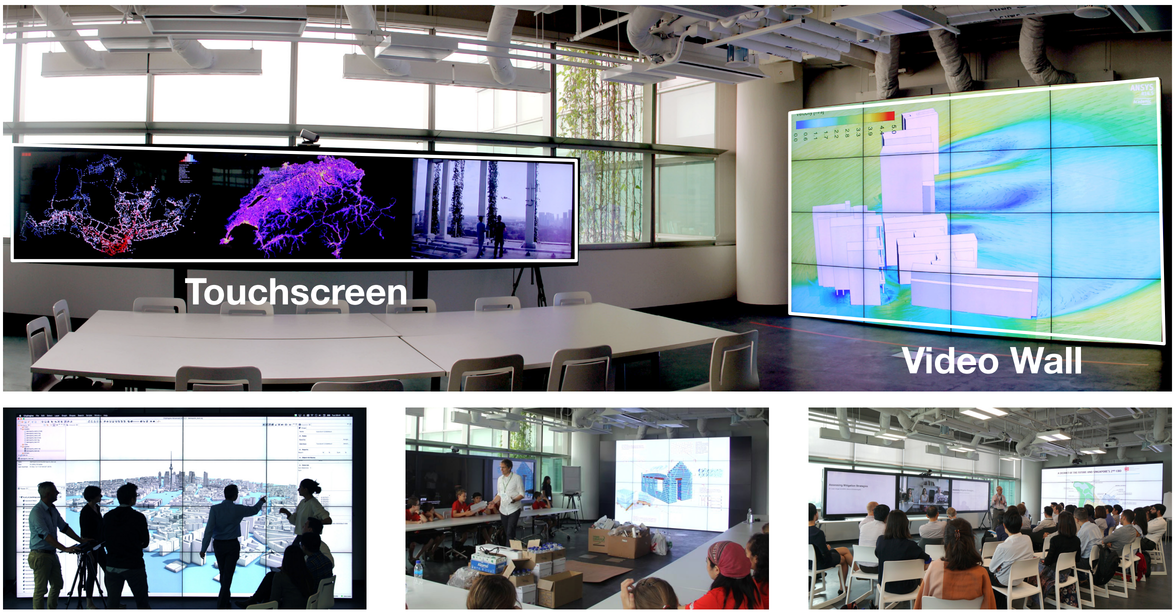
Visualization plays a key role in evidence-based urban planning and design. From the perspective of urban planning and design, visualization of the physical space is a predominant consideration, as humans tend to pay most of their attentions to surroundings which they can directly see (Gehl, 1971). Besides, a planning and design process comprises visual representations in practically all stages and for most aspects – from ideation and specification to analysis and communication (Burkhard et al., 2007). From the perspective of analysing big urban data, visualization can facilitate people's understanding, reasoning and decision making process by integrating geo-located automatic data analysis with interactive visual representations (Sun et al., 2013).

When designing interactive visualizations for evidence-based urban planning and design, enabling collaboration is one of the biggest challenges, yet it is necessary (Isenberg et al., 2011). First, in order to address problems that citizens face in their daily lives, collaboration among domain experts from various disciplines is required. For instance, to improve accessibility to goods and services, the process shall involve at least policymakers for land-use planning, architects for building design, and transportation authority for traffic management. Second, the data to be analyzed is not just becoming increasingly large and complex, but also substantially heterogeneous: one term can be used represent different concepts (e.g., "mobility" as in (Gonzalez et al., 2008), (Zeng et al., 2014), (Andrienko et al., 2017)), and multiple terms to represent the same concept (e.g., "mobility", "trip", and "movement"). To address the heterogeneity problem, sophisticated data integration techniques are needed (Barbosa et al., 2014), which again require collaborative work from different disciplines.

Figure 1: Illustration of a collaborative visual exploration framework, which consists of both physical and digital environments.

To enable researchers to gain information and knowledge from collaborative visualizations of urban data, a framework as illustrated in Figure 1, which consists of both *physical* and *digital* environments, is needed. At Future Cities Laboratory (FCL), the CIVAL team has addressed technical challenges of designing and implementing such an environment to support **C**ollaborative **I**nteractive **V**isualization and **A**nalysis for urban planning and design. The physical environment, i.e., Value Lab Asia, will be introduced in Section II. Then, we will provide detailed descriptions about the interface development, including design principles and implementation solutions (Section III). Finally, we will present a case study illustrating how our framework can be used to support evidence-based urban planning and design (Section IV). The chapter concludes with an outlook and final remarks.

II. Value Lab Asia



Research Education Communication

Figure 2: Value Lab Asia is a central facility for *research*, *education*, and *communication* at FCL.

Value Lab Asia is designed as a collaborative, digitally augmented environment for a wide range of applications, such as participatory urban planning and design, stakeholder communication, information visualization and discovery, remote teaching and conferencing (Anwar et al., 2015). Nowadays, the lab has become a central facility for research, education, and communication at Future Cites Laboratory.

The lab is approximately 12m wide, 16m long and 4m high, and mainly consists of:

- **Video Wall:** The Video Wall is made up of 16 units of Samsung 55" displays in 4x4 grid, resulting in a 33-megapixel display. The wall is approximately 4.9m wide and 2.7m height. The ultra-high resolution display is driven by a backend server with Intel Xeon E5-2643 processor, 128GB DDR3 memory, and four NVIDIA Quadro M6000 units.
- **Multi-Touch Screen:** The multi-touch screen is made up of three units of Samsung 82" displays with customized mount brackets and tempered glass, arranged in 3x1 layout horizontally. The touch functionality is enabled through a PQ Labs G3Plus multi-touch overlay and a Kramer DVI Cat 5 transmitter and receiver for each display.

The video wall and multi-touch screen run on separate computers running Windows 7 system. In addition, the lab is complemented by a number of smaller, mobile multi-touch enabled displays, and a Projection of Reality (PoR) system with a Kinect 2 for gesture detection and four high-resolution projectors for augmented reality applications.

One primary goal for Value Lab Asia is to enable collaboration for researchers and stakeholders from different disciplines. The goal is accomplished by supporting mainly the following functionalities:

- **Viewing:** Both the video wall and multi-touch screen support multiple users viewing at the same time. The free space at the lab can be configured according to different needs, e.g., multiple researchers standing in front of the video wall to facilitate discussions (Figure 2 bottom-left), students sitting in a U-shape so they can all communicate with the lecturer easily (Figure 2 bottom-middle), and all participants facing the touch screen for remote communication (Figure 2 bottom-right).
- **Interacting/exploring:** Multi-user interactions are integrated to support exploring the digital applications, including basic mouse controls, a customized iPad app for volume control and monitor switch, multi-touch interactions on the multi-touch screen, and hand gestures of the PoR system.

III. Singapore Views

On the basis of the physical environment of Value Lab Asia, the CIVAL team is actively developing an interactive visualization platform, named *Singapore Views*, aiming to provide researchers, stakeholders, and the public a digital platform to share and communicate their research progress and outcomes. The platform is developed with careful considerations of the requirements for supporting collaborative visualization in evidence-based urban design. This section summarizes the development goals for each module in the *information visualization reference model* (Card et al., 1999), i.e., input data, design principles, and system implementation.

A. Input Data and Formats

An urban planning and design project takes place within the context that can be summarized as built environment (e.g., buildings, transportation networks), legal environment (e.g., land use, property ownership), and natural environment (e.g., land cover, geology structure) (Schubiger et al., 2017). The environments are usually stored in the following data formats:

- **Vector GIS Formats**: Most legal and natural environments, and partial built environment are organized in vector geographical information system (GIS) formats.

Shapefile is by far the most common vector GIS file format, which contains rich geospatial information that can be categorized as point-based features (e.g., trees, wells), line-based features (e.g., rivers, roads), and polygon-based features (e.g., building footprints, lakes). Besides geospatial information, each item in a shapefile usually has additional attributes, such as name or type. Nowadays, many planners and designers are switching to other types of vector GIS formats, e.g., GeoJSON, KML (Keyhole Markup Language), and OSM (OpenStreetMap).

- **Raster GIS Formats**: Another common GIS formats are raster data type, which represents geography via grid cells with each cell recording a single value.

  Compared with vector GIS data, raster data is more suitable for storing continuously changing values over space, e.g., elevation and heat. Besides, the data is fast and flexible for computer programs, as many programs are designed to do matrix calculation in a fast way. On the other side, it is hard for raster data to preserve topology information, e.g., true shape and size of a built environment, making it hard for raster data to conform to high-quality maps. This requires multiple levels of raster data to be kept at high-resolution. For instance, Google Map shows the entire world at level 0, and detailed streets and buildings at level 21+. Common raster data formats are GeoTIFF, JPEG, PNG, etc.

- **3D Model Formats**: Often the built environments cannot be adequately represented in 2D vector GIS formats, e.g., buildings and bridges. But there are increasing needs to model the planning context with rich information in 3D (Schubiger et al., 2017).

  Planners and designers are usually experienced with applications for 3D models, e.g., 3D Max, Maya, Rhino, AutoCAD, Revit, Blender, SketchUp, and CityEngine. These applications can output 3D models commonly in DXF/DWG, KML, OBJ, DAE, FBX, and CityGML formats, which usually contain 3D geometry information of the models. Taking OBJ for an example, the format stores the position of each vertex, the UV position of each texture coordinate vertex, vertex normals, and the faces that make each polygon defined as a list of vertices, and texture vertices.

These data formats are usually employed to represent static built environments. Nowadays, as the advancement of various sensing technologies, vast amounts of dynamic urban data have been collected, e.g., human mobility, and environmental statistics. These dynamic urban data are usually organized in:

- **Geo Database:** Tabular data stored in a database system is arguably the most common data formats, but also XML or CSV are widely used. The data is organized in a tabular fashion, where each row represents a record, with the corresponding columns represent attributes of the record. The attributes usually comprise spatial (e.g., latitude and longitude) and temporal information as urban data are ‘invariably tagged to space and time’ (Batty, 2013) and may also include 2D or 3D geometric features.

Besides, planner and designers usually generate many **Multimedia** files illustrating their project progress and results, including images in the formats of BMP, JPG, PNG, TIFF, etc., and videos in the formats of AVI, MOV, MP4, etc.

B. Design Principles

It is a nontrivial and challenging task to design an effective user interface, which should meet the collaborative visualization requirements, fit the physical environment of Value Lab Asia, and present the various types of input urban data. A proper visual design is expected to meet the following design principles:

- **Overview + Details:** To present all information in one static view that can satisfy all user requirements is not feasible. The visualization system should follow the “Overview first, zoom and filter, then details on demand” mantra (Shneiderman, 1996). Effective user interactions, such as filtering and selection, need to be integrated in the system.

- **Multi-perspective:** To enable effective collaboration, analysts from different backgrounds demand to probe complex input data from multiple perspectives. Our system should provide multiple views, and establish links between them to present the information in different dimensions.
- **Visual Consistency:** To facilitate multi-perspective analysis, the system should keep visual consistency across different visualization modules. To accomplish it, the design needs to keep consistent view layouts, colour mappings, font styles, and glyphs, etc.
- **In-Place Design:** To achieve better user experience, our system adopts in-place design from two perspectives: 1) The data to be visualized is constrained to mainly Singapore, no more than ASEAN + three region. 2) The interface is targeting for the Value Lab Asia, especially the high-resolution video wall with its intrinsic 4x4 tiling scheme.

After defining the design principles, we formulate a series of visual elements:

- **Colour scheme**: We employ a dark bluish-grey background, as dark color 1) reserves smooth luminosity across different panels, 2) is highly visible with the yellowish FCL-slide template background, and 3) attenuates strong lights on users' eyes in the video wall. The typographies and glyphs are in white.
- **Transparency & blur**: We adopt transparency and blur effects to accomplish focus + overview visualization. A focused object is positioned in the center of the screen with solid color, while overview objects are translucent and blurred. The effect is also applied in between the map view and information panel.
- **Typeface**: We select two types of fonts, Lato and Adelle, for different purposes: the former is a san-serif font for the main and detailed information, while the latter is a slab-serif font for the titles and headings.
- **Layout**: We present a map view over the whole screen, and other information in part of the screen according to the 4x4 tiling scheme, i.e., multiples of one quarter in both horizontal and vertical dimension.

We further follow the user interface design processes (McKay, 2013): 1) to make storyboards, which simulate who are the users, why and how they use Singapore Views; 2) to make static visual mockups for each identified step in the storyboard using the Sketch (https://www.sketchapp.com/); 3) to combine all the mockups as an interactive prototype using the Invision (https://www.invisionapp.com/).

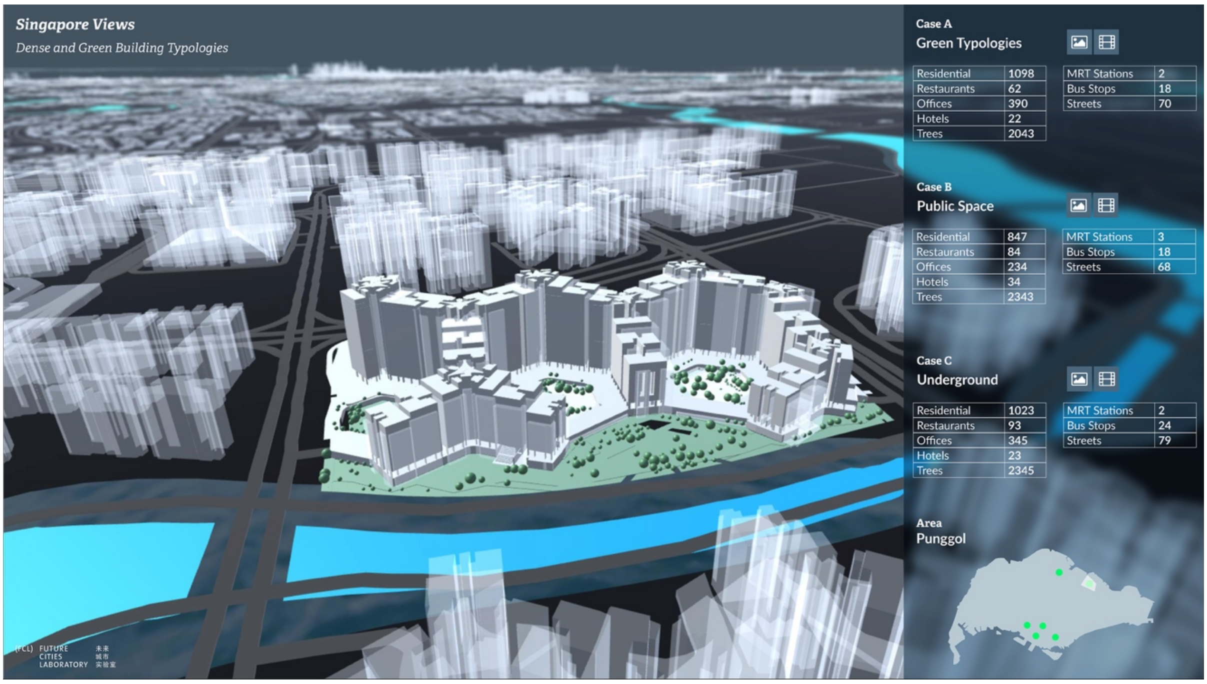


Figure 3: Visual mockup of Singapore Views featuring *Dense and Green Building Typologies* project.

Figure 3 illustrates an exemplary visual mockup of Singapore Views featuring *Dense and Green Building Typologies* project. The mockup mainly consists of the following components:

- **3D Map View**: The mockup is filled with a 3D map view of Singapore to present the spatial information of built environments and dynamic urban data. When users select an object, it will be highlighted and positioned in the center of the screen.
- **Panel**: Besides spatial information, additional statistics are illustrated in a panel covering one quarter width of the screen on the right side. Specifically, a map overview is always presented in the bottom of the panel covering one quarter height of the screen, with current camera position highlighted. In the case of *Dense and Green Building Typologies* project, we present statistics comparing effects of three different design strategies on the highlighted building.
- **Project Title and FCL Logo**: In addition, we show the project title on the top-left corner, and FCL logo on the bottom-left corner. This layout is consistent across different projects, unless specially specified by users.

C. System Implementation

Singapore Views is implemented with the Unity game engine (Unity, 2017) which is used as the underlying technology for processing and rendering. The decision to use Unity as the main development platform is due to: 1) The build-in support for primitives (cubes, spheres, terrain, planes, particles) that are beneficial for data visualization, which can lead to reduced development time; 2) Its straight-forward scene editor and scripting support allow rapid prototyping; 3) Moreover, it supports cross-platform and VR, and has an extensive support for plugins which makes it even more versatile.

Interested readers can refer to our preliminary paper for implementation details (Perhac et al., 2017).

IV. Case Study

A. Study 1: Dense and Green Building Typologies

Singapore Views has been applied to visualize the *Dense and Green Building Typologies* project. The input data includes geographical positions, 3D models, and images and videos about the team's buildings they are studying. All studying buildings are represented as 3D green cubes on the map, with several buildings they have already studied highlighted as yellow dome. Users can further switch to 3D buildings models to explore more details. Additional information is presented on the panel illustrated in Figure 3.

Figure 4: Singapore Views application for Dense and Green Building Typologies, presented by Dr. Michelle Jiang.

The application has been successfully presented to many college students at Value Lab Asia, as shown in Figure 4. The visualization is demonstrated in presentation mode, with camera positions and view options preconfigured. The configurations are switched with a Logitech wireless spotlight held by the presenter, such that the presenter can better interact with the audiences. Feedbacks have been collected from the students, with most of them are positive. Here we list some representative comments: "With the sense of space, statistics is easily shown, unlike traditional forms of data presentation", "Smooth transition of interactive presentation makes it more engaging than powerpoint presentation", "It engages me more during the presentation as I feel more situated in the particular locations".

B. Study 2: Cooling Singapore

A collaboration with the *Cooling Singapore* team led to the development of an interactive visualization that showcases Urban Heat Island (UHI) effects. The visualization uses 3D histogram and 3D density map to represent the UHI data. The input dataset, in CSV format, containing 1M+ records of temperature measurements within the area of Singapore, is spatial and temporal in its nature which led to a spatial division based on record’s latitude and longitude and temporal grouping of records into one hour long time groups. This allowed to get the matrix values for the output 3D density map and 3D histogram, both of which were color-coded in the output form. The color-coding was based on the temperature scale values; lower UHI values were presented by colors on the blue spectrum, higher values were presented by colors on the red spectrum as shown on Figure 5. The panel has been modified to showcase “Current Situation” and “Baseline” temperature readings next to each other as a dynamic picture updated based on the chosen time.

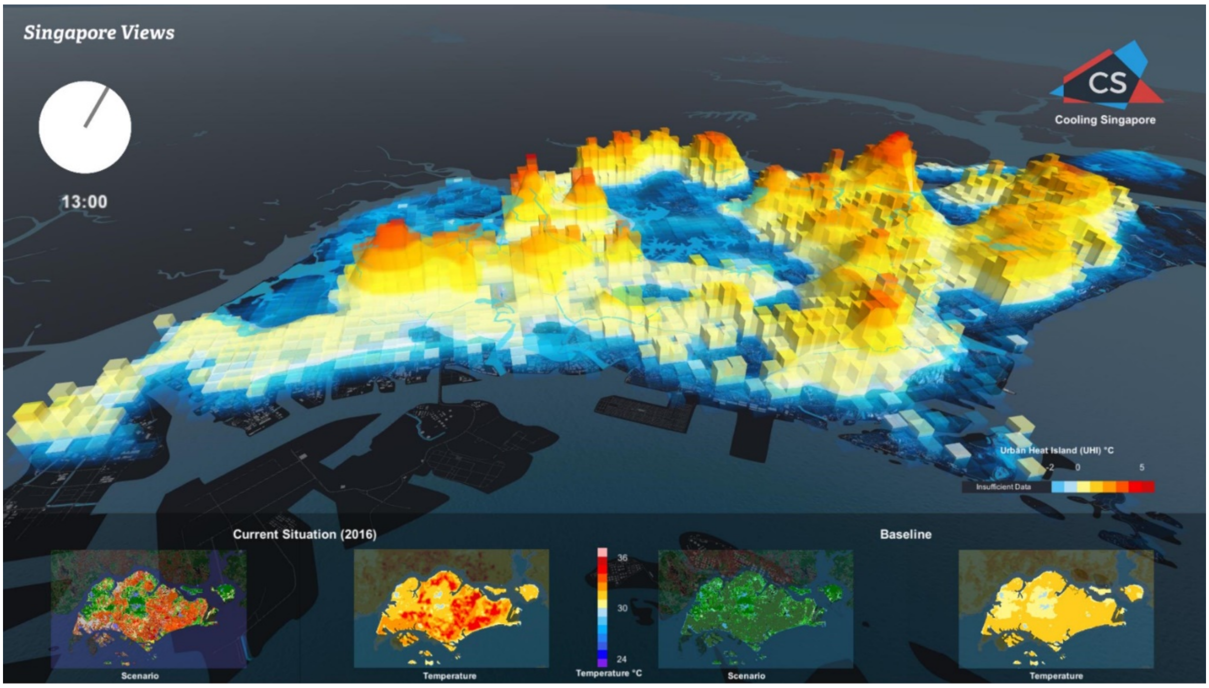


Figure 5: UHI readings produced by Cooling Singapore, visualized by Singapore Views

A video showing the preliminary results of the Cooling Singapore team was presented during the CREATE 10th Anniversary Symposium, December 2017. The video was used to highlight the importance of UHI for the thermal comfort of residents in Singapore also by indicating the areas that are most affected by the UHI. It greatly contributed to the message the Cooling Singapore Team wanted to deliver, namely that a combined effort from many stakeholders is necessary to sustainably reduce the UHI effect.

V. Conclusion and Future Work

Many platforms have been developed for collaborative visualization and analysis, e.g., ManyEyes (Viegas et al., 2007). However, to the best of our knowledge, few of them have been dedicated to supporting collaborations among architects, stakeholders, and the public. In this book chapter, we have introduced the necessity and challenges to develop such a framework. We describe the efforts done in CIVAL, FCL to address such challenges, specifically for the Value Lab Asia which is our main physical environment, and Singapore Views which is our digital environment. The framework has been proved effective in many case studies such as *Cooling Singapore* and *Dense and Green Building Typologies.*

From the development of Singapore Views, we learn that close collaborations can greatly facilitate the development process. The cooperation partners include: 1) domain experts in the fields of urban planning and design who can specify analysis tasks and prepare input data, 2) UX designers who can map the data into visuals and design interactions, and 3) software engineers who can implement the views and interactions.

Nevertheless, our work is still in progress. Besides incorporating more projects and data related to urban planning and design into the framework, we see mainly two venues for future work. First, we plan to integrate more visualization and interaction options in the system, such as VR glasses and hand gestures. This is in line with the prescient visions of extending Value Lab Asia, and built-in support of such functionalities in Unity. Second, we intend to study visual perception differences among architects, planners, and the public. The results can be applied to improve visual designs to fulfil different analytical tasks across multiple domains.

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