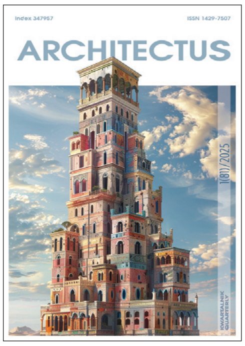

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Tomasz Dzieduszyński*, Olga Czeranowska-Panufnik**

School streets implementation: A machine learning perspective

Abstract

This study explores the application of generative adversarial neural networks in the implementation of school street closures, a concept aimed at improving safety and reducing traffic around schools. The research analyses various school street closure programs worldwide and identifies common challenges. Based on an analysis of 51 successful school street closure programs and a proposed urban feature extraction method, a supervised machine learning model was developed to facilitate the selection of the potential school street candidates. The developed tool aims to streamline the selection process and make the design more effective and context-sensitive. Despite certain limitations, such as the inability to represent all spatial contexts and small-scale urban details, the system can propose a meaningful definition of a school street closure zone. This research contributes to the limited academic literature on school streets and play streets, providing a new perspective on urban traffic regulation.

Key words: school streets, machine learning, smart city, generative adversarial networks, computer aided architectural design

Introduction

School Street is a road outside a school with a temporary restriction on motorized traffic at school drop-off and pick up times (School Street Initiative 2019). The idea to close down the traffic for the sake of children is already over one hundred years old and can be traced back to the idea of "play streets" implemented in Cincinnati as early as in 1920 (Reeves 1931). However, the modern understanding of the concept of school streets is relatively new in urban studies, as the first contemporary school streets in Europe were implemented in the late 1980s in Bolzano, Italy (Brand, Böhler and Rupprecht 2021; Pressl 2011). The idea is insufficiently explored in peer-reviewed literature (Davis 2020). There is a gap between the need for their implementation and the theoretical foundations as well as available tools, especially in Poland, where the school street closure programs are just in their infancy.

* ORCID: 0000-0003-2571-5128. Faculty of Architecture, Warsaw University of Technology, Poland, e-mail: tomasz.dzieduszynski@pw.edu.pl

** ORCID: 0000-0002-8210-5265. Faculty of Architecture, Warsaw University of Technology, Poland.

This study aims to analyse contemporary worldwide examples of school streets to identify issues in the studied pilot programs and develop a machine learning tool for selection and analysis of school streets candidates based on their successful worldwide implementations. The study is divided into three main parts: literature review supplemented by qualitative analysis of school street closure programs, definition of a training dataset based on the selected positive examples paired with the corresponding urban features, and development of a supervised machine learning algorithm based on generative adversarial network (GAN) architecture (Goodfellow et al. 2014; Isola et al. 2017).

State of the art, school street programs review

The academic sources on both school streets and play streets are limited (Davis 2020; Bridges et al. 2020). A supplementary Web of Science query from April 2024 for the tags "school streets" or "school street" returned only 10 relevant peer reviewed publications (Clarivate 2024). The sources on the subject consist mostly of grey literature pilot program reports, non-peer-reviewed studies, survey results, local press reports and practical implementation toolkits. The present study analyses a selection of school street closure programs from the years 2016 to 2022

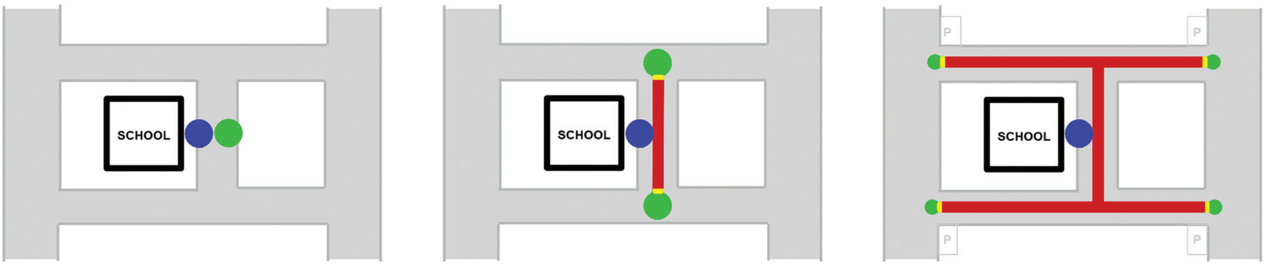

Fig. 1. The geometric intuition behind the school street closure zones (red) near the school access points (blue). Increase in the number of drop-off nodes (green) reduces the related traffic problems and enhances safety (elaborated by T. Dzieduszyński, O. Czeranowska-Panufnik)

Il. 1. Geometryczna intuicja stojąca za strefami zamknięcia ulic szkolnych (czerwone linie) w pobliżu punktów dostępu do szkoły (niebieskie punkty). Zwiększenie liczby punktów wysiadania z pojazdu (zielone punkty) zmniejsza związane z tym problemy komunikacyjne i zwiększa bezpieczeństwo (oprac. T. Dzieduszyński, O. Czeranowska-Panufnik)

localized mostly in Great Britain, the current world leader in the number of school street closure zone implementations (Clarke 2022). The conducted analysis included London (Noble et al. 2021), Hackney (Linton et al. 2021), Edinburgh (Lawrence, Murrell 2016; City of Edinburgh Council 2020), Southampton (My Journey 2021), East Lothian (Stubbs 2016; Ritchie 2016), Solihull (Keaney, Tovey 2018; Solihull Metropolitan Borough Council 2021), Perth and Kinross council area (Perth and Kinross Council 2022), but also Victoria, Canada (880 Cities 2019; City of Victoria 2022), Warsaw, Poland (Mikołajczyk 2021; Urząd m.st. Warszawy 2022) and Wrocław, Poland (Grabowska, Szmigiel-Franz 2020).

In the analysed grey literature the implementation of school streets was mainly motivated by safety concerns (Fig. 1), but the premises encompassed a variety of factors. In Southampton, the program aimed to enhance safety and air quality. It promoted outdoor exercise and encouraged alternative transportation like bikes and scooters, while also reducing traffic congestion (My Journey 2021). East Lothian's program aimed to increase road safety by reducing traffic, congestion and air pollution near school gates. It also encouraged active travel among students and their families and fostered an environment for social interaction (Stubbs 2016). Solihull's initiative was introduced to address increased traffic during school drop-off and pick-up times, which often led to potentially dangerous situations caused by the drivers (Keaney, Tovey 2018). In London the school street initiative gained popularity thanks to the "Streetspace for London" program launched as an emergency response to the COVID-19 pandemic. The program aimed to make social distancing easier while traveling in London, encourage people to walk, cycle and scoot, prevent an increase in car use enabling emergency services and essential vehicle journeys and to enhance the air quality. As a result of the program, over 300 school streets were implemented in London (Noble et al. 2021). Generally, the COVID-19 pandemic vastly accelerated the development of school street programs more than doubling the worldwide number of cities participating in the initiative (Clarke 2022).

In the analysed sources, the selection and design process of the school street closure zones was based on several urban criteria, mostly focused on the road network surrounding the candidate school. In East Lothian, factors such as road type, existing speed restrictions or traffic regulation orders were considered, as well as the recorded accident history and availability of larger municipal parking. Additionally, the preferences and habits of the students and their parents were recognized through the analysis of the number of students dependent on road transport (Stubbs 2016). In Solihull, UK, the selection was based on the type of road, the absence of more intense throughfares and the feasibility of traffic reorganization. The supplementary contexts consisted of the neighbourhood structure, the percentage of students living within the walking distance from the school and the willingness of the school and the local community to cooperate (Keaney, Tovey 2018). In Wrocław, Poland, the criteria focused on the possibility of practical traffic organization to bypass the closed section, the registered reports of dangerous situations or increased traffic during school hours and previous participation of a candidate school in the programs implemented by the Sustainable Mobility Office (Biuro Zrównoważonej Mobilności). The character of the neighbourhood was also considered, including the distribution of students living within the 15-minute radius from the school and the accessibility to public transport (Grabowska, Szmigiel-Franz 2020).

Overall, the analysed school street pilot programs were mostly successful. In the reviewed reports 51 examples of implementations were recognized as unambiguously positive, and only 5 school street pilots failed and had to be terminated (Fig. 2). However, even the successful programs encountered some problems. In certain cases, the program could be implemented more strictly and the traffic regulation orders could be better executed. Some drivers were still speeding or passing through the street during a closure. To some extent this was often caused by confusion of drivers not aware of the traffic regulation order in place. The implemented regulations were often chaotic. It was not obvious when the restrictions were active, as they were not consistent across different months or days of the week. It was also not clear who was exempt from the restrictions (Keaney, Tovey 2018). To make the situation clearer, in some cities parents or the school were responsible for setting up a scissor gate. The school street could also be monitored by a city

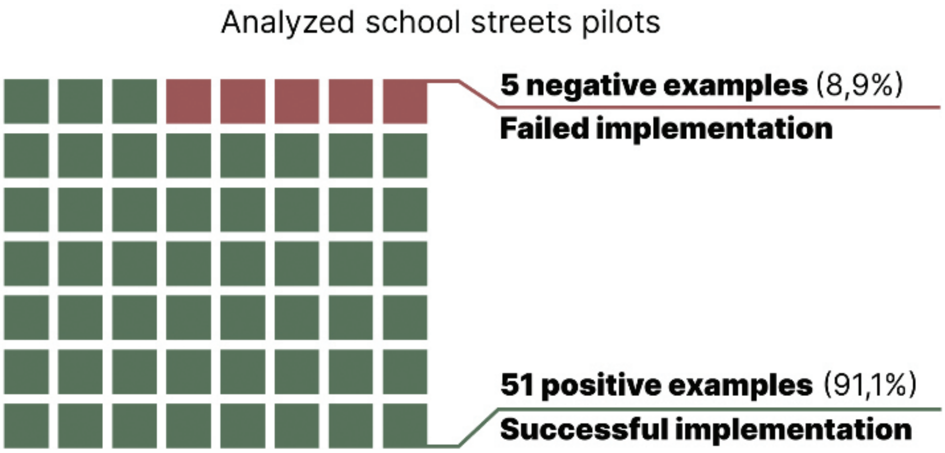

Fig. 2. The ratio of successful school street implementations to failed ones based on the grey literature analysis (elaborated by T. Dzieduszyński, O. Czeranowska-Panufnik)

Il. 2. Stosunek udanych wdrożeń programów zamknięcia ulic szkolnych do nieudanych, na podstawie analizy literatury szarej (oprac. T. Dzieduszyński, O. Czeranowska-Panufnik)

guard (Keaney, Tovey 2018; Grabowska, Szmigiel-Franz 2020). In many cases, the implementation of school streets impacted many stakeholders of different needs and interests (Grabowska, Szmigiel-Franz 2020). The programs required extensive informational campaigns and personal consultations to be supplemented. Moreover, the closures often burdened the inhabitants of school streets. While local residents typically received a certain number of passes, some complained about the inability to receive guests during the closures (Keaney, Tovey 2018). Additionally, these programs heavily burdened parents, necessitating sudden changes of routines. Some parents even questioned the necessity of the programs and believed that the reasons for their implementation were non-existent. In one of the reviewed cases, the way to school became perceivably more dangerous after the implementation of a school street closure zone, since children had to cross a large road (Keaney, Tovey 2018). A few critics of the idea raised a claim that the problems of chaotic parking, dangerous traffic and air pollution were not solved by the closure programs, but were just moved to another place or caused a "wave effect" (Grabowska, Szmigiel-Franz 2020; Lawrence, Murrell 2016). While this could be true for incorrectly designed traffic regulation orders, a school street closure zone with numerous, well-designed drop-off nodes would have a tendency to better distribute these issues across a broader area, thus decreasing their severity (Fig. 1). To a large extent the mentioned problems were caused by the insufficient consideration of the contexts and available data, as well as too hermetic social consultations. A wider implementation of data-driven tools (such as the one proposed in this study) could potentially alleviate the negative effects of school street implementations related to the lacking recognition of local urban contexts.

Machine learning perspective

Following a comprehensive review of school street closure programs implemented between 2016 and 2022, a prototype machine leaning context-analysis algorithm was developed in 2023 and 2024. This algorithm was trained on the selection of 51 successful school street pilot programs identified through grey literature analysis. During inference, the prototype uses the coordinates of a candidate school. It then extracts the most relevant spatial contexts from OpenStreetMap (OpenStreetMap Contributors 2024) and translates these contexts into the proposed closure zone, together with the proposed drop-off nodes and school access points. In its current iteration, the tool functions as a preliminary analysis instrument, focusing solely on readily accessible open-source urban contexts. This approach avoids the need for additional viability and social analysis. These contexts are compiled in the form of three voxel maps representing the urban tissue (buildings, car parks, bridges), extents of the analysed school (school area) and the communication network (roads, paths, tunnels and waterways). These maps can be represented as a 512 × 512 RGB image, where each of the colour maps represents one of the context groups and the intensity of the pixel's colour corresponds to the height of the urban tissue and the intensity of the transit mode on the communication network map (Fig. 3). One pixel represents an area of 1.5 × 1.5 m, the extent of the context map corresponds to the pedestrian shed defined by a 5-minute walk radius, approximately 400 m (Perry 1929).

The algorithm is based on a generative adversarial neural network (GAN) (Goodfellow et al. 2014), a type of neural network used for generating data similar to a given dataset. Its structure was inspired by the pix2pix architecture (Isola et al. 2017). From the conducted school street programs review, 51 the most successful examples of closure zones were selected and RGB target maps were manually labelled. The red channel on the target map represents the closure zone, the green represents the drop-off node and blue represents the school access point. Coordinates of the selected schools were compiled in an XML spreadsheet. A custom script was used to automatically download the urban feature maps from the Mapbox Static Image Service (Mapbox 2023) through API and pair them with the hand-labelled target maps. The training dataset was augmented through random cropping, random jitter and random mirroring to reduce the risk of overfitting. U-Net (Ronneberger, Fischer and Brox 2015) was used to generate the proposed school street closure zone based on the given feature map. A patch discriminator was applied to try to distinguish the generated maps from the original target maps. The L1 and GAN loss were calculated based on the algorithm's performance and

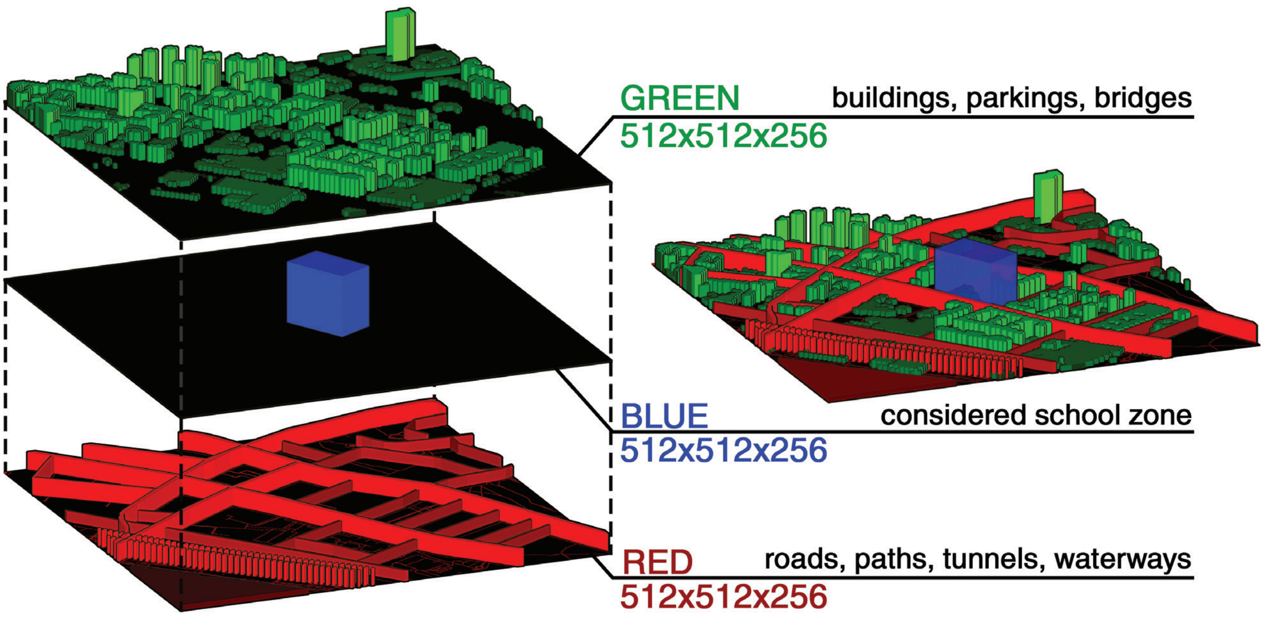

Fig. 3. The context map represented as an RGB image. The green channel represents the height of the urban tissue, blue channel represents the extents of the analysed school land, the red channel represents the intensity of the communication network. The map is extracted from OpenStreetMap (OpenStreetMap Contributors 2024) through Mapbox Static Images Service (Mapbox 2023) (elaborated by T. Dzieduszyński, O. Czeranowska-Panufnik)

Il. 3. Mapa kontekstów przedstawiona jako obraz RGB. Kanał zielony reprezentuje wysokość tkanki urbanistycznej, kanał niebieski przedstawia zasięg terenu analizowanej szkoły, a kanał czerwony intensywność sieci komunikacyjnej. Mapa została pozyskana z OpenStreetMap (OpenStreetMap Contributors) za pośrednictwem usługi Mapbox Static Images (Mapbox 2023) (oprac. T. Dzieduszyński, O. Czeranowska-Panufnik)

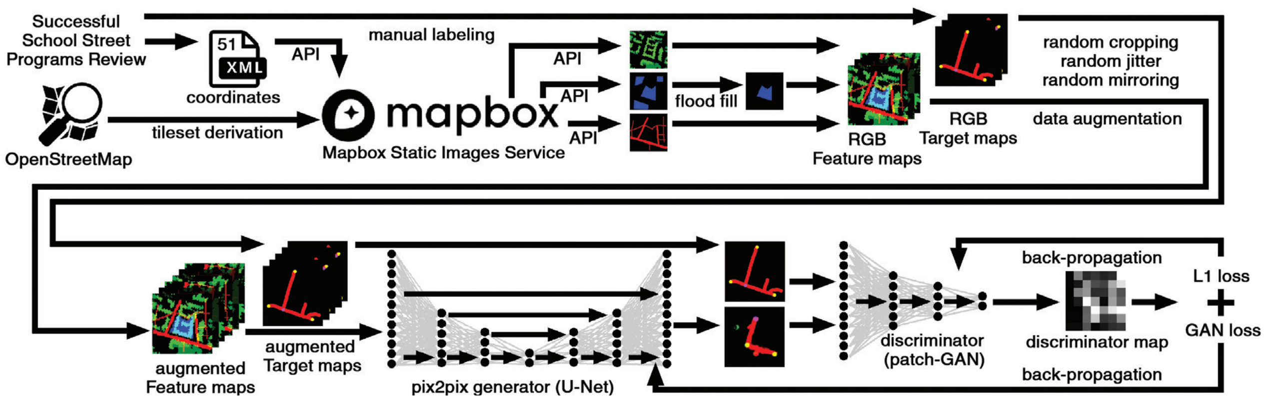

Fig. 4. The training diagram of the utilized generative adversarial neural network (elaborated by T. Dzieduszyński, O. Czeranowska-Panufnik)

Il. 4. Diagram przedstawiający proces treningu zastosowanej generatywnej sieci przeciwstawnej GAN (oprac. T. Dzieduszyński, O. Czeranowska-Panufnik)

back-propagation was used to train both of the networks in an ensemble (Fig. 4). Hyperparameters were tuned using the random search method. The lambda hyperparameter was tuned during training, increasing the weight of the L1 loss function in the later phases of training. The algorithm was trained for 31 hours on Nvidia GF RTX 2080 Super. During inference only the generator is used.

The developed algorithm was tested on the selection of candidate schools for the Warsaw "Droga na szóstkę" school street viability evaluation program (LPW 2020), as well as four negatively assessed schools described in the analysed pilot reviews. These schools were not included in the training data. The trained neural network successfully generated meaningful school street closure zones in 90% of validation cases (Fig. 5). The inference time on a mid-range consumer laptop fits in the range of 1–3 s, which allows for automated batch-processing of large sets of candidate schools.

Case study

In this section, we provide detailed examples of the algorithm applied to real-world scenarios, specifically in Warsaw's Elementary School No. 195 and No. 175. By adjusting road class parameters and rerunning the algorithm, we explored different closure scenarios for these schools.

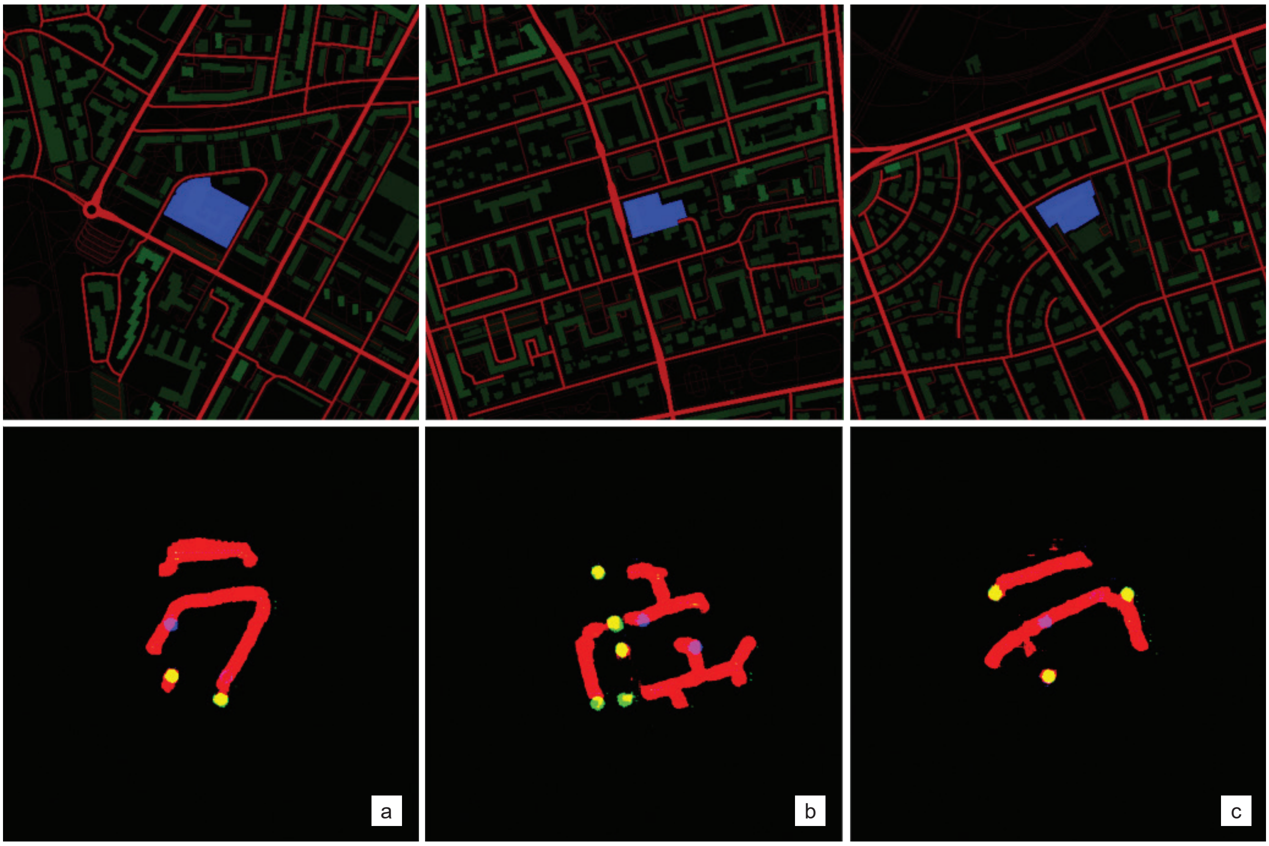

Fig. 5. School street closure zones generated by the trained algorithm for the three Warsaw candidates for the school street closure program (LPW 2020): a) Elementary School No. 175, b) Elementary School No. 157, c) Elementary School No. 373. Red channel of the target space represents the closure zone, green the drop-off nodes and blue the school access point (elaborated by T. Dzieduszyński, O. Czeranowska-Panufnik)

Il. 5. Strefy zamknięcia ulic szkolnych wygenerowane przez wytrenowany algorytm dla trzech warszawskich kandydatów do programu ulic szkolnych (LPW 2020): a) Szkoła Podstawowa nr 175, b) Szkoła Podstawowa nr 157, c) Szkoła Podstawowa nr 373. Kanał czerwony przestrzeni celu przedstawia strefę zamknięcia, zielony – punkty wysiadania z pojazdu, a niebieski punkt dostępu do szkoły (oprac. T. Dzieduszyński, O. Czeranowska-Panufnik)

The main purpose of the developed tool is the facilitation of the school street selection process. The algorithm receives the coordinates of the queried school, extracts the urban contexts and in a few seconds, it outputs the proposed school street closure zone. The generated proposal can be used to assess the sensibility of the closure zone implementation and can be later used as a baseline during the later stages of evaluation and design process. The second use case is the urban redesign analysis. The input feature maps do not have to correspond to the current urban contexts, but can represent the planned urban interventions. These interventions could relate to road classes, number of car parks, redesign of the urban tissue, changes in pedestrian paths network or change in development intensity. The varying input feature maps result in different target maps generated by the algorithm and can help urban designers better understand the relationships between school streets and their surroundings. This use case was tested and demonstrated on the example of changing road classes surrounding the Warsaw Elementary School No. 195 and No. 175. Lowering the class of the road results in the extension of the possible closure zone, while increasing the class leads to its reduction. To compensate for the shrinking of the school street, the algorithm generates additional peripheral drop-off nodes, thereby enhancing the efficiency of the closure program (Fig. 6).

The results demonstrate the adaptability of the tool in urban design. For example, lowering the road class surrounding Elementary School No. 195 significantly expanded the closure zone, while increasing the road class around No. 175 led to more distributed peripheral drop-off nodes. These applications demonstrate how changes in urban features affect the overall design, providing a flexible solution for urban planners.

Discussion

As demonstrated, the system can propose meaningful school closure zones. This can be beneficial during the selection process of school street candidates and can be utilized during urban redesign analysis. Although the results are promising, the developed tool is currently only a prototype and it has many limitations, which reduce its practical applicability in urban planning. One of the key limitations is that the tool does not fully reflect the complexity of the school street selection process. It does not account for important social contexts, such as stakeholder dynamics, local policies or preferences of students and

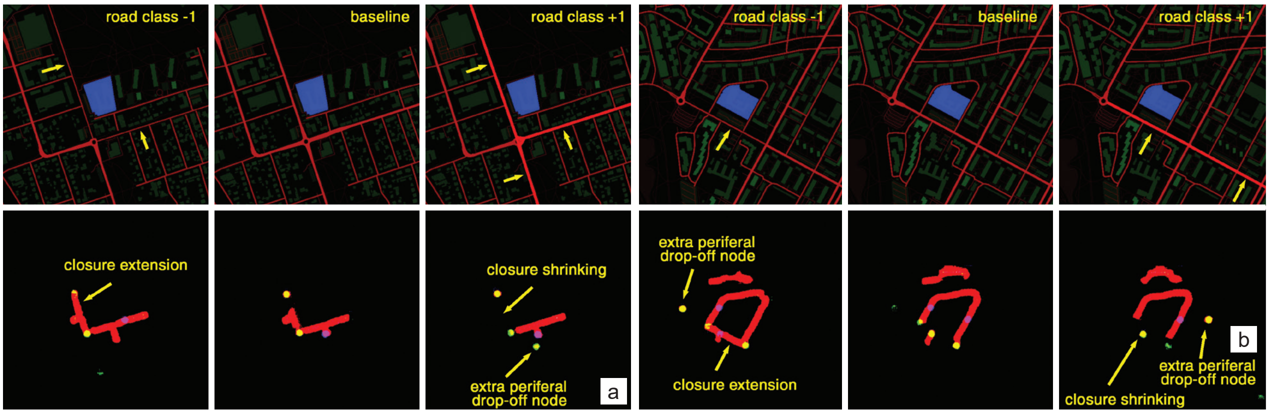

Fig. 6. Utilization of the trained neural network in urban redesign analysis demonstrated on:
a) Warsaw Elementary School No. 195, b) Warsaw Elementary School No. 175.
Changes in road classes affect the proposed school street closure zones (elaborated by T. Dzieduszyński, O. Czeranowska-Panufnik)

Il. 6. Wykorzystanie wytrenowanej sieci neuronowej w analizie przekształceń urbanistycznych pokazane na przykładach:
a) warszawskiej Szkoły Podstawowej nr 195, b) warszawskiej Szkoły Podstawowej nr 175.
Zmiany w klasach dróg wpływają na proponowane strefy zamknięcia ulic szkolnych (oprac. T. Dzieduszyński, O. Czeranowska-Panufnik)

their families. These factors play a significant role in the successful implementation of school street closures, and their absence in the model reduces the sensitivity of the tool to such nuances. It is important to note that the tool was not developed to replace the complex urban analyses required for these projects but to complement them by providing an additional layer of analysis that makes the design process more context-sensitive.

The proposals generated by the neural network were sometimes hard to interpret. By machine learning standards, the training sample was very small, consisting of only 51 successful training examples represented in the reviewed literature. This problem was partially mitigated by data augmentation, but overall, the small training sample significantly reduced the algorithm's generalizability, as it could not encounter many context scenarios during the training. Such case can be visualized on the example of the Bonaly Primary School in Edinburgh, which closely neighbours the Edinburgh highway bypass. Since this specific situation was not represented in the training set, the algorithm decided to generate the drop-off points in the middle of the highway (Fig. 7).

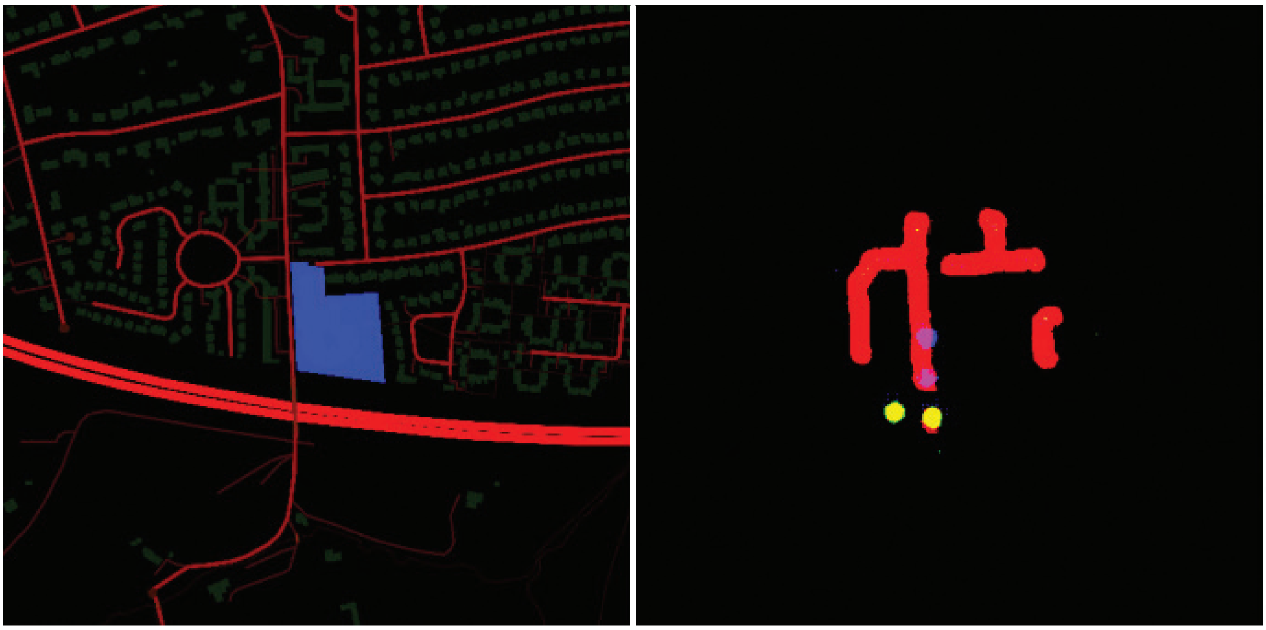

Fig. 7. An example of an incorrect school street closure program proposed by the algorithm for the Bonaly Primary School resulting from the small training sample. The algorithm generated the drop-off nodes in the middle of a highway (elaborated by T. Dzieduszyński, O. Czeranowska-Panufnik)

Il. 7. Przykład nieprawidłowego programu zamknięcia ulicy szkolnej zaproponowanego przez algorytm dla Szkoły Podstawowej Bonaly, wynikający z niewielkiej próbki treningowej. Algorytm wygenerował punkty wysiadania z pojazdu na środku autostrady (oprac. T. Dzieduszyński, O. Czeranowska-Panufnik)

To some extent the failure in this case could be partially justified by the negative assessment of viability of the Bonaly Primary School for the implementation of a school street closure program (Lawrence, Murrell 2016). Due to the limited training sample, the algorithm was trained to always generate a closure zone, even if the contexts are not favourable. This hard requirement sometimes leads to incorrect proposals. As the tool was being developed, a large number of school street programs were implemented as a result of the COVID-19 pandemic (Clarke 2022). Currently, a much larger dataset of successful closures can be compiled to train the next iteration of the algorithm. Another large problem arises from the incompleteness of the analysed contexts and the low resolution of the accessible data. The utilized feature maps do not fully reflect the real-world complexities of implementing school street closures. While the tool could definitely benefit from more extensive, high-resolution data, such data is not readily available or machine-friendly. These extended contexts could include:

– traffic analysis, such as the road safety audit, recorded incidents affecting the school community and traffic intensity measurements,

– communication habits of the students and their parents,

– functional audit,

– database of stakeholders affected by the closure and their characteristics,

– air quality and pollution measurements,

– records of other programs related to school street closures at the candidate school, including physical activity encouragement projects, play streets, school gardening initiatives, local community activization, etc.

A more comprehensive data collection and integration could improve the tool's effectiveness and would probably increase the capabilities of the system. However, an increase in the number of compiled context sources would also reduce the applicability of the algorithm only to the areas, which have these contexts recorded and accessible. The current version of the algorithm can be applied to any school that is represented on OpenStreetMap. Future research should focus on expanding the dataset and improving the algorithm's adaptability to diverse urban contexts. Additionally, a collaborative approach involving stakeholders from various sectors, including education, transportation, and public health, is crucial for the successful implementation and scaling of school street programs. By doing so, cities can create safer, healthier and more vibrant urban spaces that prioritize the well-being of children and the entire urban community.

Conclusions

In conclusion, this study demonstrates the potential of data-driven approaches to enhance the planning and implementation of school street programs. The integration of machine learning tools can streamline the selection process and improve the design of these interventions, making them more effective and context-sensitive. Policymakers and urban planners should consider investing in the development and deployment of such tools to support their urban mobility goals.

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Streszczenie

Wprowadzanie ulic szkolnych: perspektywa uczenia maszynowego

Tematem artykułu są ulice szkolne, a zwłaszcza proces ich tworzenia z perspektywy uczenia maszynowego. Autorzy przedstawili w nim możliwości zastosowania generatywnych sieci przeciwstawnych typu GAN we wdrażaniu koncepcji zamknięcia ulic szkolnych, której celem jest poprawa bezpieczeństwa i zmniejszenie natężenia ruchu wokół szkół. Przeanalizowali programy ulic szkolnych na całym świecie, identyfikując powtarzające się wyzwania i proponując rozwiązania. Na podstawie analizy 51 skutecznych wdrożeń oraz nowej metody ekstrakcji cech miejskich opracowali model uczenia maszynowego, który wspomaga wybór potencjalnych lokalizacji ulic szkolnych. Tak przygotowane narzędzie ma służyć usprawnieniu procesu wyboru i zwiększeniu efektywności projektu przez lepsze dopasowanie do lokalnego kontekstu. Pomimo pewnych ograniczeń, takich jak trudność w odwzorowaniu wszystkich kontekstów przestrzennych, system dostarcza wartościowych wniosków dotyczących regulacji ruchu miejskiego. Badanie wypełnia lukę w literaturze naukowej i oferuje podejście oparte na danych do projektowania bezpieczniejszych przestrzeni miejskich.

Słowa kluczowe: ulice szkolne, uczenie maszynowe, smart city, generatywne sieci przeciwstawne, projektowanie architektoniczne wspomagane komputerowo