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Aggregated versions of the data and the best performing models are available at <https://dataverse.harvard.edu/dataverse/Facelift>. The code for training the generator can be found at <https://github.com/sagarjoglekar/synthesizing>. The code for analysis of data can be found at <https://github.com/sagarjoglekar/ExplainingUrbanEmotions>.

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SJ carried out the design and development of the framework, did the data analysis, generated results and contributed in writing of the article; DQ, MR and LMA conceived the study, provided insights and valuable direction to the analysis and contributed to the writing of the article; TK developed the data visualization for the results and conducted the expert survey; NS gave feedbacks on the manuscript. All authors gave final approval for publication

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FaceLift: A transparent deep learning framework to beautify urban scenes

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In the area of computer vision, deep learning techniques have recently been used to predict whether urban scenes are likely to be considered beautiful: it turns out that these techniques are able to make accurate predictions. Yet they fall short when it comes to generating actionable insights for urban design. To support urban interventions, one needs to go beyond *predicting* beauty, and tackle the challenge of *recreating* beauty. Unfortunately, deep learning techniques have not been designed with that challenge in mind. Given their “black-box nature”, these models cannot be directly used to explain why a particular urban scene is deemed to be beautiful. To partly fix that, we propose a deep learning framework (which we name FaceLift) that is able to both *beautify* existing urban scenes (Google Street views) and *explain* which urban elements make those transformed scenes beautiful. To quantitatively evaluate our framework, we cannot resort to any existing metric (as the research problem at hand has never been tackled before) and need to formulate new ones. These new metrics should ideally capture the presence (or absence) of elements that make urban spaces great. Upon a review of the urban planning literature, we identify five main metrics: walkability, green spaces, openness, landmarks and visual complexity. We find that, across all the five metrics, the beautified scenes meet the expectations set by the literature on what great spaces tend to be made of. This result is further confirmed by a 20-participant expert survey in which FaceLift have been found to be effective in promoting citizen participation. All this suggests that, in the future, as our framework’s components are further researched and become better and more sophisticated, it is not hard to imagine technologies that will be able to accurately and efficiently support architects and planners in the design of the spaces we intuitively love.

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1. Introduction

Whether a street is considered beautiful is subjective, yet research has shown that there are specific urban elements that are universally considered beautiful: from greenery, to small streets, to memorable spaces [1–3]. These elements are those that contribute to the creation of what the urban sociologist Jane Jacobs called ‘urban vitality’ [4].

Given that, it comes as no surprise that computer vision techniques can automatically analyse pictures of urban scenes and accurately determine the extent to which these scenes are considered, *on average*, beautiful. Deep learning has greatly contributed to increase these techniques’ accuracy [5].

However, urban planners and architects are interested in urban interventions and, as such, they would welcome machine learning technologies that help them recreate beauty in urban design [6] rather than simply predicting beauty scores. As we shall see in Section 2, deep learning, by itself, is not fit for purpose. It is not meant to recreate beautiful scenes, not least because it cannot provide any explanation on why a scene is deemed beautiful, or which urban elements are predictors of beauty.

To partly fix that, we propose a deep learning framework (which we name FaceLift) that is able to both *generate* a beautiful scene (or, better, *beautify* an existing one) and *explain* which parts make that scene beautiful. In so doing, we make two main contributions:

- We propose a deep learning framework that is able to learn whether a particular set of Google Street Views (urban scenes) are beautiful or not, and based on that training, the framework is then able to both *beautify* existing views and *explain* which urban elements make them beautiful (Section 3).
- We quantitatively evaluate whether the framework is able to actually produce beautified scenes (Section 4). We do so by proposing a family of five urban design metrics that we have formulated based on a thorough review of the literature in urban planning. For all these five metrics, the framework passes with flying colours: with minimal interventions, beautified scenes are twice as walkable as the original ones, for example. Also, after building an interactive tool with “FaceLifted” scenes in Boston and presenting it to twenty experts in architecture, we found that the majority of them agreed on three main areas of our work’s impact: decision making, participatory urbanism, and the promotion of restorative spaces.

2. Related Work

Previous work has focused on: collecting ground truth data about how people perceive urban spaces; predicting urban qualities from visual data; and generating synthetic images that enhance a given quality (e.g., beauty).

Perception of physical spaces. From Jane Jacobs’s seminal work on urban vitality [4] to Christopher Alexander’s cataloging of typical “patterns” of good urban design [1], there has been a continuous effort to understand what makes our cities livable and enjoyable. In the fields of psychology, environmental design and behavioral sciences, research has studied the relationship between urban aesthetics [7] and a variety of objective measures (e.g., scene complexity [8], presence of nature [9]) and subjective ones (e.g., people’s affective responses [10]).

Ground truth of urban perceptions. So far, the most detailed studies of perceptions of urban environments and their visual appearance have relied on personal interviews and observation: some researchers relied on annotations of video recordings by experts [11], while others have used participant ratings of simulated (rather than existing) street scenes [12]. The Web has recently been used to survey a large number of individuals. Place Pulse is a website that asks a series of binary perception questions (such as ‘Which place looks safer [between the two]?’) across a large number of geo-tagged images [3]. In a similar way, Quercia *et al.* collected pairwise judgments about the extent to which urban scenes are considered quiet, beautiful and happy [2] to then recommend pleasant paths in the city [13]. They were then able to analyze the scenes together with their ratings using image-processing tools, and found that the amount of greenery in any given scene was associated with all three attributes and that cars and fortress-like buildings were associated

Symbol	Meaning
I_i	Original urban scene
Y	Set of annotation classes for urban scenes (e.g., beautiful, ugly)
y_i	Annotation class in Y (e.g., beautiful)
\hat{I}_j	Template scene (synthetic image)
I'	Target Image
C	Beauty Classifier

Table 1: Notations

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with sadness. Taken all together, their results pointed in the same direction: urban elements that hinder social interactions were undesirable, while elements that increase interactions were the ones that should be integrated by urban planners to retrofit cities for happiness. Urban perceptions translate in concrete outcomes. Based on 3.3k self-reported survey responses, Ball et al. [14] found that urban scenes that are aesthetically beautiful not only are visually pleasurable but also promote walkability. Similar findings were obtained by Giles et al. [15].

Deep learning and the city. Computer vision techniques have increasingly become more sophisticated. Deep learning techniques, in particular, have been recently used to accurately predict urban beauty [5,16], urban change [17], and even crime [18,19]. Recent works have also showed the utility of deep learning techniques in predicting house prices from urban frontages [20], and from a combination of satellite data and street view images [21].

Generative models. Since the introduction of Generative Adversarial Networks (GANs) [22], deep learning has been used not only to analyze existing images but also to generate new ones altogether. This family of deep networks has evolved into various forms, from super resolution image generators [23] to fine-grained in-painting technologies [24]. Recent approaches have been used to generate images conditioned on specific visual attributes [25], and these images range from faces [26] to people [27]. In a similar vein, Nguyen *et al.* [28] used generative networks to create a natural-looking image that maximizes a specific neuron (the beauty neuron). In theory, the resulting image is the one that “best activates” the neuron under consideration. In practice, it is still a synthetic template that needs further processing to look realistic. Finally, with the recent advancement in Augmented Reality, the application of GANs to generate urban objects in simulated urban scenes have also been attempted [29].

To sum up, a lot of work has gone into collecting ground truth data about how people tend to perceive urban spaces, and into building accurate predictions models of urban qualities. Yet little work has gone into models that generate realistic urban scenes that maximize a specific property and that offer human-interpretable explanations of what they generate.

3. FaceLift Framework

The main goal of FaceLift is to beautify an existing urban scene and explain its beautification. To meet that goal, it performs five steps:

Step 1 Curating urban scenes. Deep learning systems need considerable amounts of training data. Our initial set of data is limited and to augment it, we develop a new way of curating and augmenting the number of annotated images.

Step 2 Training a beauty classifier. We design and train a deep learning model that is able to distinguish beautiful urban scenes from non-beautiful ones.

Step 3 Generating a synthetic beautified scene. Based on our classifier’s learned representation of beauty, we train a generative model that is able to beautify an urban scene in input.

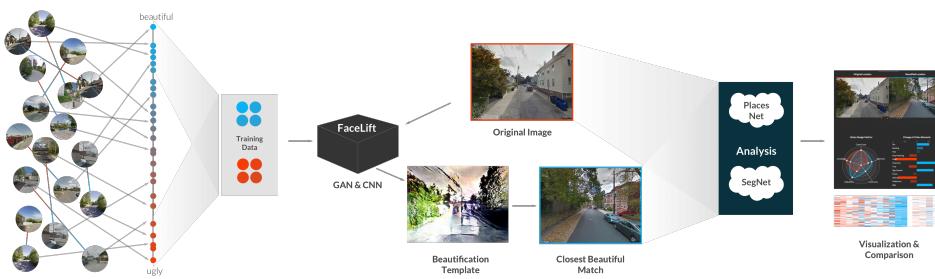


Figure 1: An illustration of the FaceLift framework. The training data of urban scenes with beautiful and ugly labels is fed into the FaceLift algorithms (GAN and CNN). These transform the original image into its beautified version. The two images - original and beautified - are compared in terms of urban elements that have been added or removed.

Step 4 Retrieving a realistic beautified scene. The generated image has a “synthetic look” - it does not look realistic. To fix that, we retrieve the image in the set of curated urban scenes most similar to the generated one.

Step 5 Identifying the urban elements characterizing the beautified scene. In the final step, the framework explains the changes introduced in the transformation process by comparing the beautified scene to the original one in terms of addition and removal of specific urban elements.

Step 1 Curating Urban Scenes

To begin with, we need highly curated training data with labels reflecting urban beauty. We start with the Place Pulse dataset that contains 100k Google Street Views across 56 cities around the world [5]. These scenes are labeled in terms of whether the corresponding places are likely to be perceived beautiful, depressing, rich, and safe. We focus only on those scenes that are labeled in terms of beauty (the focus of this study) and that have at least three judgments. This leave us with roughly 20,000 scenes. To transform judgments into beauty scores, we use the TrueSkill algorithm [30], which gives us a way of partitioning the scenes into two sets (Figure 2): one containing beautiful scenes, and the other containing ugly scenes. The resulting set of scenes is too small for training any deep learning model without avoiding over-fitting though. As such, we need to augment such a set.

We do so in two ways. First, we feed each scene’s location into the Google Streetview API to obtain the snapshots of the same location at different camera angles (i.e., at $\theta \in -30^\circ, -15^\circ, 15^\circ, 30^\circ$). Yet the resulting dataset is still too small for robust training. So we again feed each scene’s location into the Google Streetview API, but this time we do so to obtain scenes at increasing distance $d \in \{10, 20, 40, 60\}$ meters. This expands our set of scenes, but does so at the price of introducing scenes whose beauty scores have little to do with the original one’s. To fix that, we take only the scenes that are *similar* to the original one (we call this way of augmenting “conservative translation”). Two scenes are considered similar if the similarity of their two feature vectors (derived from the FC7 layer of PlacesNet [31]) is above a certain threshold. In a conservative fashion, we choose that threshold to be the median similarity between rotated and original scenes.

To make sure this additional augmentation has not introduced any unwanted noise, we consider two sets of scenes: one containing those that have been taken during this last step, i.e., the one with high similarity to the original scenes (*taken-set*), and the other containing those that have been filtered away (*filtered-set*). Each scene is represented with the five most confident scene labels extracted by PlacesNet [31]. We then aggregate labels at set level by computing each label’s frequency fr on the *taken-set* and that on the *filtered-set*. Finally, we characterize each label’s propensity to be correctly augmented as: $prone(label) = fr(label, taken-set) - fr(label, filtered-set)$. This reflects the extent to which a scene with a given label is prone to be augmented or not. From Figure 4, we find that, as one would expect, scenes that contain highways, fields and bridges can be augmented at increasing distances while still showing

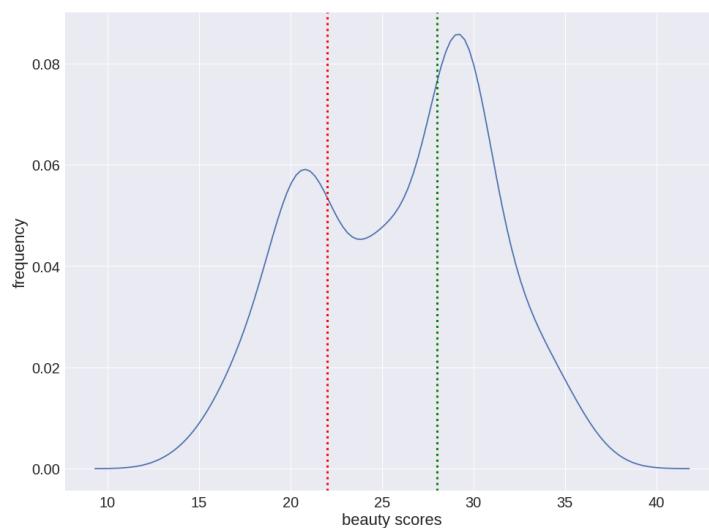


Figure 2: Frequency distribution of beauty scores. The red and green lines represent the thresholds below and above which images are considered ugly and beautiful. Conservatively, images in between are discarded.

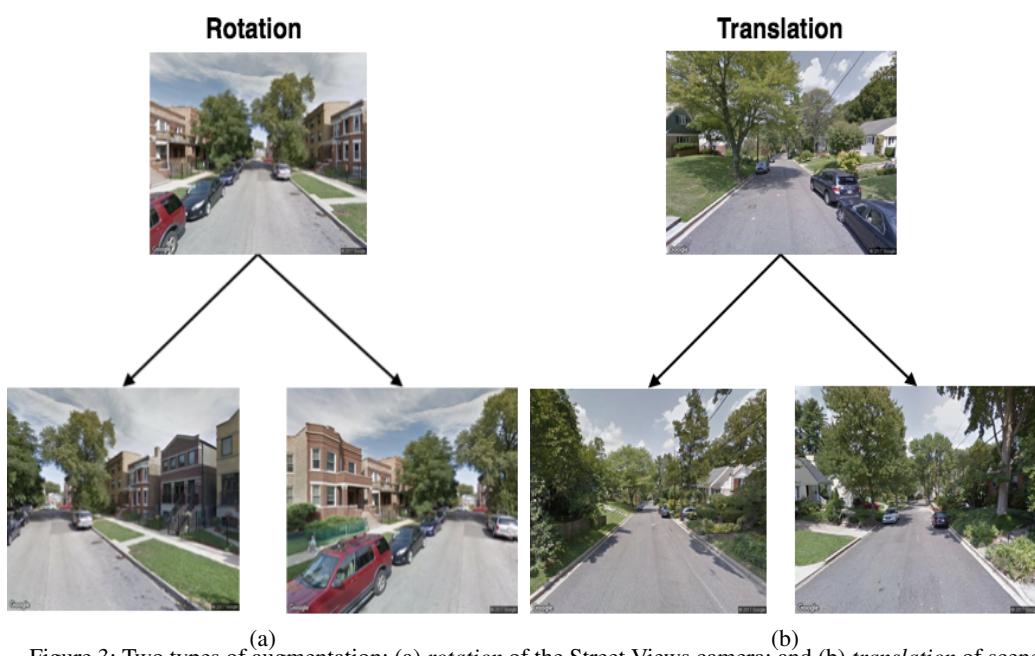
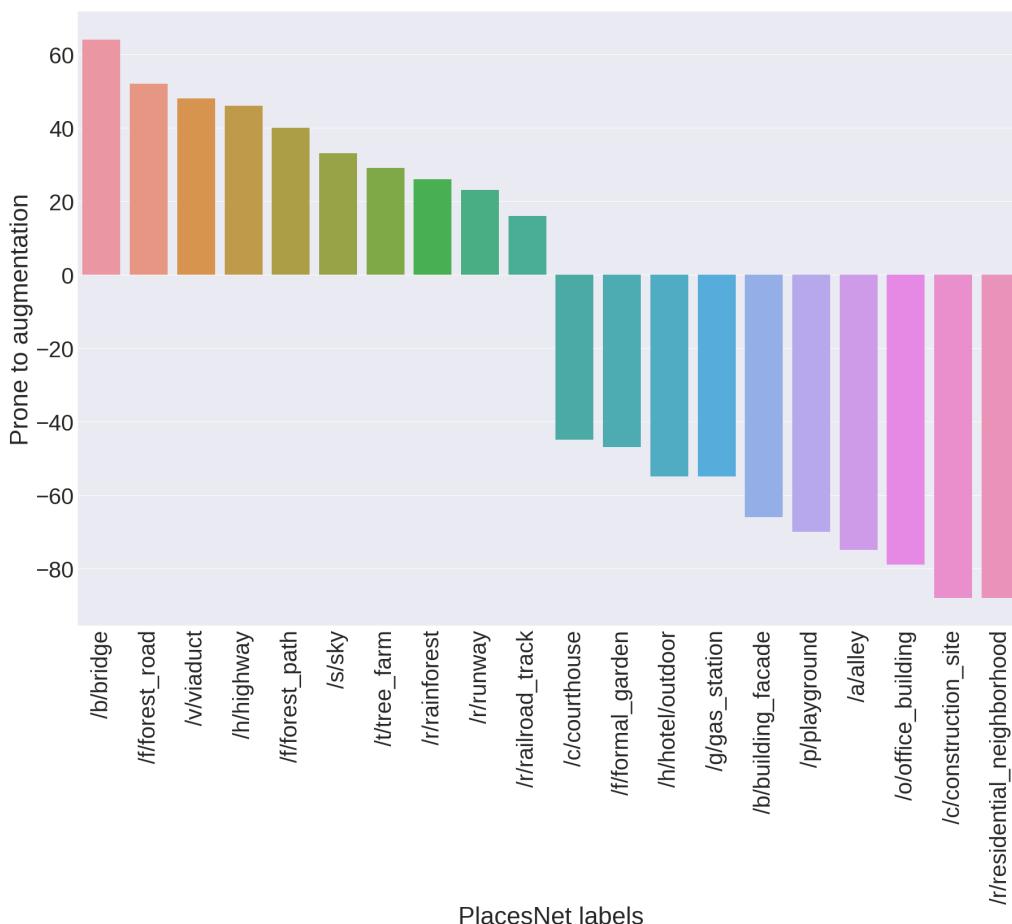


Figure 3: Two types of augmentation: (a) *rotation* of the Street Views camera; and (b) *translation* of scenes at increasing distances.

resemblances to the original scene; by contrast, scenes that contain gardens, residential neighborhoods, plazas, and skyscrapers cannot be easily augmented, as they are often found in high density parts of the city in which diversity within short distances is likely to be experienced.



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Figure 4: The types of scene that have greater propensity to be correctly augmented with similar scenes at increasing distances.

Augmentation	Accuracy (Percentage)
None	63
Rotation	68
Rotation + Translation	64
Rotation + Conservative Translation	73.5

Table 2: Percentage accuracy for our beauty classifier trained on sets of urban scenes that have been differently augmented.

Step 2 Training a beauty classifier

Having this highly curated set of labeled urban scenes, we are now ready to train a classifier. We choose the CaffeNet architecture as our classifier C . This is a modified version of AlexNet [32,33]. Its Softmax layer classifies the input image into one of two classes of beautiful(1) and ugly(0).

Having C at hand, we now turn to training it. The training is done on a 70% split of each of the training sets, and the testing on the remaining 30%. The training sets are constructed as increasingly augmented sets of data. We start from our 20k images and progressively augment them with the snapshots obtained with the 5-angle camera rotations, and then with the exploration of scenes at increasing distance $d \in \{10, 20, 40, 60\}$ meters. The idea behind this data augmentation is that the model's accuracy should increase with increasing levels of augmentation. Indeed it does (Table 2): it goes from 63% on the set of original scenes to a value

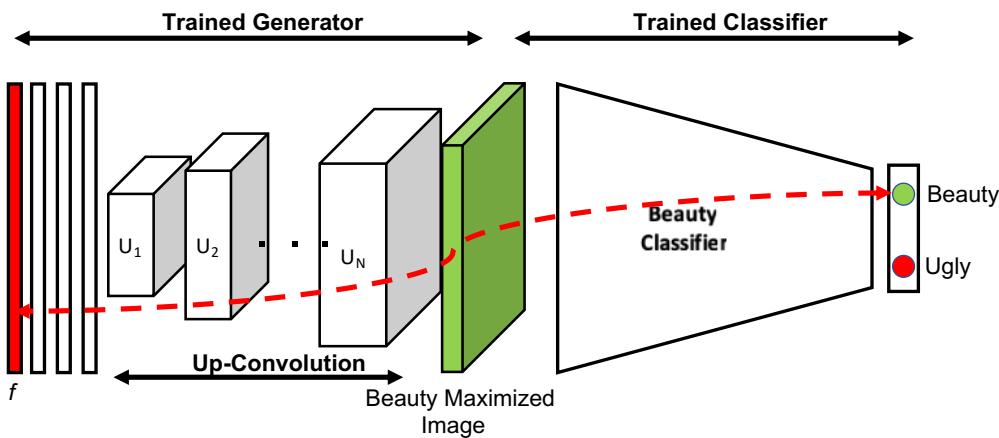


Figure 5: Architecture of the synthetic beauty generator. This consists of a generator of synthetic scenes concatenated with a beauty classifier. The green block is the beauty maximized template \hat{I}_j , which is subject to forward and backward passes (red arrow) when optimizing for beauty.

as high as 73.5% on the set of fully augmented scenes, which is a notable increase in accuracy for this type of classification tasks (the state-of-the-art classifier was reported to have an accuracy of 70% [5]).

Step 3 Generating a synthetic beautified scene

Having this trained classifier at hand, we can then build a generator of synthetic beautified scenes. To build such a generator, we retrain the GAN described by Dosovitskiy and Brox [34] on our curated urban scene dataset. This network is trained by maximizing the confusion for the discriminator between the generated images $G(f)$ and the original ones I_f [22]. The resulting generator is concatenated with our beauty classifier (Figure 5). As a result, given the two classes of ugly y_i and beautiful y_j , the end-to-end model transforms any original scene I_i of class y_i (e.g., ugly scene) into template scene \hat{I}_j that maximizes class y_j (e.g., beautified scene).

More specifically, given an input image I_i known to be of class y_i (e.g., ugly), our technique outputs \hat{I}_j , which is a more beautiful version of it (e.g., I_i is morphed towards the average representation of a beautiful scene) while preserving the way I_i looks. The technique does so using the “Deep Generator Network for Activation Maximization” (*DGN-AM*) [28]. Given an input image I_i , *DGN-AM* iteratively re-calculates the color of I_i ’s pixels in a way the output image \hat{I}_j both maximizes the activation of neuron y_j (e.g., the “beauty neuron”) and looks “photo realistic”. This is equivalent to finding the feature vector f that maximizes the following expression:

$$\hat{I}_j = G(f) : \arg \max_f (C_j(G(f)) - \lambda ||f||) \quad (3.1)$$

where:

- $G(f)$ is the image synthetically generated from the candidate feature vector f ;
- $C_j(G(f))$ is the activation value of neuron y_j in the scene classifier C (the value to be maximized);
- λ is a L_2 regularization term.

Here the initialization of f is key. If f were to be initialized with random noise, the resulting $G(f)$ would be the average representation of category y_j (of, e.g., beauty). Instead, f is initialized with the feature vector corresponding to I_i and, as such, the resulting maximized $G(f)$ is I_i ’s version “morphed to become more beautiful”.

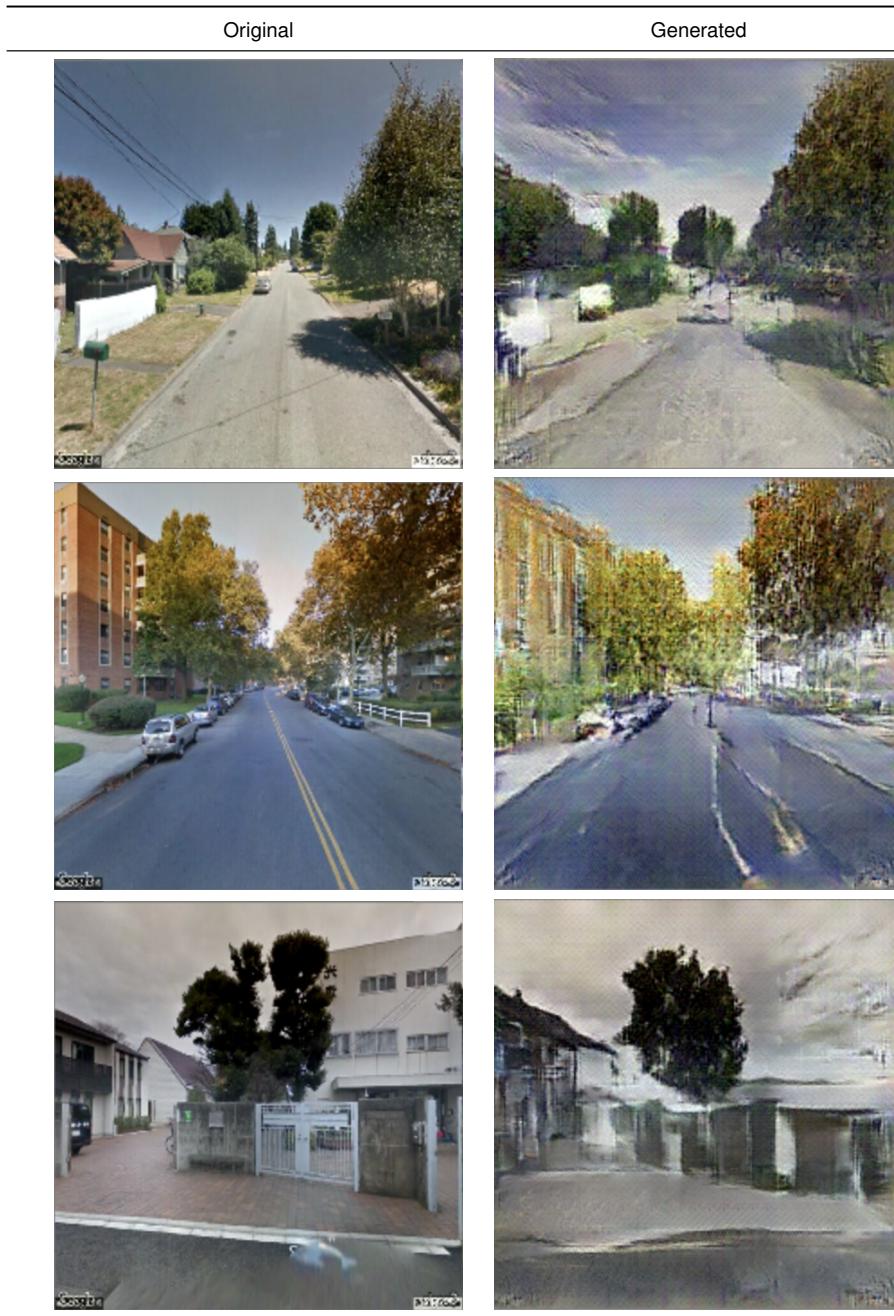


Table 3: Examples of our generator's outputs. The original scenes and the generated ones are shown side by side.

The input image is also key. It makes little sense to beautify an already beautiful image, not least because such beautification process would result in a saturated template \hat{I}_j . For this reason, to generate an image that maximizes the beauty neuron in the classifier C , we restrict the input set to ugly scenes. We do the opposite when maximizing the ugly neuron.

Step 4 Returning a realistic beautified scene

We now have template scene \hat{I}_j (which is a synthetic beautified version of original scene I_i) and need to retrieve a realistic looking version of it. We do so by: *i*) representing each of the scenes in our augmented set plus the synthetic image \hat{I}_j as a 4096 dimensional feature vector derived from the FC7 layer of the PlacesNet [31]; *ii*) computing the distance (as L_2 Norm) between \hat{I}_j 's feature vector and each original scene's feature vector; and *iii*) selecting the scene in our augmented set most similar (smaller distance) to \hat{I}_j . This results into the selection of the beautified scene I_j .

Step 5 Identifying characterizing urban elements

Since original scene I_i and beautified scene I_j are real scenes with the same structural characteristics (e.g., point of view, layout), we can easily compare them in terms of presence or absence of urban elements extracted by computer vision tools such as SegNet and PlacesNet. That is, we can determine how the original scene and its beautified version differ in terms of urban design elements.

4. Evaluation

The goal of FaceLift is to transform existing urban scenes into versions that: *i*) people perceive more beautiful; *ii*) contain urban elements typical of great urban spaces; *iii*) are easy to interpret; and *iv*) architects and urban planners find useful. To ascertain whether FaceLift meets that composite goal, we answer the following questions next:

Q1 Do individuals perceive “FaceLifted” scenes to be beautiful?

Q2 Does our framework produce scenes that possess urban elements typical of great spaces?

Q3 Which urban elements are mostly associated with beautiful scenes?

Q4 Do architects and urban planners find FaceLift useful?

Q1 People’s perceptions of beautified scenes

To ascertain whether “FaceLifted” scenes are perceived by individuals as they are supposed to, we run a crowd-sourcing experiment on Amazon Mechanical Turk. We randomly select 200 scenes, 100 beautiful and 100 ugly (taken at the bottom 10 and top 10 percentiles of the Trueskill’s score distribution of Figure 2). Our framework then transforms each ugly scene into its beautified version, and each beautiful scene into its corresponding ‘uglified’ version. These scenes are arranged into pairs, each of which contains the original scene and its beautified or uglified version. On Mechanical Turk, we only select verified masters as our crowd-sourcing workers (those with an approval rate above 90% during the past 30 days), pay them \$0.1 per task, and ask each of them to choose the most beautiful scene for each given pair. We make sure to have at least 3 votes for each scene pair. Overall, our workers end up selecting the scenes that are actually beautiful 77.5% of the times, suggesting that “FaceLifted” scenes are indeed perceived to be more beautiful by people.

Q2 Are beautified scenes great urban spaces?

To answer that question, we need to understand what makes a space great. After reviewing the literature in urban planning, we identify four factors associated with great places [1,35] (Table 5): they mainly tend to be walkable, offer greenery, feel cozy, and be visually rich.

To automatically extract visual cues related to these four factors, we select 500 ugly scenes and 500 beautiful ones at random, transform them into their opposite aesthetic qualities (i.e., the ugly ones are beautified, and the beautiful ones are ‘uglified’), and compare which urban elements related to the four factors distinguish uglified scenes from beautified ones.

We extract labels from each of our 1,000 scenes using two image classifiers. First, using PlacesNet [31], we label each of our scenes according to a classification containing 205 labels (reflecting, for example,

	Original (I_i)	Latent Beauty representation (\hat{I}_j)	Beautified (I_j)
1			
2			
3			
4			
5			
6			
7			
8			
9			
10			
11			
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Table 4: Examples of the “FaceLifting” process, which tends to add greenery, narrow roads, and pavements.

Metric	Description
Walkability	Walkable streets support people's natural tendency to explore spaces [35–37].
Green Spaces	The presence of greenery has repeatedly been found to impact people's well-being [1]. Under certain conditions, it could also promote social interactions [2]. Not all types of greenery have to be considered the same though: dense forests or unkempt greens might well have a negative impact [4].
Landmarks	Feeling lost is not a pleasant experience, and the presence of landmarks have been shown to contribute to the legibility and navigability of spaces [2,35,38,39].
Privacy-Openness	The sense of privacy conveyed by a place's structure (as opposed to a sense of openness) impacts its perception [35].
Visual Complexity	Visual complexity is a measure of how diverse an urban scene is in terms of design materials, textures, and objects [35]. The relationship between complexity and preferences generally follows an 'inverted-U' shape: we prefer places of medium complexity rather than places of low or high complexity [10].

Table 5: Urban Design Metrics.

landmarks, natural elements), and retain the five labels with highest confidence scores for the scene. Second, using Segnet [40], we label each of our scenes according to a classification containing 12 labels. That is because Segnet is trained on dash-cam images, and classifies each scene pixel with one of these twelve labels: road, sky, trees, buildings, poles, signage, pedestrians, vehicles, bicycles, pavement, fences, and road markings.

Having these two ways of labeling scenes, we can now test whether the expectations set by the literature of what makes urban spaces great (Table 5) are met in the FaceLifted scenes.

H1 Beautified scenes tend to be walkable. We manually select only the PlacesNet labels that are related to walkability. These labels include, for example, *abbey, plaza, courtyard, garden, picnic area, and park*. To test hypothesis *H1*, we count the number of walkability-related labels found in beautified scenes as opposed to those found in uglified scenes (Figure 6): the former contain twice as many walkability labels than the latter. We then determine which types of scenes are associated with beauty (Figure 7). Unsurprisingly, beautified scenes tend to show gardens, yards, and small paths. By contrast, uglified ones tend to show built environment features such as shop fronts and broad roads.

H2 Beautified scenes tend to offer green spaces. We manually select only the PlacesNet labels that are related to greenery. These labels include, for example, *fields, pasture, forest, ocean, and beach*. Then, in our 1,000 scenes, to test hypothesis *H2*, we count the number of nature-related labels found in beautified scenes as opposed to those found in uglified scenes (Figure 6): the former contain more than twice as many nature-related labels than the latter. To test this hypothesis further, we compute the fraction of 'tree' pixels (using SegNet's label 'tree') in beautified and uglified scenes, and find that beautification adds 32% of tree pixels, while uglification removes 17% of them.

H3 Beautified scenes tend to feel private and 'cozy'. To test hypothesis *H3*, we count the fraction of pixels that Segnet labeled as 'sky' and show the results in a bin plot in Figure 8a: the *x*-axis has six bins (each of which represents a given range of sky fraction), and the *y*-axis shows the percentage of beautified vs. uglified scenes that fall into each bin. Beautified scenes tend to be cozier (lower sky presence) than the corresponding original scenes.

H4 Beautified scenes tend to be visually rich. To quantify to which extent scenes are visually rich, we measure their visual complexity [35] as the amount of disorder in terms of distribution of (Segnet) urban

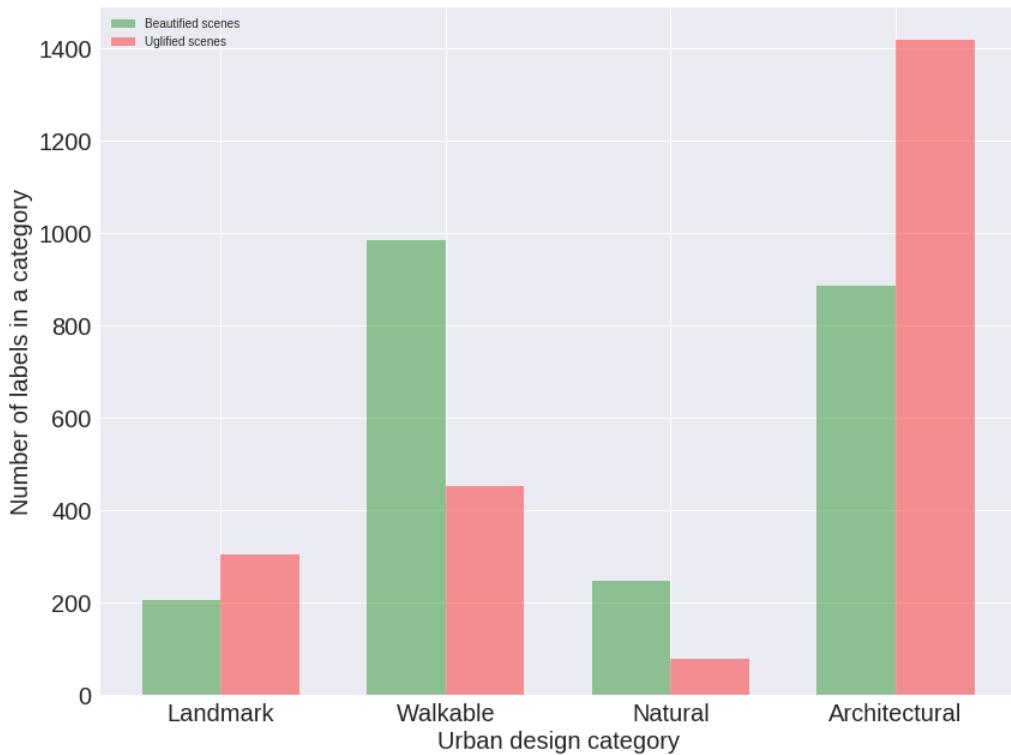


Figure 6: Number of labels in specific urban design categories (on the x -axis) found in beautified scenes as opposed to those found in uglified scenes.

Pair of urban elements	β_1	β_2	β_3	Error Rate (Percentage)
Buildings - Trees	-0.032	0.084	0.005	12.7
Sky - Buildings	-0.08	-0.11	0.064	14.4
Roads - Vehicles	-0.015	-0.05	0.023	40.6
Sky - Trees	0.03	0.11	-0.012	12.8
Roads - Trees	0.04	0.10	-0.031	13.5
Roads - Buildings	-0.05	-0.097	0.04	20.2

Table 6: Coefficients of logistic regressions run on one pair of predictors at the time.

elements in the scene:

$$H_I = - \sum p(i) \log p(i) \quad (4.1)$$

where i is the i^{th} Segnet's label, and $p(i)$ is the proportion of urban scene I containing the i^{th} element. The total number of labels is twelve. The higher H_I , the higher the scene's entropy, that is, the higher the scene's complexity. It has been suggested that the relationship between complexity and pleasantness follows an 'inverted U' shape [10]: we prefer places of medium complexity rather than places of low or high complexity. To test that, we show the percentage of beautified scenes that fall into each complexity bin (Figure 8b): we do not find a strong evidence of the 'inverted U' shape hypothesis, in that, beautified scenes are of low to medium complexity, while uglified ones are of high complexity.

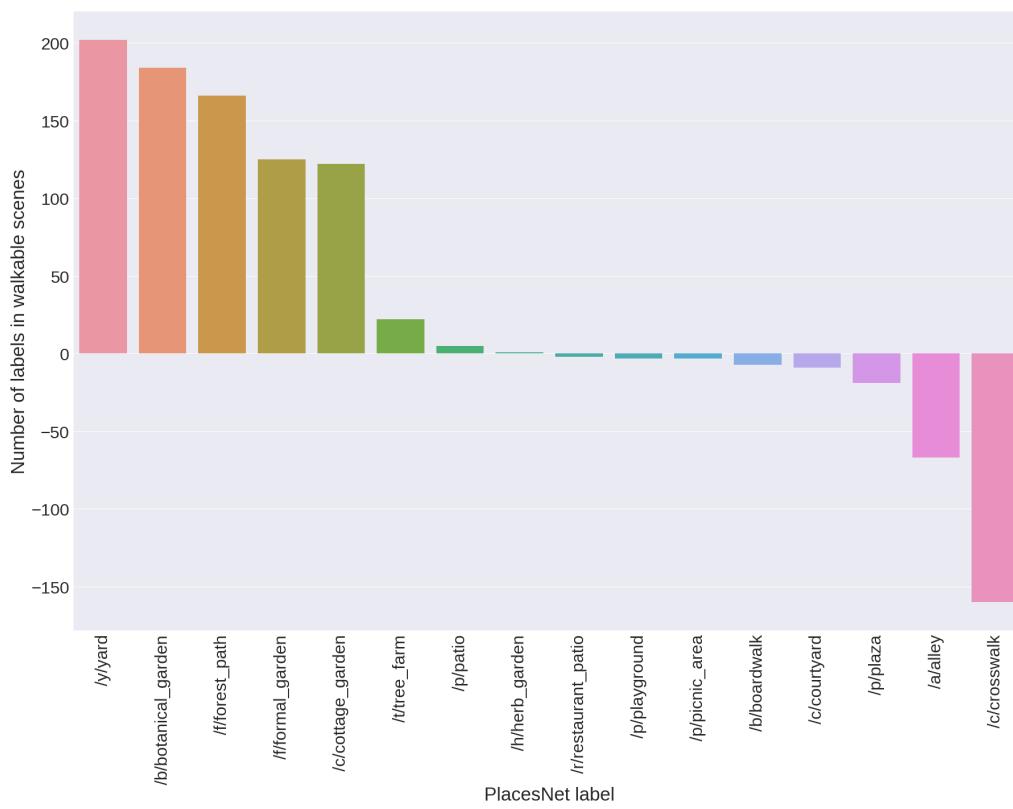


Figure 7: Count of specific walkability-related labels (on the x -axis) found in beautified scenes minus the count of the same labels found in uglified scenes.

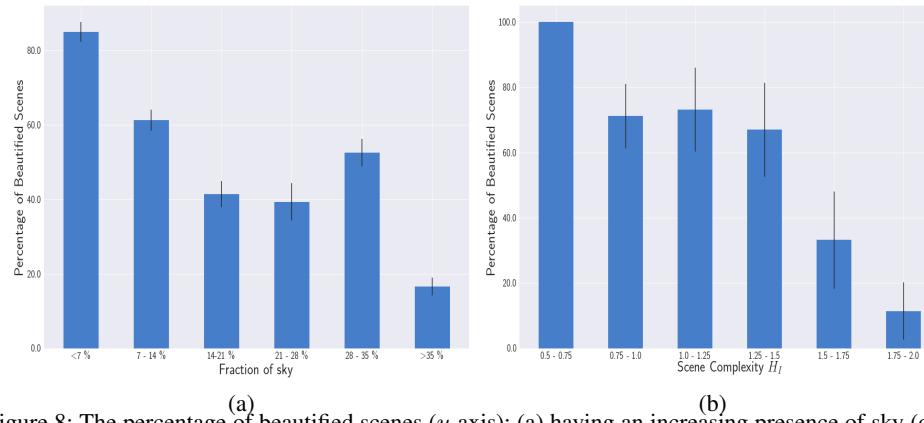


Figure 8: The percentage of beautified scenes (y -axis): (a) having an increasing presence of sky (on the x -axis); and (b) having an increasing level of visual richness (on the x -axis). The error bars represent standard errors obtained by random re-sampling of the data for 500 iterations.

Q3 Urban elements characterizing beautified scenes

To determine which urban elements are the best predictors of urban beauty and the extent to which they are so, we run a logistic regression, and, to ease interpretation, we do so on one pair of predictors at the time:

$$Pr(\text{beautiful}) = \text{logit}^{-1}(\alpha + \beta_1 * V_1 + \beta_2 * V_2 + \beta_3 * V_1.V_2) \quad (4.2)$$

Use case	Definitely Not	Probably Not	Probably	Very Probably	Definitely
Decision Making	4.8%	9.5%	38%	28.6%	19%
Participatory Urban Planning	0%	4.8%	52.4%	23.8%	19%
Promote Green Cities	4.8%	0%	47.6%	19%	28.6%

Table 7: Urban experts polled about the extent to which an interactive map of “FaceLifted” scenes promotes: (a) decision making; (b) citizen participation in urban planning; and (c) promotion of green cities

where $V1$ is the fraction of the scene’s pixels marked with one Segnet’s label, say, “buildings” (over the total number of pixels), and $V2$ is the fraction of the scene’s pixels marked with another label, say, “trees”. The result consists of three beta coefficients: β_1 reflects $V1$ ’s contribution in predicting beauty, β_2 reflects $V2$ ’s contribution, and β_3 is the interaction effect, that is, it reflects the contribution of the dependency between $V1$ and $V2$ in predicting beauty. We run logistic regressions on the five factors that have been found to be most predictive of urban beauty [1,2,35], and show the results in Table 6.

Since we are using logistic regressions, the quantitative interpretation of the beta coefficients is eased by the “divide by 4 rule” [41]: we can take the β coefficients and “divide them by 4 to get an upper bound of the predictive difference corresponding to a unit difference” in beauty [41]. For example, take the results in the first row of Table 6. In the model $Pr(\text{beautiful}) = \text{logit}^{-1}(\alpha - 0.032 \cdot \text{buildings} + 0.084 \cdot \text{trees} + 0.005 \cdot \text{buildings} \cdot \text{trees})$, we can divide $-0.032/4$ to get -0.008 : a difference of 1% in the fraction of pixels being buildings corresponds to no more than a 0.8% *negative* difference in the probability of the scene being beautiful. In a similar way, a difference of 1% in the fraction of pixels being trees corresponds to no more than a 0.021% *positive* difference in the probability of the scene being beautiful. By considering the remaining results in Table 6, we find that, across all pairwise comparisons, trees is the most positive element associated with beauty, while roads and buildings are the most negative ones. These results match previous literature in urban design of what makes spaces great, adding further external validity to our framework’s beautification.

Q4 Do architects and urban planners find it useful?

To ascertain whether practitioners find FaceLift potentially useful, we build an interactive map of the city of Boston in which, for selected points, we show pairs of urban scenes before/after beautification (Figure 9). We then send that map along with a survey to 20 experts in architecture, urban planning, and data visualization around the world. Questions were asked with a non-neutral response Likert scale (Table 7). That is because previous work [42,43] has shown that such a scale: (i) pushes respondents to “take a stance”, given the absence of a neutral response; and (ii) works best if respondents are experts in the subject matter of the survey as responses of the “I don’t know” type tend to be rare (as it is has been indeed the case for our survey). The experts had to complete tasks in which they rated FaceLift based on how well it supports decision making, participatory urbanism, and the promotion of green spaces. According to our experts (Table 7), the tool can very probably support decision making, probably support participatory urbanism, and definitely promote green spaces. These results are also qualitatively supported by our experts’ comments, which include: “*The maps reveal patterns that might not otherwise be apparent*”, “*The tool helps focusing on parameters to identify beauty in the city while exploring it*”, and “*The metrics are nice. It made me think more about beautiful places needing a combination of criteria, rather than a high score on one or two dimensions. It made me realize that these criteria are probably spatially correlated*”.

5. Conclusion

FaceLift is a framework that automatically beautifies urban scenes by combining recent approaches of Generative Adversarial Networks and Deep Convolutional Networks. To make it usable by practitioners, the framework is also able to explain which urban elements have been added/removed during the beautification process.

There are still two main limitations though. One is data bias. The framework is as good as its training data, and more work has to go into collecting reliable ground truth data on human perceptions. This data should ideally be stratified according to the people’s characteristics that impact their perceptions. The

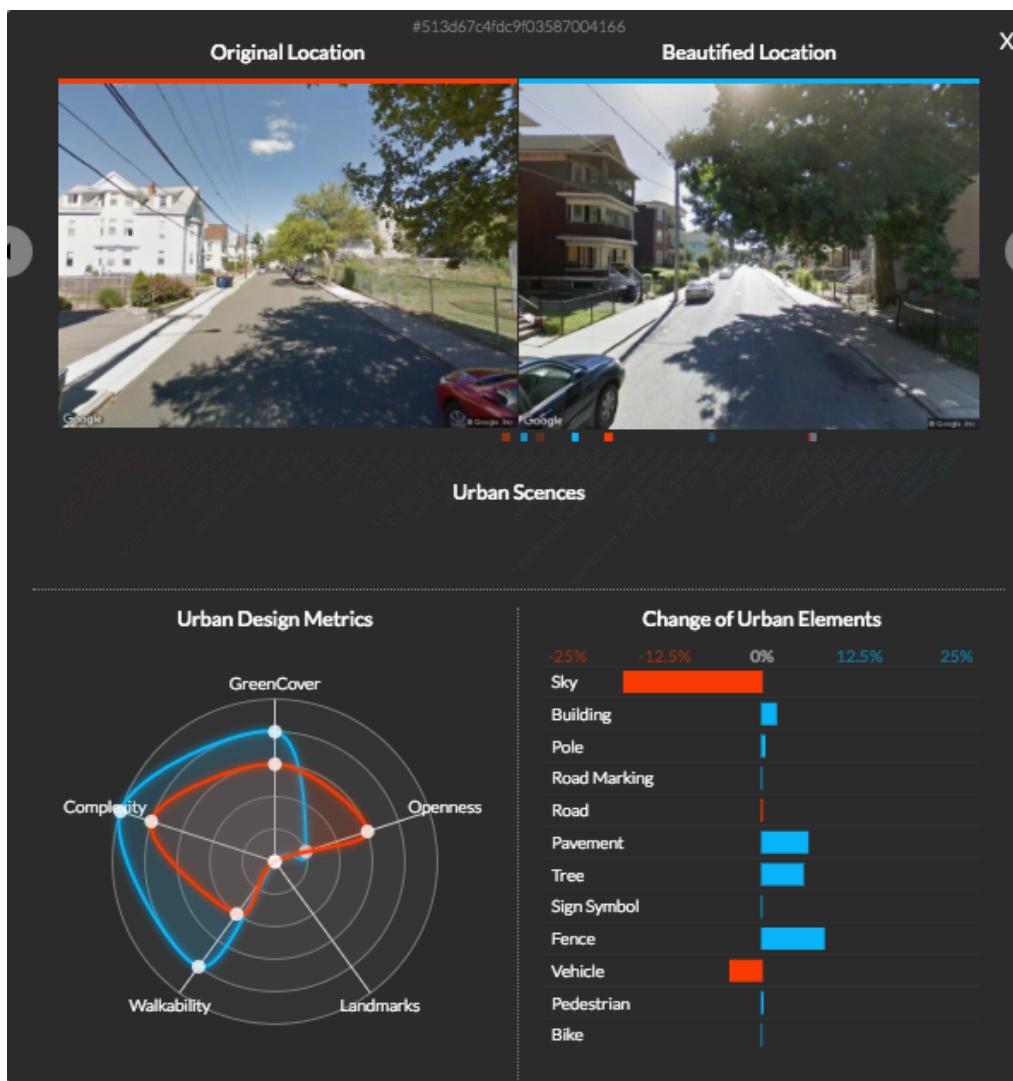


Figure 9: Interactive map of FaceLifted scenes in Boston.

other main limitation is that generative models are hard to control, and more work has to go into offering principled ways of fine-tuning the generative process.

Despite these limitations, FaceLift has the potential to support urban interventions in scalable and replicable ways: it can be applied to an entire city (scalable), across a variety of cities (replicable). To turn existing spaces into something more beautiful, that will still be the duty of architecture. Yet, with technologies similar to FaceLift more readily available, the complex job of recreating restorative spaces in an increasingly urbanized world will be greatly simplified.

Data accessibility statement

Aggregated versions of the data and the best performing models are available at <https://dataverse.harvard.edu/dataverse/Facelift>. The code for training the generator can be found at <https://github.com/sagarjoglekar/synthesizing>. The code for analysis of data can be found at <https://github.com/sagarjoglekar/ExplainingUrbanEmotions>.

Competing interests statement

We declare we have no competing interests.

Authors' contributions statement

SJ carried out the design and development of the framework, did the data analysis, generated results and contributed in writing of the article; DQ, MR and LMA conceived the study, provided insights and valuable direction to the analysis and contributed to the writing of the article; TK developed the data visualization for the results and conducted the expert survey; NS gave feedbacks on the manuscript. All authors gave final approval for publication.

References

1. Alexander C. 1977 *A Pattern Language: Towns, Buildings, Constructions*. Oxford University Press.
2. Quercia D, O'Hare NK, Cramer H. 2014 Aesthetic capital: what makes London look beautiful, quiet, and happy?. In *Proceedings of the 17th ACM Conference on Computer Supported Cooperative Work and Social Computing (CSCW)* pp. 945–955.
3. Salesses P, Schechtner K, Hidalgo CA. 2013 The collaborative image of the city: mapping the inequality of urban perception. *PloS one* **8**, e68400.
4. Jacobs J. 1961 *The Death and Life of Great American Cities*. Random House.
5. Dubey A, Naik N, Parikh D, Raskar R, Hidalgo CA. 2016 Deep learning the city: Quantifying urban perception at a global scale. *arXiv preprint arXiv:1608.01769*.
6. De Botton A. 2008 *The Architecture of Happiness*. Vintage Series. Knopf Doubleday Publishing Group.
7. Real E, Arce C, Sabucedo JM. 2000 Classification of landscapes using quantitative and categorical data, and prediction of their scenic beauty in north-western Spain. *Journal of environmental psychology* **20**, 355–373.
8. Kaplan S, Kaplan R, Wendt JS. 1972 Rated preference and complexity for natural and urban visual material. *Perception & Psychophysics* **12**, 354–356.
9. Kaplan R, Kaplan S. 1989 *The experience of nature: A psychological perspective*. CUP Archive.
10. Ulrich RS. 1983 Aesthetic and affective response to natural environment. In *Behavior and the Natural Environment* , pp. 85–125. Springer.
11. Sampson RJ, Raudenbush SW. 2004 Seeing Disorder: Neighborhood Stigma and the Social Construction of Broken Windows. *Social Psychology Quarterly* **67**.
12. Lindal PJ, Hartig T. 2012 Architectural variation, building height, and the restorative quality of urban residential streetscapes. *Journal of Environmental Psychology*.
13. Quercia D, Schifanella R, Aiello LM. 2014 The shortest path to happiness: Recommending beautiful, quiet, and happy routes in the city. In *Proceedings of the 25th ACM Conference on Hypertext and Social Media* pp. 116–125.
14. Ball K, Bauman A, Leslie E, Owen N. 2001 Perceived environmental aesthetics and convenience and company are associated with walking for exercise among Australian adults. *Journal of Preventive Medicine* **33**, 434–440.
15. Giles-Corti B, Broomhall MH, Knuiman M, Collins C, Douglas K, Ng K, Lange A, Donovan RJ. 2005 Increasing walking: how important is distance to, attractiveness, and size of public open space?. *American Journal of Preventive Medicine* **28**, 169–176.
16. Seresinhe CI, Preis T, Moat HS. 2017 Using deep learning to quantify the beauty of outdoor places. *Royal Society Open Science* **4**, 170170.
17. Naik N, Kominers SD, Raskar R, Glaeser EL, Hidalgo CA. 2017 Computer vision uncovers predictors of physical urban change. *Proceedings of the National Academy of Sciences* **114**, 7571–7576.
18. De Nadai M, Vieri RL, Zen G, Dragicevic S, Naik N, Caraviello M, Hidalgo CA, Sebe N, Lepri B. 2016 Are Safer Looking Neighborhoods More Lively?: A Multimodal Investigation into Urban Life. In *Proceedings of the ACM on Multimedia Conference (MM)*.
19. Arietta SM, Efros AA, Ramamoorthi R, Agrawala M. 2014 City forensics: Using visual elements to predict non-visual city attributes. *IEEE Transactions on Visualization and Computer Graphics* **20**, 2624–2633.

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20. Law S, Seresinhe CI, Shen Y, Gutierrez-Roig M. 2018a Street-Frontage-Net: urban image classification using deep convolutional neural networks. *International Journal of Geographical Information Science* pp. 1–27.
21. Law S, Paige B, Russell C. 2018b Take a look around: using street view and satellite images to estimate house prices. *arXiv preprint arXiv:1807.07155*.
22. Goodfellow I, Pouget-Abadie J, Mirza M, Xu B, Warde-Farley D, Ozair S, Courville A, Bengio Y. 2014 Generative adversarial nets. In *Advances in Neural Information Processing Systems* pp. 2672–2680.
23. Ledig C, Theis L, Huszár F, Caballero J, Cunningham A, Acosta A, Aitken A, Tejani A, Totz J, Wang Z et al.. 2017 Photo-realistic single image super-resolution using a generative adversarial network. In *Proceedings of the IEEE Conference on Computer Vision and Pattern Recognition* pp. 4681–4690.
24. Pathak D, Krahenbuhl P, Donahue J, Darrell T, Efros AA. 2016 Context encoders: Feature learning by inpainting. In *Proceedings of the IEEE Conference on Computer Vision and Pattern Recognition* pp. 2536–2544.
25. Yan X, Yang J, Sohn K, Lee H. 2015 Attribute2image: Conditional image generation from visual attributes. *CoRR* abs/1512.00570. .
26. Taigman Y, Polyak A, Wolf L. 2016 Unsupervised cross-domain image generation. *arXiv preprint arXiv:1611.02200*.
27. Ma L, Sun Q, Georgoulis S, Van Gool L, Schiele B, Fritz M. 2018 Disentangled person image generation. In *Proceedings of the IEEE Conference on Computer Vision and Pattern Recognition* pp. 99–108.
28. Nguyen A, Dosovitskiy A, Yosinski J, Brox T, Clune J. 2016 Synthesizing the preferred inputs for neurons in neural networks via deep generator networks. In *Advances in Neural Information Processing Systems* pp. 3387–3395.
29. Alhaija HA, Mustikovela SK, Mescheder L, Geiger A, Rother C. 2018 Augmented reality meets computer vision: Efficient data generation for urban driving scenes. *International Journal of Computer Vision* **126**, 961–972.
30. Herbrich R, Minka T, Graepel T. 2007 TrueSkill: a Bayesian skill rating system. In *Advances in Neural Information Processing Systems* pp. 569–576.
31. Zhou B, Lapedriza A, Xiao J, Torralba A, Oliva A. 2014 Learning deep features for scene recognition using places database. In *Advances in Neural Information Processing Systems* pp. 487–495.
32. Krizhevsky A, Sutskever I, Hinton GE. 2012 Imagenet classification with deep convolutional neural networks. In *Advances in Neural Information Processing Systems* pp. 1097–1105.
33. Szegedy C, Liu W, Jia Y, Sermanet P, Reed S, Anguelov D, Erhan D, Vanhoucke V, Rabinovich A. 2015 Going deeper with convolutions. In *Proceedings of the IEEE Conference on Computer Vision and Pattern Recognition* pp. 1–9.
34. Dosovitskiy A, Brox T. 2016 Generating images with perceptual similarity metrics based on deep networks. In *Advances in Neural Information Processing Systems* pp. 658–666.
35. Ewing R, Clemente O. 2013 *Measuring Urban Design: Metrics for livable places*. Island Press.
36. Quercia D, Aiello LM, Schifanella R, Davies A. 2015 The Digital Life of Walkable Streets. In *Proceedings of the 24th ACM Conference on World Wide Web (WWW)* pp. 875–884.
37. Speck J. 2012 Walkable City: How Downtown Can Save America, One Step at a Time. In *Farrar, Straus and Giroux*.
38. Lynch K. 1960 *The image of the city*.
39. Quercia D, Pesce JP, Almeida V, Crowcroft J. 2013 Psychological Maps 2.0: A web gamification enterprise starting in London. In *Proceedings of ACM International Conference on World Wide Web (WWW)*.
40. Badrinarayanan V, Kendall A, Cipolla R. 2015 Segnet: A deep convolutional encoder-decoder architecture for image segmentation. *arXiv preprint arXiv:1511.00561*.
41. Vaughn BK. 2008 Data analysis using regression and multilevel/hierarchical models. *Journal of Educational Measurement* **45**, 94–97.
42. Baka A, Figgou L, Triga V. 2012 ‘Neither agree, nor disagree’: a critical analysis of the middle answer category in Voting Advice Applications. *International Journal of Electronic Governance* **5**, 244–263.
43. Moors G. 2008 Exploring the effect of a middle response category on response style in attitude measurement. *Quality and Quantity* **42**, 779–794.