URBAN CULTURAL INHERITANCE

Generative Adversarial Networks (Gans) Assisted Street Façade Design In Virtual Reality (Vr) Environments Based On Hakka Settlements In Hong Kong

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Abstract. In Hong Kong, the Hakka settlements are the home of indigenous people who have been involved in agriculture and fishing for over 200 years, which has a special place in Hong Kong's history. However, these settlements are gradually being abandoned as ghost towns due to rapid urbanisation, where the city is progressively constructing high-density habitats to accommodate the exponentially increased population since the 1950s. This challenges designers to rethink means of preserving urban cultural heritage, while engaging in continuous urban regeneration processes. This study investigates workflows to detect historical building styles in one of the most densely-populated cities in the world - Hong Kong - that further deployed in human-computer interfaces in the virtual reality (VR) environment as a collaborative and suggestive design decision-making tool and co-design engagement tool for style infilling on urban regeneration to maintain urban culture inheritance. The workflow aims to discuss the preservation of historical buildings in the context of urban regeneration, urban cultural inheritance through digital archiving, bottom-up community engagement and education in urban design. This study discusses the impact of emerging technologies on the making of communities in human-centric discourse, rethinking social power and the right to the city in participatory mechanisms.

Keywords. Urban Culture Inheritance, Hakka Settlements, Facade Generation, Human-Computer Interaction (HCI), Virtual Reality (VR)

1. Introduction

Urban regeneration has generally become an irreversible process in modernisation.

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Designers and researchers are being challenged to consider more complex socio-technical mechanisms in the post-rational moment. Urban culture, as a reflection of a sense of belonging in community making, has raised the attention of planners. Cultural inheritance refers to the preservation and dissemination of knowledge on cultural information through communication, imitation, teaching and learning in the long term (Peedicayil, 2001). Thus, in urban cultural inheritance is the preservation and heritage of physical buildings, objects, and landscapes, but also the intangibility of how spaces are being inhabited, methods to design production and construction, and public education.

In Hong Kong, Hakka settlements are habitats of the indigenous populations who have been engaging in agricultural and fishing activities for more than 200 years; especially in the New Territories, which has a special place in Hong Kong's colonial and policy history (Kong, 2018). Lai Chi Wo, Hong Kong's oldest, largest and best-preserved rural settlement, has won UNESCO's prestigious 2020 Special Recognition for Sustainable Development award for promoting cultural heritage preservation. The social capital of Hakka villages is the relationship inside the family's settlements - goodwill, fellowship and social intercourse, which can be manifested through their settlements as the symbol foundation of a sense of belonging (Lin, 2022). However, these settlements are gradually being abandoned as ghost towns due to rapid urbanisation, where the city is progressively constructing high-density habitats to accommodate the exponentially increased population since the 1950s (Wong, 2013).

Urban regeneration may help in modernising old urban fabrics and standardisation lowers the marginal costs of construction. It can sometimes produce homogeneous environments that are not inclusive of varying community needs (Jacobs, 1961). While the visual qualities of historic street spaces may generate a sense of cultural identity and belonging, it may be difficult to accommodate typologies and other contemporary needs (Raman, 2014). Urban planning is an iterative, collaborative process that frequently only involves designers and civic stakeholders (Kim et al., 2022). Andre Leroi-Gourhan (2002) argued that "innovation happens only when technical supply matches culture demand." The digitalisation can be a backcasting to tradition and bring urban design back to everyone through the interactions between humans and machines (Negroponte, 1969). Generative adversarial networks (GANs), firstly introduced by Ian Goodfellow and his colleagues (2014), as an artificial intelligence framework mainly used to automatically generate images, are capable of this reproduction of traditional cultural embodiments in digitalisation by fusing two styles of datasets. However, such research lacks data-based metrics in terms of evaluation of user feedback and consideration of data collection, which refers to reflection on the demands of citizens. The research on Human-Computer Interaction (HCI) concerning the design and evaluation of user interfaces can address this problem by utilising the participants' responses. A digital twin is a digital replica of a physical asset, system, or process that can be used for documentation, simulation and evaluation (Ng et al., 2022). With the burgeoning VR technology, virtual environments as a representation of the digital twin allow citizens to truly experience the automated generation of urban regeneration approach, which can take advantage of the HCI approaches as well.

In this paper, we implemented a framework for participatory design in respect of replacing the city facades in an immersive VR, mainly through an online VR platform and the image generated by CycleGAN automatically. This research aims to generate design options to guide collective decision-making processes with the use of neural networks and use immersive digital twins to best utilise community engagement in VR environments with user-friendly interfaces. This study also aims to look at the transformation from historical settlements to modern society in the urban regeneration process in the revolution of digitalisation. The final goal of this research is to build participatory mechanisms and shared visions for designers and citizens in historical heritage preservation, and co-design for future cities using meaningful intercultural interactions to inherit urban culture.

2. Related Works

GANs can be used to suggest design options that act as a communicative interface between human and computer. GANs have a few variants, one of the types is CycleGAN (Zhu et al., 2017). It enables the adding of more generators and discriminators to train unpaired images and facilitates more flexibility in training processes for design and decision-making (Avinash, 2022). Since the CycleGAN is trained by having the forward model generate an output image from the input image, and then having the reversal model attempt to recover the original input image from the output image. This process helps to ensure that the output image retains the content of the original image, while taking on the style of the target domain. CycleGAN has shown to be very useful in facade design by using labelled images to customise the design of facades. For example, Sun et al. (2022) worked on fine-tuning the algorithms and optimising the dataset in CycleGAN-assisted facade generation in Renaissance, Baroque-style buildings, which has successfully been tested and applied to other urban blocks. Also, CycleGAN has been used to mix two types of facade styles that has its own characteristics for urban infill (Khairadeen Ali & Lee, 2021). In design practices, David Ruy at SciArc explored the GAN-assisted style transfer of how architectural form and design are reproduced in the digital world in mixed approaches, where the machine learning tool is acting as a speculative designer that provides design options beyond human intelligence.

Digital twins can be used for a wide range of purposes, for example, in urban archives. It is a concept that has emerged in the field of the Internet of Things (IoT), where sensors and other devices are used to gather data from the physical world and create a virtual model of it (Ng et al., 2022). In the case of Hakka settlements regeneration, digital twins can be created by capturing detailed information about the physical layout and characteristics of the architecture. The Hong Kong government has been using drone scanning to document the high-resolution photogrammetry model in all built areas since 2017, encouraging more designers and researchers to use digital twins in urban design and planning.

Participatory design has been discussed since the 1960s (Lynch, 1960; Arnstein, 1969). With the development of HCI, VR technology has the potential to be a valuable tool in participatory urban design by engaging citizens in the design process since HCI concerns the design and evaluation of user interfaces, the development of new interaction techniques and technologies, and the understanding of how people use and respond to technology. Kim et al. (2022) deployed pix2pix and CycleGAN into real-time desirable street design tools, which allows citizens to stylise their own city streets.

Leong and Janssen (2022) developed an interactive platform for citizens to preserve a heritage site in Singapore. Loyola et al. (2019) used VR immersive scenes to collect data on the human sense of the quality of space. Also, VR-generated scenarios can be used for treating psychological issues in humans using participatory prototyping and storyboarding (Flobak et al., 2019). By using VR technology, citizens and different community members can participate in the design process in a more interactive and immersive way as a collaborative intelligence.

From previous research, we found there is a lack of research on the preservation of urban cultural heritage. Also, the research on participatory design using VR is limited.

Hence, our research questions were formulated as follows:

- How to automatically generate design options with the use of GANs to inherit urban cultural heritage in the discourse of urban regeneration?
- How can immersive digital twins in VR be best-utilised co-design processes and used in community engagement?

3. Methodology

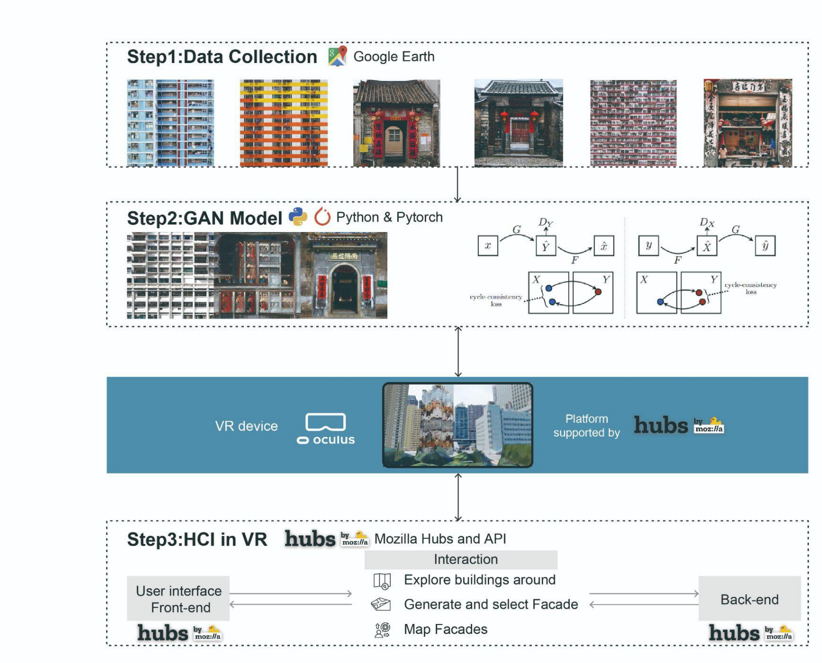

Figure 1. Participatory facades design architecture

This research project focuses on the indigenous Hakka settlements in Hong Kong. The methodology on participatory GANs-assisted automatic generation of façade design comprises three steps (see Figure 1) - dataset collection and processing, style customisation, and performance testing. In the dataset construction part, the façade photos of historical Hakka settlements are collected in high resolution and composed into a dataset that embeds cultural information as well as the normal Hong Kong high-density residential facades photo dataset. In the training and testing process, CycleGAN is used to train both Hakka settlements' façades and Hong Kong's exceptional high-density residential facades to build architectural style transfer models. In the next step of this project, we deployed the generated model as a social engagement and interactive public communication tool on urban culture, and the collaborative generation results will be adapted to virtual districts to test performance.

3.1. FACADE GENERATION

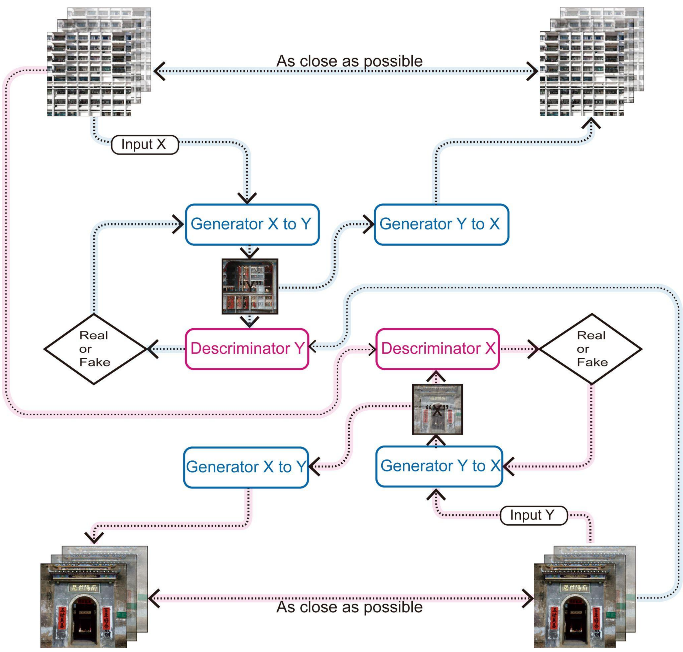

Figure 2. The architecture of generated facades by CycleGAN

The two tiles facades datasets are collected from Google Street View. We collected both residential areas of Hakka settlements and Hong Kong modernist facades settlements. In order to effectively synthesise images, we pre-processed the dataset using OpenCV camera calibration algorithm to autocorrect image distortion to ensure the quality of images. By cropping and resizing the images, we removed any unnecessary background to make sure the size of 256 by 256 pixels, is appropriate for the model. Also, the datasets were augmented by mirroring and rotation.

In the training process, two data tiles are fed into the network separately. We split the dataset into a training set (200 images) and a validation set (20 images). The training set was used to train the model, while the validation set was used to evaluate the performance of the model during training.

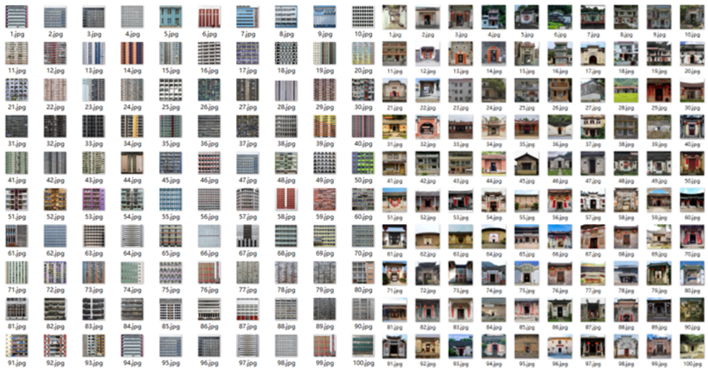

Figure 3. Image data preparation (a left) training set A from modern Hong Kong facades and (b right) training set B from Hakka facades

We defined the architecture of the CycleGAN model and involved two generators and two discriminators - Gxy and Gyx, and 2 discriminators - Dx and Dy. i.e., X to Y to capture the Hakka cultural element from training sets, while the discriminator Dy starts to evaluate the similarity (see Figure 2).

Deep learning framework, TensorFlow and Tensorflow-examples (1.15.0) were used to construct the generators and discriminators (Zhu et al., 2020; Sun, Zhou & Han, 2022). Then, a suitable loss function and optimisation algorithm should be used during training. To train the model effectively, we choose a loss function that captures the quality of the generated images, and an optimisation algorithm that can effectively adjust the model's parameters to minimise this loss.

While training, image X is passed through generator Gxy, which generates image Y^. The generated picture Y^ is passed through generator Gyx, which loops through to generate picture X^. The mean absolute error (MAE) is calculated between X and X^.

Forward cycle consistency loss: X –> generator Gxy (X) –> generator Gyx (Gxy (X)) ~ X^

Backward cycle consistency loss: Y –> generator Gyx (Y) –> generator Gxy (Gyx (Y)) ~ Y^

We used the formula (Zhu et al., 2020; Sun, Zhou & Han, 2022):

$$Loss_{GAN}(G_{xy}, D_y, X, Y) = E_{y\sim pdata(y)}[\log D_y(y)] + E_{x\sim pdata(x)}[\log(1 - D_y(G_{xy}(x))] \quad (1)$$

Cycle consistency loss was introduced to push F(G(X)) ≈ X and G(F(Y)) ≈ Y

The formula for the cycle-consistency loss used in a CycleGAN model is typically based on the L1 distance between the input and generated images after they have been transformed back and forth between the two domains (2)(3) (Zhu et al., 2020; Sun, Zhou and Han, 2022).

$$Loss_{cyc}(G_{xy}, G_{yx}) = E_{x\sim pdata(x)}[\|G_{yx}(G_{xy}(x)) - x\|_1] + E_{x\sim pdata(x)}[\|G_{xy}(G_{yx}(y)) - y\|_1] \quad (2)$$

$$Loss_{identity}(G_{xy}, G_{yx}) = \lambda_x * E_{x \sim pdata(x)}[\|G_{yx}(G_{xy}(x)) - x\|_1] + \lambda_y * E_{x \sim pdata(x)}[\|G_{xy}(G_{yx}(y)) - y\|_1] \quad (3)$$

The overall loss function used in a CycleGAN model is therefore a combination of the GAN loss, the cycle-consistency loss and identity loss, weighted by the regularisation parameters lambda (4) (Zhu et al., 2020; Sun, Zhou and Han, 2022):

$$Loss(G_{xy}, G_{yx}, D_x, D_y) = Loss_{GAN}(G_{xy}, D_y, X, Y) + Loss_{GAN}(G_{yx}, D_x, Y, X) + Loss_{cyc}(G_{xy}, G_{yx}) + \lambda_i * Loss_{identity}(G_{xy}, G_{yx}) \quad (4)$$

The values of lambda were chosen between 10 and 50 during training to improve the performance of the model. We tested 100, 200, and 300 epochs for the training process and evaluated the generated power by using the 300 epochs model.

Lastly, once the model has been trained, we synthesised new facade images by providing it with input images of the appropriate type (i.e., the Hakka style). The model then generated a transformed version of the input image, formulating a mixed-style facade. We also manipulated the training dataset at the same time, replacing part of the facades of Hakka settlements with Hong Kong modernist facades to reduce the synthetic ratio and overfitting as an attempt.

3.2. HCI WORKFLOW IN VR

We built a platform for various participants to take a tour and participate in the design by selecting and projecting the facade results generated by CycleGAN onto the buildings they have willing to regenerate according to their own purpose and preference in the digital village.

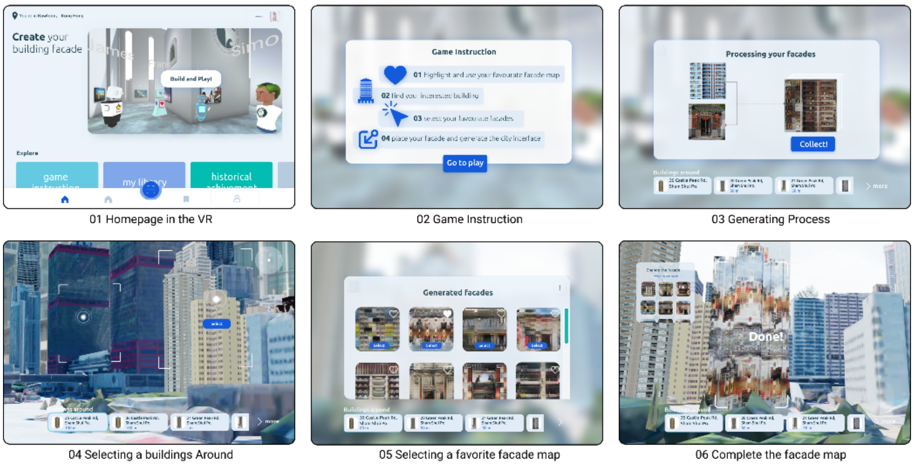

Figure 4. The user experience of the core functions in VR

The HCI development contains three parts. Firstly, we built a Hong Kong-based city scene for the tour and interaction in the digital twin environment. We used Spoke to export the Blender scene to the Mozilla hubs, which enables the tour with VR devices. Secondly, a series of user-friendly interfaces (UI) in the VR was designed for citizens to play and interact with. Thirdly, we designed multiple interactive functions concerning the user experience, which embedded the real-time CycleGAN style transfer algorithm to achieve real-time generation. The user experience includes exploring the buildings around, selecting the facades, and selecting and mapping the facades (See Figure 3). For visualising the generated facades in 3D view, we used the projecting UV map function in Blender 2.91.0, an open-source 3D modelling software (See Figure 4). The visualisation integrated both a bird's eye view and a panorama view, which provides citizens with an immersive and comprehensive view of the generated facades.

The digital version of this reproduction has the capability of simulating different design scenarios and evaluating their impact on the conservation of cultural heritages by allowing the local community and design team to collaborate and explore different options. This HCI in VR can involve conducting workshops and other engagement activities with members of the community to gather their input and ideas for the design of the village. By involving the community in the design process, it is possible to incorporate their cultural values and traditions which can help to preserve the unique character of the Hakka community to accommodate the preferences of the citizens.

Figure 4. Demonstration of bird's eye view and 360° panorama view of generated design proposals

4. Discussions

This research demonstrated a participatory workflow by deploying the CycleGAN style transfer model of Hakka settlements into an HCI system. The CycleGAN style transfer model proved useful as a tool to stylise facades as design options using cultural images. The HCI workflow enables citizens' participation in the customisation of street facades, to ensure the engagement of the community making and education on the preservation of urban cultural heritage. Through the community engagement, there will be certain potential to see greater citizen awareness of the conservation of abandoned settlements and Hakka inhabitants gaining a sense of belonging in contemporary environments.

There are a few difficulties that need to be addressed. Researchers need to take citizens - both indigenous Hakka communities and majority groups as actors rather than data subjects in the co-learning process, which includes the identification of design problems and appropriate informative scopes (Ng, 2022). In addition, designers should take the level of guidance and level of interactivity into account to provide design options. Also, the design of beginner-friendly and user-friendly interfaces can add value to digital tools by bridging physical and virtual interfaces, which are the key dialogue windows for communication. Furthermore, the harmonic approach of the building mixed with Hakka settlements and Hong Kong modernist buildings is relatively mediated by the algorithm. The algorithm fine-tuning is also an important step to construct identities for specific inhabitants by keeping recognizable original fabrics.

In the next stage, the design practices can be divided into three phases. In the first phase, community engagement with VR will be conducted. Designers should take the role of facilitator to provide design options and guidance, and also help citizens to visualise their visions and preferences. In the second phase, the customised design toolkit with neural networks helps us to understand the synthesis of cultural heritage with co-defined data by architects and citizens to increase the sense of achievement, integrating building functions and facade design and incorporating them into VR as immersive digital twins. In the final step, data output should be taken as a feedback loop for the next stage of community engagement.

Our future direction will be optimising the CycleGAN style transfer model by enlarging the dataset and adding labelled images into training. The image segmentation network to label the collected facades can be added to the user interface, which provides the citizens more flexibility in the co-design process.

5. Conclusion

This research presented a GANs-assisted real-time participative street facade design tool in VR environments. The design of toolkits can facilitate the generation of cultural facades and design options for citizen participation and public communication, with the purpose of generating a sense of identity, shared expression, and ensuring urban culture inheritance, using user-friendly interfaces in VR. This research specifically focused on the Hakka settlements that are under threat of being demolished, using digital twins to preserve the urban cultural heritage. As we embrace the digital, our environment explodes in complexity with various opportunities. The Digital revolution is accelerating the evolution of our living environment, providing efficient accessibility of collaborative interaction tools to co-design our cities. The participatory community forms and evolves dynamically in the metabolism in cities, which extends the consideration of urban cultural inheritance, quality of life, sustainability and well-being.

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