

Parametric assistance for complex urban planning processes

Three examples from Africa and South-East Asia

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Abstract—This paper will discuss the process of development and application of procedural methods in urban planning and design. Despite a lot of progress being made at architectural scale to consider a planning area as an integrated system of infrastructure, constructions, uses, socio-economic indices and many more, there is a gap in approaching larger urban areas with a similar degree of coherence.

Addressing this challenge, we were working on a framework that would facilitate communication and discussion during decision-making processes between various fields of expertise. Using a modular approach, we developed a design and analysis workflow for a city-scale project in Ethiopia, district-scale developments and neighborhood-scale interventions in Singapore. The number of examples shows the flexibility of the approach and its prospect for more effective transdisciplinary collaborations.

The method applied has proved a high potential due to approaching several aspects simultaneously: the speed and, hence, number of variations considered can be increased drastically enlarging the design space with no significant time investments; a modular work flow breaks down the linear sequence of the design process and gives opportunity for changes at any stage without affecting all the decisions made afterwards; automatization of a larger part of decisions makes it possible to correct the direction of the initial strategy, as a simple draft with any level of detail is enough to generate the best possible solution on its basis. These case-studies have also shown that parametric interventions can be most effectively made in several phases of project development that include analysis, design generation and evaluation.

Keywords-urban design, modular design process, parametric design, case study

I. INTRODUCTION

In recent years a huge technological progress was made in order to digitalize and automatize design processes and to integrate various types of analysis from related disciplines into

one workspace. Despite seemingly simplified ways of exchange between expertises, the design process is treated in the same way fundamentally. There is an established order, in which every stage, as a check or input from the experts, can only start upon completion of the previous one. In this case, introducing minimal changes to decisions made at the earlier stage of design can lead to very costly modifications of the overall project when done at later stages. This not only puts the most of responsibility onto earliest, often only conceptual stages with very general numbers in operation, but also restricts designers from introducing desirable changes later, because the cost of changes outweighs achievable benefits.

Breaking the linear sequence of the design process is not possible by point interventions, but by reconsidering its whole structure and a way of approaching it. It can be more efficient in a form of an interconnected network of actors and processes [1], where each one can be modified, added or removed at any time, immediately reflecting changes at all other network components. This approach, applied in information technologies in form of open-source developments [2], turned out to have an undeniable number of advantages, including compatibility with the most of widely-used data formats, and the development process, independent of limited number of founders.

From the perspective of urban planning, there is a recognized peculiarity of large-scale urban developments – it lacks a naturally evolving complex relationship between its component parts. From the modern capital of Brazil to the new towns in the United Kingdom to the ghost cities in China, these places are created with an inherent hierarchical structure (a “tree”) not providing for any overlap of its subsystems [3]. In contrast, an open modular design process allows setting up the structure of each subsystem (module) independently, not in a form of a design solution, but rather a formula, regulating its basic principles and limitations to adapt for any possible context. It is already being developed for architecture as an Open

Architectural Design (OAD) model [4], but applications for a larger scale with even more complex relationships between both internal and external factors are yet to be explored [5].

The major challenge we addressed in our projects is the communication of processes, expertise and the transparency of decision making. In the case-studies discussed, we developed similar algorithms for every project, nevertheless several possible outcomes for each one varied significantly. Each of the variation sets had different initial aims: either it was same-principle solutions for different geographical and climate environments or several conceptual proposals for the same area. Observing how urban systems in generated design proposals react on these differences, the principles behind each algorithm become more visible. Moreover, professionals from different fields of expertise might see the influence of their own design principles (rules) on other components, therefore the design proposal turns into a very objective negotiation space.

The method was applied on three case-studies varying in the scale, context and degree of intervention: new towns in Ethiopia, district planning and neighborhood design in Singapore. For all case-studies' proposals we used a modular parametric design method combining expertise from architecture, urban planning and design and computer science with specific input from transport planners and energy systems specialists.

II. METHODOLOGY

In all projects presented here we divided the workflow into phases of analysis, design and evaluation. Experience shows that in such a complex matter as urban planning splitting the task into sub-tasks with their own evaluation criteria might be seen as oversimplification [6], [7]. Therefore, the system of interconnections and evaluation cycles had to be customized for each specific case (Fig. 1).

The software used for testing the methodology was Grasshopper and Rhinoceros. It proved itself for the application in architecture allowing the combination of an increasing number of plugins and professional tools, e.g. for engineering, constructions, energy consumption, etc. It is especially valuable and mostly used for conceptual design solutions, although, its application for problem solving is gaining popularity. Currently studies are mostly focused on specific problem solving [8], while we are proposing to consider parametric approach as a unifying framework.

Generally, the approach implied a phase of analysis to take the role of prior site analysis, of defining problems and potentials, establishing design requirements, specifying and collecting all data needed. Depending on the scope of the task, the interested parties involved and planner's expertise, the analysis phase might end up both with a strict limitations and concrete numbers, or with an opportunity to think out of the box, overcoming locally established guidelines. In our approach this question stayed flexible. Nevertheless, there was a predefined criterion signifying completion of this phase before moving to the next one. We had to be sure about all sources of data (further: inputs) needed for the design process and we had to know the values of which were fixed and which were flexible. In the case of a limited from all sides city space, the site border might be a

fixed input and the planned population density might be flexible and varying according to the evolving concept.

The design phase was structured more precisely: for each case-study we divided the process into generative modules, sometimes with micro-cycles of evaluation and re-generation. The module devoted to the creation of the street network might have one iteration with one design proposal as the output. In the next module, when we had to define the street width and fix vehicle- and pedestrian routes, the generated street network was evaluated for traffic situation based on which the width was adjusted if the result was unsatisfying. In a similar way, almost all other modules had Design-Evaluate-Redesign cycles (Fig. 1) for getting optimized by a relatively small number of criteria. Larger cycles also took place: if the outcome of one module could not be optimized to the accepted level using the solution generated by previous ones, then we had to step back even more. The outputs of one module could work as inputs for another one that allowed modules to be interdependent when it was needed and autonomous otherwise.

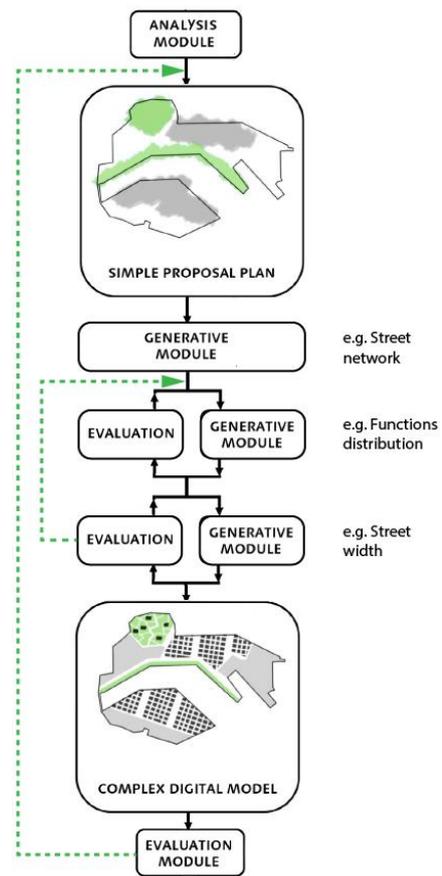


Figure 1. Scheme of the method

Evaluation of design was made on two levels – a micro-cycle evaluation within each module and the evaluation of the final proposal. The latter one can be as concrete as the cost of construction, and as open as the microclimate in public spaces. Evaluation criteria on a larger level were meant to compensate a possible lack of integrity between smaller modules, as two perfectly optimized solutions might not get along well in situation of a particular combination of factors. This might be a

successful cultural or commercial attraction in a mixed-use neighborhood that will attract a high amount of visitors, but by doing so will increase noise and traffic for local residents. Such situations are hard to predict quantifiably and they are too location-, culture- and regulations-sensitive, and require further expertise. But it will only be worth to spend the efforts on if other requirements are already met. Micro-scale evaluation was adapted individually for each module; there were defined criteria for optimization and domain of input parameters to choose from. In our case, the decision-making (search for the most optimal solution) was mostly done manually. For example, possible distribution of land uses in the function-distribution module had many variations. A solution was manually selected by the designer and was based on more appropriate arrangement, e.g. more public uses near well-integrated streets, and coherence with existing functional pattern (creating new schools on reasonable distance from the existing ones).

III. CASE-STUDIES

In this paper we present three projects realized during the last two years. Each of the case-studies we conducted varied significantly in all aspects: from the points of intervention of parametric tools to the outcome format, be it a design (Ethiopian towns, district planning in Singapore), design space or evaluation report (Urban elements for the neighborhoods in Singapore). In some cases it was possible to base the whole design process on parametric techniques and in others to just introduce them in a few points of intervention. Non-less important, the application of parametric techniques varied between analysis, design and evaluation, sometimes combining and interconnecting all three.

A. Case study #1: 10K town in Ethiopia

Project “Syncity” was launched as a design studio at the Bauhaus-University Weimar, Germany, in 2016. The background was a collaboration between the university and the Ethiopian Institute in Addis Ababa (EiABC) to address current challenges in Ethiopian urban development. The process of rapid urbanization with thousands of people coming from rural areas to cities annually caused a shortage of resources, infrastructure, housing and job offers, at the same time rapidly shifting economy away from agriculture – currently the main economic driver.

One possible response to these processes was to disseminate migrating population to a huge amount of new developments, so-called “10K towns”, positioned somewhere in-between the status of a village and a city and combining the benefits of both [9]. Citizens of new towns would take advantage of advanced infrastructure, improved living conditions and emerging job opportunities, while keeping relatively low population density and available agricultural land for cultivation. Considering the ubiquitous diversity of the country spreading from a variety of languages and religions to the landscapes and climatic conditions, the task to design several thousands of new towns would be unfeasible in a short period of time.

In this context, the first use of a parametric approach in urban design was to facilitate and optimize multiple similar actions that are following similar principles. We applied the method on

three topographically different locations in the Ethiopia (Fig. 3). Creation of the new city “skeleton” would always consist of the street network, main facilities distribution, land use and density schemes, and housing typologies (Fig. 2). In most cases these modules would be used in similar sequence and consider the same number of conditions for their design. General input data was defined during the phase of analysis: as locations given with a design brief had no built-up surroundings, we used the terrain geometry and existing main road.



Figure 2. Five modules for 10K cities in Ethiopia

The main design phase consisted of five modules including: defining city border, sketching basic streets, specifying secondary street network and street blocks, distributing basic facilities and, finally, housing typologies. The city boundary was created based on natural limitations, such as steep slopes or fertile ground. Basic streets were to solve several tasks simultaneously: to remove water and prevent floods in rainy seasons and to collect and store water in periods of droughts. So, the main streets always depended on the terrain and followed watersheds. The final street network was intended to be modular and adaptable for various functions, therefore secondary streets were created with 100-meter step starting from the existing

arterial road and those blocks that exceeded 500 meters in length were split. At this stage, it was possible to reveal the best integrated blocks to create the main and local commercial centers and to assign other specific land uses. Finally, five housing typologies, derived from existing studies on Ethiopian cities, were distributed from the commercial centers outwards, gradually decreasing density but still preserving mixture, also the mix of target income groups.

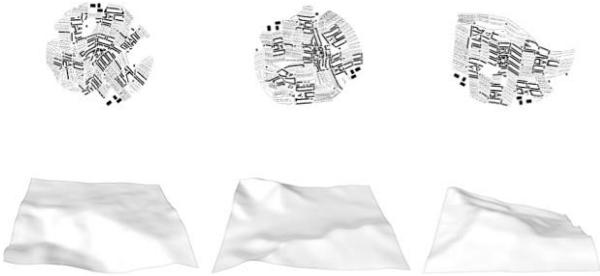


Figure 3. Masterplan variations for 3 areas in Ethiopia: Haro Welabu, Anko Golma and Fefa Dildy kebele^a

a. Administrative division unit

In this case evaluation was only executed individually for each module, while the overall design proposal was a combination of the generative modules outcomes.

Once the parametric framework was set up, only a few manual interventions had to be introduced. These were only necessary in non-uniform cases, in which adjusting some unsatisfying solutions would have taken considerably more time and resources when trying to define a case-specific rule for them (for example, if the terrain was too plain to generate clear watersheds or too steep to form a street). Another feature of this project was its almost complete isolation from the surrounding context allowing a lot of flexibility and variations, straightforward module-to-module transition and evading the effect on something already generated. It was one of the benefits facilitating the process, as existing and evolving urban fabric would always have non-uniform and hard to categorize elements, for example, secondary school classes being taught in a public space or a road being pedestrianized for several days weekly.

B. Case study #2: Waterfront Tanjong Pagar

The second case study was devoted to the development of a large-scale urban district in Singapore. It was launched as a design studio for the Bauhaus-University students in 2017 in collaboration with Future Cities Laboratory (FCL), Singapore, and focused on the proposal for district planning. Tanjong Pagar, an industrial zone of 400 ha, is planned to be relocated, releasing for development a centrally-located land near the waterfront. Compared to the previous case study, it has a very similar scale and degree of freedom: to start on a large scale, from street network and land uses, and go smaller into details up to building heights and road setbacks.

Here parametric variations were created not to fit into multiple sites, but instead to reflect opportunities within one fixed border. Our goal was to create several proposals based on different conceptual ideas for the site (Fig. 5).

One of the missions was to illustrate sometimes hidden similarities with the conventional design process and to emphasize the interconnectivity between these approaches. Therefore, our workflow was intentionally approximated to a traditional urban design workflow, in which conceptual decisions play a crucial role and are being introduced and reconsidered through all the process. The biggest conceptual decisions are, however, made at the earliest stage and consequent proposals are further treated as three separate scenarios. The analysis phase played a much more significant role compared to the first project, as we were experimenting with fixed and flexible input parameters. Except for having a specific border, surroundings, expected population and height restrictions, our three established scenarios had their additional (flexible) inputs, which values could vary (Fig. 5). For each of them we predefined configuration of green recreational areas, location of high-density CBD extension and the outline of the shore, elastic enough to effect potential built-up area.

The project had five modules as well: street network, shoreline, uses, transportation and buildings (Fig. 4). Major streets, outlining large districts, were predefined as an extension of existing ones, while the secondary street grid was generated automatically. It needed the desired size of the street block and its proportions to be set as an input. Furthermore, the general contour of the shoreline was drawn manually according to the conceptual proposal, be it the same amount of land as existed or reclaiming more areas to achieve lower density. Again, following a design concept to achieve more visual connection to the water, we created urban elements, further referred to as fjords. They finalized the formation of the street network by carving small channels radiating from the waterfront and walking alleys alongside. This element might later have become a point of negotiation with the customer (because of the cost) or engineers (because of the dimensions). Therefore, size and proportions, as well as number and location of fjords stayed as a flexible input with option to be adjusted any time later.

The next module was devoted to functional distribution across the area. One of our flexible inputs here was the relation between expected and current demographic structure and dependent on it the change in functional demand (lower percentage of younger population would require fewer amount of childcare institutions). Further, each particular function had its specific principle or rule of distribution, such as biggest retail being placed next to the most integrated streets or secondary schools being distributed equally within walkable distance from all households. While this rough distribution of functions had too many possible combinations for each street block, we used the insights from the Multi-Scale Energy Systems for Low Carbon Cities team from FCL and their study on energy efficient combination of uses within a block [10]. Setting up the database with energy efficient functional templates, it was possible to retrieve the best option from all variations. Having the distribution of uses, density and street network at our disposal, we could simulate the traffic flow using a calculation method based on an activity-based approach, which was simplified to trip generation tables [11]. We assigned a minimal number of lanes for each road segment and calculated the Level of Service (LOS) for them [12]. For the segments with unacceptable LOS (insufficient traffic capacity) the number of lanes was increased,

and in total four iterations of simulations were made until the width of all segments became sufficient. Finally, the rule for building typologies was implemented. Generally, typologies were divided in three groups depending on the density and relation to the coast. In each group there were predefined templates with functional combinations (developed earlier based on energy performance), so we created a specific rule for building arrangement and heights for each combination and for each of the three groups.

The micro-cycle evaluation of every module of this project had exceptional significance: in the land use distribution module the evaluation micro-cycle was intended to optimize the energy performance; the road width module evaluation was providing an optimized amount of space for traffic. Moreover, the fully digital model could be used for any kind of physical simulations (e.g. solar radiation, wind simulations), urban analyses (e.g. accessibility to facilities, green vs. built-up ratio) and cost calculations. They might be used further for creation of evolutionary algorithms and embedded optimization of all modules in the design phase. It can be used as well as a platform for negotiations, especially in the case of confronting interests of stakeholders.

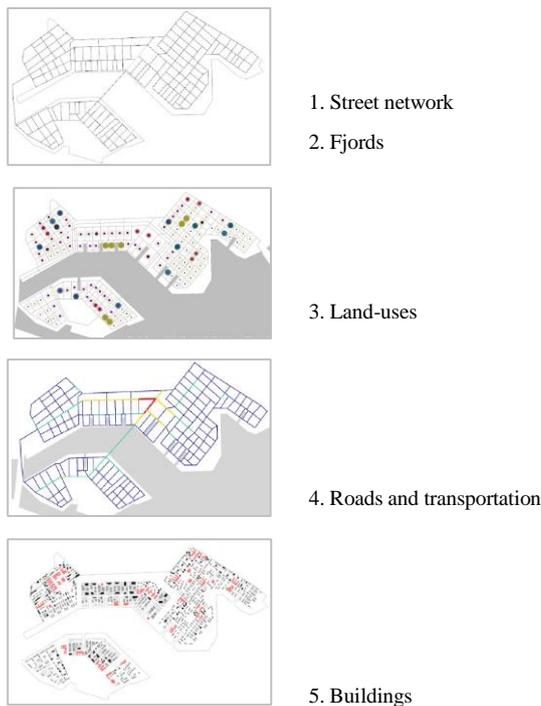


Figure 4. Five modules for Waterfront Tanjong Pagar development

One of the biggest challenges of the project was to consider the surrounding context in each step of evaluation. This required a lot of data and a lot of approximations to correspond to the categories developed within the project, e.g. the type and size of existing institutions, road categories etc. Nevertheless, this case study was the most helpful to reveal the opportunities for the parametric approach to be efficiently integrated into the conventional one. It also allowed us to go successively through all phases (analysis, generation, evaluation), at each step leaving

the process transparent and negotiable for all possible stakeholders (from engineers to citizens).

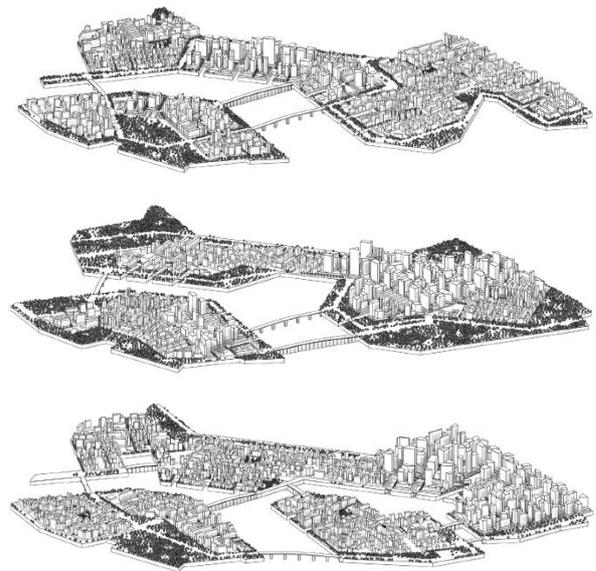


Figure 5. Three scenarios generated by the modular algorithm for the same site in Waterfront Tanjong Pagar

C. Case study #3: Urban elements

The next example was developed to support a design studio in the Advanced Studies in Urban Design course. The studio's aim was to develop the design proposals for four areas in Singapore, where each has specific context and challenges. The whole project was related to very case-specific urban issues. In such situations an automatized evaluation at a specific point of development cannot provide assistance, as urban systems are too complex for the problem to be found within a small area. Therefore, the success of a design solution depends on the designers and their ability to provide for any possible future scenarios.

The parametric workflow was even more integrated into the traditional design process, only providing additional input at specific points to support or refute the validity of particular solutions; to draw the design space defined by previously specified limitations; or to reveal the multiplicity of reasonable solutions. The four sites were unique in the scale of the design, desired outcome and level of detail. Also, all cases required intervention at different stages of design, which means that the effect of the parametric assistance was not comparable between sites.

For most of cases, the overall design project took a role of an analysis part for the parametric interventions. In the context of a design project executed mostly with traditional methods, a very restricted space of freedom was left for parametric proposals and their optimization. The task was narrowed down to only one module in each proposal and in the following we will describe two of them.

One issue addressed with a parametric approach was forming a streetscape with a variety of functions (Fig. 6). The conceptual idea behind was to preserve the diversity of views

along the street, but still mixing functions in a specific proportion. Keeping a facade (plot) width range for each kind of function, the algorithm was able to fit necessary amount of plots in the block for keeping the ratio. Moreover, setback norms also varied from function to function, keeping the design in accordance with the legal regulations and providing for more diversity.

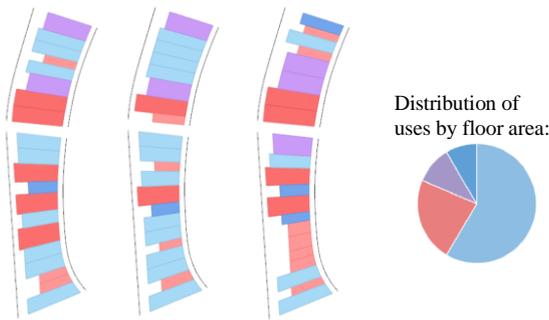


Figure 6. Function distribution algorithm variations applied to shop-house typology; evaluation parameters

Another issue was the building volume distribution (Fig. 7). It had four variables to operate: function of each building, height limitations, desired GFA for each street block and total proportion of residential vs. non-residential floor area in the neighborhood. Designers had the freedom to adapt the initial requirements according to the visual and quantitative outputs, forming the design space of acceptable solutions.

The evaluation phase consisted of specified quantitative characteristics that were informing designers during the decision-making process. In the example of the first module, there was a simple single-objective optimization, namely a well distributed mix of functions, which designers should have matched with their vision. In the second case, optimization was almost intuitive, as any design decision would affect all evaluation criteria (e.g. changing the function of one building; adjusting height limitation rules; changing the desired residential vs. commercial space ratio).

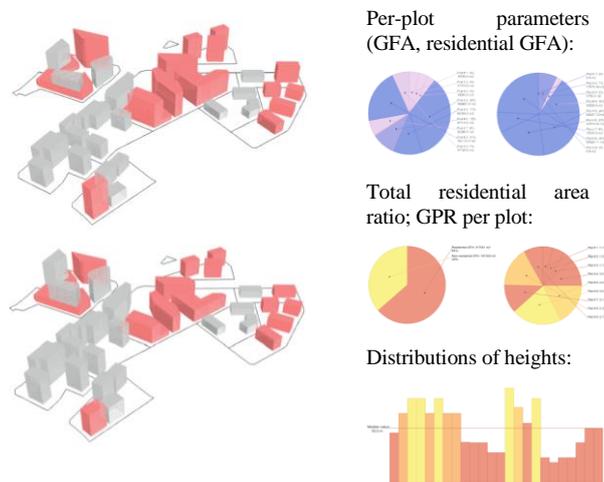


Figure 7. Volume distribution algorithm variations; evaluation parameters

The first module allowed the fast sketching of conceptual ideas with a 2D-design proposal generated immediately. This module was very context and typology specific and was helpful as a fast drafting tool. It helped to see how realistic the expectations of both designers and stakeholders were about the appearance and uses of the site. The second one allowed to explore the distribution of uses and volumes on the site within the restrictions placed by building regulations, which supported the creation of guidelines, e.g. for GPR requirements of street blocks.

IV. DISCUSSION

Summarizing the experience from three case-studies, we can conclude that parametric assistance might be of value in situations with very different design priorities (e.g. the speed of development in Ethiopia and sustainability in Singapore), data availability (including legal and language barriers to get necessary information), and aspects considered (wide-ranging fields of expertise for Tanjong Pagar and only one specific problem for each of urban elements).

It is worth mentioning that in the first two case-studies we were performing the roles of both designers and developers of the parametric algorithm, while in the last example the modules were developed for external designers' use. This impacted more on the workflow than on the results, as many specifications arise during the development of the algorithm and might affect design solutions. It is impossible to divide the process into a design part and a software development part, as an algorithm does not provide a ready product in the end, but a tool assisting design and evolving along with new ideas, proposals and restrictions.

The biggest benefit, expected and achieved, was the possibility to rapidly test out alternatives by changing parameters both within a module (see Urban Elements and individual modules optimization) and using the framework to create different scenarios (see Tanjong Pagar). It was an undeniable advantage for establishing and improving communication between stakeholders, e.g. planners and developers, showing the immediate feedback (in a form of new proposal) on newly introduced corrections. Its modular structure made the process easily readable and flexible for introducing additional parts, removing existing ones, or tracing the influence on each module while adjusting one of them. It also brought in exclusive transparency and objectivity in decision-making, especially for those experts, whose professional inputs were rarely or never confronted during the design process itself (energy systems specialists, transport planners, ecologists).

V. LIMITATIONS OF THE APPROACH AND FUTURE WORK

One of precautions of the approach is to find an appropriate balance between the degree of automatization and degree of artistic freedom, especially when it comes to the smaller architectural scale. A number of cities around the world proved that they might only benefit from decentralized planning, sometimes even when different parts are ideologically and culturally incoherent.

The main limitation of the approach was caused by the ubiquitous nature of urban planning and design. Most of the case-studies required a lot of manual customization, even though

the same task should have been performed, e.g. generation of street grid. Even in the context of one city with similar regulations and cultural context, there were differences either with terrain peculiarities, or street block typologies, or traffic situation. Except for design generation, the micro-evaluation within each generative module also required a lot of manual interventions, which in some cases compromised the efforts spent on automatizing this micro-evaluation (the optimal width of the vehicle roads might be too high for the coastline and prevent pedestrians from enjoying the view).

Considering our three case-studies, in which the parametric approach was extensively used and evaluated, there might be similarities in the sequence and set of modules, but differences in the details and underlying principle of them. Based on this, we can conclude that the development of ultimate modules suitable for any case is not feasible, but what can be helpful is to predefine the module set (vehicle street network, pedestrian routes, land uses), the elements to operate within each (street axes, sky bridges, denomination of uses) and their quantifiable characteristics (street width, bridge height, land uses compatibility). However, this can only be confirmed by testing the framework in different urban planning and design projects with different requirements. The conclusion is that although the framework in itself is flexible, the modules are not easily transferable across projects.

Furthermore, future work will look at integrating optimization algorithms to (semi-) automatize the optimization process currently mostly done manually, for example, using interactive evolutionary multiobjective optimization as proposed by [13] and implemented for Grasshopper by [14]. This requires collecting information about areas of design regulations and quality measurements (only areas, because precise values will vary, e.g. setback rules (distance), acceptable street slope (angle), walking accessibility (distance) etc.). It is, nevertheless, necessary to keep in mind that urban planning and design is in-between art and science and even quantifiably failed solutions (hidden and unsafe public space) might be a ground for unexpectedly successful projects (street art and local events).

VI. CONCLUSIONS

The paper discussed opportunities for conventional urban design frameworks to be reconsidered and complemented with the use of parametric tools. We questioned the resilience of linear design processes with limited options for Design-Evaluate-Redesign cycles, especially on the scale of the whole project. The suggested methodology of breaking up design into a network of interconnected modules proved its expected advantages, such as more efficient exchange of expertise, variability of the design and transparency of decision making, and appeared to be helpful for urban designers during the project development. One of the problems we addressed – complicated and not responsive communication between involved parties – was resolved by using a platform where all parts of design were embedded into one system and immediately adopted changes from all other parts (Fig. 8).

The modular structure also provided for variability and adaptability: using the same algorithm we were able to create three district planning proposals for one project site, and three town masterplans corresponding to three different areas.

Variations, moreover, were not time consuming, as they were either fully automated (in case of changing landscape for town masterplan) or semi-automated (only changing the value of “flexible” inputs, such as outline of the shore, expected demographic structure etc.). Nevertheless, the introduction of a modular structure into the design process requires a new way of approaching design. Therefore, it needs to prove its validity and added value by applications on more case-studies with more ways, and more flexible ones, to integrate into established design workflows.

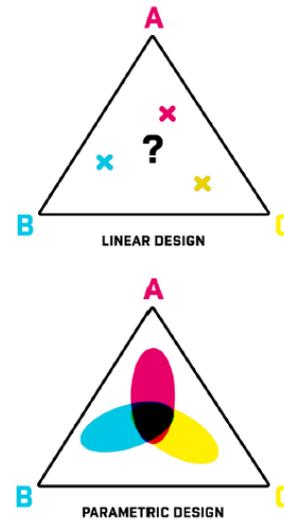


Figure 8. Solution space in parametric design

Parametric interventions in the design process might be introduced in one of the phases (analysis, design or evaluation) or combine all of them. They might represent a design proposal, a space of design solutions or just an objective evaluation. The method can be helpful for designers to convince other stakeholders and to make fast sketches with clear pictures of the outcome; for the specialists of different fields to find common ground by understanding the effect on each-others work; for the customer to quickly evaluate cost efficiency and other quantifiable characteristics of one or more proposals. The application list can be extended and we are working towards it in upcoming case studies.

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