P2P URBANISM

Collaborative Generation of Spatial Plans Through Paper Cutting

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Abstract. This research presents a vision-based Tangible User Interface that was designed to facilitate the investigation of urban spaces. The analogue-digital process made use of inexpensive paper material and commonly accessible technology like a modern camera-enabled phone. Citizens will use a paper-cutting approach to shape the urban space within an urban block and use the phone as the processing agent communicating with a server in the cloud. A three-dimensional visualisation of the urban block may then be viewed on the phone or the computer. A prototype implementation has been developed that allows simple urban massing to be generated. Preliminary tests with groups of users showed promising results. Instead of a conventional design workshop engagement, participants were able to set up the tool in their own time and space and work collaboratively in small groups to developed diverse types of urban layouts.

Keywords. P2P Urbanism; Tangible User Interface; OpenCV; Human-Computer Interaction.

1. Introduction

Participatory Urban design is an effective method for engaging citizens in the design of the urban environment. Several papers reported that the designed spaces at the end of the process often better fulfil the wishes and aesthetic preferences of the citizens (Crewe, 2001). Citizen involvement in the design process could also directly contribute to their wellbeing and the frequent utilisation of the designed space (Anderson & Baldwin, 2017). In a traditional participatory urban design using the physical medium, participants would undergo active discussion and mediation in a workshop setting where people interact face-to-face. Modern web technology has transformed the way people work, engage with a tool, and with one another. The Peer-to-peer(P2P) urbanism movement (Salingaros, 2010) argues for a network-based planning process that incorporates citizen participation and co-design. It proposes an informal environment supported by Information and Communication Technologies (ICTs), where people can contribute to planning decisions through their collective knowledge.

Numerous researchers have been investigating how co-designing by citizens can be facilitated through different visualization methods (Mueller et al., 2017).

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Typically, such methods and tools will rely on a digital modelling approach, often within a web-based environment. Compared to the physical medium, digital visualization tools are often able to communicate more complex solutions and provide a platform for citizens to quickly iterate and compare with past designs (Al Kodmany, 2001). However, digital environments tend to discourage collaborative discussions between multiple people in real-time. Furthermore, for non-experts, creating and modifying digital models is often seen as a frustrating process.

Tangible User Interface (TUI) is an active research field that looks at coupling digital computation with human interaction in the physical space. This research posits that TUI can combine the benefits of both traditional and digital mediums. Participants in a TUI-enabled design engagement will be able to discuss and evaluate complex designs in real-time.

For instance, the Walter Segal Model was a tool created by Frazer and his team to involve the self-builders in the design process. The tool featured acrylic sheets that served as an abstraction of the panels used in Segal's timber framing construction method. Users fitted the processor pins attached to each sheet into the sockets of a gridded circuit board. Each embedded acrylic sheet contained information of the material and form of the panel, allowing a three-dimensional model to be generated on the computer, along with necessary construction drawings and metrics that evaluated the cost. This tool served as a substitute for the Architect and presented a case where an architect's intelligence had been successfully transferred to the tool. Without the presence of the architect, participants were able to successfully generate, visualise, and evaluate their models with the digital tool. Prior to the tool, the architects would be involved in the translation of the matchstick abstractions and sketches into architectural drawings, while explaining the design concerns (Frazer, 1982). MIT's CityScope allows participants to interact with a digital urban model through physical LEGO blocks. Each LEGO module was tagged with a unique grid pattern that is representative of its type. After capturing the layout using computer vision technologies, complex simulations are calculated and projected onto the table in real-time (Hadhrawi & Larson, 2016). These projects used complex algorithms to provide an environment for citizens to collaborate and create spaces. However, the chip-based and projection-based technologies often require elaborate set-up and are often very costly. They may not be deployable at the community scale and would limit the number of citizens that can participate in the design process.

A web-based co-design platform would allow for a broader reach while keeping the set-up time and cost relatively low. For example, the Quick Urban Analysis toolkit was developed as a tool for presenting and manipulating urban geometries on the web (Mueller et al., 2018). On the platform, citizens place modules from a library of geometries onto a map. The geometries represent urban features and may be published and viewed by other participants on the platform. The project has shown how a web tool may be beneficial for active participation in the design and evaluation of urban environments. However, beyond rating submitted designs, such environments tend to discourage collaborative discussions between multiple people. Multiple participants do not have the option to collaborate on the same map at the same time. The strengths and weaknesses of the digitally-enabled projects are consistent with the analysis presented by Al-Kodmany.

This research aims to develop a web-based participatory tool that combines the benefits of both traditional and digital mediums in its design. It evaluates the use of a web-hosted, paper-based tangible user interface as a cheap and accessible method for participatory urban design. The next section discusses the tangible operations possible with paper modules, followed by a section that discusses the digital algorithms and methods for processing the paper modules. A prototype was implemented and tested with two groups of participants. This paper concludes with the results and a discussion of future work.

2. Paper-based TUI

This research proposes a hybrid analogue-digital approach that allows citizens to generate urban proposals using paper cut-outs, a mobile phone app, and a web-application. The paper cut-outs are placed on a print-out of the site plan and are used in various ways to define either urban massing or urban spaces. The thin planar nature of paper makes it very malleable to different forms of expression. It is also a very accessible material and may be bought from any stationery shop at an affordable price. Paper can vary from one another in its density, texture, and colour. As a TUI powered by vision-based technologies, this research posits that colour may be used as rule indicators for generating a 3D model. Participants will directly manipulate paper and create cut-outs shaped to their desired spaces. The colour of the paper will inform the digital processing agent which rule to use to generate the model.

2.1. COLOUR OPERATIONS

Two basic relationships have been identified as colour operations. In an additive colour operation, paper cut-outs are generated as physical objects. For subtractive colour operations, the cut-outs are used to carve out or subtract spaces. Different colours can be used to define different colour operations. More complex relationships may be defined when multiple colour operations are used in combination.

2.2. PAPER OPERATIONS

Paper shapes may be rotated, flipped, or moved around on a printed site map. They may also be cut down into smaller shapes. These basic operations either transform the paper module on the site map or directly changes the shape of the module. They are straightforward as the nature of their transformation is not affected by the change of material colour. On the contrary, folds, and overlays with different coloured paper open more opportunities for expression (Figure 1).

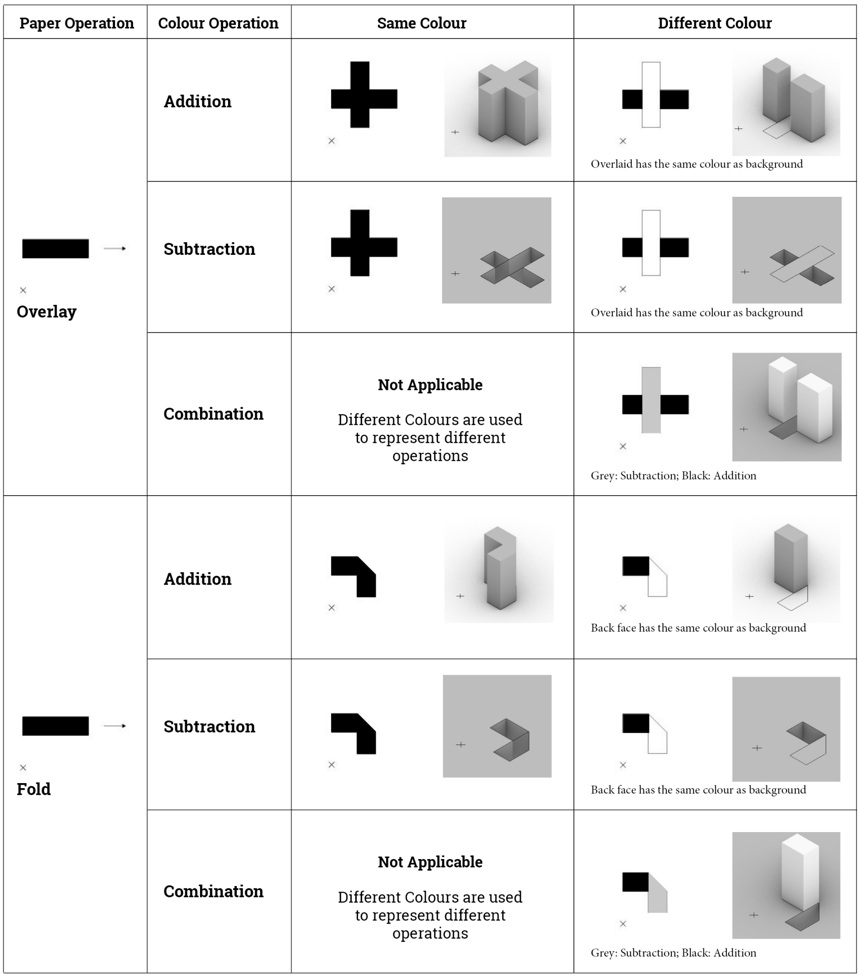


Figure 1. TUI Paper Operations.

2.2.1. OVERLAYS

Two modules of the same colour overlaid on one another may be perceived as a single module. Overlaying a module of another colour effectively splits the lower module. In other words, the overlay operation may be operated similarly to the “union” and “difference” operations found commonly in conventional CAD environments.

2.2.2. FOLDS

When a module with different colours on each side is folded, the size of the original module is reduced. Folding a module of uniform colour mirrors and unions itself on the folded axis. In other words, the folding method may perform similarly to the cut and overlay method. However, folding allows for convenience as the operation directly operates on a single piece of paper.

3. Proposed P2P Urban Design Method

The focus of the proposed method is to get feedback from citizens on the types and configurations of urban spaces that are desired. For the proposed method, a platform is envisaged for citizens to select urban sites anywhere in the city and to create massing proposals that incorporate public spaces for various purposes.

The proposals were to incorporate desirable urban spaces, while at the same time meeting the required gross floor area (GFA) targets. Citizens can provide suggestions for the type of urban space that would serve the community. Developers will receive a variety of solutions that will inform the citizens' desires and preferences. Ultimately, citizens will gain awareness of the new development and benefit from a more inclusive urban space inspired by the collaborative efforts.

The steps are as follows:

1. **Location:** Citizens gather in small teams, with access to a laptop, a mobile phone, a printer, and a set of coloured papers. This could be at people's homes.
2. **Preparation:** The teams print out the design materials on various coloured papers, consisting of the site plan and a library of 2D shapes that can be placed on the plan. The colours represent the rules used for generating a design. The teams cut out the library of shapes.
3. **Analogue Exploration:** Teams proceed to make urban design proposals by arranging the shapes on the printed urban plan. Since this process is totally analogue, the team can sit around a table and discuss different options, moving around the cut-out shapes.
4. **Digital Generation:** The mobile phone is used to take photos of the design proposal and upload them to the web application running on the server. The photos are converted to vector drawings using the OpenCV library. For each photo, a 3D urban model is then generated, together with various analysis results, using a series of parametric models. Within a few seconds, the 3D model with analysis results is visible on the laptop.

Computer Vision (CV) and Geographic Information Systems (GIS) are the key supporting technologies.

OpenCV is an open-source computer vision library. The library contains a collection of optimised algorithms ranging from basic image processing to advanced machine learning processes. Although the core library only supports non-browser programming languages like C++, Python, and Java, the recent development of Web Workers allows the library to be precompiled into WebAssembly modules and be run on a web browser.

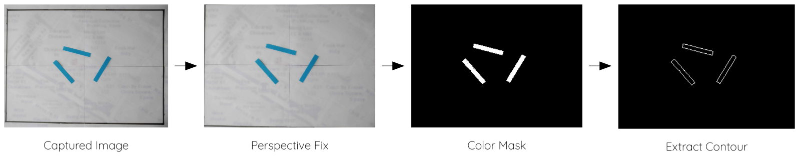


Figure 2. A captured image goes through resizing, perspective fix, colour fillter, and contour extraction.

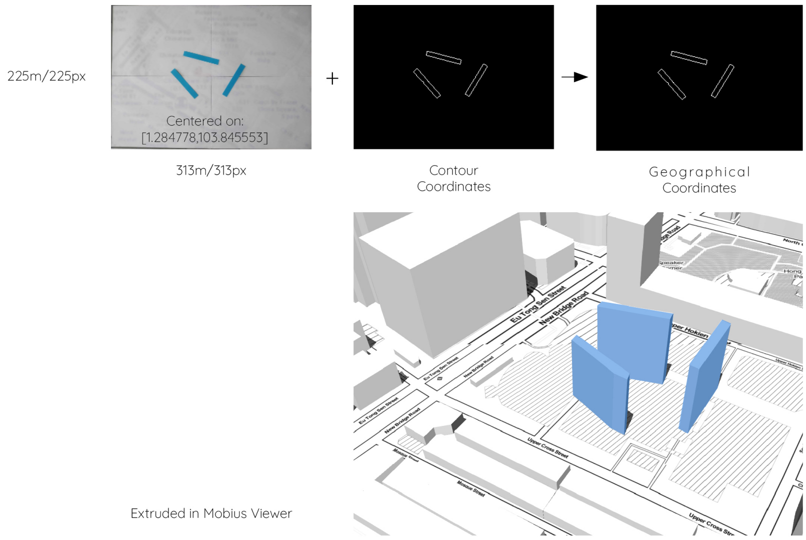


Figure 3. Contour to GIS parametric model.

The captured image goes through the following steps in the digital generation process (Figures 2 & 3):

1. **Resize and Fix Perspective:** The map boundaries are detected from the image and the defined area of interest is then stretched and skewed to fit the image canvas.
2. **Colour Layers:** Participants may define different colours to be extracted from the image. The colours will be separated into layers which may be used to define different operations.
3. **Contours:** Filtered shapes from the same colour layer are converted into contours. The closed poly-line shapes are simplified to reduce the number of coordinates.
4. **Geospatial Context:** The geolocation, image resolution, and dimensions of the printed map are known. The coordinates of the 2D polygons can therefore be automatically converted into geospatial coordinates (Figure 3).

5. **3D Model:** To generate 3D models, an existing web-based parametric modelling tool was integrated into the generation pipeline. The tool is called Mobius Modeller (Janssen, 2016). Parametric scripts may be set up to process the geographical output of the different colour layers.

4. CtySketch Web Application

A tool named CtySketch was developed. Additive paper operations were explored in the first version of the tool. The paper cut-outs represent building footprints that were generated as simple extruded forms. In future versions, the repertoire of modeling operations will be expanded, to allow a greater variety of forms to be generated.

CtySketch is a web application written using the React JavaScript Framework and is hosted on the Amazon Web Services cloud. Users will only require readily accessible technologies such as laptops, mobile phones, and desktop printers (Figure 4).

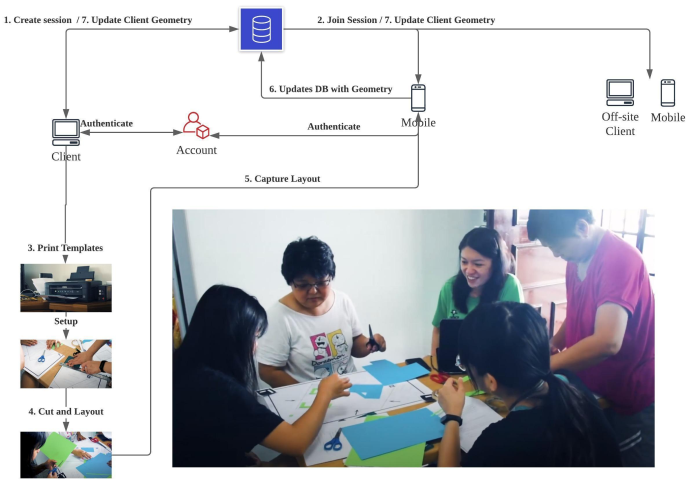


Figure 4. CtySketch Workflow.

1. A new user may create an account and start a design session for a selected site.
2. A unique room number is administered for the session, which may be shared to other off-site participants to view the design as it changes live.
3. Participants on-site will then print out the site drawing and scaled modules.
4. The modules are cut out and arranged to the site drawing to the desired design.
5. The room owner may also access the same room using a portable device to easily take a photo of the prepared site.
6. The image is processed, and the identified geometries are then updated on the database.

7. All participants may view the generated design layout on the computer screen, discuss, change the layout, and regenerate with the same process.

A specific site in Singapore was chosen to provide a controlled environment for testing and evaluation. The Hong Lim residential estate in Central Singapore was constructed in the 1970s to provide housing for squatter residents displaced by the renewal developments. This research posits a scenario where the entire urban block will be cleared for redevelopment due to age and operational inefficiencies. The block was chosen for its size, existing program, and proximity to a variety of historic and financial developments in central Singapore. By keeping the site size to the bounds of an urban block, we constrained the investigation to a scale familiar to untrained residents

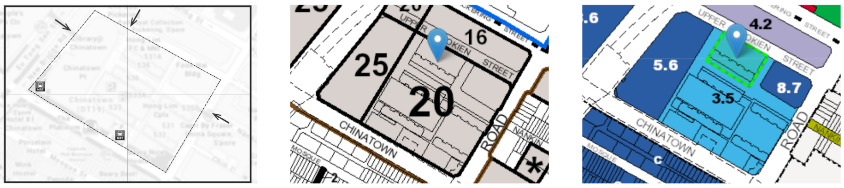


Figure 5. Existing Site Constraints.

Two basic building functions have been identified for the plot: Commercial and Residential. Participants were to relate to the neighbourhood and provide urban layouts that satisfy the required Gross Floor Area (GFA) of the block. GFA was calculated following the land use and plot ratio guidelines in the Master Plan. A different colour was assigned to each function and participants placed the different coloured paper cut-outs on an A2 sized plan (Figure 5). Surrounding context such as key circulation paths and transport nodes were provided on the site map. Footprint templates printed on a 10x10m scaled grid were also provided to the participants to enable a better sense of the scale. A Mobius Modeller script was created to generate the building massing. For each polygon detected and processed from the captured image, a simple extrusion was generated on the location.

5. Pilot Test

Two voluntary groups of 5 to 6 people participated in the pilot test. The two sessions were independent and explorative. They serve to report on the successes and insufficiencies of the application. Participants were tasked to create layouts that satisfied their design goals and the required GFA. Two different coloured paper were used for the test. Blue was used to represent commercial footprints while green was used to represent residential footprints. Often, the participants were quick to get started. They would each pick up a sheet of gridded coloured paper and start to simultaneously develop small parcels of the map with their individual coloured cutouts. The application would then inform the participants of the computed GFA for each coloured function. By making quick and simple organisations at the start, participants were able to quickly familiarise themselves with the technology. However, disagreements quickly arose as the group had not agreed to a clear organisation strategy for the entire block. In their following discussions, participants were able to quickly shift the paper cut-outs around, or pick one up and make non-destructive operations like overlaying and folding. Some participants were also quick to tear their creations to trim them into smaller shapes. The short waiting time between capturing a photo and the result showing on the shared computer screen allowed participants to better visualise their ideas and come to a consensus.

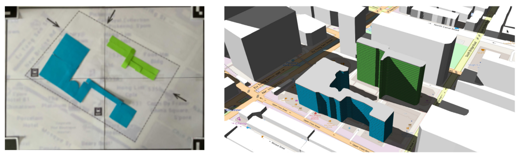
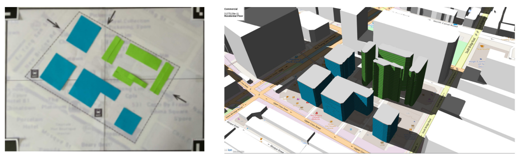
Urban Plaza Strategy: Few, large footprints Result: Large, continuous urban space	
Urban Park Strategy: Many, small footprints Result: Linear/Pocket urban space	

Figure 6. Urban Plaza: Large Footprints; Few Buildings.

Over the course of the sessions, more than twenty layouts were collected from the users' experiments. In all of the designs, participants took into consideration the key East-West circulation directions and the access locations to the nearby public transport nodes. We have classified the generated urban spaces into two types (Figure 6). Generally, participants created layouts with many, small footprint cut-outs, or few, large footprint cut-outs. The former had the tendency to generate linear and pocket urban spaces, which we classified as "Urban Parks". The latter created large and continuous urban spaces, which we classified as "Urban Plazas". In the featured Urban Park example, participants also pointed out their intention to create an enclosed space within the residential cluster.

Feedback was also obtained from the groups:

- **Simple:** Most of the participants were unsure of how to start on a design. However, they got the hang of it after going through the full workflow a couple of times: cutting, arranging, and generating. The printed templates allowed participants to get started quickly and visualise their results.
- **Enjoyable:** Participants felt that the nature of the activity was quite fun
- **Inexpensive:** Participants were amazed that the generated result was derived from paper cut-outs.
- **Relatable:** Most of the participants felt that they were able to relate to the context well and the circulation arrows and transport nodes marked on the map

were helpful.

- **Comprehensible:** Participants were able to understand to the effects of changing the size of the cut-outs on the extruded height.
- **Collaborative:** Participants enjoyed developing ideas in a collaborative face-to-face group setting in the comfort of their own home, with discussions focusing on both the decisions about paper cutouts and the results generated by the computer.
- **Limited Flexibility:** Some issues surfaced during the generation. Participants had attempted to make holes and bridges which the algorithm was currently unable to account for.

6. Conclusion

An inexpensive TUI prototype was developed to enable citizens to contribute to the creation of urban environments using simple paper cut-outs. In the spirit of P2P Urbanism, the prototype was also enabled by accessible ICTs, allowing participants to contribute from the comfort of their own homes. Experiment results have shown that participants were able to create of conventional urban spaces like urban plazas and parks while meeting the maximum GFA of the site. Using paper and a portable phone camera, participants collaborated to express their ideas, and to visualise relatable extruded models on screen.

The TUI prototype coupled an analogue planar material with digital generation algorithms that were defined by the material colour. Further research will look at more complex relationships and algorithms. A framework will be developed to provide a guide for the decision-making support necessary for this new remote collaborative design process. Augmented Reality may also be explored to provide more active interaction between participants and the generated model.

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