Simulation Platform

Highlights 2010-2015

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Simulation Platform

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Foreword

Future Cities Laboratory (FCL) is a major interdisciplinary research project dedicated to producing the knowledge and ideas that cities need to become more sustainable. By bringing together scientists, engineers and architects, FCL aims to develop future-oriented strategies in building technology, urban design, and territorial planning.

One of the challenges of such an ambitious programme is how to deal effectively with the rapidly growing volumes of urban-related data. Within FCL, these tasks are the main responsibility of one research module, the 'Simulation Platform', whose work is described in this special issue of the FCL Magazine. This research module aims to develop new methods for simulating and visualizing the complex processes that shape a modern city, and to help other researchers make the best use of their data.

To fulfill these functions, the Simulation Platform has developed a superb facility – the ValueLab Asia – for capturing and presenting 3-D and other multidimensional data. This provides not only an essential research tool, but also a means for translating research into instruments for practitioners. For example, architects and planners can visualize the changing plumes of heat swirling around buildings as the wind changes, and explore how new designs might affect the city's heat balance. Or they can gain a bird's eye view of the city's traffic flow through street networks, and test how new developments – adding a bus route, for example, or giving motorists real-time information about congestion – would affect traffic patterns. Not surprisingly, the ValueLab Asia attracts a steady stream of visitors from industry, government agencies and other research institutes. In this volume we describe some of the outstanding achievements of the Simulation Platform in increasing the value of urban data for researchers, planners, decision makers and the broader public.

Peter Edwards

Editorial

In 2010 five principal investigators teamed up under the lead of Gerhard Schmitt, the founding director of the Singapore-ETH Centre (SEC), and became the Future City Lab's (FCL) research module "Simulation Platform". The yellow booklet of SEC, which outlines the activities of FCL describes the "Simulation Platform" as the overarching research group, comprising all urban scales from neighbourhood to territorial in its research focus. It has also supported the other research modules for data and software requirements. In addition we have been involved in many of FCL's synergy projects like Addis 2050, Cooler Calmer Singapore, Rochor+ and Tropical Town.

Our research framework follows the logic of transforming urban data into information and later into knowledge. This is accomplished by means of photogrammetry, crowdsourcing, and field surveys. For example our researchers have collected raw data about shape and demeanour of urban phenomena. Data mining and filtering is then applied to the raw data in order to extract meaningful patterns of information from the noise. So far the transformation process can be solved by computational algorithms, yet the very step towards transformation of information into knowledge is beyond the capability of today's computers and artificial intelligence. Furthermore, to help user understanding, our research explored multimodal data representation, visualization, and last but not least stakeholder interaction. Urban planning is regarded as a collaborative enterprise of interdisciplinary (urban planners, scientists, engineers…) and transdisciplinary stakeholders (politicians, researchers, citizens…), where the "Simulation Platform" was interested in how this dialogue can be fostered. A key feature of the ValueLab Asia is the physical space where our research is conducted.

The successful midterm review of 2013 paved the way for FCL's next five year phase (FCL2), and the transition workshop in Spring 2015 highlighted key events within SEC. As a result, the Simulation Platforms continues its research in three distinct paths: The project "BigData-Informed Urban Design" joins methods of information architecture, complexity science and urban planning by using big data approaches to help architects explore the complex nature of cities; "Cyber Civil Infrastructure" tackles the engineering problems of aging urban infrastructure; and the "Collaborative Interactive Visualisation and Analysis Lab" (CIVAL) will advance the ValueLab Asia as well as simulation and visualisation techniques.

The cover – designed by Ludovica von Richthofen – of this FCL Magazine Special Issue features the "Simulation Platform" as a rational in a two-fold metaphor: Where the outer cover articulates the transition from reality to knowledge and the inner cover page tells the digital story of data to information.

Matthias Berger

CONTENT

Operating Simulations

A discussion between Stephen Cairns and Gerhard Schmitt

Stephen Cairns How did the Simulation Platform operate at the Chair of Information Architecture before FCL and to what extent did it develop here in Singapore? The ValueLab Zürich existed already, but what sorts of things changed and varied by being located here in Singapore and over the course of the research of FCL.

Gerhard Schmitt A fundamental issue was certainly our research-based conviction that in architecture and planning, a development in science would have an analogy: next to experiment and theory, simulation will play a major role. In architectural design it is difficult to isolate topics to the degree that they can be solved individually and then would lead to generalizable knowledge. We immediately would recognize the side effects of these isolations. As a consequence, the two major tasks are the simulation on the one hand, and the view of a city as a complex system on the other hand. We can attempt to simulate the city as a complex system, but that is much more difficult than traditional simulation in architecture. Simulation of individual aspects include those of geometry, of future geometry, of future movement of people through this geometry, of energy use, of districts, of entire cities, of transportation flows through cities. Individually, all these simulations have existed before, but not as a whole. To change this was the motivation to build the Simulation Platform.

SC One of the things I observed about some of the tools that were developed in the Simulation Platform was the reaction of people who saw them for the first time. Politicians, government agents or representatives from funding agencies who were shown the tools usually expressed surprise and delight particularly around multiple parameters interacting. That was obviously a conscious part of the Simulation Platform program to start to look at those complex interactions rather than individual components of systems and their behaviors.

GS Yes absolutely. The multitude of parameters that the user or designer can adjust and manipulate during the design process is definitely a great feature of geometry simulation. An example is City Engine, a program written at ETH, and then developed into a spinoff company called Procedural, which now has become a part of ESRI. However, these rule based and parameter adjustment driven form generation programs have little to do with analysis or simulation. The feedback in those programs is primarily three-dimensional geometry. The real challenge we try to confront with the Simulation Platform is to comprehend the interdependency between this geometry and the urban stocks and flows that we observe in the Future Cities project.

SC I recall from the very beginning one of the great challenges was really the question of data, given that the more refined the data the more sophisticated the interactions could be. What were your reflections in retrospect on the question of data? How determining was that in the end in relation to your original expectations? I know there were many creative ways in which researchers got around some of those problems. Does that remain still a determining question with regards to the Simulation Platform project?

GS Data is a most challenging topic because it is an area of incredibly fast change and growth. At the beginning of the Future Cities Laboratory planning phase in 2007, it was still seen as a field where you collect data specifically for a purpose. You saved the data, you stored them, you protected them and then you could use them. It was like buying ingredients for cooking: you know exactly what you need: flour, salt, sugar, but you do not buy the entire content of the store and then figure out how to make a meal out of this.

This has definitely changed with the technological ability to store and process massive data - an abundance of data coming from smart phones, sensors and other devices, totally overwhelming us in terms of the amount compared to all the selectively acquired data of the past. This growth happened during the course of the first years of the Simulation Platform. Consequently, we could move from data collection and acquisition towards data analytics, making sense of the massive amount of data – often totally without specific purpose, without direction, without meaning, to say it in a drastic way. The two directions - specific and pre-specific, coexist now. The big data part is swelling every year: doubling, tripling, quadrupling, and this will continue, whereas the selective data part does not grow much; but the protection around these specific data is still intact. It is a quite curious development, as we observe the fossilization of specific data in highly protected silos.

In the first months and years of the Simulation Platform the situation was reflected in our discussions with the Land Transport Authority and other agencies in order to access historic data. Now the free flowing data has become more available, but it is much harder to extract something meaningful with regards to design out of big data, because you have to literally search the needle in the data haystack.

SC I imagine that both of these threads will continue to find work for the Simulation Platform, both ends of data but each one requires different set of skills to make sense of and to make useful in the context of urban planning and urban development and so on.

GS: Both of them also represent a different attitude towards architecture and design. I can see this reflected in the actual development of new cities and new buildings. It has almost become a traditional versus new world approach. Yet in regards to design, the new data world is really unexplored.

SC: Could you identify an example of a kind of old data and new data of a building or attitude of a city?

GS: Yes. An example for the traditional use of specific data is a building that has been defined and optimized for one purpose. It has been built with a predefined set of knowledge. This knowledge is derived from information, and the information is derived from data. Everything is nicely in order, the details are solved and the building is functioning according to specification. It is like a machine that you design by predefining all the parts and their interaction. You are in control. This controlled architecture we see a lot in all parts of the world: very clean (when new), specified, minimized construction costs, with clear indications how much it will bring financially over the next 10, 20, 15, 100 years and how long the primary, the secondary and the tertiary structure will last.

The opposite example will be what emerges from the work of Brillembourg & Klumpner in South America and in South Africa. The Chair of Information Architecture is involved through programming human computer interface design Apps. For the Shack project in South Africa we will be able to take any data flowing in from any source, analyze the data, and reflect the findings back

Fig. 01-02 Stephen Cairns, Gerhard Schmitt

to the people in the neighborhood using those Apps. This will be a basis for the inhabitants to move or expand the buildings and to see the effect in terms of space, visibility, circulation, and safety in real time. They can interactively pre-compute their environment, informed by data streams from which the Apps extract the necessary information to support the design process. The approach would also be helpful for the disaster stricken areas of the world, such as Nepal, to avoid planning mistakes that might occur under pressure.

SC: Both paradigms are part of the story, part of the future narrative with regard to data.

GS: Right. In between the two paradigms stands the high-density mixed-use city that will be the habitat for a large percentage of the human population. Its design and operation requires a combination of the 2 approaches. There will be a long-term structural aspect of urban knowledge and urban information. The associated time series data on history, geology and material behavior have to be very, very precise and stable – for as long as 50 or 100 years. They form a robust, long-term knowledge structure, in analogy to the primary structure of the building. But everything that happens within those stable knowledge structures can be derived from big data approaches.

SC: What do you think that means then for big data? Obviously this question is partially determined by the available technologies most significantly being the smart phone. I presume that there would still be then room for other forms of field work where you have to design particular methods and approaches to capture data which is not gathered through mobile phones for example. In the area of data capture, what sorts of innovation do you think in addition to mobile phone data is looming around?

GS: In terms of data capture, researchers in the Simulation Platform have performed serious groundwork already. Take the example of Unmanned Aerial Vehicles or drones. Using drones in 2015 is mainstream, but it was quite new when Armin Grün with his group started in 2010. The collection of data for the simulation and falsification work of Ian Smith will become much more sophisticated in the next years. I think the biggest change will evolve from the interaction with the other FCL research modules and with the ETH, as well as with European research projects. The reason is the long-term strategic vision of Europe on the basis of a large and extremely well educated research community.

Another new area is the systematic quantification and mapping of the psychological impact of architecture and urban environments on people. It can directly be measured, taking into consideration the cultural background, the time of day and year, along with many kinds of environmental factors. Right now, our researchers still have to wear heavy backpacks and clumsy instrument crowns, consisting of 13 GoPro cameras, along with a multitude of sensors. They directly record what you see and to a degree what you feel and how your metabolism is changed by what you see in this urban environment. The equipment is now very heavy, but I am sure most of it will be in smart phones very soon. Our researcher's findings about the human experience of architecture and the city will make a big difference, including the direct relation to health and safety. People will wear on their body gadgets to encourage walking. They will receive advice for the most walkable parts of the city, and advice where not to go and why, based on previous experiences of other citizens. All this will produce new big data sets.

SC: Obviously then one of the things that the Responsive City tries in a way to get around or to negotiate is the question of privacy. Because the idea of the calibrated self and people voluntarily offering data about themselves can very quickly flip to scenarios whereby centralized agencies gather more and more information about populations and become more and more adept to manipulating and managing those populations. What do you think are the main challenges on the promise and threats of big data?

GS: That is really a serious challenge, but I am sure it is solvable. We must learn that data from the urban stocks and flows are surrounding us, just like bacteria or ants, but surprisingly more durable. We have to somehow learn to domesticate those data and put them to our use, rather than the other way round. In the long run, it will not be meaningful to have a centrally administered data repository for all persons and things. Instead, I hope for the control and use of data by the individual.

SC: So developing practices of data literacy or practices of using data becomes more and more important for all of us rather than ...

GS: Yes. Just to say one more thing. The Simulation Platform covers 3 big areas. The first is data acquisition, becoming dynamic and fast developing. The second area is information modeling with behavior simulation and interactive modeling. Information modeling, behavior simulation and interactive modeling are relatively mature and stable, and become more precise as we make use of Big Data. I am not saying that these simulations are entirely developed and stable, but they are quite useful already for other research modules in the Future Cities Laboratory. They draw from the data that are produced during data acquisition. The third area is dynamic visualization. To understand simulations we must also accept new communication channels. Visualization is crucial for communication and understanding because of the brain's graphical processing capacity. Yet preparing effective simulations and dynamic visualizations takes much more time than raw data collection.

SC: What struck me about the Simulation Platform is it began to be a kind of common medium and a common space but especially common media for different projects that were being conducted in FCL. So people with the background in sociology for example or landscape architecture or maybe architectural conservation came to explore ways of managing data and having data and visualizing data. I recall that was part of the vision for the platform. Could you maybe reflect a little bit more on the way in which different disciplines worked together or on the challenges for that trans-disciplinary conversation around the goals of providing better pathways for the cooperation in the future.

GS: This is indeed a continuing challenge because each discipline exists with its own view on data and simulations - and we cannot request from those researchers to learn the Simulation Platform visual language. That will most likely not change in the future. We therefore develop the middleware LUCI that makes it much easier to exchange data and information between the different modules. Using LUCI, more module applications will be able to talk to each other and access the common database.

SC: I've also noticed that one of the areas in which the Simulation Platform has invested in is it's interface design. That's incredibly valuable particularly to encourage people who don't normally interact with data in the same way and to reduce the threshold to entering into that world a little bit. Will you continue to have more investments in design and interface design and further experiments in that area?

GS: Yes, massively. Let me give you two examples. The first one – designing power grid structures in Africa - is based on the work of our future Principal Investigator Markus Schläpfer from MIT. Based on the cell phone usage in Senegal he discovered and classified the settlement or urban infrastructure in those places of the country that nobody had reliably mapped before. As a matter of fact, the presence of humans using cell phones will determine where power lines, where streets, where infrastructure will be constructed, rather than the other way around, as it often is today. This is a direct use of data collection leading to data visualization, which in turn is superimposed on the GIS model of the country . The simple to use, yet sophisticated graphical interface will bring life to the GIS models and show where villages or where emerging cities and infrastructure could develop.

The other example for the power of visualization and human machine interaction is just one image - and one can develop an entire story out of this one image. This is the one you chose for the first page of the responsive cities proposal.

SC: With Diana interacting?

GS: Yes. Almost everything is in that image. It is an abstracted map of Ethiopia, superimposing bright data points representing cities and settlements. It is interactive: you can communicate and design directly through the interface on the large touch screen - by using sliders representing time. Or you place power generators from hydro to wind to photovoltaic precisely on the map, then connect it to the grid and see the effect on the entire network. In the still image we discuss we can see the finger and the hand interacting with the touch sensitive screen. What is not shown is the underlying database, or the names of the persons who actually developed the software in the framework of the Addis 2050 project: Dirk Hebel, Eva Friedrich, Matthias Berger, and others. It is now also connected to Diana Alvarez because she is the one interacting with it. It shows the importance of the interface.

SC: I agree that it is a very powerful provocative image. It's a very beautiful image that suggests the power of data is at your fingertips; in this sense, it is a very personal and intimate interaction with big data. This fingertip relationship suggests a sensory relationship between an individual and the data. Again coming back to the question of security, the flip side of that intimacy is the vast quantity of data. How do we secure and sustain the positive implications of that image rather than succumbing to the negatives of vast amounts of data in the hands of very few people?

GS: This is difficult to answer, and your observation before is absolutely right. The image suggests that the future is at your fingertips: it's easy. This is structured and perhaps positivist thinking: you just do something and you will solve all problems.

Therefore, the sequel to an image of this type will be that many people work with new interfaces with information objects on the screen at the same time: As citizen design scientists who interact more consciously with the complexity of the projects. In the sequel to this image, citizens will interact directly with representations of urban stocks and flows. This provides a better and more accurate, but also more complex representation of the city than just one aspect, such as electricity.

But you are absolutely correct in your observation: For the protection of the individual contribution and also of individual measurements, it will be necessary to domesticate those data and individualize their control. Because in the long run, it might be too complex to have all data from the Internet of People and the Internet of Things stored with central control, excluding the control of the individuals who contributed the data in the first place. There are a few exceptions, such as the central storage of urban stocks and flows data: they must be transparent for review to support understanding, planning, design and management of the city by all citizens.

SC: The other images I've seen also from a Simulation Platform suggest a much more contested data field. These images show different people pulling at the data from different positions, different stakeholder positions and so on. More people are around the table and for me that's when the positioning the design of the data, the calibration of the data all that backend work that gets done to support a higher quality discussion and often the input stations they become super interesting and probably a stronger image of a future has been practiced then the single person interacting with the screen.

GS: Right.

SC: You can have the last word.

GS: I am thankful for this discussion. It is a necessary foundation for the next level of citizen supported urban design. To define this level will be the challenge of the BigData informed Urban Design project. At the end of the project in 2020, we will have the next generation image, showing the interaction of citizens with Big Data to improve their habitat.

Fig. 03: Members of the FCL Research Module Simulation Platform

Image Credits Fig. 01-03: FCL

Cooler Calmer Singapore

Towards comfortable tropical urban environments

Matthias Berger, Peter Buš, Verina Cristie, Ashwani Kumar, Jonas Lauener

The research project Cooler Calmer Singapore investigates the urban climate in dependency of anthropogenic and environmental characteristics in the city of Singapore. One way of understanding local phenomena is to monitor the weather and record time-lapse videos. Several modelling and simulation approaches have also been developed to find strategies and guidelines to improve urban spatial conditions within the high-density tropical city, which could reduce temperature and noise levels. Such an improvement can positively influence secondary effects as well: health, liveability, air pollution, energy consumption and related costs. We addressed the problem of a heat and noise pollution through case studies in selected areas of Singapore. In the last showcase, simulation results for traffic's heat and noise are fed into a digital interactive environment that can serve as information base for further urban planning decisions or in the policy making processes.

Fig. 01 View from I-cube building towards south-east; one frame every 8 minutes

Introduction and Motivation

Imagine we could make Singapore 4°C cooler – how would it feel? What needs to be changed in the built environment and in urban policies to make this change happen? Which scientific knowledge is missing to better model & simulate the urban microclimate? What is the relationship between heat and noise emissions? Those ideas have been developed by Prof Gerhard Schmitt and Dr Matthias Berger in the early years of FCL, and even so 4°C lower ambient temperature might sound like dreaming in the first place, the idea took off and became a major component of Singapore's research agenda on land and liveability. Together with our colleagues from RP5 of TUM CREATE under Prof Alois Knoll and Dr Heiko Aydt we decided to launch the project independent of funding support from the L2 NIC grant call in 2013.

Singapore as a city state is a unique place where aggregated data on national energy consumption in different sectors corresponds directly to the anthropogenic heat emissions over the course of the year. Average values of consumption can furthermore be combined with diurnal profiles in order to compare the time dependency of anthropogenic and insolation (incoming solar radiation), to learn about the relative magnitude of the man-made heat contribution. Two sectors have been chosen for the investigation: the first was traffic, since its direct energy consumption of over 20% of the total together with the ubiquitous noise would be a perfect target for a comparison to electric vehicles (less noise & heat) and link us with TUM CREATE; the second was the built environment, which has rather small heat emissions of about 5%, but contributes largely through geometric shape, density and structure to the urban heat island, which we want to mitigate.

Weather Time Lapse

Studying the second chosen sector of buildings, we originally planned to combine high spatial resolution measurements of wind speed etc. with many sensors at a building's façade or on the roof over a period of one to two weeks with computational fluid dynamic (CFD) simulations. In parallel we would install our weather time lapse setup on the roof (the same or approximately) to contrast the measurements with the prevailing local weather conditions (Fig. 02). Where would clouds form, where does rainfall start and how does it propagate? What where the wind directions on different altitudes? From the videos we obtained even the diurnal movement of the planetary boundary layer (Fig. 01).

The implementation of the weather time lapse project had several hardware and software challenges. For the camera, we used the Canon EOS M (a shutterless DSLR) equipped with a F2.8/8mm fisheye lens and customized firmware. The obvious solution of using a GoPro was giving unsatisfactory results in early tests we conducted due to low luminous sensitivity during night time. Based on one picture per minute in variable exposure and shutter time with customized firmware either a 30fps or a 60fps video can be compiled. With the latest SD memory cards up to two weeks of observation can be captured. Remote control and data transmission by Wi-Fi or 4G was out of scope, because the setup running for two weeks would produce 5 MByte per Raw image x 60 (minutes) x 24 (hours) x 14 (days) x 3 (cameras) = over 300 GByte. Each camera is mounted on a tripod, has a weather-proof casing and can run independently from the user. We record a 120° field of view with a single camera in 4k final video resolution; a setup of three cameras to record the full 360° plus a weather station have been built (Fig. 02 and 03).

On the software side we created a dialogue which pre-renders the data overlay and produced a 3x4k video. The original intend was to implement an interactive visualization, where the user can manually adjust timing and parameters to be visualized (wind speed, direction, rain fall, luminosity, temperature, and humidity). However, the processor load for three 4k videos in one could not be handles by any software.

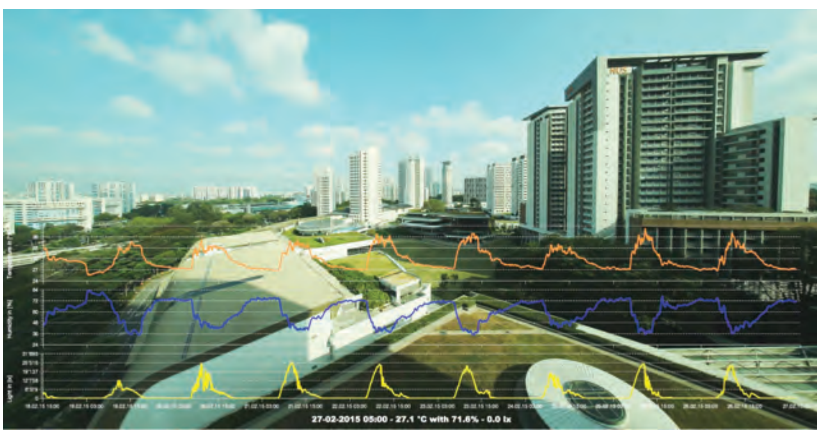

Fig. 02 Early test case: weather time lapse video in a time period of two weeks shows the urban environment of the CREATE campus and neighboring surroundings in a fish-eye view and stores information about the current temperature, the light level and the humidity. The observer has overall visual and numerical data and information about the measured weather conditions of each day in a selected time horizon as one continuous record.

Fig. 03 Final setup of weather time lapse cameras and weather station on the rooftop of the I-Cube building at NUS campus

Urban Traffic's Heat

No doubt, heat and noise from traffic are directly and negatively affecting the comfort and quality in urban areas. Architects, urban planners, engineers and governmental organizations are trying to capture the necessity of urban transport into the planning, design, and overall decision making processes in order to setup guidelines to improve public urban space. The research project Cooler Calmer Singapore mostly deals with anthropogenic or waste heat from traffic. The distribution of heat from vehicles and dispersion of heat from the vehicles within the direct environment are studied by simulating the micro climatic conditions in two case studies for Singapore, which have been introduced in the FCL Magazine's 3rd issue (Berger and Aydt 2015). The former article focused on the engineering and computational aspects of the problem, whereas now we shift our attention towards modelling, interaction, stakeholders and what we call the simulation-design-loop (Fig. 04).

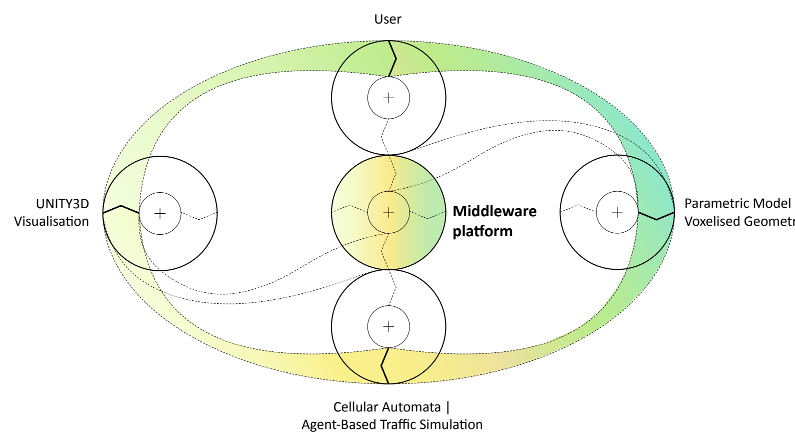

Fig. 04 The workflow of an iterative simulation-design loop process. The user is capable of modifying the geometry of the environment in a parametric model and send the spatial data sets for the heat simulation by means of the middleware platform. The simulation is visualised in the UNITY3D and the visualisation results consequently influence the user decision to remodel urban environment if necessary. The process is based on the pseudo-real time data exchange.

The results of the cellular automata based simulation are a function of input to our visualization to observe yields visual and understandable information about heat and thus outdoor thermal comfort within the investigated areas. Understanding the traffic's urban heat emissions as a significant issue in the tropical cities would serve as a base for further implementation during the planning processes in terms of improvement of the urban environment.

A case study of a specific simulation scenario has been created in order to observe simulation design loop process with the visual outcomes. As such, a selected part of Singapore has been considered into the framework of the simulation process, namely part of the Ayer Rajah Expressway (AYE) in Singapore (Fig. 05).

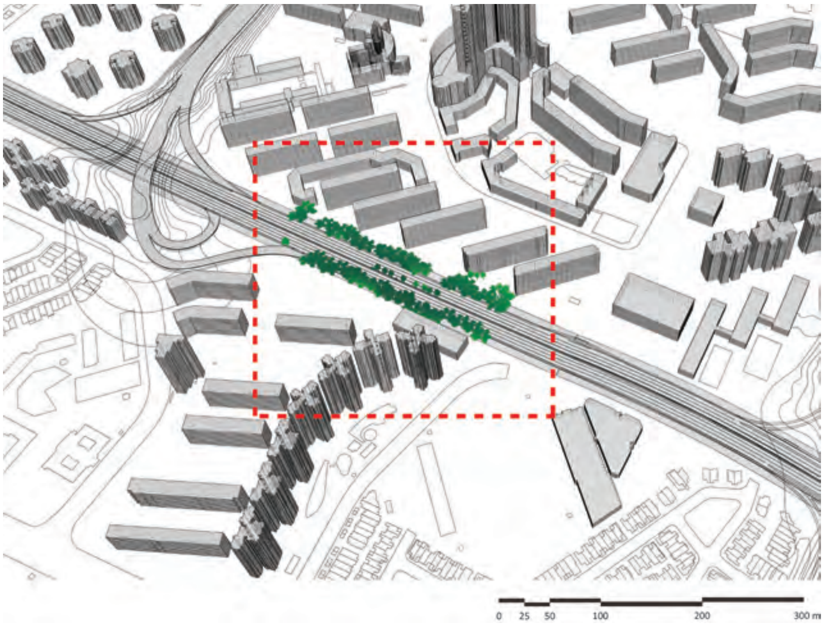

Fig. 05 An axonometric diagram of the investigated urban area of the Ayer Rajah Expressway (AYE) in Singapore, 1°18′44.0″N 103°45′44.8″E

Middleware Platform and Parametric Model

In order to make the planning and decision making process faster and more convenient the parametric model has been considered as a middleware platform between 3D model, simulation and visualization, controlled by the user. The environmental (spatial) information has been integrated into a CAD parametric modelling interface with direct and interactive control as a full customized modelling environment (Fig. 06). The middleware is capable to inform the simulation inputs and serves as a main data communication channel between the particular parts of the whole simulation process (Fig. 07). As such, the user is able to modify various geometric parameters in the CAD urban model established in Rhinoceros/Grasshopper platform in order to obtain different spatial scenarios for further simulation process (Fig. 08). Rhinoceros as a modelling CAD application and together with Grasshopper as a visual programming tool allow the user to implement various parameters into the model and keep the modelling history still accessible during the whole modelling process (Fig. 09 and 10).

Simulation of the Traffic Heat Distribution

The overall simulation itself is a custom based process developed by means the Python language as an external source, modelled by Wagner et al. (2015) with the TUM CREATE team in Singapore. It consists of an agent based traffic simulation and physical simulation of the heat distribution according to a vehicle scale. After simulation's run, the results are sent into the visualization software Unity3D where they are animated in an interactive way. The traffic's heat distribution is modelled by means of cellular automata representation (CA) as an appropriate simplification of the dynamic urban phenomena. 3D cellular automata are used as well as an appropriate visual representational form taking into account the spatial and physical conditions of the selected area. In that way CA are capable to simulate the heat distribution through the air in a higher resolution than done by CFD.

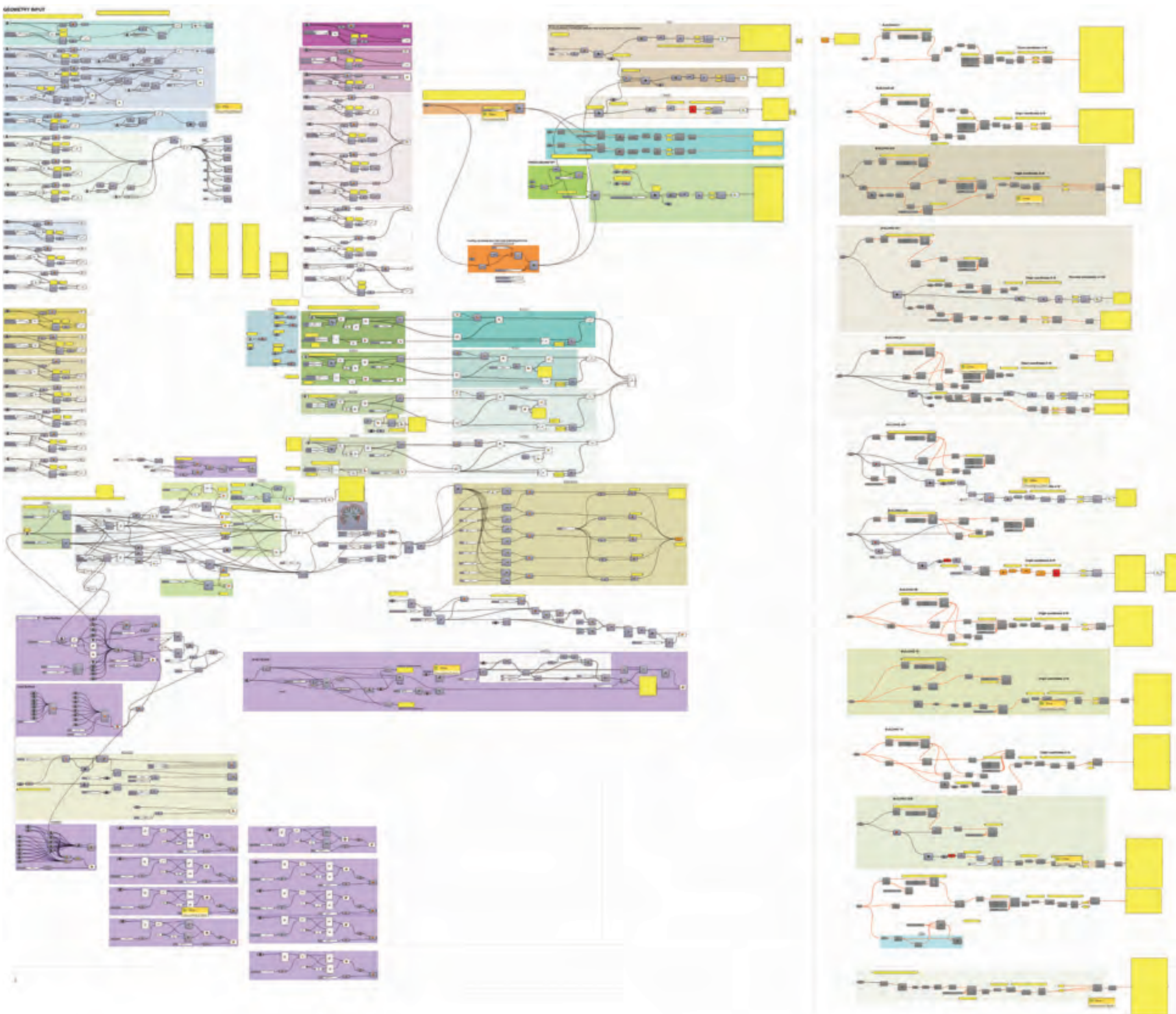

Fig. 06 The visual programming interface - Grasshopper definition of the middleware platform. Parametric geometry setup for the buildings, roads, tree library and voxelisation algorithm. The output from the middleware is input for the cellular automata traffic heat simulation.

Fig. 07 Definition of the routing and road network in terms of XML hierarchy in Grasshopper. The XML files define the traffic relations within the investigated environment. Later, the datasets serve as input for the agent-based model developed in the SEMSim application by TUM CREATE team.

Fig. 08 User interaction with the 3D model and middleware platform in the ValueLab Asia on touch screens.

Fig. 09 The investigated part of the Ayer Rajah Expressway (AYE). The parametric model allows users to modify parameters via a control panel directly within Rhinoceros' graphical user interface.

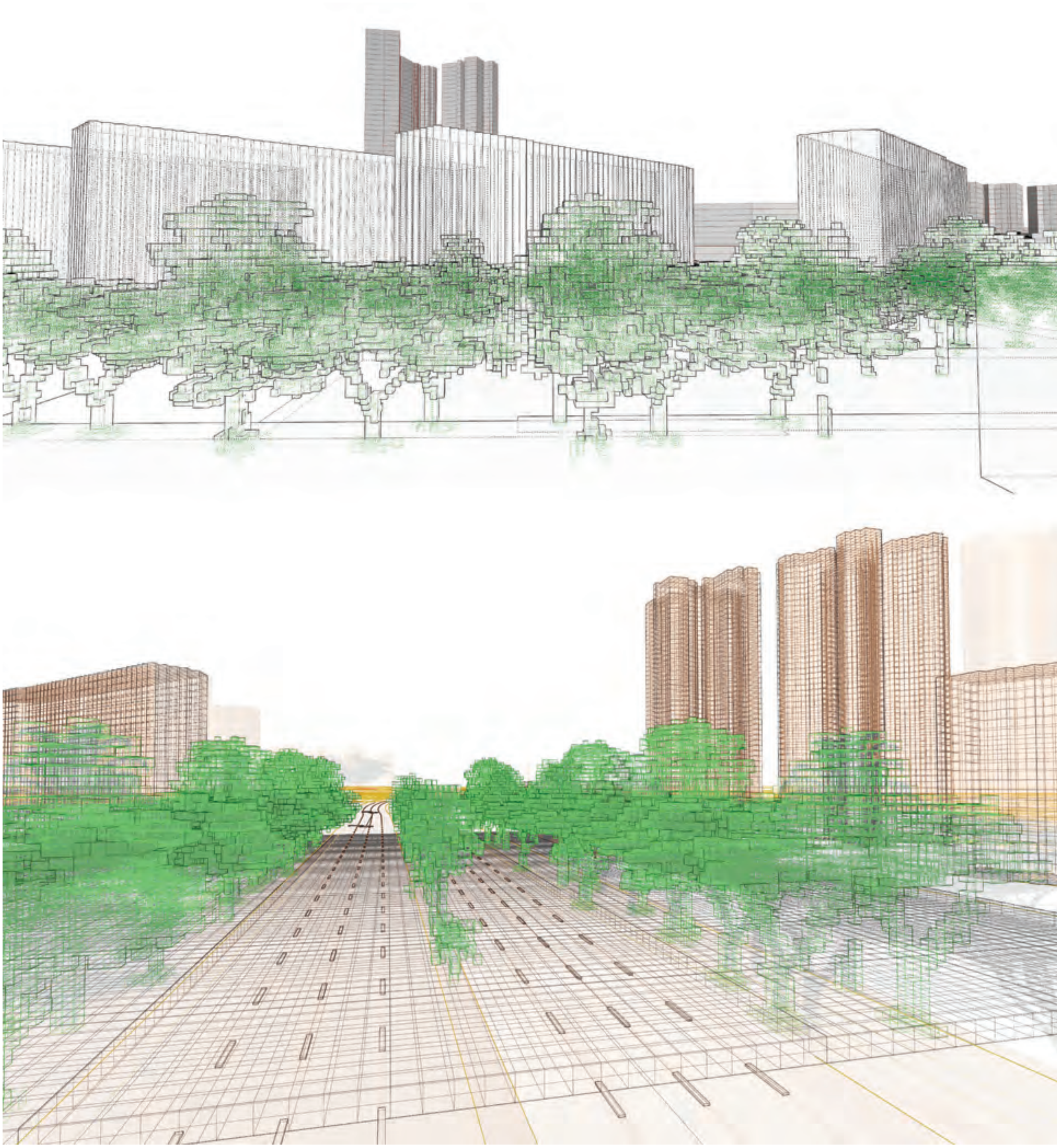

Fig. 10 The investigated environment after the voxelisation process. Voxels and its spatial attributes are used for further physical 3D cellular automata simulation of the anthropogenic waste heat.

Visualisation in UNITY3D

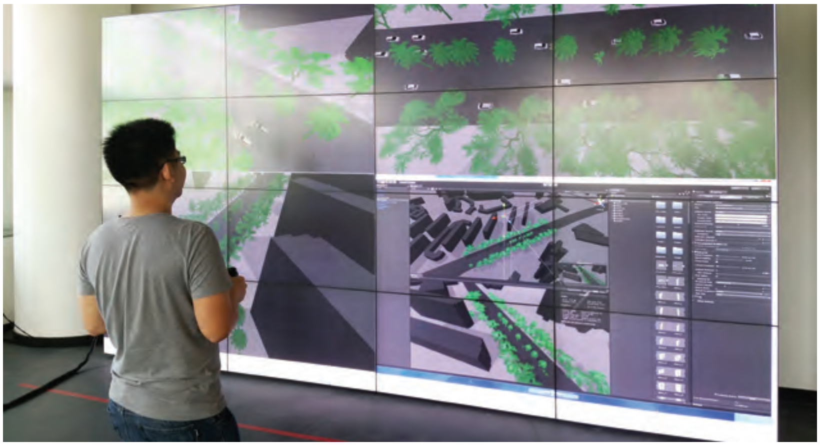

Fig. 11 Urban planners and other stakeholders could now explore the investigated site and find their specific point of interest using a Nintendo Wii game controller. Multiple views enhance the immersive experience and give a more complete picture of the overall landscape.

We use the technology of a game engine, namely Unity3D to visualize heat data in the simulation space, similarly as Stone et al. (2014). With a game engine it is possible to build the virtual urban environments as several studies have shown (Indraprastha and Shinozaki 2008, 2009). Unity3D provides a built-in 3D world system with a configurable camera and rendering system. It could run across many operating platforms and devices without requiring a license for playback. We directly import buildings, roads, and tree models from Rhinoceros. The user is able to move around to find particular points of interest or to have an overview of the whole simulation space and observe it throughout the simulation period of time (Fig. 11). A time slider is implemented so that the user will be able to move back and forth in time to understand the dispersion of heat from vehicles.

In the preliminary version, we choose to visualize temperature data points in 3D space with cubes as the most straightforward representation of the cellular automata. The volume of the cubes represents the volume of air simulated as a cell, and the color of the cubes indicates the air temperature (Fig. 12). As the amount of data is huge, occlusion is unavoidable. To overcome this, we choose to only animate cubes with temperature above ambient. A filter allows users to display only certain range of temperature cubes, and the color range can be selected accordingly. In order to have a complete overview, we also choose to visualize the temperature over many screens. Each screen has its own respective viewing angle. Top, bottom, left, right, front, and back are the commonly used views, but user can also save their own preset angles. Temperature view in the XY plane, XZ plane, or YZ plane are also implemented to overcome the issue of occlusion. Plain color without texture is used for buildings, roads, trees, and vehicle elements, as the focus is heat. Information about vehicle traffic and the simulation site are also shown such that the user can correlate the temperature seen with the initial parameters.

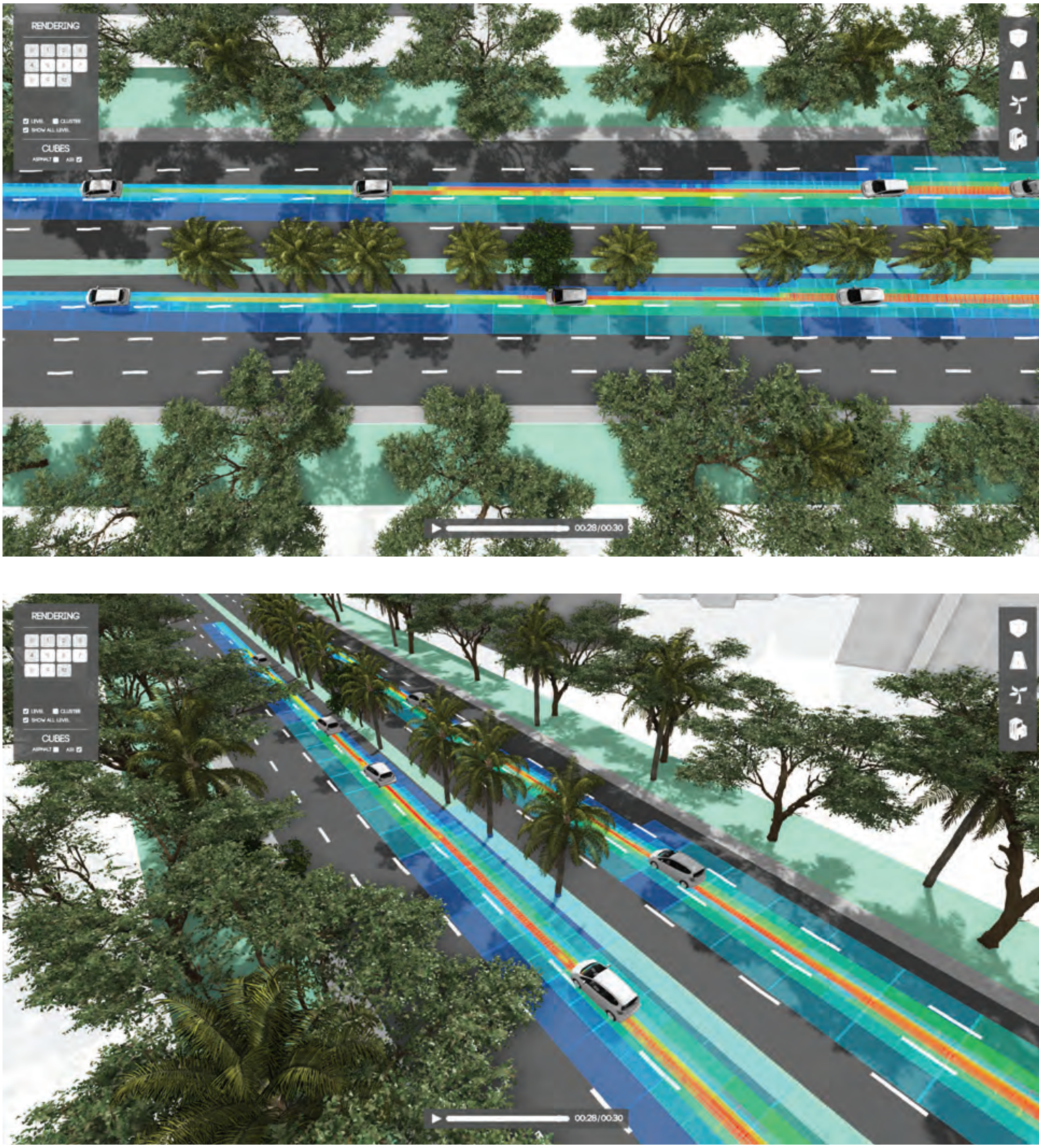

Fig. 12 Heat distribution based on cellular automata is visualized using temperature cubes. Users are allowed to set the value and color of the maximum and minimum temperature they want to see. Play/pause slider bar allows users to see the movement of the heat.

Open simulation framework and towards outdoor sound propagation

The workflow framework of the Rhinoceros/Grasshopper middleware platform, simulation and Unity3D interactive visualization have been established as scalable and extendable modelling, simulation and visualization tools based on a pseudo real time dataflow between particular applications. The visual simulation results invite the user to further manipulations and setup of geometry parameters within the middleware system in a parametric model when necessary. The open and flexible framework of the middleware system allows the urban planners to integrate various geometric characteristics of the investigated urban environment into the modelling process, and to send the datasets into various formats for further physical simulation. By means of Unity3D, it is possible to observe simulation results in a visual and interactive way. The integration of the Unity3D into the computer aided design connected with the simulation process as an interactive visualization tool makes the whole process more convenient and visually understandable. Current work has been focused on a traffic heat distribution within the selected urban environment in Singapore and its visualization in Unity3D system. The further research will continue in the field of the outdoor sound propagation and address traffic noise (Fig. 13). The integration of the traffic heat distribution and outdoor noise into one interactive modelling and visualization environment shall yield more complex insight into the characteristics of the tropical urban environments in terms of their liveability and comfort improvement. Considering the visual outcomes in a simulation model as a decision making tool it will be possible to assess the environmental and spatial conditions of the investigated environment. From observed results, planners or stakeholders will be able to involve more complex properties of the urban areas in the framework of planning and decision processes.

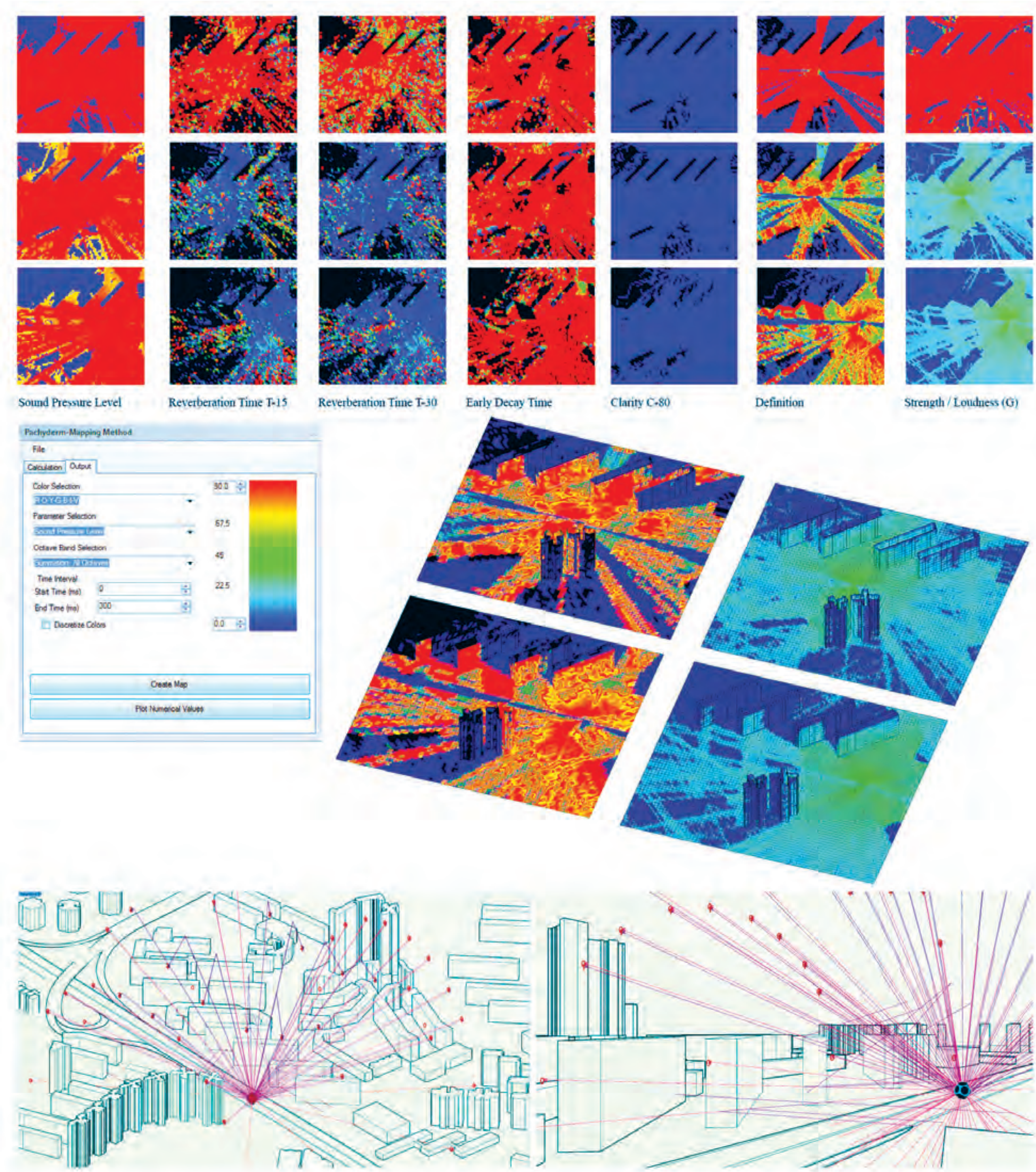

Fig. 13 Preliminary visual interpretation of the outdoor sound propagation in the investigated urban area. The diagrams represent the sound ray distribution in a coloured surface map of the environment when the sound source is moving.

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www.mcneel.com

www.perspectivesketch.com/pachyderm

Image Credits

Fig. 01-13: Research Module Simulation Platform

The Tool Library

One-click reconfiguration for the Value Lab

Bernhard Klein

Many contemporary research tasks require complex decision making and interdisciplinary collaboration among different groups of experts and stakeholders. Nowhere is this more apparent than in the planning and design of future cities - rapidly growing cities where the development and allocation of energy, housing, transportation and other scarce resources requires the active participation of architects, urban planners, government stakeholders and private citizens.

We introduce the ValueLab Asia as a model for collaborative planning and value creation, and show how a multi-screen display management framework called the Tool Library integrates the laboratory's physical and software infrastructure with the planning process. Recent advances in display technology have created new opportunities for participatory urban planning, e.g. touch screens enable direct screen interactions and high-resolution video walls offer human-scale scenario visualizations. However seamless integration of these display technologies into the planning process remains an issue. Challenges such as lengthy setup of urban simulation environments and their reconfiguration require a solution.

The Origins

The Singapore-ETH Centre's Future Cities Laboratory commissioned the development of the ValueLab Asia, a research space designed to remove barriers and promote an environment that encourages people from different backgrounds to work together to dream, design and build future cities. The Value Lab consists of a 4.9 m x 2.7 m high resolution video wall complemented by three 82" multi-touch displays on the side, four 3D scanning devices, video projectors and the Tandberg video conference system. The video wall is composed of 16 Samsung 55" displays powered by two industrial strength graphics processors while the touch screens are equipped with PQ Labs multitouch overlays that let users to work with content directly and interactively. Touch screens enable direct screen interactions and high resolution video walls offer human-scale scenario visualizations. Both the video wall and the multi-touch displays run on separate desktop computers running Windows 7.

Fig. 01 Configuration of workshop sessions. The left part of the image shows the user interface of the drag-and-drop editor and the right part an example workshop web page generated by the editor.

Together, the entire ValueLab Asia system forms a simulation pipeline that enables urban data acquisition, interactive modeling, behavioral simulations and urban visualization. Since developed research tools and content is typically stored on privately owned computers and storage devices, there was no convenient way for researchers to share or build on the work of others, or access media, content and tools developed by their colleagues. To encourage interactions between projects, a commonly accessible repository for tool archiving and sharing was urgently needed.

This was the starting point for the development of the Tool Library. The Tool Library is a web based content management system in the ValueLab Asia that give all users, regardless of their level of technical expertise, access to complex modelling and visualization tools developed at the laboratory without having to go through complicated configuration processes. The content manager hereby enables the user to upload tools, models and data and their corresponding meta data to the cloud and categorize it. Tools are essentially research products. They range from basic presentations and videos to advanced web or desktop based simulations and data visualizations. The file type determines how the file will be handled by the ValueLab Asia computer system e.g. a file of type URL will be opened in a web browser, a PDF file will be opened by a portable document format reader while a java application will be opened by running a java executable. Once a tool is uploaded to the Tool Library, they can be sorted into organisational or event groups. Users can create their own groups around a research theme e.g. urban transportation or special groups for specific events e.g. Transition workshop of the Simulation Platform. Individual researchers can log into the Tool Library, add any tool in the library that fits their requirements and explore different event groups or tools of their colleagues, at their convenience.

Creating coordinated multi view perspectives

Setting up design workshops is a complex and lengthy task as the tools must be individually found on the hard drive, correctly configured and started on the respective screens. Even worse, this process has to be repeated whenever the project progress requires a change in the tools support moving from modelling to simulation and finally to visualisation tools. Due to this cumbersome interaction with the multi-screen environment it is mostly used for presentations and demonstrations.

This situation has not been satisfactory and has led to the extension of the Tool Library with an advanced display management system (Tool Library) for multi-screen environments that gives researchers the ability to start selected applications on specific screens or the video wall. By this, they are able to setup related urban planning tools on the touch wall or complementary views on the video wall to better compare different solutions or measures (Fig. 03).

Fig. 02 Simple drag-and-drop editor to configure complementary views on the video wall.

The software architecture of the Tool Library (shown in Fig. 02) consists of three main parts apart from the content management component: A one-click remote control to launch pre-planned screen configurations or exchange individual tools on the respective screen, a service manager to start applications on the touch wall and computational services on the backend server, and virtual display manager to handle predefined tile layouts on the video wall and launch individual visualisation tools.

Researchers can then use the remote tool launcher (which runs on an iPad or similar tablet device) to search for uploaded tools and launch them on specified screens in the ValueLab Asia. The remote tool launcher lets users easily integrate these tools into their workflow with minimal disruption. Commands are issued from the tool launcher to the Tool Library server using Application Programming Interfaces (APIs), centrally managed by the Tool Library server running on the Ruby on Rails web framework. Once issued, commands are stored in a queue which the service manager polls at regular intervals. The service manager runs silently in the background and polls the Tool Library server at one second intervals. If it detects that the remote launcher has sent a new command, the command is retrieved and executed. The Virtual Display Manager is a lightweight utility that launches virtual screens on a multi-screen display. It allows users to run and position different applications on each of the sixteen high resolution displays on the video wall, thereby enabling customization of the video wall's content and layout without having to manually open, resize and position applications. This entire process takes place in real time.

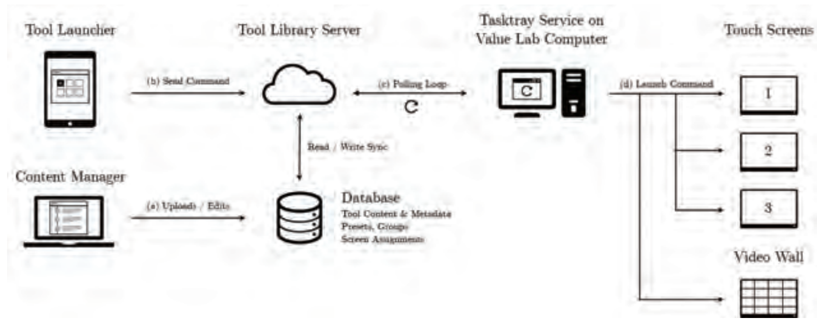

Fig. 03 Tool Library - The Interplay between the Content Management and Display Management System.

Focus on Simplicity: Visual Drag and Drop Composition Technique

The multi-screen display management system provides intuitive composition techniques to produce workflow and screen flow models. Workflow systems enable a high-end orchestration of services within the simulation pipeline. These services can be mapped to the natural workflow of researchers or stakeholders. In order to ease the Value Lab reconfiguration between workshop sessions, a workshop agenda editor has been exemplarily (Fig. 04). As a result of this editing process, a workshop web page is generated with specific workshop sessions that can be executed by tipping on the event hyperlink.

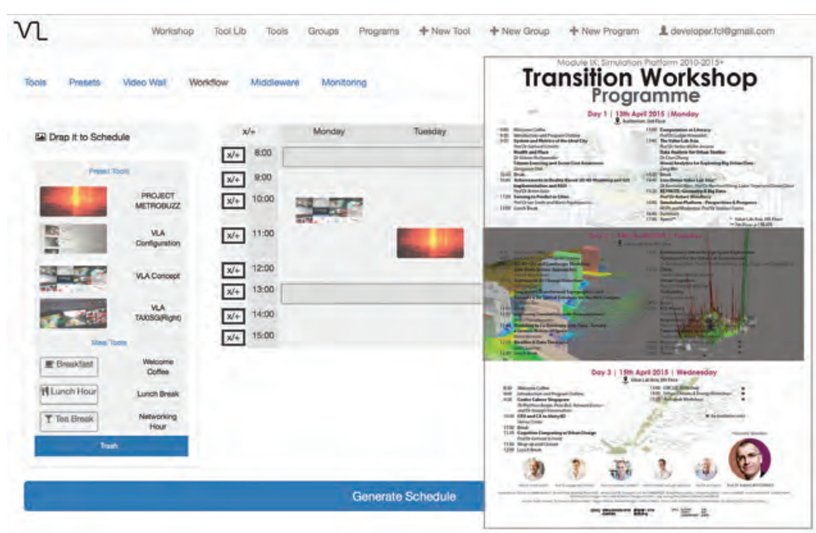

Fig. 04 Simple drag-and-drop editor to configure complementary views on the video wall.

A popular feature of the multi-screen display management system is the ability to execute presets. Presets are sets of tools saved to a given group preconfigured to run on different screens. The screen editor is used to define for each task individual screen setups by dragging multimedia content or applications on icons representing a given screen.

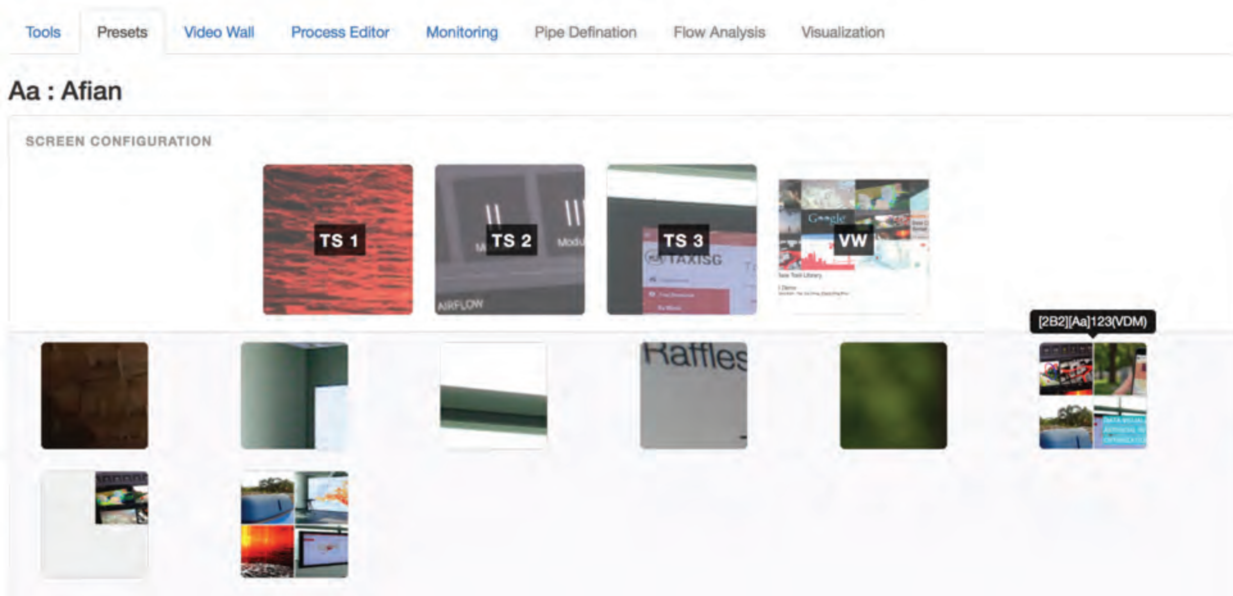

Fig. 05 Screen configuration for ValueLab Asia. The bottom box represents a tool box from which the urban planner can choose different content and the box on the top the chosen screen assignments. The editor can store these screen assignments and execute them during the workshop via icons.

Tools on the video wall can either be displayed in full screen or as a tiled display, thereby giving users the option to configure custom video wall layouts to fit their needs. An architect leading a design research studio on simulation driven urban planning might want to use a "Design Studio Exploration Panel" layout that shows 3D simulation renderings of the planning site complemented by graphs and charts of different performance measures produced by the simulation. These custom tile arrangements are generated using the screen tile editor that lets users drag and drop tools into different content boxes and layout templates. These custom layouts are saved as batch files, instruction sets that associate programs with specific displays. When the remote launcher is used to run a selected layout, the service manager retrieves this command and instructs the video wall computer to execute the corresponding batch file and uses the Virtual Display Manager to populate the video wall's tiled display.

Fig. 06 ValueLab Asia

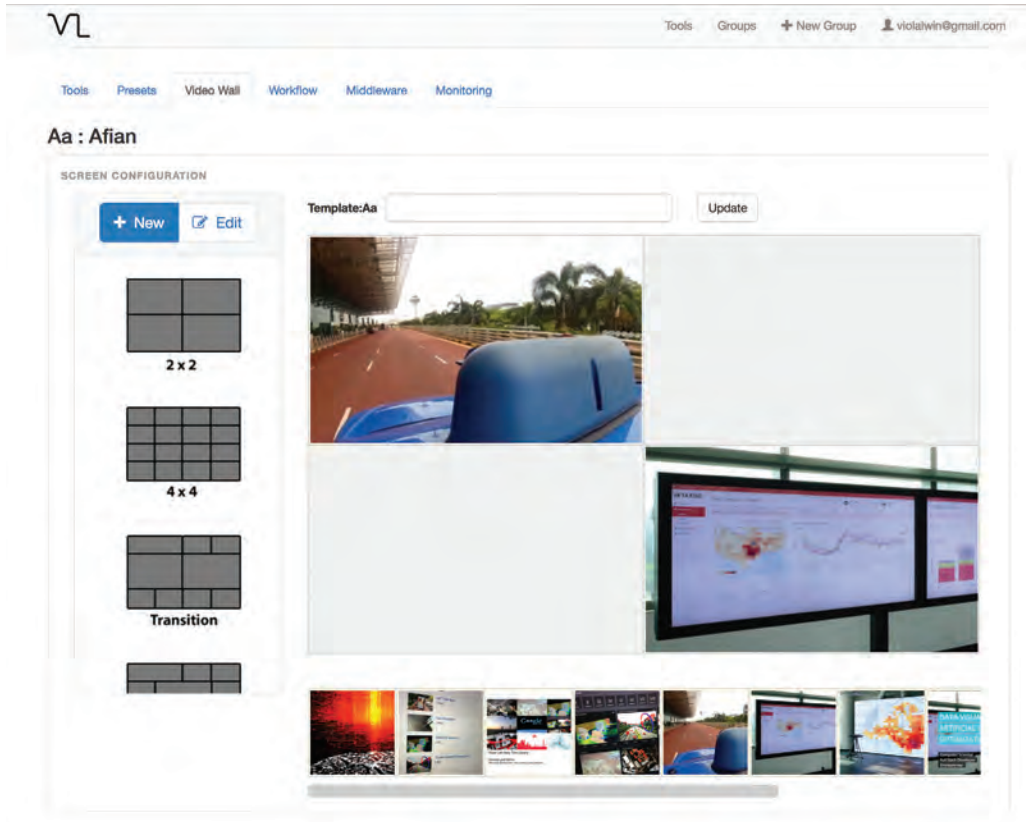

Fig. 07 The video wall editor. On the left side users can choose between available tile templates to create new tile configurations or existing setups for further editing. To create a new tile layout urban planners can drag available contents on the tiles in the layout panel.

Fig. 08 Complementary multi-view representation of an hypothetical planning site in Singapore.

Experience and Impact

The numerous meetings conducted at Value Lab Asia also utilize the same tools, e.g. a typical introduction meeting has an agent based simulation running on touch screen 1, research videos playing on touch screens 2 and 3 and a standard corporate presentation displayed on the video wall. The IT support staff would spend time setting up these tools before each meeting, but with the remote launcher, the meeting chair simply executes a preset to immediately launch tools on preconfigured screens. Our initial observation with the Tool Library shows how the Value Lab has changed the interactive experience. Instead of using the same tools repeatedly, people seem to experiment more with new tools and vary them more often within workshop sessions. This is due to the fact that starting them in the Value Lab has become much easier. Researchers commonly agreed that they liked the familiar web based interface and found the drag and drop functionality intuitive and user friendly. In the simulated workshop setting, all participants agreed that the Tool Library's remote tool launcher made it easier for them to present research content on the fly. Another observation has been that people from other departments are much more aware of tools outside their domain and use them more frequently in their context. The ability to configure and launch different screen setups and video wall tile assignments at the click of a button led to users creating sophisticated comparative visualizations, which led to active discussions in the simulated workshop session.

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Image Credits

Fig. 01: Stefan Müller Arisona

Fig. 02: Afian Anwar

Fig. 03: Wei Fang

Fig. 04, 06-08: Bernhard Klein

Fig. 05: Stefan Müller Arisona

Computational Urban Planning

Using the Value Lab as Control Center

Reinhard Koenig, Bernhard Klein

Urban planning involves many aspects and various disciplines, demanding an asynchronous planning approach. The level of complexity rises with each aspect to be considered and makes it difficult to find universally satisfactory solutions. To improve this situation we propose a new approach, which complement traditional design methods with a computational urban planning method that can fulfil formalizable design requirements automatically. Based on this approach we present a design space exploration framework for complex urban planning projects. For a better understanding of the idea of design space exploration, we introduce the concept of a digital scout which guides planners through the design space and assists them in their creative explorations. The scout can support planners during manual design by informing them about potential impacts or by suggesting different solutions that fulfill predefined quality requirements. The planner can change flexibly between a manually controlled and a completely automated design process.

The developed system is presented using an exemplary urban planning scenario on two levels from the street layout to the placement of building volumes. Based on Self-Organizing Maps we implemented a method which makes it possible to visualize the multi-dimensional solution space in an easily analysable and comprehensible form.

Interactive Computational Urban Planning

The main intention of computational urban planning is to evolve urban designs according to specified requirements and to provide feedback about spatial configurations showing their potential advantages and problems.

As base technologies, we use data clustering algorithms like self-organizing maps (SOM) and evolutionary many-criteria optimization (EMO) based on evolutionary algorithms (EA) as technique for synthesizing designs. We use SOM because of its capability to simplify representations of complex multi-dimensional data. EMO is used as a kind of navigation system for design space exploration (DSE). The combination of SOM and EMO is used as control mechanism for the systematic generation of alternative designs. When we extend classical EA to include more sophisticated selection mechanisms that are able to consider more than one objective function for the evaluation of design solutions, we speak of evolutionary multi-criteria optimization (EMO). The EMO selectors filter the non-dominated solutions out of all generated solutions, especially if we have to deal with a variable set of contradicting and non-contradicting criteria. The generative mechanism is used to create a maximum possible variety of possible topologically and geometrically different solutions. So far, we have implemented mechanisms for generating road networks and building volume layouts.

Evaluation mechanisms are used to provide various fitness values for the objective function of the EMO. The criteria that can be calculated depends on the available evaluation algorithms. For data exchange we focus primarily on the basic geometrical input that is needed for the evaluations and return the calculated values in raw format, so that they can be assigned to the corresponding set of spatial entities represented by a chromosome. In a planning context we need an easily understandable way of presenting all solutions during the synthesis process at any time. A possibility for visualizing a multi-dimensional pareto-front is a pairwise mapping to two-dimensional pareto-front curves. As an alternative we use SOM for mapping multi-dimensional data into a two-dimensional map. This allows a planner to visually analyse clusters of similar solutions with respect to geometrical similarity, how they correspond to the objectives, and other parameter values.

With our DSE tool we can generate numerous designs within a short period of time and compute corresponding quantitative measures. Human designers, on the other hand, can draw on their design expertise and thus are able to easily identify design proposals of good or poor quality. Therefore we need to ensure that there is a good interaction between human and machine by offering an interactive DSE that integrates human design strategies with design synthesis methods. Figure 01 illustrates how the DSE is conceptually integrated into the Value Lab.

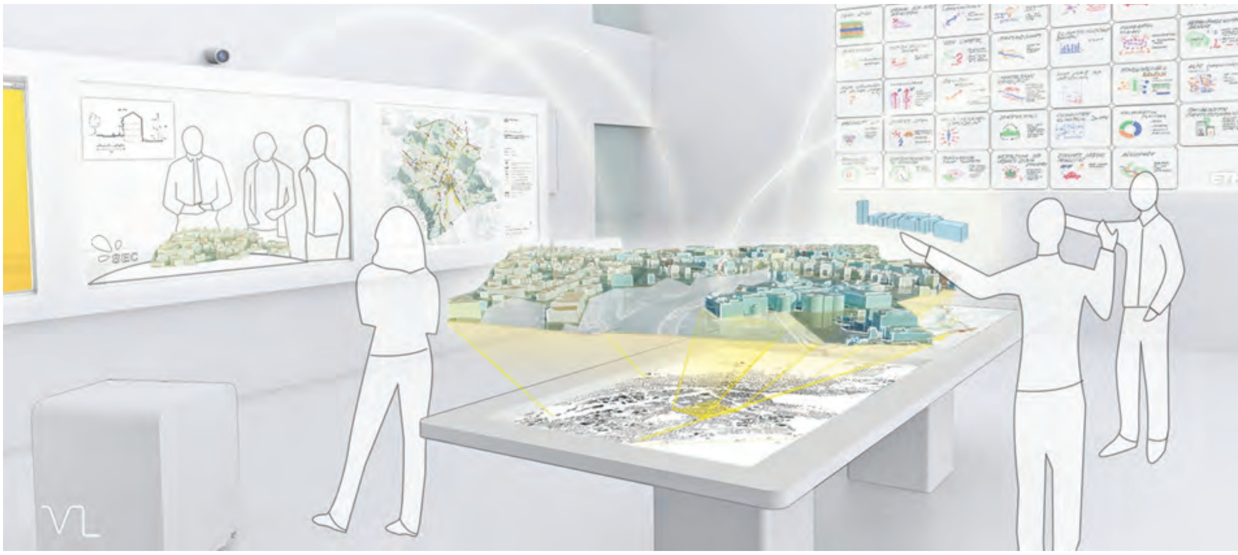

Fig. 01 Human - computer interaction concept of the evolutionary multi-criteria optimization tool adapted to the ValueLab Asia

Redesigning Rochor – A Case Study

In the following we describe a use case scenario during an imagined design research workshop using an example scenario in the district Rochor in Singapore. This exemplary area in Asia emphasizes the urgent need for fast and comprehensive planning systems. Necessary data for the existing street network was taken from OpenStreetMap, and information about neighbouring built structures in 3D was available from the Future Cities Laboratory of the Singapore ETH Centre.

The planning process starts with the empty planning area shown im Figure 03 (a) which defines the border for placing new street segments and the starting street segments (initial nodes) from which the street network is grown. The starting segments are taken from the existing network where it intersects with the planning area. The user has to initially execute the EMO for the street layouts and later for the building placements by specifying the right properties on the very right hand of the tool window shown in Figure 02 (d). The user can, for example, select the size of the population, the number of generations to calculate optimal layouts and the size of the archive to store the solutions. The user interface (UI) shown in Figure 02 is structured in three main areas for visualizing the generated spatial configurations. Figure 02 shows the archives of best variants for the building layouts (b) and street networks (c) generated so far, respectively, and (a) presents a 3D view that shows the configurations selected by a user out of the archives.

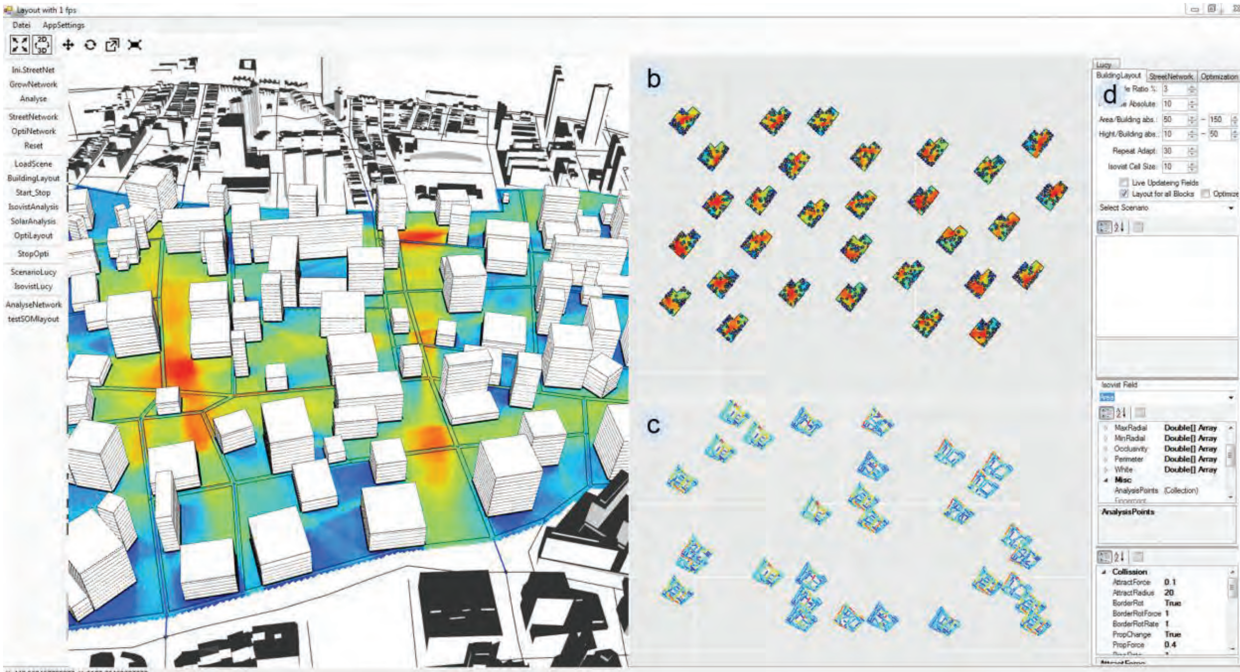

Fig. 02 Software prototype showing the main areas of the user interface: (a) a 3D view combines one solution out of each archive, design solutions of the archives for (b) buildings layouts and (c) street networks, and (d) fields for the user input of size of population, number of generations, etc.

The centrality analysis can also be run for the new network connected to the existing network in a user-defined radius around the planning site. They are combined with each other and the environment's geometry. Based on the chromosome structure, our software prototype makes it possible to move, rotate and scale individual objects (street segments and building volumes) during the planning and optimization process. Corresponding view control functions for zooming, panning and rotating the view are placed on top of the DSE tool. After some user interaction we update all chromosomes of a population, so that all genes (that represent an object such as a building) affected by the user manipulation are assigned new parameter values. This ensures that the changes will be consistent for at least some iteration. After several iteration steps, streets graphs and building layouts appropriate to the objective values are found. Figure 03 shows the results of our prototype for a proof on concept. The results can be improved by adding more detailed restrictions and objective values. We can call this kind of computational planning process evidence-based planning. It helps the designer to meet explicitly formulated design requirements and to eliminate potentially problematic solutions.

Figure 04 and 05 show a typical design workshop using the computational planning tool on the touchscreen panels and displaying the results with different visualisations on the videowall.

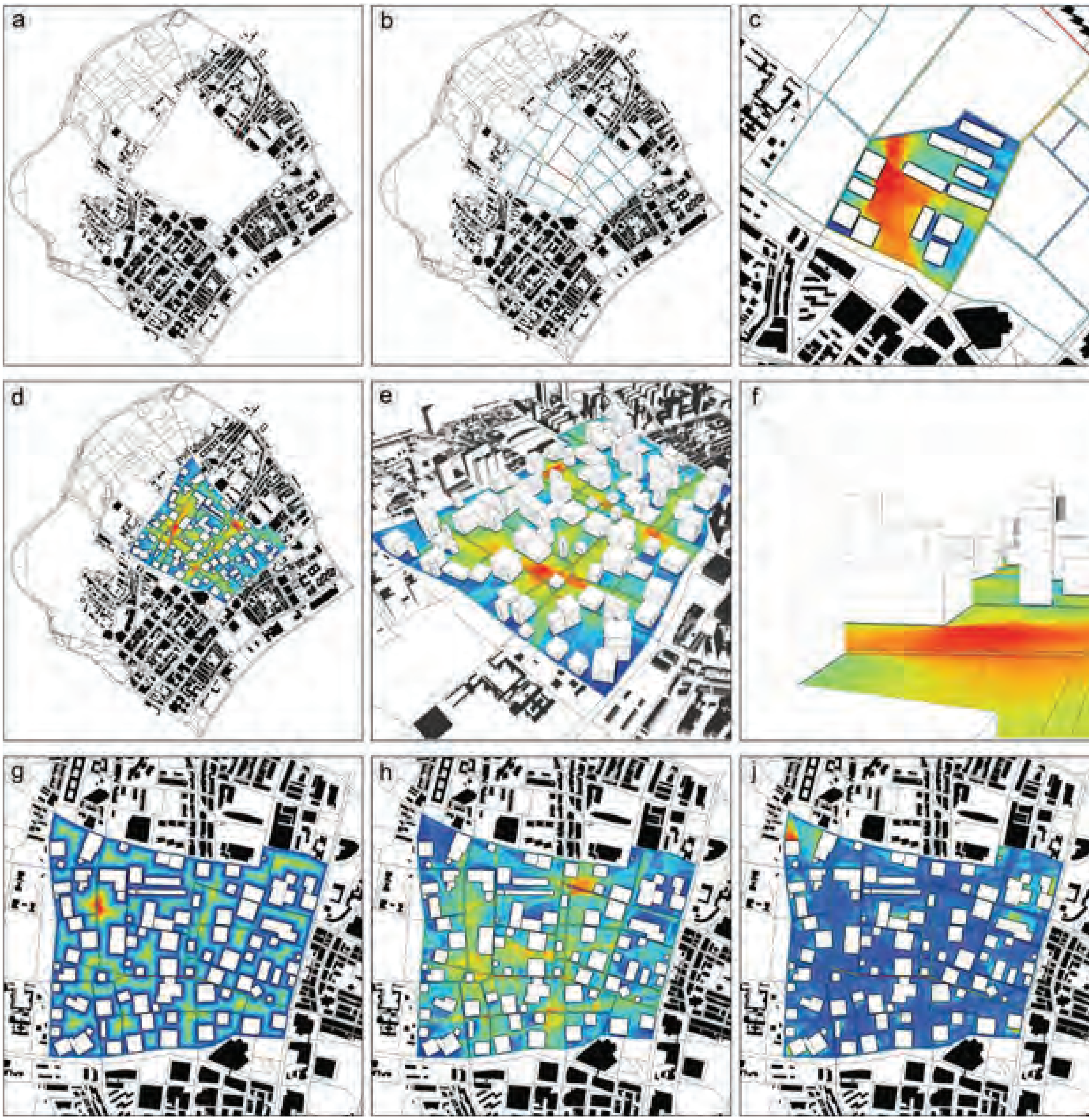

Fig. 03 Planning steps. (a) the vacant planning area, (b), the site filled with a generated street network and area Isovist field, (c) a block filled with a generated building layout and area Isovist field, (d) all blocks filled with generated building layouts and area Isovist field, (e) perspective view with area Isovist field, (f) detailed perspective view, (g) min radial Isovist field analysis, (h) occlusivity Isovist field analysis, (j) compactness Isovist field analysis.

Fig. 04 Simulated Design Workshop during the Transition Workshop. The Touchwall on the left side shows the 3D Map navigation, panels for the Selforganizing maps for street and building layouts and input panels for the optimization process. The video wall on the right side shows a planning site at Pungol in Singapore for different measurement criteria.

Fig. 05 The videowall shows a building layout proposition for the isovist, sunexposure and other measurments.

Conclusions and Future Work

We present an experimental software prototype that exhibits an advanced user interface for representing planning problems, changing them interactively, and presenting many-dimensional design spaces by means of SOM. SOM allow an understandable map for further exploration. The obvious advantage of this mapping is that we find similar solutions close to each other and that we can clearly identify the number of generally different design solutions since they form separated clusters. The software may be considered as an interactive planning support system that guides urban planners efficiently through an ever-changing search space. The search space changes at the moment when the user interacts with the DSE by adding a constraint, or by manipulating or adding geometrical elements. An important aspect is that the user always controls to which degree the design process is automated in accordance with the planner's needs and the respective planning problem. The ability for the user to interact with the generated solutions is crucial for the general applicability of the DSE.

In a future project at the FCL we want to expand the integration of urban data in the planning process, because in future, algorithmic modelling approaches will likely gain in importance as they have the potential to exploit various large urban data sources. This would enable us to achieve an even more holistic planning perspective. The architecture of the DSE framework is designed in a way that allows the integration of new urban data types by adding new generative and evaluation algorithms. The presented research approach shall be considered to develop design support tools that lead to a more evidence-based design approach.

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Image Credits

Fig. 01: Lukas Treyer

Fig. 02-03: Reinhard Koenig

Fig. 04-05: Miro Roman

Lightweight Urban Computation Interchange

Why another middleware for urban planning?

Bernhard Klein, Lukas Treyer

In the last decades the visualisation, analysis and communication of information was explored in more spatial ways than before. Recent technological trends included immersive visualisations with the intention to embed the view in the urban landscape, 3D visualisations to provide realistic urban scenarios, video conferencing to integrate people from the outside participatory planning approaches to compensate ever increasing urban complexity. We introduce an open geospatial middleware for urban planning that includes a geo-data repository and an asynchronous job management engine that allows a supervised execution of modelling, simulation and visualization tasks in a network.

The aim of Leightweight Urban Computation Interchange is to simplify the middleware approach to a stage where local planners are able to install and run it at the ease of any other desktop application. We think this is necessary to enable architects, planners and stakeholders to plan a smart city or a smart neighbourhood, which in turn potentially fosters a bottom up and participation culture – an ever-growing topic in (western) modern urban planning.

Simulation Pipeline – Decision for a Proprietary Middleware Approach

The Future Cities Laboratory (FCL) is a trans-disciplinary research programme focused on sustainable urbanisation on different scales in a global perspective. The work of the Future Cities Laboratory takes place through 10 research modules such as construction, energy management, urban sociology, transport planning, territorial planning and urban simulation. The Simulation Platform provides research services for all other research modules and has implemented diverse tools ranging from data acquisition, urban modelling, interactive simulations and 3D visualization. The seamless integration of all these tools into a simulation pipeline has been a major research objective throughout the programme. This is usually achieved with a middleware, an additional layer of abstraction, that assembles and coordinates software components through remote procedure calls or a more loosely coupled messaging system. This additional abstraction layer between the computer hardware and the software has several advantages easing for instance the software development, establishing data standards and simplifying the software maintenance as individual components can be exchanged on the fly without a requirement for managing new software releases. Since design tasks are usually not repetitive a loosely coupled approach is more suitable as it allows for more flexibility.

Unfortunately urban planning requirements change from one project to another, requires rich functional support along the planning process chain, and increasingly demand of scalable computing solution to verify or calibrate complex urban models with urban data. As standard middleware solutions cannot satisfy these strong planning requirements we decided to implement our own middleware solution that we call Lightweight Urban Computation Interchange (LUCI).

Workflow Integration versus Parallel Computing Models?

Figure 01 shows a schematic scenario of the LUCI integration scenario. LUCI follows a layered architecture where the geometry repository together with an event notification system builds the core of the LUCI system. Converters are implemented on top of the core to allow the integration of urban planning software and various data sources. Administrative functions ease the configuration of the LUCI network. The two dominant integration styles are sequentially forming a digital workflow chain, or parallel following publish-subscribe model where events are instantly propagated to all interested parties.

Achieving a tool support for the entire urban design workflow linking e.g. data acquisition, urban modelling, simulation and visualization by providing data format converters between them has been the research focus for several years. Data mapping is often challenging due to divergent conventions across sources, missing entries, inconsistent columns and unclear labelling. Adaptors for 2/3D map data like OpenStreetMaps and CityEngine will be implemented in near future. Just very recently with additional urban data and computing power becoming available the focus has shift toward exploitation of parallel programming models to provide better support for trans-disciplinary research approaches. Publish-subscribe systems enable the asynchronous linking of various urban models and tools leading to richer view on the entire urban planning scenario. Such models can simulate different aspects of a city such as air flows and quality, urban traffic, water and energy grids and other aspects of our physical environment. All models are synchronized through a GIS repository storing information about the urban environment. Changes in the street and building layout become automatically communicated through the middleware and are updated instantly. This middleware infrastructure utilizes hereby different services hosted on a computer cluster and communicating with each other to fulfil the intended design and evaluation task.

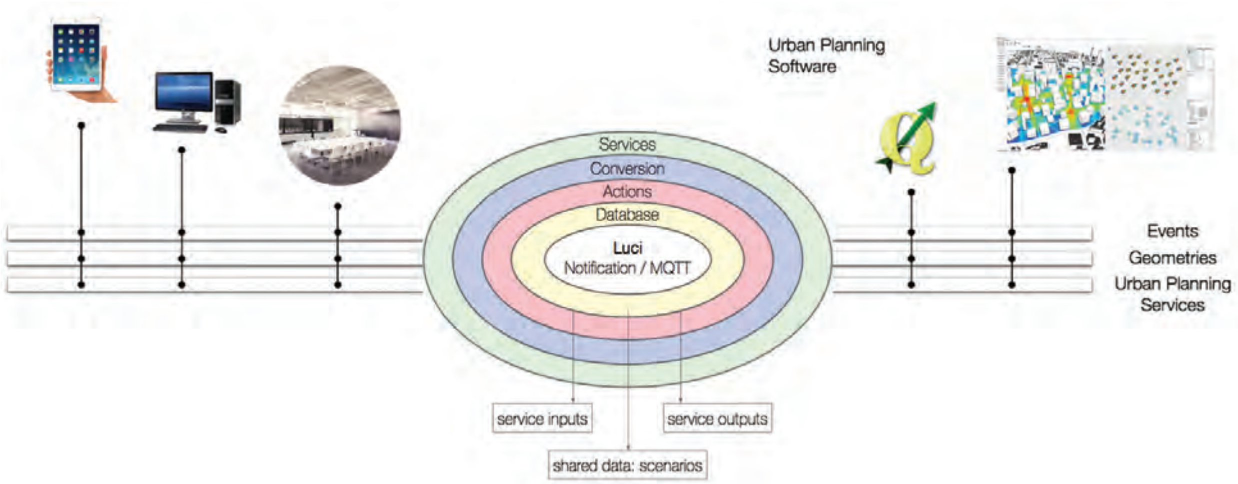

Fig. 01 LUCI middleware integration scenario: device, data and service integration and the layered architecture of the LUCI middleware

Focus on Simplicity – Plug-in Middleware and Web Configuration

A major highlight of the LUCI middleware is the fact that it can be embedded in any web system through web sockets. This opens the door for a wide variety of HTML5 web applications – one of them being a visual configuration interface that further facilitates LUCI's usability.

This visual service composition framework provides intuitive composition techniques to produce workflow, screen flow and process flow models. It contains a basic component model, a catalogue system, drag and drop modelling editors, and the Tool Library as the service execution environment. The components can be divided into user interface elements (screen layouts and flows), design and evaluation services, and geographic, as well as thematic urban datasets. All components are described with metadata for service identification, description and model validation. They are stored in respective service or data repositories. They can be categorized into user interface elements (screen layouts and flows), design and evaluation services, and geographic, as well as thematic urban datasets.

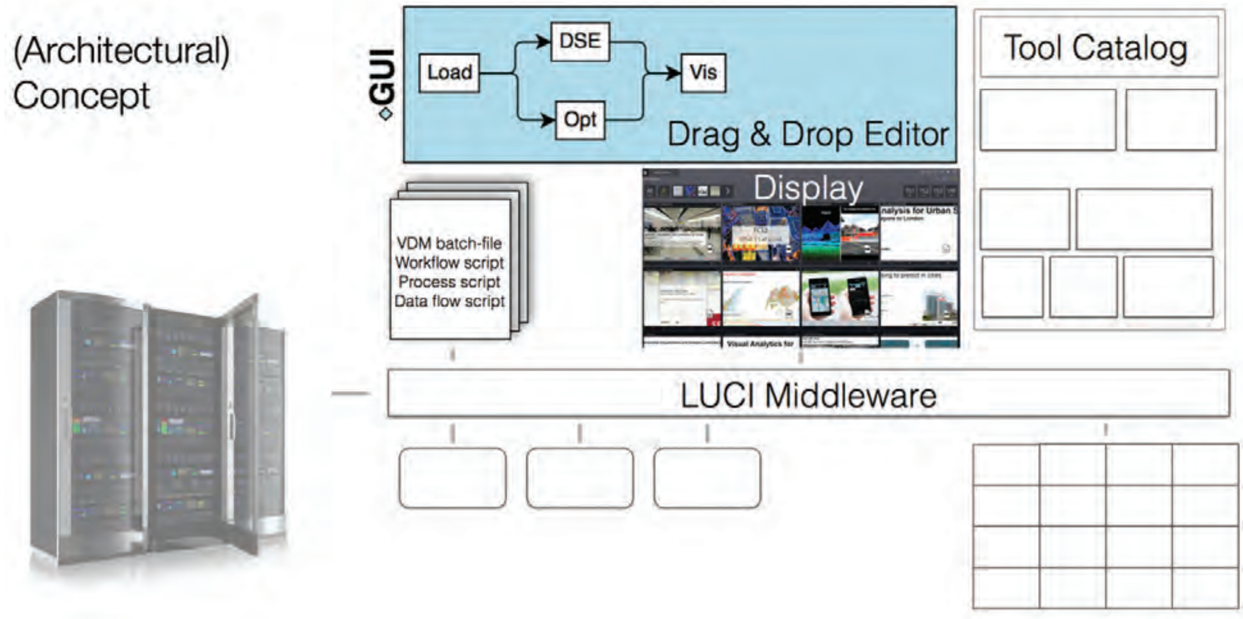

Fig. 02 Service composition framework

Urban planners can use the Tool Catalog (component catalogue shown on the left side of Figure 03 to look for appropriate components and drag them on the editor pane. They may then specify networks of LUCI modules by drawing web-based interactive flow diagrams with arrows, where the entities represent services, scenarios and configuration settings. Arrows describe how individual components are linked together. Visual links support different camera positions and zooms on the urban scenario and enable various model filters. Two boxes below the process flow diagram specify static and dynamic parameter linking. Dynamic parameters are joined through ports from the outgoing and to the ingoing LUCI component. Services can get their data by linking them to data sources or foregoing services and can be assigned to screens thus enriching their output. By this, for instance, a real-time filtering mechanism between two screens can be established. With publishing of the screen flow and process flow models the editors generate executable scripts which can be interpreted by the LUCI middleware or the Tool Library display management system. In near future, the service composition framework will be able to provide instant status feedback to the configuration interface. Based on status information like dispatcher queue lengths, service completion rates, and hardware related parameters like processor and ram usage, researchers can optimally adapt the LUCI network based on current load conditions or even add new simulation tools on the fly.

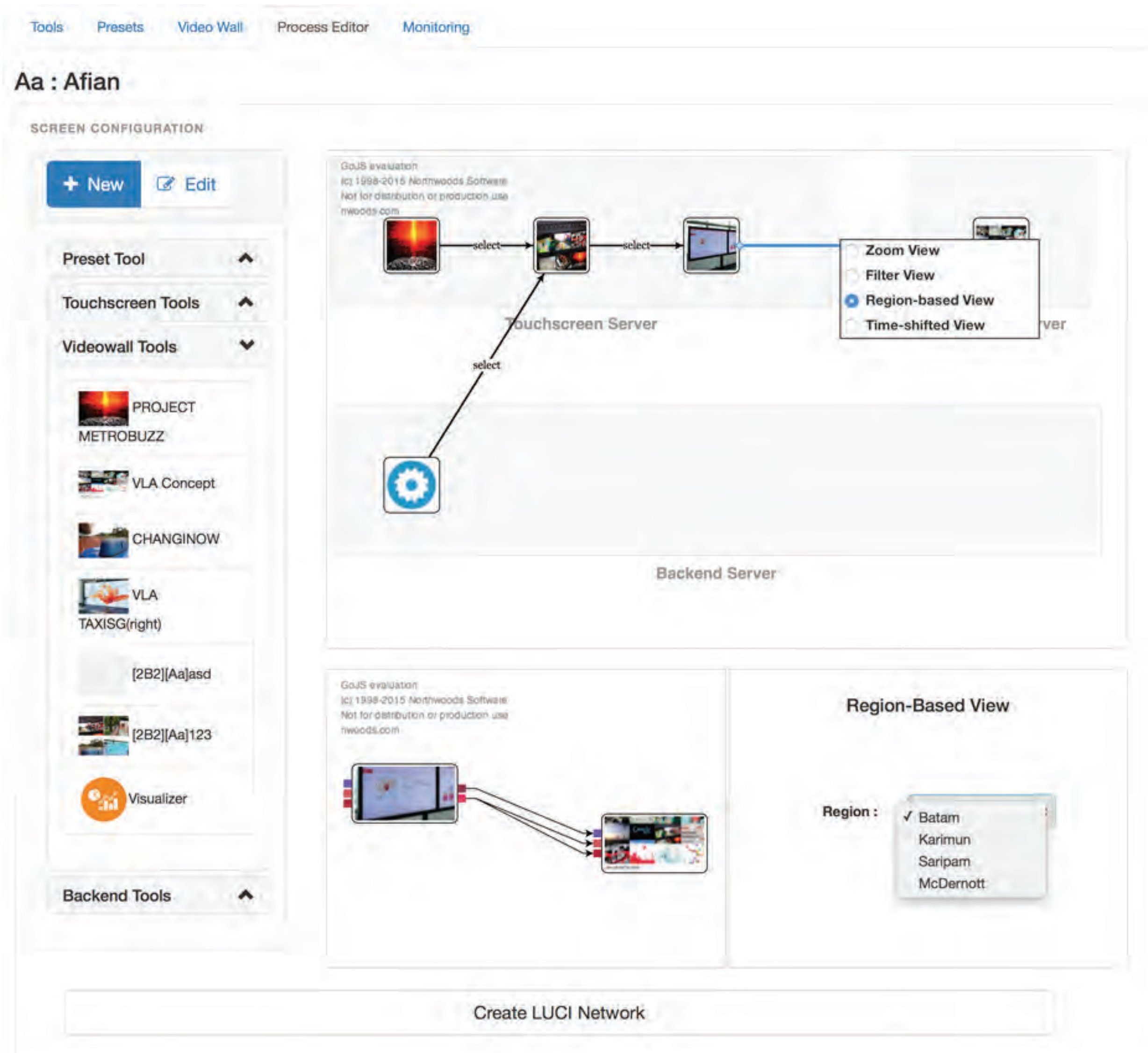

Fig. 03 Web based visual configuration and monitoring interface for the LUCI middleware. The left panel represents the Tool Catalog, The upper panel the LUCI service network and both panels in the bottom static and dynamic parameter assignments to manage the information exchange between the currently selected LUCI components.

Early Experiences and Future Use Cases

Equipped with an early prototype of LUCI we conducted a workshop called "Design Space Exploration for Urban Compaction" at the SmartGeometry conference held at Chinese University Hong Kong in 2014. For this workshop we developed a multi-screen setup showing several complementary urban planning views that were very well received. May 2015 we presented a new release of the LUCI middleware on the Transition Workshop hosted at the Singapore ETH Centre. During this workshop we demonstrated the technologies behind a simulated urban planning workshop and highlighted the main use cases for the LUCI middleware such as urban data integration, multi-model computations, and coordinated multi-view scenario evaluation. Figure 04 shows on the left touch wall the service log file that are executed on computers in the backroom of the Value Lab (Fig. 05).

Our future plans for LUCI include a better integration with the visual service composition framework to simplify LUCI network setup and the extension of the use cases. These include better middleware scalability, the integration of the PISA repository to manage multiple design paths and the application of City Design Science methodologies to enable ongoing democratisation of the urban design process.

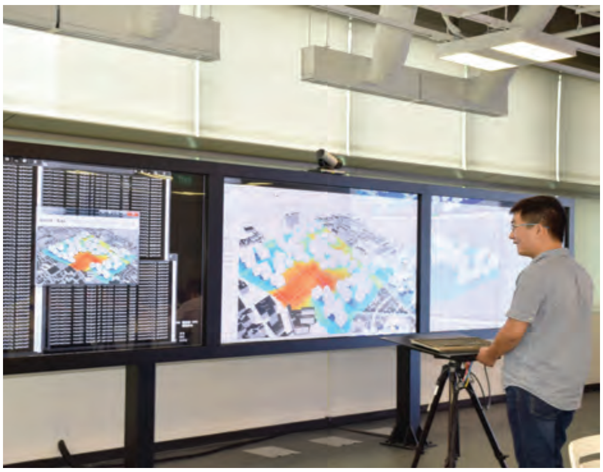

Fig. 04 Photo showing a simulated design workshop at the Transition Workshop, April 2015. The left screen shows the load balancing situation for three different computation services.

Fig. 05 Backend server rack ValueLab Asia

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Fig. 04: Wei Fang

Fig. 05: Stefan Müller Arisona

Visual Analytics for Urban Public Transport

Using visualizations to reveal the underlying movement patterns of urban public transport in Singapore

Zeng Wei, Stefan Müller Arisona

Public transport systems (PTSs) play an important role in modern cities, such as Singapore. Vast amounts of urban public transport data have been collected automatically and pervasively, promoting more research focus on analyzing and exploring public transport data when studying PTSs. However, analyzing massive urban public transport data is a challenging task due to its high-complex, large-size, multi-mode and spatio-temporal char-acteristics. To get over these challenges, visual analytics show great potential as they can make the way of processing and analysis of public transport data transparent: Visual analytics can provide interactive means for transport researchers and decision makers to examine the actual processes of analyzing data instead of just the results.

This article investigates advanced visualization technologies for analyzing and exploring massive urban public transport data that consists of massive commuter RFID card data (EZLink data), transport network and transit schedule in Singapore. To address various analytical tasks raised by transport researchers, a family of novel visual analytics systems have been developed. Specifically, three scales of origin-destination (OD) information (Fig. 01), which are essential in transport modeling and analysis processes, have been extracted from the input dataset for visualization and exploration.

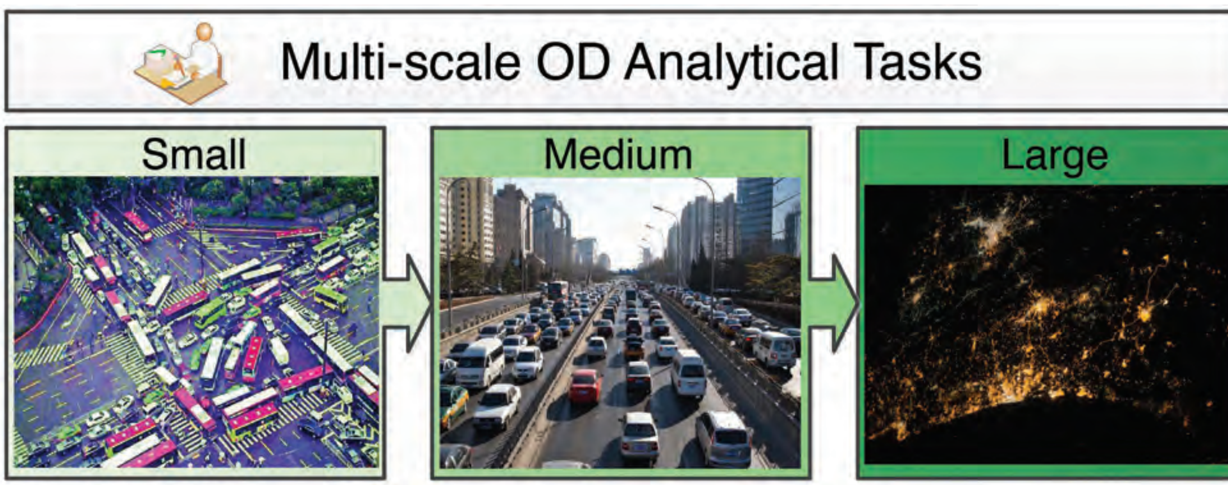

Fig. 01 Multi-scale analytical tasks of OD patterns emerged from transport domain. 1) Small-scale: analyze how moving objects redistribute themselves at junctions, e.g., crossroads, bus stops; 2) medium-scale: study origins and destinations of the trajectories successively passing through an entry and exit waypoints; and 3) large-scale: explore all reachable destinations from a starting location within certain time period.

Small-scale: Interchange Patterns

A small-scale OD pattern, which is referred to as interchange pattern in this article, describes how moving objects redistribute when entering/passing through a junction node in the transport network. Interchange pattern is a highly valuable means not only for unveiling human movements at junctions, such as crossroads and bus stops, but also for assisting transport planning. For instance, interchange information can help reveal the road junction utilization and suggest crossroad design, e.g., adding a fork.

To support efficient visualization of interchange patterns that emerged from EZLink data, we designed a novel visual representation, namely the interchange circos diagram, for presenting the redistribution of people at junction nodes. Incorporated with various advices from domain experts, we revised and customized the circos figure (Krzywinski et al. 2009) for presenting commuter interchange: a flyover ring to denote the junction node itself, bi-directional bundling to reduce visual cluttering, and an optimized color assignment on linkages to enhance the visual connections between neighboring interchange circos diagrams, as shown in Figure 02.

The interchange circos diagram has been customized to analyze the interchange patterns at train stations of the Singapore MRT system. As shown in Figure 03, we can pick a train station and visualize its interchange pattern for a user-selected time interval, which is 08:00 - 10:00 in this case. By examining these four interchange circos diagrams, we can see the relative flow volumes for different possible routes at these train stations, e.g., the major movement directions at each station as well as the relative flow volumes among the four stations. Since the selected time interval is in the morning, we can observe unbalanced flow volumes in the bundled ribbons as well as in the node-connecting links.

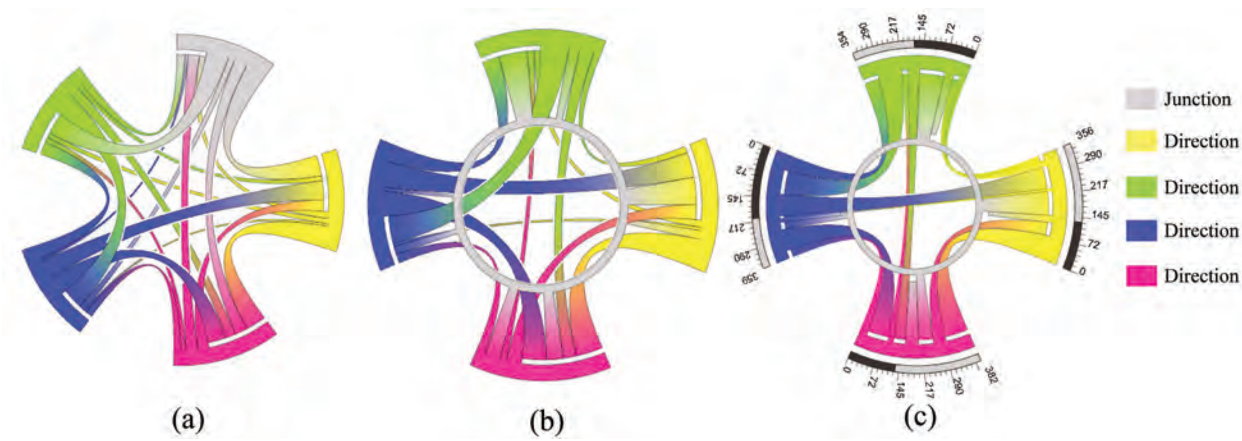

Fig. 02 Developing the interchange circos diagram from the original circos figure: (a) the initial design; (b) use a gray-colored flyover ring (like a source/sink) for the junction itself; (c) bundle pairs of bi-directional ribbons to reduce the visual cluttering.

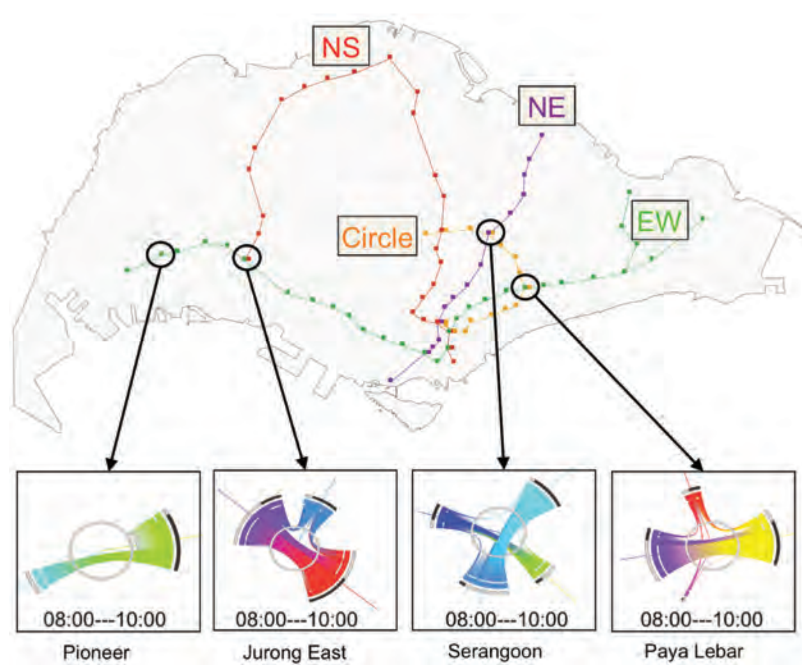

Fig. 03 Interchange patterns at different train stations in the Singapore Metro system.

Medium-scale: Waypoints-constrained OD Patterns

A medium-scale OD pattern, which is referred as waypoints-constrained OD pattern, associates with trajecto-ries that successively pass through entry and exit waypoints in the transport network. Such aspect has not been explored in previous visualization research, and has practical value in transport. For instance, the study by Wang et al. (2012) showed that only a few (less than 2%) of the road segments in urban areas give rise to congestions. This motivates us to study OD patterns subject to specific locations/paths rather than to the en-tire city.

To address such waypoints-constrained OD analytical tasks, we elaborated a set of design principles and rules, and then developed a novel unified visual representation, called the waypoints-constrained OD view, by care-fully considering the OD flow presentation, the temporal variation, spatial layout, and user interaction. The waypoints-constrained OD view has three main components: in-flow view, OD-flow temporal view, and out-flow view, as shown in Figure 04. These components work together to support the analytical tasks.

The visualization has been applied to explore the daily pendulum movement patterns in the Singapore MRT data on a normal working day. In transportation, pendulum movements describe an obligatory urban mobility pattern that is highly predictable and recurring on a regular basis (Rodrigue et al. 2013): Employees who commute from residential to working areas contribute to the A.M. peak flow; when they return home, they contribute to the P.M. peak flow. By comparing Figure 05(a) & (b), we can easily observe the pendulum move-ments pattern. First, both waypoints-constrained OD views identify nearly the same set of major origins and destinations, but with swapped roles, e.g., in the morning, many trajectories end at EW23, EW21, and EW15, while in the evening, many trajectories start from these stations. Second, we can see that the flow volumes between the same OD pair in A.M. & P.M. with reversed directions are almost the same, e.g., flow volume from NS stations to EW23 in Figure 05(a) and that from EW23 to NS stations in Figure 05(b) are nearly equal.

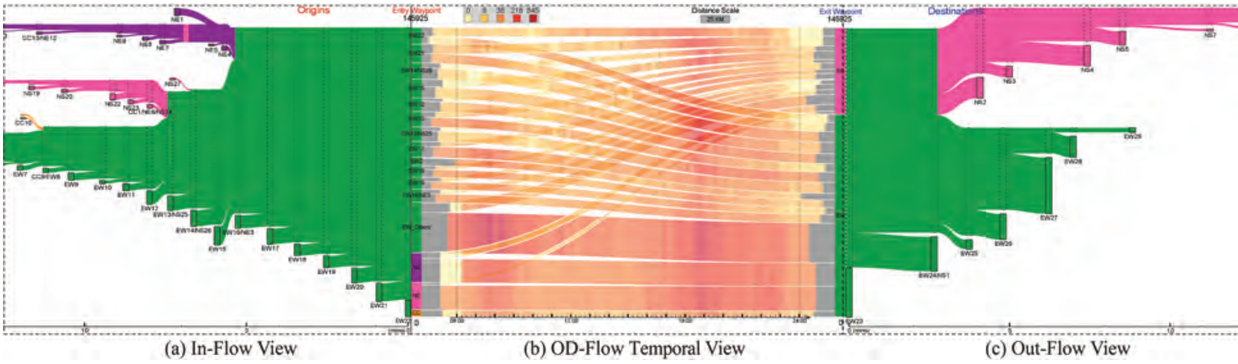

Fig. 04 An example waypoints-constrained OD view with three components: (left) in-flow view, (middle) OD-flow temporal view, and (right) out-flow view, as an integrated and coordinated solution to support the waypoint-constrained OD visual analytical tasks.

Large-scale: Mobility Patterns

A large-scale OD pattern explores all reachable destinations from a starting location within certain time period, which considers the mobility in the entire transport system. Mobility measures a transport system's ability to move goods and people to their destinations based on the quantity and quality of physical travel (Handy 2002). Traditional transport planning aims at improving the mobility of transport systems. Thus, studying the mobility of a transport system is highly beneficial to both individuals as well as an entire city as a whole.

However, developing visual analytics methods to meet this goal is a highly challenging task: First, public trans-portation systems are increasingly complex. Second, existing works in visualizing public transportation net- works mostly employ network visualization methods and focus on presenting the network topology across stops. Lastly, the mobility-related factors vary dynamically with both time and space, and could also exhibit round-the-clock patterns. To address the above issues, we developed a visual analytics framework to visualize and explore mobility-related factors in a public transportation system with three visualization modules:

- Isochrones map view (Fig. 06), which presents geographical regions accessible from a given starting location within certain duration;
- Isotime flow map view (Fig. 07, left), a novel strategy that linearizes a flow map in a parallel isotime fashion, enabling visualization and exploration of various mobility-related factors; and
- OD-pair journey view (Fig. 07, right), which enables interactive exploration of various mobility-related factors, and their temporal variations, along the origin-destination journeys.

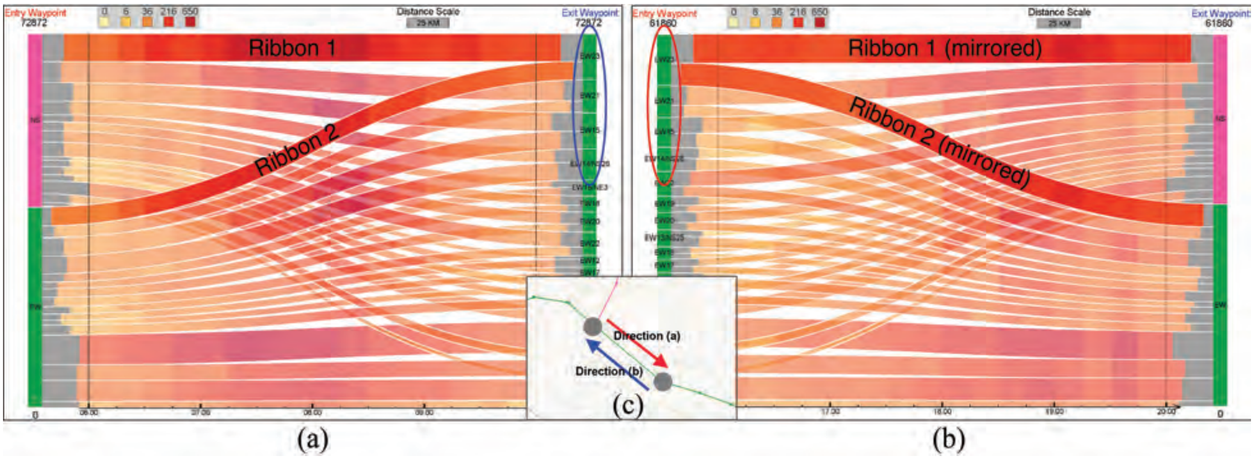

Fig. 05 Daily pendulum movement exploration. (a) & (b) present an interesting pendulum movement pattern, which illustrates home-to-work movements through the red arrow in (c) in the morning (6:00-10:00), and work-to-home movements through the blue arrow in (c) in the evening (16:00-20:00).

The visualization can facilitate the exploration of PTS mobility over different locations in a city. Figure 06 presents the isochrone map views related to two different locations on the map: Changi airport (left) and Boon Lay (right). Though the starting time for both visualizations is 8 A.M., the isochrone map views reveal very different sizes of reachable dominions from the two locations. From the isochrone map view on the right, we can clearly see the reachable regions are much larger, since Boon Lay is an important interchange center in the Singapore MRT system, while Changi airport is located far away from the city.

Conclusion

This article has presented three intuitive and informative visual analytics tools developed to depict the knowl-edge emerged from the input EZLink data. The ultimate goal is to facilitate transport researchers' exploration and analysis of the data, such that to help them manage the traffic flow and improve the PTS design. These works were published recently in prestigious visualization research journals IEEE Transactions on Visualization and Computer Graphics (IEEE TVCG) (Zeng et al. 2014) and Computer Graphics Forum (CGF) (Zeng et al. 2013) & (Zeng et al. 2015). We have also contributed our source code to URA for their further tool development.

Fig. 06 The isochrone map views present spatial-reachability regions from 8 A.M. at origin (red icons) Changi Airport (left) and Boon Lay (right), by contour lines and areas over the geographical map. Dark blue and light blue indicate [0, 30] and (30, 60] minutes, respectively.

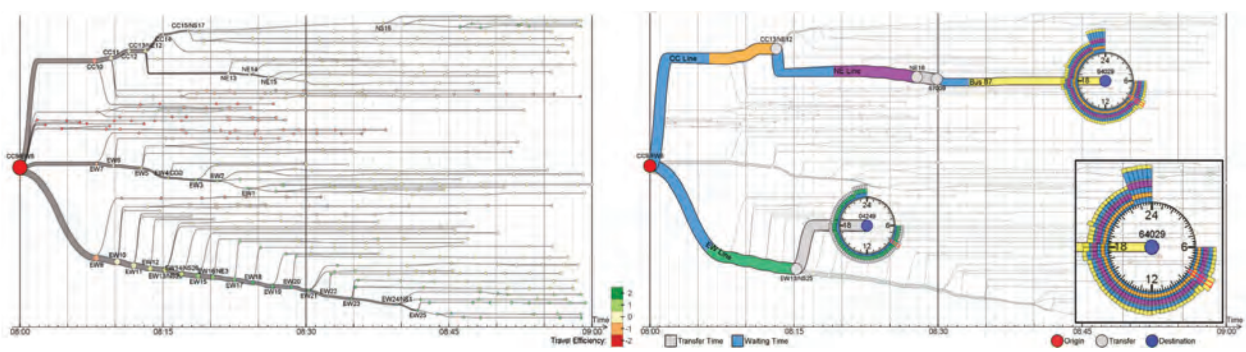

Fig. 07 Left: the isotime flow map view overviews time-efficient routes from a source location in a parallel isotime fashion. Right: the OD-pair journey view enables us to explore temporal variations of mobility-related factors for specific time-efficient routes.

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Fig. 01-07: Wei Zeng

Improving wind simulations using measurements

Application to full-scale building systems in Singapore

Maria Papadopoulou, Didier Vernay, Ian Smith

Emerging challenges for cities in the next decades include those that are related to environmental protection and meeting energy needs, particularly in warm or tropical climates. The wind environment could have an increasing role in mitigating issues linked to outdoor thermal comfort, air quality, as well as building energy consumption and natural ventilation. For example, groups of buildings need to be configured in order to maximize the beneficial effects of wind. Improving knowledge of wind flow around buildings has consequently become important and much recent research work has focused on wind prediction. While accurate wind prediction is important, the modeling process is complex and predictions are often incompatible with measurements due to large uncertainties associated with modeling as well as inherent climatic variability. This article reports research contributions towards improving wind predictions around buildings using a combination of simulations and full-scale measurements. Main findings are that the accuracy of wind predictions can be increased using a time-dependent model falsification approach and measurements from strategically placed sensor locations.

Current situation and challenges

The method used for predicting wind around buildings depends on the size of the study area and for small-scale studies concerning a few buildings (distances up to 1-2 km), computational fluid dynamics (CFD) simulations have been commonly employed. The advantages of CFD simulations are that they allow treatment of a wide range of complicated geometries and provide detailed information on wind flow. Although CFD simulation results are often reasonable, predictions can be very different from field measurements (Schatzmann and Leitl 2011). Uncertainties are unavoidable in wind simulations and arise from modeling assumptions, which are associated with the choice of mathematical models, geometry, surface roughness as well as the large number of other parameters that needs to be defined, including those that characterize time-dependent atmospheric boundary conditions (Mochida and Lun 2008).

Inverse modeling can be used to improve simulation predictions at unmeasured locations through estimating parameter values with the measurement data. Inverse modeling is the inverse of traditional modeling (also known as forward modeling), since values of parameters are inferred from measurement data by comparing them with simulation predictions. Inferring parameter values of CFD simulations using measurement data, is a challenge because of measurement and model-class uncertainties. Model-class uncertainties are those associated with the model that cannot be accounted for when parameter values are varied. Among the inference approaches proposed to date, model falsification is the most robust when values of uncertainty correlations between locations are not known (Goulet et al. 2013).

Regardless of the approach to data interpretation, field measurements are necessary in order to ensure that CFD predictions are sound. Good measurement locations are important in improving simulation predictions, since they influence the information content of the measurements and hence affect decision making (Schatzmann and Leitl 2011). Nevertheless, determining the right number of sensor locations remains a challenge in wind studies (van Hooff and Blocken 2012) and hence, has been mostly performed through educated guess. Recent studies have proposed systematic sensor placement methodologies, yet these required either costly and time intensive pre-deployments of wind sensors (Krause et al. 2008, Wu et al. 2012) or CFD simulations (Du et al. 2014) without considering the effect of systematic model-class errors nor the risk of selecting sensors that have similar information content.

Multiple-model CFD simulation

The aim of this research is to enhance wind predictions around buildings using a combination of CFD simulations and full-scale measurements. An inverse modeling approach is proposed that employs multiple CFD models to account for uncertainties associated with parameter values. The approach uses, instead of one model, discrete populations of models that provide predictions of wind speed and direction at potential sensor locations and at unmeasured locations. Multiple simulations are performed through varying values of parameters that are not precisely known within plausible ranges, defined by engineering judgment and recommendations in the literature. A specific combination of input values of parameters, and the corresponding wind predictions at all locations of interest, is one model instance. The generated discrete population of model instances is called *initial model set.*

Figure 01 illustrates an example initial-model-set comprising of over 1000 model instances using a parallel axis plot, which is a common way of visualizing high-dimensional data. Each line on the plot represents one model instance that contains the input and output values of one simulation.

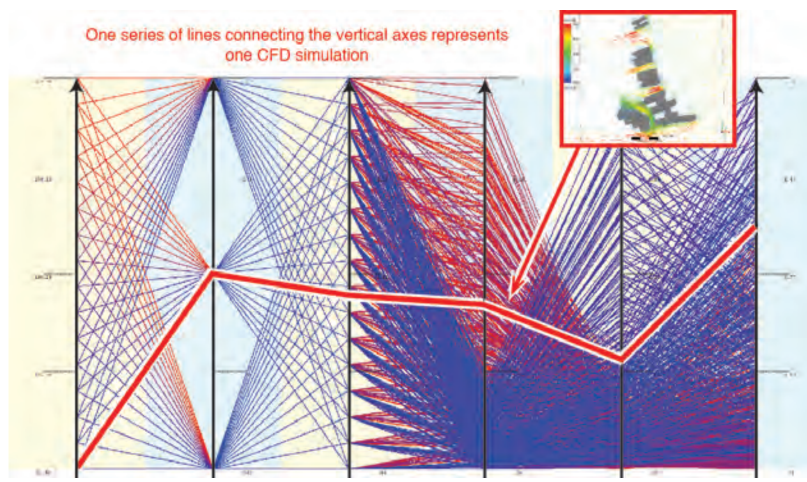

Fig. 01 Illustrative example using a parallel axis plot of over 1000 CFD model instances generated using 3 input parameters and obtaining predictions at 3 potential sensor locations. Measurements are taken at 2 of the 3 locations, while the 3rd location is used to evaluate predictions.

Hierarchical sensor placement

The generated discrete population of predictions is used to select optimal sensor locations prior to field measurements, in situations when limited information is available, taking into account estimates of model-class and measurement errors. The hypothesis is that the optimal sensor configurations should enhance model falsification approaches, such as (Goulet, Coutu et al. 2013, Vernay et al. 2014), and provide maximum information content in order to improve predictions.

A novel strategy has been developed that employs a hierarchical algorithm and the concept of joint-entropy to select sensor locations (Papadopoulou et al. 2014). The important advantage of the algorithm is the use of a tree-data structure that allows evaluating the mutual information between sensor locations, when no measurement data is available, without a significant increase in computational cost. The benefit of the hierarchical organization is that it takes advantage of an O (constant) computational complexity with respect to the number of sensor locations and linear with respect to the number of model instances (equivalent to the number of simulations).

Figure 02 provides a schematic of the hierarchical sensor placement algorithm for selecting the first three sensor locations. At each stage during sensor placement, an optimal sensor location is added to the configuration, while subdividing the existing subsets of model instances, from the previously selected sensors, into smaller subsets. The maximum number of subdivisions is restricted to the number of model instances within the subsets.

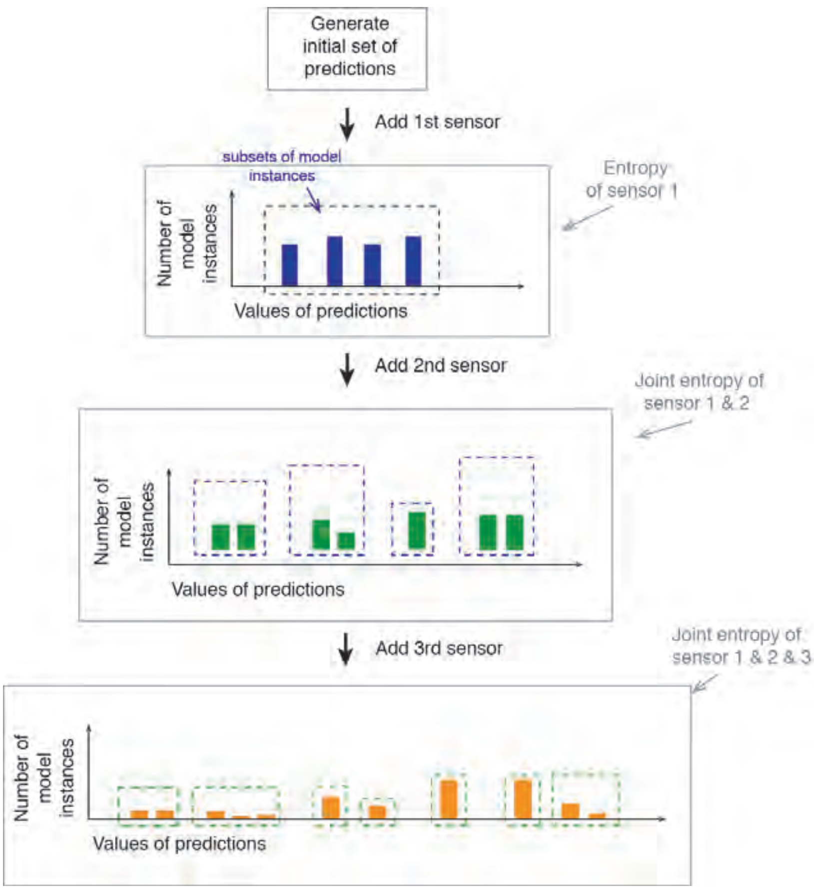

Fig. 02 Schematic of the hierarchical sensor placement algorithm and the joint-entropy calculations for the sensor configuration involving 3 sensors.

Falsification using confidence intervals

Model falsification is performed at each optimal sensor location by comparing measurements and model predictions at that location. Model instances are then rejected if the difference between predicted values and the measurements falls outside threshold bounds at any one location. The interval width at each sensor location is obtained through combining model-class and measurement uncertainties at that location and using a confidence level of 95%. An illustration of the falsification process is shown in Figure 03. The goal is to use the remaining model instances – called candidate models – to improve predictions at unmeasured locations.

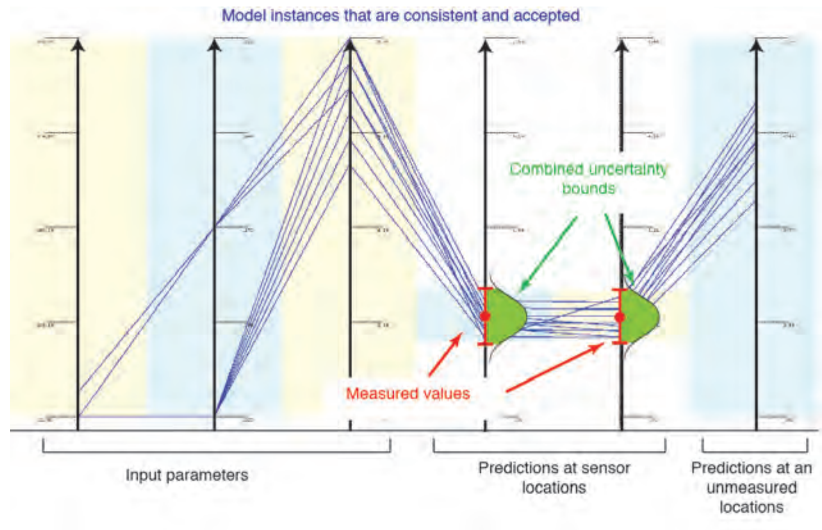

Fig. 03 The model falsification process at two sensor locations using measurements and the updated predictions at another unmeasured location. Model instances are rejected when simulation predictions at one time step fall outside the threshold bounds of the measured value.

The model-class used commonly in wind engineering consists of Reynolds-Averaged Navier-Stokes (RANS) equations under isothermal conditions. This is one of the most computationally efficient approaches to approximate turbulent flows (Rodi 1997), therefore allows multiple simulations to be run. The disadvantages are that fluctuating velocities are averaged over time and that the effect of temperature variations on the wind flow is not considered. Hence, using such an approach leads to an evaluation of model-class uncertainties.

Uncertainties associated with RANS modeling and turbulent fluctuations lead to spatially distributed uncertainties. A methodology has been developed to estimate such uncertainties using a large eddy simulation (LES). LES provides more accurate predictions than RANS and accounts for turbulent fluctuations (Zhou 2006), however it is computationally demanding and therefore performing multiple CFD simulations is prohibitive. LES results are not perfectly correct. Thus, levels of uncertainties estimated in this work are lower-bound estimates. Disregarding the effect of temperature variation on wind flow leads to time-dependent uncertainties with systematic biases in simulation predictions. These uncertainties have been evaluated using statistical methods on historically measured data. Finally, these uncertainties are combined with uncertainties associated with sensor characteristics using the Monte Carlo method (Fig. 04). Threshold bounds are then defined, for 95% confidence levels, which are used during the model falsification process.

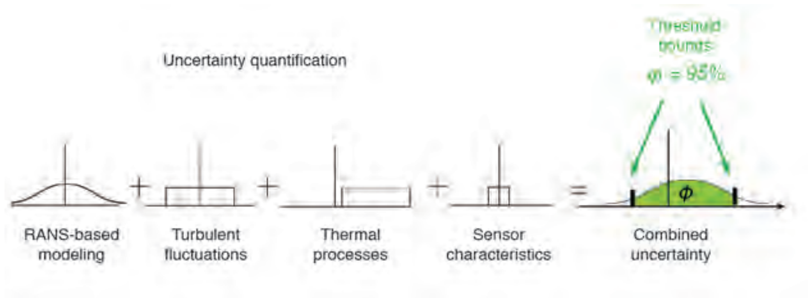

Fig. 04 Schematic of uncertainties during modeling and measurement that are combined into an uncertainty distribution to quantify threshold bounds with 95% confidence level.

Full-scale case studies

Three full-scale case studies are selected for evaluation: the BubbleZERO, the CREATE Tower and Treelodge at Punggol. The building systems are all located in Singapore and are of varying size with different scope of study. The purpose of the BubbleZERO case study is to test and compare the sensor placement strategies for their performance in improving wind predictions. The CREATE Tower is a larger case study with dramatically different building geometry that is used to evaluate the scalability of the methodology. The final case study involves Treelodge at Punggol with the aim to generalize the applicability of the framework to large building systems.

Figure 05 illustrates the main stages of the three full-scale studies, as well as the general results. Using the hierarchical sensor placement and the time-dependent model falsification, on average 55 to 74% refinement is achieved in the predictions of wind speed and direction. The reliability of predictions (percentage of time that the test data fall within prediction ranges) has varied from 85% to 98%, while in all studies less than 10 sensors were used. The initial potential locations have varied from 63 to 290. Parts of these results have been published (Papadopoulou, Raphael et al. 2014, Vernay, Raphael et al. 2014, Papadopoulou et al. 2015). In conclusion, this research provides empirical evidence of the potential to improve wind predictions around building systems of various sizes, using a combination of simulations and full-scale measurements.

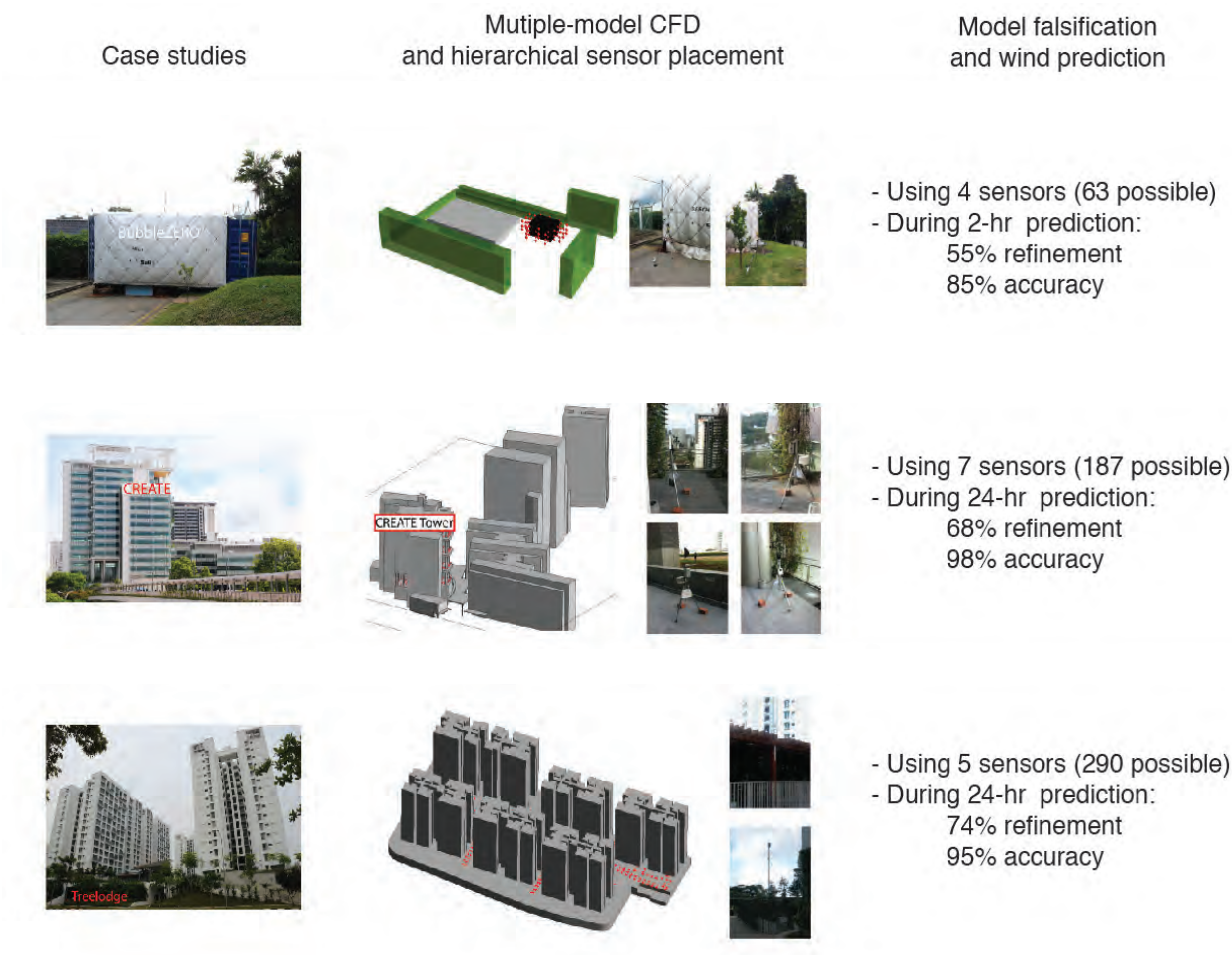

Fig. 05 Illustration of the full-scale studies a) BubbleZERO, b) CREATE Tower and c) Treelodge at Punggol, using multiple CFD simulations, hierarchical sensor placement and model falsification to improve predictions of wind speed and direction.

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Educating the world about interdisciplinary urban planning

Matthias Berger, Estefania Tapias

In spring 2014 a joint team from the Chair of Information Architecture at ETH Zürich and the Simulation Platform module at the Future Cities Lab kicked-off producing the first Massive Online Open Course (MOOC) about the topic of Future Cities under the lead of Gerhard Schmitt. Part of ETH Zürich's trial phase on MOOC-based teaching our MOOC together with the ETHx lectures on "Autonomous Mobile Robots" by Roland Siegwart and "Computing: Art, Magic, Science" by Bertrand Meyer became a huge success story. Currently the second MOOC on Future Cities is in production, to be broadcasted from September 2015 onwards, where we deepen particular aspects. A third MOOC is in preparation.

Fig. 01 Production of MOOC II – Livable Cities

Real classes, but different

Connecting and teaching people with an interest in urban planning and design from all over the world about future cities – this is the purpose of the edX MOOC "Future Cities". But first, what is a MOOC actually? The abbreviation MOOC stands for Massive Online Open Courses. These words describe the target audience of these courses perfectly; the online courses are open to everyone, preferably reaching out to a massive audience. From retirees over university degree holders to ordinary students and lay people, there is no prior knowledge required to understand our lectures. People with different backgrounds from all over the world are welcome to join our online classes and learn more about urban planning and other fields related to future cities. The ETH Zürich's are free of charge accessible online on the website www.edx.org.

Let's get into the peculiarities of our Future Cities MOOC. It consists out of ten thematic blocks, corresponding to the length of the lecture in weeks. Not a single professor but several lecturers with expertise in different academic fields teach the participating students more about a certain topic related to urban planning and design. In this way students will learn more about the interdisciplinary nature of the topic, as it is represented in the research endeavor of the Future Cities Lab itself. The challenge is now to avoid the technical language of science and architecture and tell the narrative in common wording. We strongly believe that it is important to make science accessible for more than only the academic community.

From a performative point of view, the MOOC's are coming close to real-life classes. The lectures are, among others, presented by professors and researchers of ETH Zürich and the Future Cities Lab in Singapore. Like in normal class, the lectures are enriched by a slideshow containing examples, formulas, or images. The lecturer is facing the recording camera like a class in the auditorium. However, there are definitely differences between a real-life class and these online open courses. First of all, the lectures' duration is significantly shorter. There is one thematic block every week which exists out of three short video clips of four to ten minutes. Gerhard Schmitt is always the first lecturer of each week, he introduces the thematic blocks. The other two video clips are lectured by him or the other lecturers are going more in-depth.

An important reason to have three short video clips is to keep the attention of the students. Feedback and analysis from previous online lectures have shown that the maximum engagement time with any educational video is about six minutes on average. Students have a much shorter attention span when watching educational videos online rather than attending real-life classes. With only a few minutes of recording time, it is a challenge for the lecturers and the post-production team to create lectures in such a way that they transfer as much knowledge to the students as possible.

An interactive experience

Besides shorter lectures, the online course also offers a more interactive experience. Directly after the video clips, the students are asked to answer a set of multiple-choice review questions. These are easy questions, but the student can prove that he or she paid the required attention to the video clips by answering these questions. Secondly, exercises are created next to the review questions. These open questions ask the student to go more into details. Students dig into national and global policies, develop solutions for environmental issues, or learn to read graphs. Students are also asked to work with online available tools and applications. More examples will be presented later on in this article. A better engagement and a better understanding is expected by letting the students make use of interactive tools and ask them to put theory into practice. Finally, the students have the opportunity to participate in interesting discussions on the webpage. A discussion topic is presented almost weekly. The result of the discussion are mightily interesting and are having a high value of diversification due to the different educational- and international backgrounds of the students.

One of the reasons why the MOOC is suitable for everyone who is potentially interested is the flexibility of the course. The students can take the courses on their pace. You do not have to attend the course weekly at 9am in the morning; it is your choice when you want to attend the course. Besides that, the MOOC gives the student the option to either only audit the classes or to also earn an honor code or verified certificate of achievement. The certificates will be sent to the students after the end of the course.

MOOC II "Future Cities – Livable Cities"

The first MOOC "Future Cities" of the Future Cities Laboratory (FCL) started in September 2014. A revised version was released in April 2015 including new exercises. At the same time we produced in Singapore and Zürich the second MOOC on "Future Cities" with special focus on livable cities. Lecturers include the initiator Gerhard Schmitt, the scientific director of FCL Stephen Cairns, the director of the Singapore-ETH Centre Peter Edwards, Jane M. Jacobs from Yale-NUS College, Matthias Roth from NUS, Jan Carmeliet from ETH Zürich, and from the senior researcher level Matthias Berger, Alex Erath, Estefania Tapias, and Ulrike Wissen Hayek. The chosen topics of the second MOOC were ecology, urban climate, energy and mobility – all related to the question 'what makes a city livable'. From September 2015 onwards the second MOOC is going to be broadcasted on edX. Come join the new learning experience!

Fig. 02-05 Production of MOOC II – Livable Cities

Fig. 06 Filming at the ValueLab Asia

Image Credits

Fig. 01-05: Estefania Tapias

Fig. 06: Denise Weber

Acknowledgements

We would like to thank Willemjin Hut, who finished her master programme in Human Geography and Urban Planning at the University of Amsterdam for the preparation of the MOOC lecture materials.

Principle Investigator Reviews

Armin Grün

Armin Grün

The Geomatics group of SEC-FCL was responsible for two Workpackages: (a) Automatic generation of reality-based city models (to develop a more automated pipeline for 3D city modelling from aerial imagery with the focus on robust 3D point cloud extraction and modeling, and on facade analysis and semantic description), and (b) 4D Singapore – Dynamic modeling of change in a city over time (to detect changes in terrain, buildings, streets, vegetation and water bodies and to model and quantify these changes to extract information valuable for urban analysis and planning). For the work under (a) a multi-senor approach was chosen, with very high resolution data from UAV images and point clouds from a terrestrial Mobile Mapping System. This was worldwide the first time that such very high resolution data was used for city modeling. Many new insights could be gained and algorithmic developments initiated. The work under (b) culminated in the PhD thesis of Rongjun Qin (3D Change Detection in an Urban Environment with Multi-temporal Data), where he investigated 4 different practically relevant data scenarios and developed automated data processing procedures.

In addition the group had to set up, run, maintain and make available a Geographical Information System (GIS), which accommodates most of the data used in the different modules. In this context the architecture of a Spatial Data Infrastructure (SDI) has been designed and implemented, considering the special requirements of urban research, which are different from those in general data sharing and service. Currently, the GIS database includes a rich collection of data from Singapore and partly from Indonesia, Thailand, China and Malaysia. The Geomatics group was imbedded into the Simulation Platform. Some of the R&D topics have been:

Fig. 01 Partially textured 3D city model of Punggol, Singapore. The model was derived from a WorldView-2 stereo-model by using CyberCity Modeler.

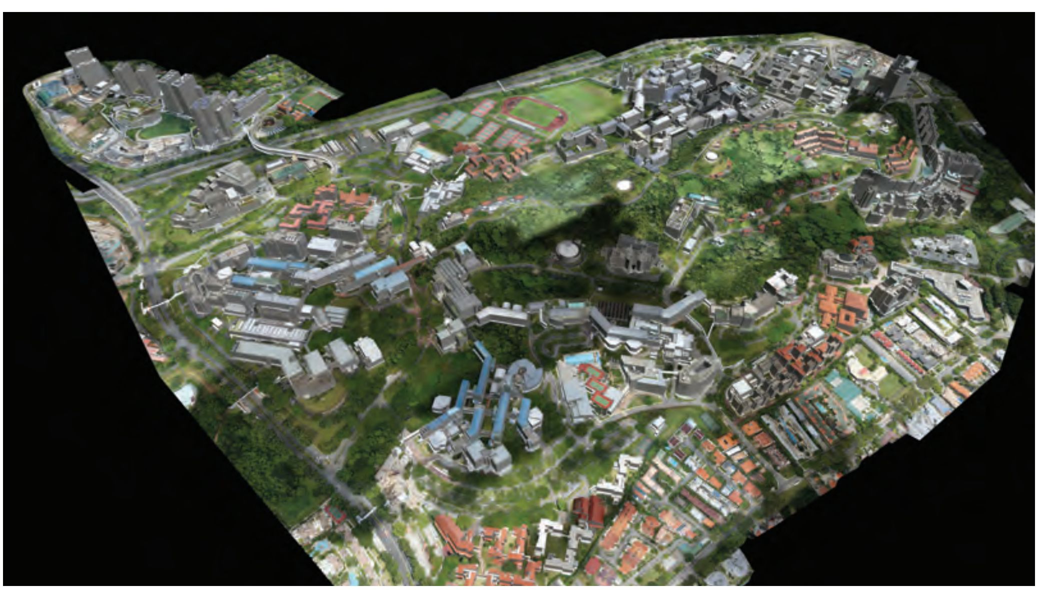

Fig. 02 Textured 3D model of the NUS campus, derived from UAV images

Image Credits

Fig. 01-02: Qin Rongjun, Fang Wei

- Automatic or semi-automated generation of Digital Surface Models (DSM) from satellite, aerial and terrestrial images and/or LiDAR data
- Further development of the semi-automated techniques (like CyberCity Modeler) onto a higher level of automation
- Integrated automated and semi-automated processing of laser
- scan point clouds and images, both from aerial and terrestrial platforms
- Streamlining the processing pipeline for UAV image data projects
- Exploring the various applications of UAV-based thermal imaging
- Set-up of GIS with 3D/4D capabilities
- Change detection and updating of databases
- Combination of real and synthetic (e.g. planned) objects (reality-based and generic modeling)
- Handling of dynamic and semantic aspects of city modeling and simulation. This leads to 4D city models

It is a particularity of Singapore that regular aerial images are not available, they are still highly classified. Therefore we have produced 3D city models for some areas of interest from high-resolution satellite images. We have generated 3D models for the traditional shophouse-dominated district Rochor ("Little India") from IKONOS stereo-images and for the newly built-up area Punggol from WorldView-2 stereo-images. The Rochor district data was used by more than 15 researchers from 5 different modules. Figure 1 shows a view onto a part of the Punggol model, which carries texture from satellite images on the terrain and on the roofs.

A major effort was devoted towards setting up a pilot project with the goal to collect very high resolution data of various types (images and point clouds) over the NUS (National University of Singapore) campus area. With this data methods of 3D data processing for city model generation should be exercised, further developed and refined. The input of our work was: (1) raw point clouds from a Mobile Mapping System (MMS); (2) UAV images; (3) few Ground Control Points (GCPs), (4) optional: Terrestrial images for geometric modeling of façades and texture mapping. The UAV part of the project is described much in detail in Qin et al., 2012, while the integrated processing of aerial and terrestrial image data and laser-scan point clouds from a Mobile Mapping mission is addressed in Huang et al., 2013. This was the first photogrammetric UAV project executed in Singapore. Figure 02 shows a view onto our textured campus model.

Furthermore, the Geomatics group contributed substantially to the following projects:

- Chilliwung river modeling by applying UAV technology (Module VII)
- Landfill project (Module III and AP M. Topalovic)
- Work on historic maps and archives (Module III)
- Generating data for Singapore-Delft Water Alliance
- Modeling of airflow around buildings (Prof. I. Smith, Simulation Platform)
- NUS administration. Using our campus model for facility management

The Group´s work found much interest with Singaporian government agencies, research groups and private companies. We had project- related and informative meetings and discussions with

- IDA (Infocomm Development Authority) Singapore – UAV technology
- NEA - Detection of breeding grounds of Dengue fever mosquitos by UAVs (pilot project)
- SLA - 3D change detection
- PUB - Flood modeling
- URA - 3D building and vegetation models
- NParks - 3D model of Botanical Garden
- PSA - Using UAVS for quality control of cranes
- ST Electronics
- HOPEtechnik
- Ryobi-G

In conclusion it can be said that the working conditions at CREATE campus were excellent. The work in a highly interdisciplinary team was very beneficial. Despite all the limitations in data acquisition, Singapore turned out to be an excellent proving ground for introducing new technologies in Geomatics, as applied to Future and Smart City issues.

Gerhard Schmitt

Gerhard Schmitt

The Ideal City has been a dream since centuries, never achieved, but always aspired to. Ideal has different meanings in different times and locations, but we want to associate it with liveable, safe, prosperous, creative and attractive cities. A contemporary method to imagine such a city is simulation, taking advantage of precise metrics driven by the rapidly rising amount of data. Simulation has become a valuable part of the design process of buildings, cities, and territories. As in science, it has developed into a crucial component next to theory and experiment. The urban system is an active field of research at ETH Zürich since the 1970s and the city as a complex system is a unifying concept of the Future Cities Laboratory since its inception in 2006. During the first phase of the Future Cities Laboratory since 2010, the urban system as a globally active research and application area of complexity science has evolved. Cities can be seen and modelled as complex systems, and as such will benefit from and inspire complex systems research. At the same time, alternative views on the urban system, such as the quantum city approach, must be possible.

A total of five principal investigators set out to realise the Simulation Platform: Prof Armin Grün from photogrammetry, Professor Ludger Hovestadt from computer aided architectural design, Dr Stefan Müller Arisona from computer graphics and music, Prof Ian Smith from computational structural engineering, and the author from information architecture. These different backgrounds, competences and approaches resulted in a rich research environment that achieved most of the goals set in the beginning.

We had high expectations when the Simulation Platform of the Future Cities Laboratory started operation in the fall of 2010. From the very beginning, one goal was to provide a safe deposit for the data and information collected and generated by all research modules of the laboratory, and to guarantee that everybody could retrieve more from the Simulation Platform than she or he put in. A second goal was to visualise the information generated and to run visual analytics on it. A third goal was the fluid interaction with data and information objects and to apply the information or knowledge gained to design and territorial planning. In addition, the Simulation Platform suggested to design and construct a physical laboratory to support the goals. This visual laboratory became known as ETH ValueLab Asia.

The path from idea to reality was short. In 2010, there were neither space nor researchers to support these goals in Singapore. Thus, the first task was to find the appropriate Ph.D. students and postdocs. To explain the idea of the Simulation Platform to the other research modules, to the emerging group of researchers and to the general public, we chose to break down the activities of the Simulation Platform into urban data acquisition, urban information modelling (including behaviour simulation and interactive modelling) and urban visualisation and communication. By the end of 2011, almost all of the 16 Ph.D. students were on board either in Singapore or at ETH Zürich. At the same time, the design and of the physical space and equipment for the Simulation Platform took shape. It was clear from the success of the ValueLab at ETH Zürich that the space had to be lofty and day lit, and that it had to feature the most advanced visualisation

Fig. 03 ZeroFossil Zürich

Fig. 04 An UAV presented by Armin Grün to Swiss Federal Councillor Alain Berset and Singapore Minister for Environment and Water Resources Vivian Balakrishnan is the in the ValueLab Asia.

Fig. 05 Spiro Pollalis, Ng See-Kiong, Dieter Läpple, experience the "Projections of Reality" at the Midterm Review event.

Fig. 06 Gerhard Schmitt explaining "Addis 2050" to President of Singapore Tony Tan.

Image Credits

Fig. 03: Jan Halatsch

Fig. 04-06: FCL

hardware and software. Experiences with research projects at the Chair for Information Architecture at ETH Zürich showed the need for a very large high-resolution screen to visualise the complex relations between the urban environment, its buildings and the performance data connected to those buildings. Also, seminal images generated in the ETH ValueLab determined the usefulness of large realistic perspective views of the city that provided a deeper understanding of the relationships between form, climate, landscape, and aesthetics than maps, diagrams or photographs. Early in 2012 we moved into the completed ValueLab Asia in the new NRF CREATE campus in Singapore.

Once the ValueLab Asia was designed and built - based on the ingenuity of Dr Stefan Müller Arisona and Dr Remo Burkhard - it could begin to support urban simulation software development and human computer interaction. The more urban features the ValueLab Asia was able to visualize, the more possibilities and requests emerged. The entire island of Singapore, with the simulated emission of heat from all buildings displayed on more than 36 million pixels was one of the first results that showed the power of the new device in 2012. The minute-by-minute recording of the Singapore sky and landscape, seen from the CREATE tower, visually overlaid by several meteorological data streams, is a recent use of the large display. In between were, for example, the presentation of an array of Self Organising Maps or SOMs, depicting the research landscape of the Future Cities Laboratory, the display of three-dimensional models generated with the aerial photographs from the unmanned aerial vehicle UAV, the transportation simulation for the entire island, or the airflow simulation through the CREATE campus.

One of side effects of the ValueLab Asia is its development into a highly frequented science policy platform, with literally thousands of decision-makers from science, industry, and politics as visitors and participants. Large displays of the Urban Heat Island UHI effects on urban climate, the dynamics and the transformation of Singapore's topography between 1924 and today, the prediction of airflow around high-rise buildings to improve computational fluid dynamics predictions by optimal sensor locations, the visualisation of pedestrian risk exposure through aerosols, visualising mobility and public transportation systems with isotime flow maps, or inferring dynamic building functions using urban transportation data, are just some of the highly detailed and interactive displays in the ValueLab Asia that decision makers and opinion leaders have seen and used for discussion.

By 2015 the research thrusts of the Simulation Platform had evolved into six major streams. At the core was still visualisation and visual analytics. Data acquisition and sensing had become more sophisticated, also due to the increased use of drones. Reality based and generic modelling began to show very concrete results, while alternative city theory and city models formed a new direction. Advanced multiple simulations, as well as GIS and geospatial analysis became standard. Urban design support, the main raison d'être of the entire ValueLab Asia, and a major tool to design ideal cities, slowly gained acceptance and is now a leading force towards the development of the Responsive Cities project.

Finally, the Simulation Platform results are also the subject of the first two Massive Open Online Courses MOOCs from the Future Cities Laboratory. With more than 23,000 participants in the first course alone, the ideas developed and tested in the Simulation Platform reach a far larger audience than originally expected. This opens the door to a development that will be researched and developed in the Responsive Cities scenario. The BigData-informed Urban Design, the Cyber Civil Infrastructures, the Engaging Mobility, and the Cognition, Perception, and Behaviour projects will be making use not only of specific data collected from dedicated sources, but also from data that participants in the MOOCs will provide. Thus, citizen science will develop into Citizen Design Science CDS, and design computing will involve through the participants in the MOOCs towards Cognitive Design Computing CDC.

In conclusion, the Simulation Platform provided the basis to collect, organise, and visualise data and to turn them into information and knowledge for design. This extensive data and knowledge base is available for all research modules, and evolved into one of the major assets of the entire Future Cities Laboratory. Finally, Massive Open Online Courses will lead to Citizen Design Science, and eventually to Cognitive Design Computing. The future Responsive Cities project, a modern interpretation of the ideal city, starting in the Fall of 2015, will build heavily on the results of the Simulation Platform.

Ian Smith

Ian Smith

The information obtained from sensors helps improve the way cities are designed and managed. There are a range of quantities of interest. For example, there are environmental quantities such as temperature, rainfall, pollution, wind speed, humidity and sunlight; city-flow quantities such as traffic, transit usage, food and water consumption, electricity demand and pedestrian behaviour; and finally, there are sensors that measure city-stock quantities such as bridge behaviour, water-reservoir levels and oil reserves. Realizing the importance of such information for sustainability, Singapore is actively increasing the number of installed sensors that measure all of these quantities and more.

Sensor information adds value to many activities. Sensors are used to record information for subsequent analysis; to control variables such as room temperature, traffic flow and building access; and finally to help improve prediction of behaviour. This last activity has been the focus of the research in Singapore under my supervision during the first phase of the Future Cities Laboratory.

While the data obtained from sensors can be treated through signal-analysis methods to provide predictions without using physics-based behaviour models, these predictions are only useful for situations when predictions are required at the same location of the sensor and for identical boundary conditions and topologies. The combination of physics-based models with measurements provides more flexibility for predicting behaviour at locations where there are no sensors and for studying the effects of changes in geometry, topology and boundary conditions.

For the first time, we applied a model-based methodology that has been used successfully in the area of structural identification to improve simulations of wind around buildings. In addition we used this methodology to devise a new method for optimal sensor placement and we illustrated our proposals using three full-scale case studies. It was a pleasure for me to work with a long standing colleague, Professor Benny Raphael, formerly at NUS and now at IIT Madras on this challenging project. Singapore has been an excellent platform for such research since simulation of wind is important for natural ventilation and since several groups at NUS had already used wind sensors.

Thanks are due to two PhD students who did all the work, Maria Papadoupoulou and Didier Vernay; Benny Raphael for his support and for the original idea of the project application area; as well as Chandra Sekhar for taking over at NUS when Benny left for India. Prof N.H. Wong, Associate Prof. M. Roth and Assistant Prof. C. Winston provided sensing equipment and Prof. em. A Gruen and his team at the Future Cities Laboratory provided the 3-D models for the CREATE building study. Finally, the MIT SMART group at CREATE, provided the information for the case study at Punggol. It is very rare to be able to collaborate so closely with so many good people.

The experience over the past five years has definitely exceeded my expectations. While I initiated this project hoping to work with people at ETH, MIT and at NUS, I did not expect to connect with such amazing people and achieve such good results. It has been for me an excellent example of the advantages of combining expertise. The working environment, with stimulating colleagues and excellent support staff, has created a situation where researchers are able to concentrate on obtaining and communicating new research results. The vibrant environment of Singapore, where one has the impression that all things are possible, has been fabulous and I am very much looking forward to the next phase of the project.

Transition Workshop

Bernhard Klein

As the research program of the Future Cities Laboratory came to an end in August 2015, it was time to review achievements, and outcomes of the Simulation Platform research module, including the impacts of the work of Principal Investigators (PIs), PostDocs and PhD students. For this reason, a three day Transition Workshop was held at the Singapore-ETH Centre on April 13-15th to show past and present research. Over 60 workshop participants were invited, including representatives from Singapore government organizations e.g. NRF, URA SLA, NEA, NParks and IDA, local and international universities e.g. NUS, NTU, SUTD, NCU Taiwan, UTHM Malaysia, and industry such as Sheer Industries Group, Autodesk, Singtel and the ESRI group. The agenda began with an overview by Prof. Gerhard Schmitt reviewing the original idea of System and Metrics for an Ideal City. In the following, presentations were mixed with live demonstrations to report not only on scientific advancements but also make them more tangible for a wider audience.

The keynote speech was delivered by Prof. Robert Woodbury, Program Chair in Interactive Arts and Technology at the Simon Fraser University. Prof. Robert Woodbury presented with his speech "Geometry & Big Data" potential transitions between Phase 1 and Phase 2 of the Future Cities Laboratory research program. Three workshops on the final day were organized to discuss future research directions for the Responsive Cities scenario, to strengthen collaborations with the Low Carbon Living CRC research initiative in Australia and to establish a stronger collaboration with the Industry in Singapore.

Fig. 01 Peter Edwards, Director of the SEC in Singapore, during the Transition Workshop

Fig. 02 Presentation during the Transition Workshop


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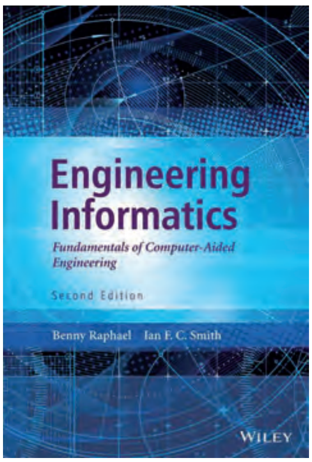
Fig. 03 The ValueLab Asia


Mumbai

Fig. 04 Participants of the Transition Workshop

Image Credits Fig. 01-04: FCL Research Module Simulation Platform

Book Reviews

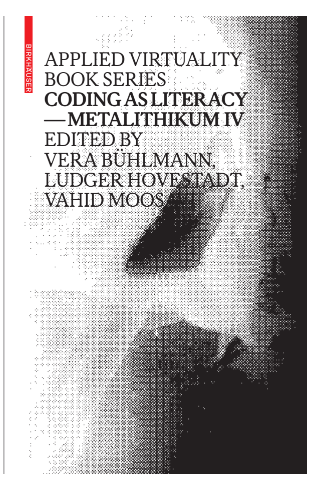


Engineering Informatics

Raphael, B. and Smith, I.F.C. Engineering Informatics – Fundamentals in Computer Aided Engineering, 2nd Edition, Wiley, 2013, 333p

This book describes fundamental principles of computing as well as algorithms and representations that are useful for engineering tasks. This information is independent of engineering software tools and hardware performance and thus, it provides general background knowledge that will remain valid throughout engineering careers. It is probably the only book of its kind that illustrates computing concepts using examples taken from building, civil and mechanical engineering. It currently serves as a text book for undergraduate and graduate courses in several countries.

The second edition of this book was prepared in part during residence of the second author as a Principle Investigator at the Future Cities Laboratory in 2012. Compared with the first edition, several additions and modifications were made. Most important to research work at FCL, parallel-axis plots have been introduced as an effective technique for visualizing multi-dimensional solution spaces. These plots have been used extensively by two FCL Phd students, Maria Papdopoulou and Didier Vernier, to visualize simulation results of candidate-model sets.



Coding as Literacy – Metalithikum IV

Hovestadt, L. Bühlmann, V. and Moosavi, V. Coding as Literacy, Applied Virtuality Book Series, Vol. 4, Birkhäuser Verlag GmbH , 2015, 352p

Recent advancements in computer science, namely in data-driven modeling techniques, have opened up a new level of design culture that also affects architecture. This book collects contributions to this emergent topic from information scientists, mathematicians, philosophers, design culture theorists, and architects. The overall interest of this Metalithikum conference was twofold: to think about, data in data-driven modeling in theoretical terms from quantum physics, and to consider computational procedures beyond a strictly case-based analytical paradigm, in a more principal role to see them embedded in a more comprehensive "computation literacy". Such a literacy in coding relates to a skill form that allows many degrees of sophistication to be distinguished, and hence reintroduces the criteria of adequacy and proportionality back into the realms of computability. The concrete point of reference for these discussions was one particular procedure called Self-Organizing Maps (SOM). The change in perspective discussed in this book reveals SOM to have great potential in relation to data-driven modeling that has yet to be explored.

Some of the contributions in this fourth volume of the Metalithikum series are aimed at specialists of information science, while others are more readily accessible and introduce the theme of data-driven modeling. The philosophical contributions help grasp the broader relevancy of the theme.

With a preface by Teuvo Kohonen, who invented and introduced SOM more than thirty years ago. And with contributions by Dr. phil. Vera Bühlmann, Chair for Computer Aided Architectural Design (CAAD), ITA, ETH Zürich; Prof. Michael Epperson, Center for Philosophy and the Natural Sciences, College of Natural Sciences and Mathematics, California State University, Sacramento; Prof. Barbara Hammer, CITEC cluster of excellence, Bielefeld University; Prof. Dr. Timo Honkela, Department of Information and Computer Science, Alto University; Prof. Ludger Hovestadt, Chair for Computer Aided Architectural Design (CAAD), ITA, ETH Zürich; Vahid Moosavi, Chair for Computer Aided Architectural Design (CAAD), ITA, ETH Zürich and Future Cities Laboratory, Singapore-ETH Centre; Prof. Sha Xin Wei, Director of School of Arts, Media + Engineering, Herberger Institute for Design and the Arts, Arizona State University, also Founding Director of Topological Media Lab, Concordia University, Montreal and Dr. Elias Zafiris, Department of Mathematics, University of Athens.

Quantum City

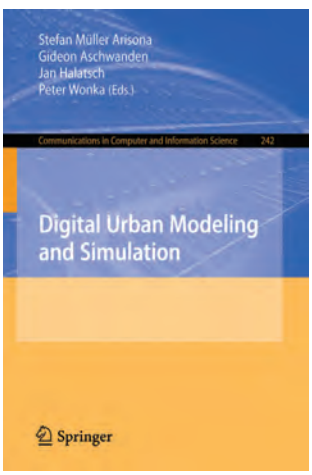
Alvarez-Marin, D., Roman, M. and Michael S. A Quantum City, Mastering the Generic, Applied Virtuality Book Series, Vol. 10, Birkhäuser Verlag GmbH, Hovestadt L. and Bühlmann V. (Eds.), 2015, 824p

We know the specific strengths of various cities, are aware of their ranking, are able to discuss their density and growth. But what do all cities have in common, what do we know about the ”lowest common denominator“? The ”city as a species“, the ”primal genetic material of the city“: this is the subject of A Quantum City. This colossal work is a love letter to the city and intellectual culture.

A Quantum City invites you to tap into the wealth of indexes belonging to our world. You get introduced to Orlando, a person with no noteworthy qualities, nor any particular properties: a human being who has not yet travelled. And it’s because of this that Orlando is singled out by the gods. He sets sail from Crete towards Athens in 320 BCE, hoping to find evidence of perfection. Throughout the book you follow him on his Odyssey through Western civilisation; though Orlando never quite ends up where she intended to go. And yet, by the time she arrives in the New York of the 1960s, all the decisions that have been made must be called hers. Orlando’s adventure is to challenge the collective origin of intellectual nature. In doing so, Orlando becomes neither an authoritarian functionary, nor a restless activist, nor a comfortable member of a bourgeoisie, but a citizen of the digital age, a Quantum Citizen.

This is not a book as you might expect. It doesn't offer a theory about cities; rather it speaks of any theory. It is not engaged in solving problems, but it is outraged at the kind of stupidity that cultivates ignorance, at the oppressive and anonymous demand that any solid formulation of a problem should be simple. And above all it takes you onto a journey to (re-)discover The City...

The book is divided into four interrelated chapters and can be read page by page in a discursive manner, however randomly browsing through the book also offers new and multi-faceted interpretations. Great intellectual achievements are compared with obscure and mundane events. A Quantum City offers an inspiring view of the city that is in us and around us.



Digital Urban Modeling and Simulation

Stefan Müller Arisona, Gideon Aschwanden, Jan Halatsch, Peter Wonka (Eds.)
Communications in Computer and Information Science (CCIS) 242, 2011

Abstract: In the last few years, the use of computers to study and solve urban planning and design problems has become widespread. More recently, and also thanks to the advances of computer technology, the focus has shifted toward integrative approaches that attempt to look at urban systems at multiple scales, both in terms of space and time. However, such approaches also imply being connected to a growing number of fields, and it can be hard to keep track of the connections and – more importantly – of the connection points. Thus, many solutions computer and information science might have to offer are simply not recognized.

This book is thematically positioned at the intersections of urban design, architecture, civil engineering and computer science, and it aims to provide specialists coming from respective fields with a multi-angle overview of state-of-the-art work currently being carried out. It addresses both newcomers who wish to obtain more knowledge about this growing area of interest, as well as established researchers and practitioners who want to keep up to date. In terms of organi- zation, the volume starts out with chapters looking at the domain from a wide angle and then moves focus toward technical viewpoints and approaches.

Contributors

as they appear in the magazine

Prof. Dr.Peter Edwards
SEC Director and Principal Investigator of Ecosystem Services in Urban Landscapes.

Peter Edwards is the SEC Director and Principal Investigator of the Ecosystem Services in Urban Landscapes project at the Future Cities Laboratory in the Singapore-ETH Centre. He obtained his Ph.D. degree from the Cambridge University. Since 1993 he has been professor of plant ecology at the Swiss Federal Institute of Technology (ETH), where he has also served as chairman of the Department of Environmental Systems Science. His recent research has focused particularly on large-scale processes in terrestrial ecosystems.

Dr. Matthias Berger
Senior Researcher at FCL Research Module Simulation Platform

Matthias Berger is a senior researcher and Module Coordinator of the Simulation Platform research module at the Future Cities Laboratory in the Singapore-ETH Centre. He studied electrical engineering in Germany and received his doctorate in energy science from ETH Zürich. Prior to that he was working with EADS Astrium and Space Transportation on satellites and spacecraft propulsion.

Prof. Dr. Stephen Cairns
Scientific Coordinator of the Future Cities Laboratory

Stephen Cairns is the Scientific Coordinator of the Future Cities Laboratory in the Singapore-ETH Centre, and Professor at the Department of Architecture at ETH Zürich. He is a member of KRUPUC, an independent interdisciplinary, multi-sectorial research, planning and design platform focused on issues of urbanisation in the Southeast Asian region.

Prof. Dr. Gerhard Schmitt
Lead Principal Investigator at the FCL Research Module Simulation Platform

Gerhard Schmitt is the Lead Principal Investigator of the Simulation Platform research module at the Future Cities Laboratory in the Singapore-ETH Centre, and Professor of Information Architecture at the ETH Zürich. He was the founding Director of the Singapore-ETH Centre in Singapore, and ETH Zürich Senior Vice President for ETH Global. Gerhard Schmitt initiated and conceptualized the Zero Emission ETH Science City Campus and received for this work the 2010 European Culture of Science award.

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Ian Smith

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