Human-driven and machine-driven decisions in urban design and architecture

A comparison of two different methods in finding solutions to a complex problem

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The authors of the paper research the aspects of two approaches in human-computer collaboration to solve an urban scale problem: positioning a new cycling-pedestrian bridge in the city of Warsaw. The first approach is a machine-driven stochastic optimization combined with the shortest walk algorithm; the second one is a human-centered process involving an interactive table as a way of communication and data input. Both approaches were explored as part of a one-week student workshop. The article covers the undertaken techniques in detail and presents the outcomes of both studies. It concludes with a reflection on the necessity to inspire a discussion about the future of the architecture among apprentices of the profession: with all the potential threats and opportunities deriving from computer automation.

Keywords: interface, TUI, optimization, PSO, generative design, programming

The question of potential collaboration between two intelligent but dissimilar systems - the man and the machine - was raised long before humanity had reached its current technical development. In contrast to visions of intelligent machines being a menace to humanity and Mumford’s pessimistic thoughts on technology being a limitation to human spirit, Nicholas Negroponte in ‘The Architecture Machine’ (Negroponte 1973) presented guidelines for good practices in possible human-machine interactions, disproving general distrust and opening the possibility for future symbiosis.

Negroponte distinguishes two ways of involving computers in a design process: it can be either computerized or computer-aided. As computerized process we understand a situation in which a problem is presented to the machine (with all necessary initial data) as input and a solution is calculated in an uninterrupted way and submitted as output - final and accurate. A computer-aided process, on the other hand, can be explained as a dialogue, in which the machine provides user with constant feedback during work but does not impose solutions. The user specifies his own criteria and follows his or her intuition, taking advantage of computer’s fast local calculations.

The authors investigated the aspects of computerized and computer-aided design as part of a one-
week student workshop, during which the participants were to investigate walking and cycling accessibility within the city of Warsaw and to enhance connections by diminishing distances on the street network between two sides of the river: by finding optimal position of a new bridge or bridges. The question of optimal, however, was supposed to be tackled with two different approaches.

The first approach to the problem was a machine-driven stochastic optimization combined with the shortest walk algorithm; the second one was based on tester’s city experience and involved an interactive table as a way of communication and inputting data. The article covers the undertaken techniques in detail and presents the outcomes of both studies.

The objective undertaken during the workshop was to research potential positions for a new cycling-pedestrian bridge or bridges to enhance the connectivity and to promote sustainable transport methods.

We took into account three concepts while conducting preliminary research: Local Accessibility, Global Accessibility and Average Distance. Local Accessibility is defined as a topological distance, on the city network, from a given location to a network of points which is defined by centerpoints of a square grid of 300 by 300 meters. The Global Accessibility is calculated as a average product of all the distances on the city grid. Accessibility Distance is calculated as a average topological distance to all the grid points in the absolute distance smaller than 1 500m.

The topological distance is measured on a map generated from the Open Street Maps platform. We converted data to the network of the city. The grid consists of all class of roads and its links (excluding highways), footpaths, squares and bicycle lanes. To measure accessibility, we calculated topological distances using A* algorithm. The cost of each connection was estimated taking into account the length.

THE TASK: CYCLING INFRASTRUCTURE IN WARSAW

The city growth model of Warsaw shares many similarities with other European cities. Rome, Budapest, London or Belgrade has grown simultaneously and unevenly on two sides of a river. In Warsaw the first bridge connecting two sides of Vistula appeared as late as in the 16th century. Before that point, crossing the river was only possible on boat. The wooden bridge lasted for thirty years. Due to geographical position and unstable political situation the next bridge was not built until mid-18th century. For the next centuries Praga, the town on the east side of Vistula, suffered from the lack of connection with Warsaw. Nowadays, there are ten bridges connecting the two parts of the city, but only two of them are equipped with safe bike paths. Not surprisingly, the citizens prefer to use the closest bridge rather than the cyclist-friendly: According to studies run by the local government [1] Poniatowskiego Bridge, with no cycling infrastructure, has more users than Siekierkowski or Świętokrzyski bridges, both equipped with cycle lanes and direct connection to city bike network.

Contemporary cities are facing problems related to climate changes. Reducing energy consumption and carbon emission are key elements to protect the environment. One of the most energy intensive city activities is individual motorized transport. Facilitating walking, cycling and public transport is a very effective method to decrease carbon emission. (Mitlin & Satterthwaite 1994).

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of the connection and an average cycling speed in Warsaw (15-20 kmph). Preliminary accessibility studies (Figure 1) revealed that some parts of Warsaw (Powiśle, Saska Kępa, Gocław) considered as central are poorly connected whereas others, especially the ones constructed after second world war, are generally well-connected.

To understand the population distribution and people flow, we used two databases:

- Strava Heat Map (a community built database that maps information about bicycle and pedestrian activity) and local government information on number of inhabitants per district.
- The Heat Map reveals communication patterns in the city. Surprisingly while analyzing the intensity of the flows on the bridges, it appears that it does not respond neither to their design nor to the traffic rules. It confirms that the bike network is weak and people tend to use the shortest way rather than safe or designated one.

Interpolated data served as a reference for inhabitants flows and conformed Attractiveness Map (Figure 2). The interpolated data hierarchies the possible position of the bridges favoring the connection between the more popular areas.

Apparently Warsaw Escarpment creates a strong border for the cyclist, so there is a demand for a lower bridge and an upper bridge. The upper essentially connects the existing city grid on the left side overpassing part of the city, a very similar strategy has been applied to Poniatowski Bridge, and allows high-speed connection. The lower links to riverbanks and could be used for the low-speed, recreational bicycle connection.

To verify design concepts, we invited local activists, foundations and experts. After meeting with Warszawska Masa Krytyczna (the Warsaw Critical Mass) local biking community a potential need for two bridges was also considered. (Figure 3)

**MACHINE-CENTERED APPROACH: OPTIMIZATION**

Most of urban planning and design problems are characterized by high complexity, numerous parties and aspects involved. Traditional methods are looking for a compromise, but due to the lack of information and relatively slow solving process they may be inefficient. Applying Artificial Intelligence in such class of problems reduces the computation time and allows to consider more options and/or solution based on a larger data base.

Optimization problem was analyzed in three different scenarios - only the upper bridge was added to the system, only the lower bridge was added to the system, both bridges were added to the system. To enhance Global Accessibility two objectives has been declared. The position of the new bridge is to reduce...
topological distance between all the points on the predefined grid and favors the more popular zones. To enhance local accessibility only the topological distance is to be reduced.

According to Michalewicz and Fogel (2004) a difficult optimization problem occurs when:

- a high number of solution is possible and reviewing them is high time consuming; problem cannot be simplified because any simplification leads to useless or distorted solutions;
- might have multiple optimal solutions. Urban problems tends to be impossible to solve using analytical methods.

For such complexity of problems heuristic methods can be employed. This technique does not guarantee to find the optimal solution but is capable of finding one of the fittest solution.

For finding the most optimal solution optimization solver based on Swarm Intelligence was used. The algorithm, introduced in 1995 by Kennedy and Eberhart, is a stochastic alternative to evolutionary methods. The algorithm mimics the behavior executed by the individuals in a system such as school of fish or flock of birds while searching for the best location (global optima). The instruction depends neither on the initial state nor on the gradient information. The fact that it depends only on the value of objective function makes it computationally less expensive (faster) and much simpler to implement comparing to evolutionary algorithms. (Patnaik et al, 2012). A Grasshopper plug-in Silvereye is the first implementation of Particle Swarm Optimization into design field. The tool is significantly faster than others and it uses other classes of algorithms (Cichocka, 2016).

For modeling the problem the Global Accessibility was declared as $D_{GA} = \prod_{i=0}^{n} d_i$, where $D_{GA}$ stands for Global Accessibility [m], $\prod_{i=0}^{n} d_i$ is the product of multiplication of all distances and $n$ is the number of connections.

The objective was to minimize Global Accessibility.

Three iterations of optimization has been performed, each had 20 iteration and the initial swarm size of 20 elements. The PSO initializes with an arbitrarily dispersed set of particles assigned with random velocities. The elements fly in an n-dimensional space, then cluster together to finally converge to a global minimum area. The particle movement in the solution landscape reflects the flying experience of the individual and its neighbourhood in the swarm.

<table>
<thead>
<tr>
<th>Bridge Location</th>
<th>Accessibility Distance* (m)</th>
<th>Enhancement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Current Situation</td>
<td>2091</td>
<td></td>
</tr>
<tr>
<td>City Hall Proposal</td>
<td>2008</td>
<td>-83</td>
</tr>
<tr>
<td>Lower Position</td>
<td>1845</td>
<td>-146</td>
</tr>
<tr>
<td>Upper Position</td>
<td>1817</td>
<td>-174</td>
</tr>
<tr>
<td>Two Bridges</td>
<td>1773</td>
<td>-235</td>
</tr>
</tbody>
</table>

The comparison of Accessibility Distances in different scenarios.

We have reviewed and analysed new connections planned by the City Hall. It appears that they are going to enhance to Global Accessibility - a new bridge in a trace of a historical wooden one by 4% (distance shorter by 83m) and a bike path on The Łazienkowski Bridge by 9 % (distance shorter by 196m).

Additionally, three schemes concluded in very similar position of the bridges (see Table 1 and Figure 4), close to the Łazienkowski Bridge that is scheduled to open in late 2017. The new link between two sides of the river is going to reduce the time needed for crossing from Praga to Warsaw downtown up to 21 minutes and significantly enhances the Global Accessibility. The optimized solution roughly shares the abutment position with Łazienkowski Bridge. In order to further validate the location of the bridge more data should be implemented and A* algorithm should be enriched with the more information such as user preference, detailed topography (ideally three-dimensional shortest walk ) or city bike station position.

While modelling the optimization problem, a threat of over-constraining or discretizing problem appeared. Since the city center and bank of left-side of Vistula is much better developed and situated on the escarpment the number of possible access points for the upper-bridge is limited and dis-
crete. The possible position is almost entirely defined by the existing city grid, only far-south and far-north banks, neighbouring with Siekierkowski and Grota-Roweckiego bridges, are undeveloped. Praga’s riverside is much less developed so the problem is mostly continuous. The lower bridge could be positioned on any location on the both side of the river.

Figure 4
Global Accessibility Map with two bridges. Gradient colour indicates the average time needed to access other point on the map.

HUMAN-CENTERED APPROACH: A DEDICATED INTERFACE

In 1970s Negroponte accentuated the importance of an architect in the process of translating human needs into design language. In this process, he defined a machine (a computer) as a virtual partner with the ability to suggest alternative solutions, pointing out emerging collisions, but never imposing calculated solutions. He underlined the need to adjust the abilities of a computer to the specificity of human actions - not the other way around - and predicted a shift in the field of interfaces from a counterintuitive set of knobs and buttons towards processes based on human language. (Negroponte 1973)

In our opinion, there is still a lot of research required to fully enhance the way architects use computers in their work. Software solutions that are available today along with computers’ increasing calculation capabilities provide users with mechanisms to easily model, edit, analyze, present and share architectural projects. However, the use of possibly inadequate peripheral devices in the process of architectural and urban design may lead to difficulties in the use of CAD tools. Also the threat of skeuomorphic approach arises, technology providers are having difficulties breaking designer habits and produce pencil-like, drawing board-like devices rather than proposing a new approach.

As means for testing computer-aided approach we decided to use InteracTable - a low-cost Tangible User Interface (TUI) designed and prototyped by Jacek Markusiewicz with the assistance of students Jakub Andrzejkewski, Kacper Karpiński and Damian Lachta. The device is a table-like structure in which the tabletop was replaced with a translucent glass panel with a dual objective: to create possibility for backlit projection and at the same time to provide user with working space. The table is equipped with a camera placed above the glass panel for capturing elements that are handled by users, while the projector responsible for computer-user feedback is placed below its surface.

The direct inspiration for designing InteracTable was Reactable project - an innovative multi-user musical instrument. Reactable was conceived at Pompeu Fabra University in Barcelona as an attempt to create an intuitive tool for synthesizing music with no additional peripheral devices needed. (Jordá et al. 2005) While designing InteracTable, a series of design decisions has been made to adapt the concept of Reactable to architectural and urban design purposes, such as using a rectangular shape for the workspace instead of a circular one, and placing the camera responsible for image capturing above the table, instead of below it, to be able to implement different types of interaction.

The workflow undertaken during Warsaw Summer School 2016 was divided into three phases, and controlled by three different programs: (1) ReactIVision (an open-source framework developed by Martin Kaltenbrunner and Ross Bencina for image recognition in the Reactable project), (2) a Grasshopper definition and (3) a custom application developed in Unity3d. (Figure 5)

The first phase is the process of inputting data. A user places physical elements on the translucent surface...
of InteracTable with a map of the city projected onto it. Each physical element is equipped with a fiducial marker optimized for ReacTIVision image processing algorithm. There are three types of these elements:

- The home symbol: the starting point. By placing this element on the projected map of Warsaw, the user defines their virtual location. It is the position from which accessibility to all areas is calculated.
- The knob: defining the maximum cycling distance. By rotating this element, a user defines the longest distance they are willing to cycle. This value varies depending on the user's physical conditions and the purpose of bicycle use. It may be e.g. set to higher values when testing cycling accessibility for recreational reasons, while for everyday commuting the maximum distance may decrease.
- Pairs of arrows: start- and endpoints of new connections. By placing two arrow-like objects on the table, the user proposes new linear cycling paths. Multiple sets can be used in the process to design both bridges and new in-city links.

The camera captures the configuration of elements that is then interpreted by ReacTIVision software (phase 1) to obtain each element’s location and rotation on the table. The coordinates are then sent to the Grasshopper definition (the second phase) via User Datagram Protocol (UDP - a transmission model that enables communication between devices and programs within the same network).

The Grasshopper definition (phase 2) was developed by the workshop participants under the supervision of Adrian Krężlik. This part of the process is re-

Figure 5
A scheme presenting the workflow based on the interactive table.
sponsible for calculating cycling accessibility of different areas of Warsaw based on data received from the user. It implements Dijkstra’s algorithm (using Shortest Walk plugin for Grasshopper) to calculate connections through pre-defined network of cycling lanes and cycling-friendly streets. Each city area is then assigned a color that indicates the level of accessibility and the color map is sent using UDP to the application developed in Unity3d (phase 3).

The Unity-based software (phase 3) was developed during the workshop under the supervision of Jacek Markusiewicz and is responsible for displaying live feedback on InteracTable workspace. The city plan has been divided into roughly 30,000 small regions of similar area. The accessibility to each of these regions is estimated by measuring the shortest path length from its center to the starting point (home symbol location). If such length exceeds the maximum desired cycling distance, then the area is assigned white color. Otherwise the color is interpolated between red and orange proportionally to the length of the path. The feedback is provided almost instantaneously (125-500ms between changes made by the user and the update of color map on the screen).

Every participant of the workshop was assigned a task to propose one or more new bridge connections across Vistula river according to their own criteria. We observed different approaches. Some students were commuting to work or school using a bicycle on a daily basis, while others used bicycles exclusively for recreational purposes. Most participants were defining the starting points in either the areas with biggest population or the ones that are believed to lack bicycle infrastructure. Some however were placing the home symbol subjectively - around their houses, schools or working places. All users performed accessibility analyses for multiple starting points and multiple configurations of proposed connections attempting to compare accessibility data for:

- Current situation - with no new links
- Their subjective design proposal - where the user simulated new connections in places he or she intuitively considered advantageous
- The city authorities’ proposal
- The seemingly incorrect situation - where new links were proposed in location that the user considered illogical.

We conducted a simple survey, in which we asked every table user to select a new location for a bicycle bridge or bridges across Vistula river. We received 27 answers (10 workshop participants, 2 tutors, 15 guests on the workshop outcome presentation - see Figure 7). The most popular answer was a link in the vicinity of Poniatowski Bridge (central Warsaw - 13/27 answers). Other indicated solutions were: the proximity of Łazienkowski Bridge (south central Warsaw - 6 answers), the confirmation of the city authorities’ proposal between Karowa Street and Okrzei Street (Old Town - 3 answers), a double connection linking both river boulevards and Warsaw Escarpment on the left side of the river with the right bank confirming the optimization results (near Łazienkowski Bridge - 3 answers) and a link between Łazienkowski and Siekierkowski Bridge (south Warsaw - 2 answers).
DISCUSSION
The solutions originated from the process are the following:

1. For machine-driven approach:
   - Upper Bride, extending Ludna Street at the level of escarpment, going over Wioślarska Street, crossing the river to Walecznych Street over Wał Miedzeszyński,
   - A possible additional lower bridge, close to trace of Łazienkowski, connecting Vistula Boulevard (around Czerniakowski Port) with Saska Kępa

2. For user-centered approach: a single cycling bridge in the vicinity of Poniatowski Bridge. (Figure 8)

   The similarity of these results may be interpreted as a complementary validation of both approaches, but it also raised a question among the participants of the workshop about the role of human decisions in architectural and urban processes.

   These processes are traditionally considered as creative and it is hard to imagine they can exist when devoid of human aspect. (Meltzer 2014; [2]) However, recent history shows that unimaginable scenarios have to be taken into account. Levy and Murnane in their visionary “The New Division of Labour” made many accurate predictions about potentially automated human jobs. Interestingly enough they presented the job of a truck driver as unlikely to be replaced by a computer. The world of science needed only a decade to defy this forecast by switching the status of driverless cars’ vision from “highly unlikely” to “very close future”. (Levy and Murnane 2004 after Harari 2015)

   There is no reason to assume with full certainty that the job of an architect or urbanist will not undergo automation at least to certain extent. In this context, optimization can be the first step to introduce computer-performed tasks in architecture, where many agents - including investors - often look for efficient solutions over individual approach. Im-
implementing solutions like PSO in the workflow provides data-valid solutions in relatively short time.

Then why bother involving people in a process when it can be fully automated by an algorithm? One opinion may be that it is not always the solution that matters the most but the process itself. When working on a problem - either as individual architects, a group of designers or part of a larger community in participatory design - we take part in a cultural process that enhances one's social and often environmental awareness. Receiving a ready solution does not give us reasons to rethink our future goals or to resolve potential ethical dilemmas. Distinguishing good or bad solutions in architecture and city planning does not come from pure data. The popular example of whether a driverless car can face moral decisions (Greenemeier 2016; [3]) shows how vague our own priorities can be - not to mention priorities that may be considered optimal by a machine. While taking decisions collectively, humans act as multiple independent algorithms and - even if some of us come to incorrect solutions - the final decision is probable to meet shared priorities thanks to negotiations and mutual validation. Decisions made by a computer, if not programmed correctly, can have serious consequences.

However, maybe the question should be exactly the opposite: should we spend our resources on programming computers to work on tasks that humans are able to perform just as well? There are many situ-

Figure 8
Schematic map with positions of new bridges
ations in which computational capabilities are essential, especially when solutions require responding to big data, that we as humans are simply unable to process. “As the amount of data goes up, the importance of human judgment should go down.” (McAfee 2013 after Press 2014; [4]; [5]) Computer decisions may be free of human-specific biases and personal interests and as such may provide solutions that - even if not perfect and lacking moral validation - are better.

In fact, when asking the second question, we often assume that human effort is required to issue a command to a program or to write an algorithm. However, such assumption may be erroneous, as with the development of artificial intelligence computer programming may also be outsourced to computers. Will then the priorities of problem-solving be compatible with ours or will the artificial intelligence set new rules for potential solutions? Some think it is safer to always have a possibility for human-override of algorithm’s decisions, (Davenport 2013; [6]) assuming it is possible. And “then again, humans can be even more wrong”. (Kobielus 2015; [7])

Judging only by the voices among the participants and our personal opinions, we think that it may be beneficial to follow investigating two scenarios: human-centered and machine-centered. As of today, we cannot know what role for the architect will the future bring. In fact, from a deeper investigation of potential scenarios new ideas will surely emerge. We find it urgent to raise all these questions and arguments, especially among the students of architecture. Not doing so will lead us - architects - to a situation where the decisions about the future of our job, including its replacement by fully automated processes, will be taken without our involvement.

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