Damascus House

Exploring the connectionist embodiment of the Islamic environmental intelligence by design

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Past studies have demonstrated that connectionist artificial intelligence (AI) has superior capabilities for style-based generative design because it automatically searches, extracts, and applies features according to the data-represented probabilistic profile of an architectural style. To further navigate its architectural affordance, this practice-led research project explores employing connectionist artificial intelligence to produce Islamic-style architectural forms that have historically revealed environmental intelligence by embedding sociocultural factors in response to the physical and human environmental design heritage. The project applies the Pix2Pix model and inverts the logic of some existing studies to predict the building plans from daylight maps. Use multi-objective optimisation algorithms to iteratively optimise factors such as building porosity, spatial quality, and microclimate, and use it as a condition to apply a Pix2Pix to generate a corresponding porosity model that is parametrised for the further design process. The model was trained on 120 augmented, paired images based on the 30 selected examples of Islamic architecture from the Damascus Atlas to capture the relationship between the massing distribution of walls and the arrangement of major elements in an Islamic courtyard house and its thermal performance. This study seeks to test if connectionist AI can be used as a generative design tool to understand the historical development of spatial relationships in Islamic courtyard houses. It focuses on non-repetitive style metrics, embedding physical and cultural factors into data representation. The resulting environmentally intelligent model adapts to the context, with optimisation being a pragmatic design guide rather than the ultimate goal. Although the inference is based on objective probabilistic facts, the influence of the informational framework interpreted by the designers must be acknowledged.

Keywords: *Connectionist Artificial Intelligence, Digital Design, Environmental Intelligence, Islamic Architecture, Style-based Generative Design.*

INTRODUCTION

This study explores the feasibility of using computational tools to design houses with environmental intelligence that can be regarded as part of the collective achievement of local architectural rationality. To achieve this objective, the study employs an ongoing real-world design project of a single-family home in Nazareth, the

Middle East, to explore the practical response to this question. The project's initial programmatic requirements were structured in three suites, following traditional Islamic courtyard family houses. The clients have also indicated their desire for the project to possess a modern (or non-entirely traditional appearance) while still adhering to the foundations of Islamic spatial traditions.

This study investigates the utilisation of cross-domain translation algorithms, specifically conditional generative adversarial network cGAN models like Pix2Pix (Isola et al., 2017), to capture the implicit correlation between thermal performance, mass distribution of walls, and spatial structure in Middle Eastern quadrangle courtyard houses, which possess The aim of this study is to investigate whether neural networks can serve as a generative design tool to learn the spatial relationships and thermal performance correlations of Islamic courtyards, while considering alternative computational design tools, to capture site-specific social and cultural architectural representations for given environmental performance, thereby exploring the concept of environmental intelligence in practice.

To achieve this, the study employs the Pix2Pix model, which are employed by most relevant cases for its cross-domain translation and conditional reasoning features, to learn the spatial practices formed by local residents in response to microclimatic factors and creates building spatial forms based on them (Huang and Zeng, 2018, Chaillou, 2019, Yousif and Bolojan, 2021). Furthermore, a multi-objective optimiser is utilised to respond to the environmental demands of the project and generate site-specific daylighting conditions to inform the Pix2Pix model's generative process. The dataset design is based on the hypothesis that spatial relations and wall massing distribution in traditional Middle Eastern houses result from cultural structures and local populations' adaptation to climatic conditions. The intertwined nature of cultural and thermal aspects precludes their dissociation.

ENVIRONMENTAL INTELLIGENCE AND DESIGN TOOLS

The increasing body of commentary indicates that the employment of conventional computational design tools is frequently distinguished by an accentuation of functionality and instrumental rationality. This, in turn, gives rise to a preponderance of problem-solving approaches throughout the design process. This tendency often results in a dichotomy between the functional and cultural factors involved in design, treating them as distinct entities rather than an integrated whole. The functionalist approach typically gives rise to a hierarchical design schema, with functionality taking precedence over cultural interpretation.

However, this approach faced extensive criticism in the latter half of the twentieth century (Marion et al., 2012). Certain critics, such as the neorationalist architects, as represented by Aldo Rossi (1982), highlight the role of the built environment in reflecting the evolution of human rationality and the interplay between culture, society, and architecture . This viewpoint, in fact, emerged during the formation of the concept of style in the 18th century, regarding the collective discourse on architectural form: style is shaped by physical environmental conditions, cultural responses, and historical aggregation.

Environmental intelligence, therefore, is an architectural pattern that integrates local social and cultural factors into the challenges of the physical environment, forming a collective intelligence embedded in architectural history and designed artefacts.

The proposition put forth suggests that the collective memory of a group is constructed through architectural practices and can be viewed as a schema-construction process for a local community. It justifies the possibility of establishing a collective cognition that includes the local community's perception of their environment. Such a perception reflects the rationality of architecture, which to a considerable extent echoes the basic assumption of neorationalism.

The adaptive behaviours of human habitation in response to the physical environment are manifested at the level of cultural and social activities, and they form a tradition that evolves over time with historical development. At a specific point in time, these environmental adaptation traditions are concretised through collective representations into architectural and spatial forms with consistent deep structures. On the other hand, the rising connectionist artificial intelligence (connectionist AI), which uses artificial neural network models to emulate mental mechanism, has emerged as an approach to generative architectural forms. It enables design thinking to be addressed while the prior knowledge about the design problem is no explicit and the problem can be ill-defined defined.

The above-mentioned architectural rationality embodies a kind of environmental intelligence, in which design factors are considered in their causal relationship, rather than their hierarchical relationship. The primary objective of this research is to investigate how connectionist AI can achieve this ambient intelligence in real construction projects, and to see how architects deal with the problems it may encounter in practice.

MAJOR CHALLENGES

To achieve environmental intelligence executable and evaluable, it is further structured into the following primary challenges:

1. Investigate how to concretise environmental intelligence using connectionist algorithms and apply them to the generation of architectural forms.
2. Establishing knowledge on the connection between the architectural representation and how the region responds to climatic challenges in the Middle East within the context of connectionist algorithms.
3. Continuing the tradition of Islamic architecture, create comprehensive spatial qualities formed by microclimates and light-shadow interplay that cater to the modern living activities of local extended families. This differs from optimising spatial qualities for given programs.

RELEVANT CASES

Previous Efforts

Due to its geometric and regular characteristics, the computational generation of Islamic architectural forms is often achieved through rule-based formal systems, including shape grammars. There are numerous instances where such algorithms have been employed to generate architectural elements, including ornaments, motifs, and brickwork patterns, as well as the forms of urban fabric (Sayed et al., 2015, Ulu and Sener, 2009, Duarte et al., 2006, Özkar and Stiny, 2009).

However, the formal systems necessitate a significant amount of explicit prior knowledge, which considerably restricts their practicality when applied to handling intricate generative tasks or ill-defined design problems. The aforementioned cases typically focus on specific parts of buildings rather than the overall architectural form. Efforts to reproduce particular styles using this approach tend to be reductive in nature and can be quite time-consuming (Silvestre et al., 2016). Few attempts have been made to generate architectural forms using shape grammars, resulting in restricted formal information such as parti and partitions. This necessitates the supplementation of missing information through various methods, including traditional and digital drawing techniques (Eilouti and Hamamieh Al Shaar, 2012). In addition, the interaction between form and other factors (e.g., activity or function) will be determined by prior knowledge that may not be consistent with the source instances of style.

Connectionist Design and Conditional Inference

In the late 1980s, the rise of connectionism and the subsequent development of deep learning established a new paradigm in design. Benefiting from numerous technological breakthroughs, this design paradigm experienced rapid growth beginning in the 2010s, eventually serving as an alternative to formal systems. Paul Merrell and colleagues introduced the use of conditional methods in 2010, employing Bayesian neural networks and graph representations of architectural programs to generate spatial layouts (Merrell et al., 2010). Following the invention of cGAN algorithms, conditional image generation models have been actively explored by architects. The neural style transfer (NST) technique developed by Leon Gatys and others community (2015) demonstrated the artistic potential of convolutional neural networks and quickly resonated within the design. Capitalising on the advantages of conditional methods and convolutional graphic applications, Weixin Huang and Hao Zheng (2018) began to generate detailed and expressive residential floor plans using the Pix2Pix HD model and given spatial configurations. The ArchiGAN project (Chaillou, 2019) in 2019 further revealed the transfer capabilities of cGAN algorithms for visual features pertaining to historical styles, incorporating cGAN as building blocks within formal systems to augment the reasoning abilities of connectionist AI.

Shermeen Yousif and Daniel Bolojan's research project, Deep Performance (2021), utilised a Pix2Pix model trained on the causality between daylight and building plans, aiming to replace time-consuming traditional heuristics. Although their findings indicate satisfactory accuracy, employing latent variables for predicting solar maps derived entirely from explicit knowledge does not maximise the neural network's implicit learning capabilities. Furthermore, this approach transforms a potentially generative architectural design solution into a daylight simulation tool, where typical heuristics could provide more accurate predictions. Reversing the causality appears more logical, as it implies an architectural plan that incorporates implicit learning based on daylight conditions. Based on the aforementioned rationale, the reversed causality in the inference is deemed more reasonable. Consequently, this study inverts the causality in the Deep Performance inference while retaining the Pix2Pix model as the machine learning approach. The model will be trained to predict the corresponding building plans using the maps of the microclimatic condition within the site as design conditions. Furthermore, the ideological foundation of this study is rooted in functionalism. To concurrently consider cultural and social factors, the research must incorporate their architectural manifestations, such as distinct spatial elements with local cultural significance, into the input data by cartography.

DESIGN PROCESS

In response to the aforementioned argument, the methodology adopted in this study centres around utilising Pix2Pix's conditional cross-domain translation feature to generate architectural floor plans of Islamic buildings that respond to the local sunlight conditions. In these plans, significant spatial elements are mapped to describe the spatial representation embodied by local cultural and social factors. To execute conditional domain inference, Pix2Pix requires paired images for training (Isola et al., 2017). As such, each image is comprised of two parts: the left half serves as the input data, in which solar radiation maps are employed, while the right half represents the fundamental facts that the model is tasked with predicting. To achieve this, we require samples of Islamic courtyard residences and process them to serve as an information source for Islamic architectural features.

The Damascus House Atlas

The traditional Islamic courtyard house represents a material system deeply rooted in social, religious, and climatic contexts, evolving throughout history. Consequently, the design process for this project commenced with a case study. The book "Damascus House" (Kibrit, 2000) was chosen for this purpose, documenting a collection of residential courtyard houses constructed in Damascus's Old City during the Ottoman period (circa 1300-1922). The selection of this specific dataset aimed to encompass houses sharing a common cultural background and confronting similar climatic challenges within the region. The ultimate objective was to train a Pix2Pix model using samples exhibiting these characteristics.

Concatenating Social, Cultural, Natural and Spatial factors

To achieve environmental intelligence through AI, it is essential to capture the social, cultural, and natural representations in Islamic dwellings within the data. Consequently, a thorough interpretation of the dataset must be conducted to clarify our cartographic strategy.

Obtaining a wide variety in terms of layout and number of courtyards was the main criterion for the dataset selection. The courtyard number ranges from one in the most modest samples up to three. The dataset includes one-third of each type. The most significant feature of these houses is the structure of the walls and their massing. As illustrated in Figure 1, the wall massing diminishes as it gets closer to the courtyard. To incorporate this quality into the model, we traced the wall footprint following the figure-ground drawing technique.

The foremost spatial elements of an Islamic house are the Iwan, the Qa'a and the suites: the Salamlek (guest suite), the Haramlek (family living space) and the Khadamlek (service suite). Privacy is one of the most significant characteristics of Islamic residential culture. The Iwan faces north. It is a living room that opens to the courtyard and aligns with its central water fountain. The double space of the Iwan aims to avoid ground humidity. This double-height space is also common in the Qa'a, the house corridor that organises the rooms. A common feature of the Iwan is the Mishkat, an architectural element that uses water to increase humidity and airflow. It consists of a carved stone recessed in the wall that allows the water to flow. The room's layout around the courtyard allows the shade to pass from side to side, creating airflow that decreases the air temperature. Different plant sizes and trees aim to increase shade, airflow and purification in the courtyard. The house's main door is designed not to be opened directly to the courtyard of the Haramlek or its rooms, but to an inclined, right-angle corridor that provides privacy to the family.

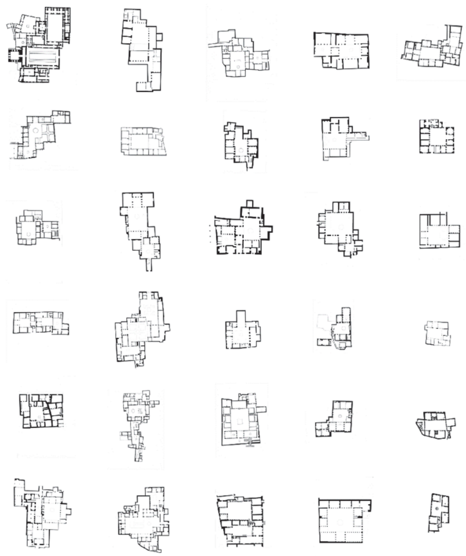

Figure 1
The Damascus House dataset.

The organisation of the succession of courtyards and its chambers also aims to provide privacy to the family suite.

Depicting Spatial Islamic-ness

To prepare training samples for the Pix2Pix model, the collected Damascus house plans are semantically segmented to annotate crucial spatial components. Given that twelve types of architectural elements must be labelled, a higher number than primary colours can identify, this study employs the Tableau 20 (tab20) colour map. This colour map encompasses the entire hue distribution and provides easily distinguishable colours, offering sufficient colour samples for the labelling task. Consequently, the graphic floor of the house displays the first-floor walls in black (#000000), with the main entrance, full-openings, and partial-openings in red (#ad4a4f), plum (#a35495), and grey

(#949494), respectively. Iwans are denoted in purple (#4f57a0), Qa'as in violet (#9c99c6), and the courtyard, green space, and fountain in brown (#bb9c3f), green (#8ba254), and blue (#69acd6), respectively. Furthermore, non-primary habitation spaces such as the arcade, balcony, and servant spaces are designated in beige (#e5c793), orange (#f08847), and pink (#e5959e), respectively (Figure 2).

After labelling output samples, input and output samples were paired and reformatted to a resolution of 512x256 pixels in RGB colour mode. It is noteworthy that the performance of convolutional neural networks is not affected by minor geometric transformations or distortions

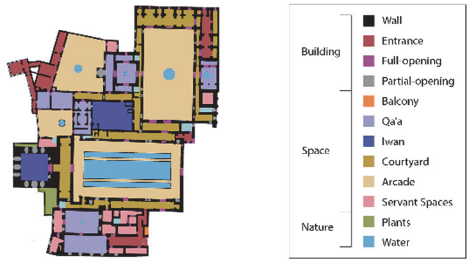

Figure 2
The main spatial elements are labelled using the tab20 (b and c) colour map.

(LeCun and Bengio, 1995). However, the term 'minor' has never been explicitly defined and is evidently not a constant. A general concern arises when the scale differences between samples (the building plans) exceed a certain degree, potentially leading to variations in the richness of details in the images, which may, in turn, cause biases in the sampling of architectural forms within the images. Consequently, this study still adopts management measures for the scale of samples. Since the original drawings lack a scale, the depth of staircases serves as a calibration metric to minimise the scale error between samples.

Thermal-Spatial Conditionalisation

Daylighting and its thermal effects are pivotal factors in shaping the microclimate and spatial practices of Islamic architecture. Hence, we employ daylighting as the conditional factor (controlled variable) for spatial form deduction. Natural light analysis was conducted to comprehend the duration of sunlight during the hottest month in 30 Damascus houses. These houses were modelled in Rhinoceros 3D and were subjected to Ladybug sunlight simulation to determine the amount of sunlight received by different spaces during the summer solstice. The analysis aimed to identify the optimal spatial organisation. The process consisted of four steps, each utilising the multi-objective optimisation model developed with the software, Wallacei, an evolutionary engine for Grasshopper 3D.

The provision of independent living spaces for each generation (namely each sub-family) of a client's family, while maintaining necessary connectivity, requires the incorporation of ample open spaces. Additionally, compact and intimate spaces are also crucial in Islamic residential culture (Husin, 2016). To achieve this, we began with a ground-level assessment and utilised techniques such as subdivision and attractors to maximise roof and courtyard areas while minimising facade length. The aim was to create a model with a high open space to compactness ratio. After considering the transition between indoor and outdoor spaces (typically involving shading applications in the region) and promoting convection, we optimised the model's daylight performance to increase roof coverage, roof and courtyard areas. Upon completion of adjustments, the compactness model began to consider vertical space organisation between floors to maximise volume, roof area, and vertical connectivity in cluster areas, ensuring the reasonable distribution of spaces for each sub-family. Finally, the deep generative model Pix2Pix was used to maximise light exposure, open space to compactness ratio, and volume for each cluster.

Conditional Inference

The Pix2Pix model was trained with an augmented dataset in which each image combined the solar radiation maps and the building plans of one building among the thirty selected cases (Figure 3).

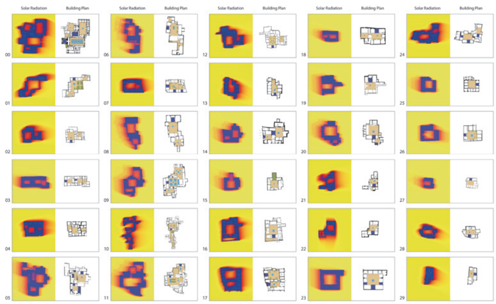

Figure 3
A snapshot of the paired-image dataset.

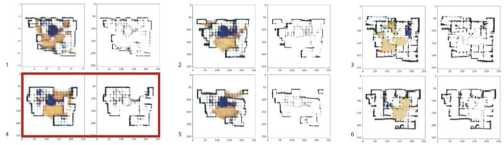

Figure 4
The six candidates generated by the Pix2Pix model. Candidate 4 was selected due to its superior comprehensive benchmark, which encompasses factors such as ground floor sunlight, volume porosity, and the volume of each cluster, making it the largest among all the generated candidates.

Given that, generally, the larger the dataset, the better the results, it is necessary to increase the size of the dataset. Thus, every image undertook a data augmentation through four random jitter processes: Every image was randomly cropped, and the cropped result was randomly mirrored in the east–west direction with a probability of 50:50. This expanded the dataset to 120 images. With the augmented dataset, the model was trained at

1000 epochs and tested with six given solar maps to generate prediction building plans as conditional options. Next, this study used a set of conditional thresholds to extract the pixels representing walls to analyse the wall massing of the candidate images. The conditions were set pixel-wise. They included: 1) a brightness value equal to or greater than 175, and 2) a difference between the R, G, B values less than or equal to16. This study then selected from these candidates (Figure 4) the best option with access to sunlight on the ground floor, volume porosity and the volume of each cluster at maximum through the last multi-objective optimisation process (Figure 5).

RESULTS AND DISCUSSION

A Contemporary Interpretation of Islamic Architecture

At the centre of the plan, the Iwan anchors two principal axes: the waterscape axis and the main corridor (Figure 6). Two courtyards dominate the building volume on the northern and southern sides of the Iwan. One courtyard has a richer spatial hierarchy that contains parking spaces, transitional landscape spaces and a half-roofed, semi-indoor swimming pool (Figure 7). In the other courtyard, which is more open, there are direct connections with the Iwan. In addition, it brings in cool air through a pair of openings that face both each other and the core interior space. Following the Islamic architectural tradition, the living space is surrounded by visibility and breathing, thus embedding the enclosed nature into the life of the occupants. The water features and plants in the courtyard are arranged in discrete patterns in accordance with the porosity model. They are shaped to integrate with

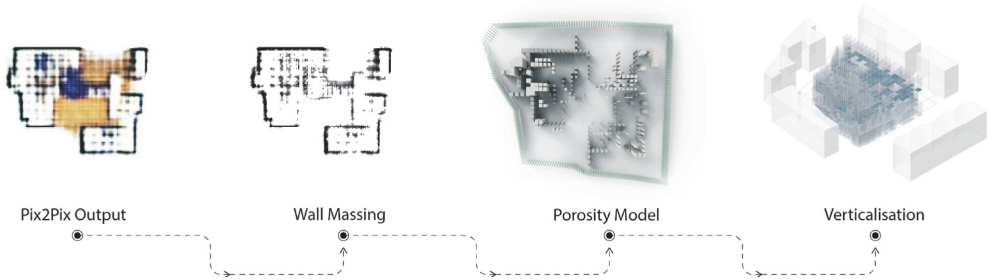

Figure 5
The selected Pix2Pix output is converted into a 3D parametric porosity model through several steps.

the courtyard's pavement to establish a microclimate regulating system.

At the end of the main corridor is the staircase that connects all the stories. It is located in the most solid (least porous) area of the building plan and surrounded by shady spaces to form a vertical ventilation path and create a spatial experience of cooling. From the solar-rich courtyard along the waterscape to the lobby of the building, the transition between indoor and outdoor spaces is completed by cooling the temperature and changing the quality of light. Outside the staircase, a well-lit corridor (Figure 8) gently brings the diffused outdoor light through the door and into the stairs, and the reverberation of the thick wall forms a multi-sensory phenomenological simulation of Islamic architecture, albeit in a modern way and via digital intervention.

Due to practical considerations, some compromises are inevitable in terms of structure and massing. In this frame structure system, the solidity is transformed into a low opening rate and column arrangement, rather than the most intuitive form represented by the wall thickness. Does this modern interpretation preserve the self-evidence of environmental intelligence and the identity of the Islamic architectural style? Is style a generalised label or an ever-evolving construction process?

Towards an Architecture Machine on Environmental Intelligence

Through the design process, an inference framework was observed that combines optimisation, generalisation, and generation. This framework integrates the features of traditional AI and connectionist AI, enabling both the observable and latent variables of the environment to be reasonably addressed within the same workflow (Figure 9). The key metrics are optimised to provide design conditions, and these conditions are then used to require cGAN (Pix2Pix) to find the corresponding "Damascus house state." This state can be understood as the projection of conditional data onto the distribution model of the Damascus

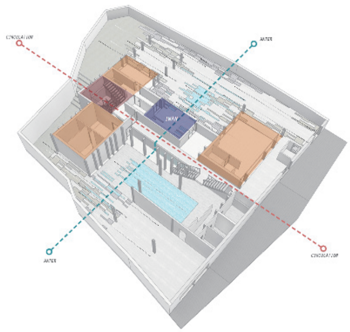

Figure 6
The two principal axes pivot the Iwan.

Figure 7
A courtyard with a semi-indoor swimming pool providing cooling and humidity tuning.

Figure 8
The corridor facilitates the penetration of conditioned daylight and airflow into the interior spaces.

House cases data. Due to the stochastic nature of neural networks, the output of each model after a single training iteration differs. Unlike traditional digital design optimisation, this random variation provides space for designer thinking engagement and demonstrates the architectural complexity of environmental intelligence that rejects the optimal singularity under the problem-solving approach. The materiality and tectonic aspects of the proposed design method deserve further investigation. This includes fortifying the physical grounding of computational methodologies and incorporating material feedback to reflect the impact of climatic factors on material selections and construction solutions.

CONCLUSION

This study focused on investigating the utilisation of connectionist AI to embody the environmental intelligence in Islamic architecture, rather than providing a comprehensive overview of the entire project. It tests the cross-domain, analogical reasoning capabilities of cGAN algorithms, such as Pix2Pix. These algorithms enable simultaneous handling of multi-dimensional design problems with designated conditions. In this project, physical and cultural design factors are consciously embedded in the data representation to share the same modalities. Rather than being widely used and repeated models in traditional generative design, the encoding and labelling of spatial elements become non-repetitive style metrics of Islamic residentials. The spatial data characteristics within these metrics are aggregated and enhanced to form schemas, which serve as the foundation for perceiving how buildings respond to natural, cultural, and social environments. This forms the framework of environmentally intelligent models that adapt to their surroundings.

It is crucial to note that the optimisation of factors such as light, heat, and other spatial elements is not the ultimate objective of the project, but rather a pragmatic means to guide the process of design inference. The model output may not perfectly meet the so-called 'optimum,' but it will come close enough. Therefore, it is important to understand that the 'optimum' does not necessarily equate to the desired interpretation of Islamic architecture to be found in the model.

Despite the subsymbolic nature of neural networks, which omits semantic information from the learning process, the inferences drawn are objective probabilistic facts. It is essential to acknowledge that the data's informational framework and interpretation remain constructed even if the model represents a collective schema of Islamic dwellings which largely depends on the designer's thoughts.

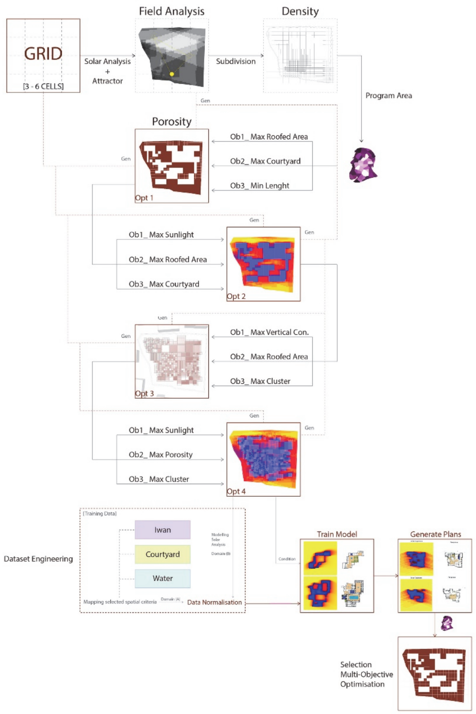

Figure 9
The design process incorporates the use of a Pix2Pix model and multi-objective optimisers.

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