COLLABORATIVE LARGE-SCALE URBAN DESIGN WITH THE FOCUS ON THE AGENT-BASED TRAFFIC SIMULATION

KATERYNA KONIEVA\textsuperscript{1}, KATJA KNECHT\textsuperscript{2} and REINHARD KOENIG\textsuperscript{3}
\textsuperscript{1}Singapore-ETH Centre, Singapore University of Technology and Design
\textsuperscript{1}konieva@arch.ethz.ch
\textsuperscript{2}Singapore-ETH Centre
\textsuperscript{2}katja.knecht@arch.ethz.ch
\textsuperscript{3}Singapore-ETH Centre, Austrian Institute Of Technology, Bauhaus-University Weimar
\textsuperscript{3}reinhard.koenig@uni-weimar.de

Abstract. The better integration of the knowledge and expertise from different disciplines into urban design and the creation of more interdisciplinary and collaborative work processes to accommodate this have been under discussion in related research for decades. Nevertheless, many barriers preventing a seamless collaborative work flow still persist. In this paper we present an experiment taking place under real-world conditions, which outlines an alternative way for more efficient collaboration by focusing on the design process rather than the result and thus providing additional insights for all parties involved. A parametric design approach was chosen to help mediate between the areas of expertise involved supporting the smooth transition of data, the mutual translation of design feedback and better informed design decisions as an outcome. The case study presented in this paper exemplifies the application of the approach in a design project on masterplan scale integrating inputs from urban design, economics and mobility experts; and shows the opportunity for transforming the formerly segregated design process into a platform for transparent negotiations.

Keywords. Parametric urban design; urban mobility; collaborative design.

1. Introduction
Rapid urbanization and climate change are the key challenges to urban design in the 21st century and add further to the complexity of urban design and decision-making processes. The better integration of knowledge from related areas of expertise has been hailed as a solution and increasingly as a necessity to create more sustainable and resilient urban environments and systems. However, the design and implementation of more collaborative, interdisciplinary urban design
processes as well as of methods and tools to support these have been slow and have been facing challenges of their own. In this paper we present the workflow and results of a collaboration between urban design, economics and mobility experts, which was devised as a ‘save-to-fail’ experiment taking place under real-world conditions. This set-up provided an alternative way to support collaboration from the technical perspective by focusing on the design process rather than the result.

The goal of the collaboration was to establish an integrated interdisciplinary workflow between urban design and transport planning to overcome the traditional sectoral approaches in urban design. The underlying assumption was that a better integration of transport planning expertise in the early stage of the design process would help to create more sustainable urban layouts by considering not only individual design proposals, but different scenarios of each depending on the transportation strategy. The advanced planning of the transportation system, preferred mobility types and the formulation of the mobility issue to address would open up many more opportunities compared to considering these only at the later design stages, as every aspect up to the built-up density and development phasing could still be manipulated and negotiated at this point. The ‘safe-to-fail’ experiment described in this paper, where several research teams with various expertise were working on a large-scale design project, allowed to set up and test the workflow between parametric design and agent-based simulation tools to support the necessary exploration and negotiation process among teams.

However, the interaction and communication between urban designers and transport planners, methods and tools as well as the establishment of a joint workflow was not free from challenges. In the following, we present the state of art in the field and the step-by-step documentation of our experiment. We describe the aims of the project, the expertise involved, as well as the detailed ways of exchanging information and evaluation results, which provided the subsequent opportunity for the informed adjustment of decisions.

2. Background

It has been argued that the challenges arising out of urbanization and climate change require a new, integrated approach to urban design, which ties together various disciplines and expertise that previously were only loosely connected in the design process (Gaffron et al. 2005, Ahern 2013). An integrated approach entails the collaboration between different practices allowing for knowledge transfer between teams with the aim to increase the sustainability and resilience of urban form by cross-validating methods and knowledge as well as to increase the transparency and deliberation of the process (Gil and Duarte 2013, Tennøy et al. 2016, Waddell et al. 2018). However, the actual implementations of successful interdisciplinary processes and the integration of disciplines in urban design remain scarce and are considered gaps in research still to be addressed (Wilson 2018). Risk averseness and fear of failure have been found to inhibit the implementation of an integrated approach (Ahern, 2013). To overcome some of the challenges affecting integrated urban design and its uptake, Kato and Ahern (2008) suggested to advance transdisciplinary collaborations in research through adaptive design in form of ‘safe-to-fail’ experiments.
Integrated computational urban design methods and tools are thereby seen as important means to help synergize expert knowledge and design integration (Wilson 2018). However, existing planning support systems (PSS) have been criticized to focus too much on technology to sufficiently support planning practice and as being primarily used to inform rather than to support design and decision-making and in consequence of lacking a lasting impact on the design process (Geertman 2006, Batty 2007, Al-Douri 2013). This has mainly been attributed to a lack of transparency and flexibility of the systems, as well as understanding of how they can be applied and best benefit the design process (Vonk et al. 2005, Al-Douri 2013).

Urban modeling techniques have been hailed as a way to overcome the limits of more traditional methods by helping to better address the complexity of modern, multidisciplinary projects, allowing to integrate new data sources and test alternative scenarios, and to thus improve the transparency and adaptability of the system (Al-Douri 2013, Wilson 2018). Modeling frameworks have tried to implement the idea of integrated, transdisciplinary work processes for real life use. For example, the modelling framework SIMULACRA allows planners to access complex urban models visually and to rapidly assess different urban scenarios, thus improving the user-friendliness and understandability for planners (Batty et al. 2013). Also, the Cognitive Design Computing framework, which proposes a modular strategy of design generation and analysis techniques based on the platforms Rhino and Grasshopper, addresses the aforementioned challenges and shortcomings (Koenig et al. 2017). The proposed framework connects design generation and analysis methods to create, evaluate, and optimize parametric urban master plans for projects on different scales and contexts (Dennemark et al. 2017, Konieva et al. 2018).

Despite the support of digital tools, the role of the designer to lead, negotiate and synergize inputs from different disciplines and stakeholders in the design and decision-making process remains. In empirical studies, Tennøy et al. (2016) found that the lack of access to and accessibility of expert knowledge for designers and the lack of understanding of the results and ability to translate expert recommendations into action can inhibit their integration. In particular, methods used by planners to analyze transport and traffic related aspects and to assess design decisions have been found to be very often based on so-called ‘tacit knowledge’ (Tennøy et al. 2016, p. 8), which stems from previously acquired knowledge and experience rather than strategic relevant domain knowledge. Alternatively, if related expertise is sought to assess the impact of design decisions, it has been found that this usually is done after a proposal has already been agreed on. However, due to the close relationship and the interdependency between urban layout, land-use, density and transport, the better integration of transport planning expertise is a requisite for sustainable urban development (Dempsey et al. 2010, Tennøy et al. 2016).

In the following we describe and discuss the results of a ‘safe-to-fail’ experiment, which allowed to test an integrated approach to urban design as a collaboration between experts in urban design and parametric design, transport planning and economics in the scope of an experimental case study.
3. Case study description

Waterfront Tanjong Pagar was launched as a synergy project in 2016 to bring together the multiple disciplines involved in the Future Cities Laboratory (FCL) in the design of a sustainable redevelopment strategy for the port area of Tanjong Pagar, Singapore. The container terminal at Tanjong Pagar will be relocated by 2027 freeing up 400 ha of land close to the waterfront and the central business district. The aim of the synergy project was to integrate and synergize research findings from different research teams into a design-based proposal for the site.

A scenario was developed based on assumptions on the future economic and demographic development, and expected changes in future mobility, advancements in technology, and challenges arising out of climate change. The guiding design principles and concepts were developed by the urban designers of the Grand Projet team in form of a master plan proposal, which provided the basis for the integration of other planning expertise. The initial design brief was created based on the economic predictions and synthetic population model, which provided the expected population number, percentage of the land uses, density limits, and distribution between private and public residential developments.

The workflow between the teams took different shapes during the development of the project. Largely, it consisted of multiple small iterative loops, in which experts from different teams gave feedback on the proposed design and provided recommendations for modification. Our Cognitive Design Computing work stream provided technical assistance in form of the translation of the design proposal with assisting CAD drawings, Excel sheets and sketches into a parametric urban model to incorporate contributions from various teams. A workflow between the parametric urban design framework and the agent-based traffic simulation software MATSim (MATSim Community 2019) was developed in collaboration with the Engaging Mobility team. The smooth design and evaluation data exchange was supposed to support integrated mobility related design-decision-making, which would trigger the necessary design adjustments at an early stage.

4. Mobility module

The mobility integration in the current experiment was regarded as an integral part of the initial conceptual proposals which contained necessary data for the meaningful simulation results. The simulation required the data sets summarized in Table 1. Several datasets were provided by the Engaging Mobility team, including existing public transport information and vehicle capacities, characteristics of autonomous vehicles (AVs), and car ownership statistics.

Other information, such as built-up area and type of land use, was generated based on the urban design concept. The master plan proposal divided the site into separate zones with distinct features for each (Figure 1). Parametric tools proportionally assigned the number of square meters for each land use type to each individual street block. The resulting information was geo-referenced and converted into csv file format that could be read and written in both Rhinoceros/Grasshopper and MATSim.
In Singapore, the road reserve types and characteristics are specified by the regulations of the Land Transport Authority (Land Transport Authority, 2018). The regulations specify the required buffer zones, as well as all other elements, including center median, carriageway and side tables (tree planting, verge and services, cycling path, footpath). The existing regulations were questioned by the Engaging Mobility group in the anticipation of the impact of AVs on street design. In particular, the implementation of AVs is expected to affect the need for parking space and the public transport fleet size (Soteropoulos et al., 2019; Zhang and Guhathakurta, 2017), which would have a direct impact on the road typology.

Several new street typologies were developed, which also included revised policy measures, such as the design speed of each road type and restrictions on private vehicle usage. They were generalized and grouped into three street categories according to their total width, vehicle capacity and buffer requirements and then distributed across the site according to their role as local (category 3, 15m), main (category 2, 25m) or arterial road (category 1, 15m) (Figure 1). The road segments configuration and characteristics were similarly transferred into csv format in preparation for the MATSim simulation.

### Table 1. Data required for the traffic simulation.

<table>
<thead>
<tr>
<th>Element</th>
<th>Road network</th>
<th>Public Transport system (subway)</th>
<th>AV system</th>
<th>Mobility demand</th>
</tr>
</thead>
<tbody>
<tr>
<td>Data required</td>
<td>- Nodes (lat/lon) - Links (from/to)</td>
<td>- Stops (lat/lon) - Lines (sequence of stops, sequence of roads, departure times) - vehicle capacities (int)</td>
<td>- Fleet size (int) - Vehicles capacities (int) - Vehicles initial location (lat/lon) - Pick-up Drop-off locations (lat/lon)</td>
<td>- Building floor area by land use type (sqm) - Road flow by time of the day (veh/hour) - Public transport ridership by time of the day (passengers/hour)</td>
</tr>
</tbody>
</table>

5. Traffic Scenarios and Design Implications

In two iterations, we collaboratively developed and analyzed four different scenarios for comparison (Figure 4). In the first iteration, pick-up and drop-off points for vehicles were generated randomly in Grasshopper and two simulations...
were executed: with the car access under present day mode share policies (scenario a); and with restrictions on private vehicle parking, pick-up and drop-off on the local streets (scenario b). In the second iteration, the predefined drop-off points were distributed in two ways: homogenously with an average distance of 400 m between each other (scenario c); and with their distribution frequency depending on the built-up density (400 m in areas with a Gross Plot Ratio below 5.0 and 200 m in areas with a GPR above this threshold - scenario d).

Figure 2. From left to right: minimum speed (km/h), maximum flow (vehicles/h/ lane) and maximum density (vehicles/h) for four scenarios for each street segment.

Figure 3. Mode share for four scenarios.

Figure 4. Minimum speed (km/h) in each street segment in each direction; warmer color represents a slower speed. MATSim simulation results visualised in Rhinoceros & Grasshopper.
We considered the following four criteria from the MATSim analysis for the evaluation of the design proposal: minimum speed (km/h), maximum flow (vehicles/h/lane), maximum density (vehicles/m of the road) for each street segment, and total number of trips per each mode share type (Figures 2, 3). The mode share indicated the number of trips made by private vehicles, MRT (subway) and 4, 10 and 20-seaters AVs.

A minimum speed parameter with a value equal to zero could either mean an extreme traffic jam with no possibility to move or a street with no vehicles passing through. Comparing the maximum flow with the full flow would indicate how much the actual number of vehicles varies from the expected number. Full density of traffic flow was defined as 1 vehicle per 7m (0.143 vehicles/m) on average, where a higher number indicates heavier traffic and zero indicates a vehicle-free road. No optimal values exist for any of these three parameters, but by combining them it is possible to find out, which points could be targeted and adjusted in the subsequent design iteration.

Comparison of the mode share revealed the lowest use of private vehicles in scenario b and the lowest total amount of trips in scenario a. Further we compared the simulation outcomes for each street category between different scenarios to establish the relationship between street network design and traffic-related aspects. A comparison of the minimum speed revealed for scenarios a, c, and d that the average minimum speed did not vary significantly between road categories 1 (arterial road) and 2 (main road). Values ranged between 6.6 and 7.6 km/h, although the assigned design speed for categories 1 and 2 were 50 and 30 km/h respectively (Table 2). In scenario b, however, the vehicle flow was significantly lower for category 2 indicating limited use of streets of this road type (Figure 6). The analysis of maximum flow for category 3 (local streets) returned low values in all scenarios, which meant vehicles were rarely passing through (Figure 6). The last parameter, maximum density, revealed that 30 to 44% of the streets of category 1 exceeded the threshold of 1 vehicle per 7 m and hence would experience traffic jams. The highest level of congestion occurred in scenarios a and d.

Several trajectories for design improvement could be laid out based on the evaluation of the simulation results. Pursuing a reduction in the usage of private vehicles as a general strategy, scenario b would constitute the most justified option, as the restriction of vehicle access in local streets impacted vehicle usage. In consequence, however, this scenario also showed a low rate of street usage indicating an unnecessary coverage of space with roads. A possible design response was a closure or repurposing of underused streets, which would create additional buildable area and reduce infrastructure cost. A disadvantage of this scenario was the limitation of car ownership for residents, which might not necessarily find favor among stakeholders in the decision-making process.

Scenarios a and d showed the highest load on the roads, with several streets prone to congestion. This could potentially be resolved by closing the most congested streets to redistribute traffic, which would need to be validated by an additional simulation. One of the biggest advantages of the scenario d, however, was the shortest average distance between pickup and drop-off points, which could be reached within 200 m in highly dense areas. This scenario would be the optimal
solution for a design concept focusing on walkability.

Scenario c had the highest total number of trips, especially by private vehicles. Nevertheless, it showed the lowest rate of congestion and second highest usage of the roads. As was illustrated, by testing various transportation strategies, one design proposal can have at least several development scenarios not only with regards to transport and mobility, but to the urban form and economic indicators.

Table 2. Average values of simulation outcome (not including the values for underground tunnel).

<table>
<thead>
<tr>
<th>Road category</th>
<th>Design speed, km/h</th>
<th>Minimum speed, km/h</th>
<th>Maximum flow, vehicles/h/lane</th>
<th>Maximum density, vehicles/m</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>a</td>
<td>b</td>
<td>c</td>
<td>d</td>
</tr>
<tr>
<td>1</td>
<td>50</td>
<td>6.07</td>
<td>7.64</td>
<td>7.39</td>
</tr>
<tr>
<td>2</td>
<td>30</td>
<td>6.69</td>
<td>6.97</td>
<td>6.90</td>
</tr>
<tr>
<td>3</td>
<td>25</td>
<td>5.54</td>
<td>3.70</td>
<td>5.45</td>
</tr>
</tbody>
</table>

Figure 5. Maximum flow (vehicles/h/lane) value for road categories 2 (left) and 3 (right).

The adoption of each scenario would result in specific design and policy implications, which would require a number of compromises. In the experiment the Speckle open source platform (Stefanescu, 2015) was used to communicate the quantitative simulation outputs visually for further negotiation among the teams involved in the project. However, discussion about the results of the traffic simulation ended at the point at which a low congestion of streets could be interpreted as affirmation of the proposed street network. Although the aim was to support integrated and adaptive urban design, it ended up following traditional models. This suggests that deeply rooted behaviorisms and habits in the collaboration between experts in urban design process need to be addressed.

6. Conclusion

In this paper we presented the results of a collaborative, interdisciplinary project, which aimed at overcoming existing traditional sectoral approaches in urban planning and, in particular, the better integration of mobility expertise in the urban design process. To this effect, we established a workflow between the parametric urban design framework and the agent-based traffic simulation software MATSim, which simplified the analysis of urban design proposals and provided a basis for discussion of necessary design adjustments for more sustainable land-use and transport planning at an early stage. The presented experiment has shown the benefits of this approach, which allowed to transfer design and analysis data
between the two applications more fluently and flexibly compute and visualize different simulation scenarios.

The presented experiment has shown the opportunities of a parametric approach, which provided the basis for quick analysis of the design alternatives based both on the urban design concept and transportation strategy. The modular approach and the openness of the software platform also provided enough freedom to allow for the integration of expert tools in the design generation and analysis workflow, in this case MATSim. The experiment did not indicate the best design solution, neither did it merely inform the mobility experts on the required strategy. Instead, it provided a platform for negotiations, where all parties could interpret the analysis of the others and adjust its own strategy.

However, the implementation of a dynamic planning model and the integration of expertise-specific analysis and knowledge faced challenges stemming both from a lack of common computational platforms as well as a lack of understanding of the expert input and its implications. It applied to the expertise-exclusive decision making and adherence to traditional models of development which reflected that the uptake of computational methods in planning and education, which allows to better facilitate integrated, interdisciplinary planning, has remained slow. In the specific case, the simulation results from MatSim were initially taken as affirmation of the proposed street network design without requesting expert evaluation laying out further possibilities for improvement. Consequently, the project followed existing models of applying expertise in urban design rather than using it to help guide the development.

It has been argued that learning how to use and apply expert input through practice supports the wider dissemination of integrated planning. In such, the synergy project as ‘safe-to-fail’ experiment provided the perfect framing and a real-world context for learning out of a mutual knowledge exchange as well as testing a workflow for better integrated urban design. This approach seems promising but that more research is needed in how to initiate discussion and negotiation to help overcome the deep rooted behaviorisms and habits of traditional urban design.

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