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Analysis of Stable Diffusion For QR Code Generation

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ABSTRACT

This paper tackles a novel approach to generating QR Codes with the use of Stable Diffusion and ControlNet, and bridges a research gap in the domain of user interaction with AI-generated QR Codes. Faced with challenges such as the scarcity of resources, appropriate datasets, and standardized guidelines, this research explores innovative QR Code generation techniques and also pioneers the investigation into user perceptions of these AI-crafted codes. Given the nascent stage of this field, no prior studies have examined the user experience with AI-generated QR Codes. This paper thoroughly evaluates existing AI QR Code generation solutions and presents a comprehensive user study aimed at understanding these solutions from a user-centric perspective. The findings shed light on user preferences, usability concerns, and potential for widespread adoption, thereby offering valuable insights for future advancements in AI-enabled QR Code applications.

1. INTRODUCTION

The progress in the field of Stable Diffusion with the invention of ControlNet has taken the world by storm and further pushed the capabilities of Generative Artificial Intelligence. An innovative concept has recently been published where Stable Diffusion model was used to produce an image with a seamlessly blended QR Code. This concept uses a ControlNet layer to produce an image that is scannable like a regular QR Code. Despite the availability of various online guides, the process of creating these enhanced QR Codes remains labor-intensive and uncertain due to the novelty of the approach. Generation of these image-like QR Codes often requires a long process of tweaking the parameters with no guarantees about the outcome. This dissertation aims to validate the generation of visually appealing and functional QR Codes.

As the technology progresses, human behaviour changes and adapts to innovation. Since QR Codes were introduced in 1994, there has been little innovation in the area of 2D barcodes. As a result, the existing studies on how people use and perceive QR Codes are now vastly outdated. This project seeks to renew the understanding of QR Code usability and human perception in practical settings. It aims to provide fresh insights into the contemporary use and perception of QR Codes in the 'wild'. Addressing the gap in current research, the usability of AI generated QR (AQR) Codes is explored in real-world scenarios through both qualitative and quantitative methods. Could AQR Codes, blending creativity and utility, become a usable standard in the future?

The original inspiration for this project stemmed from a concept proposed by the management during my summer internship at VISA Inc., which was in the process of developing an application for the Paris 2024 Olympics. The initial aim was to enhance the app's functionality by integrating aesthetically appealing QR Codes for easy access to the app's content, thereby enriching the user experience. However, due to the stringent corporate regulations and policies on the use of generative AI created by a third party provider, a direct collaboration became impractical. This unforeseen challenge necessitated a shift in focus, leading the project to pivot away from its initial goal and towards a new direction.

1.1 Research Goals

This work aims to explore and answer the following research questions:

1. Could an AQR Code be accepted by wider community as a usable standard?
2. Does a Stable Diffusion generated AQR Code lead to increased user interaction?

2. BACKGROUND

This section provides a comprehensive overview of the relevant fields and technologies including the history and development of QR Codes, their traditional uses, and recent advancements. Then the evolution and current state of Generative AI, with a particular focus on Stable Diffusion and ControlNet are explored. Additionally, this section reviews existing methodologies in QR Code generation and the integration of AI in this process.

2.1 Quick Response (QR) Codes

QR Codes were invented to allow for efficient user access to textual information [50]. This two-dimensional matrix symbol originating in Japan was later approved as the ISO/IEC 18004 international standard for print-scan channel information transmission. There are 40 versions of this code differing in module configuration. A module in this context means individual black-and-white components. Version 1 contains a matrix of 21 modules, while Version 40 contains a matrix of 177 modules

Functionality of QR Codes is implemented via several main features described in this section. Typically, a QR Code consists of black squares placed into a grid on a white background. These black squares are strategically organised into function patterns and encoding regions with the following structure (see Figure 1):

Finder pattern allows to detect the position of the QR Code and allows for readability in all directions. From all directions, the position of the black and white areas in the

finder pattern is always 1:1:3:1:1 which allows for high-speed detection.
Separators are one-module wide strips of white space. They are located between each finder pattern and the encoding region.
Alignment patterns correct the distortion of the QR Code. The number of alignment patterns depends on the version.
Timing patterns allow identification of the central coordinate of each cell in a QR Code. There are two timing patterns: a horizontal and a vertical. The horizontal timing pattern lies between the separator rows, while the vertical timing pattern is situated in the column between the separators.
Encoding region encompasses format information, version information, data, and error correction codes. Specifically, a one-module array is allocated adjacent to the top-left, top-right, and bottom-left finder patterns for format information. Additionally, for version information, a reserved area is established, consisting of a 6x3 block above the bottom-left finder pattern and a 3x6 block to the left of the top-right finder pattern.
Quiet zone is a margin space necessary for reading a QR Code.

Data encoding for the QR standard offers four modes: numeric, alphanumeric, byte, and Kanji. Each mode has a unique method for converting text into a binary format, optimized for minimal bit length. The choice of mode depends on the text's character set. Maximum size of data to encode is 23 648 bits corresponding to 7089 numeric characters [43].

Error correction is an important feature of a QR Code that enhances its readability and data integrity. The levels of error correction range from 7 to 30%. It allows the encoded data to remain readable even if the code is partially damaged or obscured, by providing redundancy to correct errors up to a certain extent. The encoded data is used to generate error correction code words through Reed-Solomon error correction[38]. QR scanners read both data and error correction code words, allowing them to verify the accuracy of the scanned information.

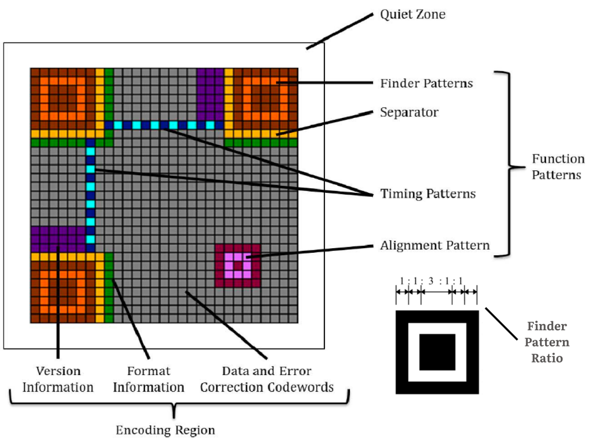


Figure 1: Structure of a QR Code [43]

Styles and usage of QR Codes varies. Inspired by Tokyo skyscrapers and the game of Go, QR Codes were initially invented with the purpose to label automobile parts [19]. Since the debut of the first mobile phone with an integrated QR Code reader in 2002, the widespread adoption of smartphones, advancements in camera technology and the freely available QR Code patent have fueled a significant rise in QR Code usage.

A QR Code, versatile in its application, can be applied to any printable surface or displayed on a screen. Its seamless integration with mobile communication technologies has led to its widespread use across various domains, ranging from industrial production to end-user applications. Notably mentioned in a book by Aktaş [7], QR Codes facilitate multi-channel marketing campaigns, effectively driving sales and disseminating information about events, opportunities, or individuals within the area of advertising. A significant advantage of QR Codes lies in their efficiency. Users experience minimal delay between scanning the code and accessing information. This speed and effectiveness extend beyond marketing, proving useful in sectors like postal and packaging services, transportation (used in travel tickets), and in professional settings such as business conferences for personal information exchange. A recent example of QR Code usage is in China's pandemic governance solution [15]. A part of the country's response to the Covid-19 pandemic was using QR Codes for encoding travel history, venue access, infection, and vaccination status.

The QR Codes commonly employed in practical applications typically exhibit a straightforward design characterized by standard square-shaped finder patterns and uniform black and white modules. However, a variety of artistic QR Code styles exist, featuring diverse shapes for the finder patterns and individual modules. These artistic QR Codes can take on forms ranging from circles, lines or crosses (see Figure 2). Despite their creative potential, the documentation and usage guidelines for these artistic QR Codes remain limited and less well-documented in comparison to their conventional counterparts.

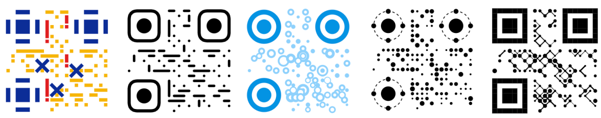


Figure 2: Different QR Code styles [13].

2.2 QR Code Related Studies

Numerous studies have been conducted in the past relating to QR Code usage. One such study focused on the use of QR Codes in the 'wild' and analysed data collected from over 87 million scans performed by users [25]. It was concluded that the majority of the scanned codes lead to website URLs with the top 5 domains being goo.gl, youtube.com, google.com, bit.ly, and facebook.com, suggesting the most common use case of QR Codes is for web-related use. Other common use cases include Wifi setup codes, authentication and at the time emerging cryptocurrencies, event passes and malicious misuses including insecure websites or apps.

A study conducted by Okazaki et al. [33] explores the use of QR Codes in different media and consumer motivation to scan. Three studies were performed in Japan that included collecting and analysing 260 publicly available QR Codes, conducting interviews in focus groups and a consumer survey. The study explores the effectiveness of QR Code mobile promotion, with a focus on the use of QR Codes in print media for promoting loyalty programs, convenience, savings, and quality. The findings from the three studies indicate that QR Codes are widely utilized in print media for promoting various aspects of marketing, particularly loyalty programs. The key informants largely agreed that their reasons for accessing the service were primarily driven by different promotional incentives, including coupons, sweepstakes, and product samples.

An innovative method for generating and displaying QR Codes was explored by Melgra et al. [46]. The study describes a way of integrating five different RGB colors seamlessly into a final image without altering the fundamental principles of QR Codes. The proposed Color QR Codes also allow for larger data storage compared to regular QR Codes. However, it is questionable whether such Color QR Codes could gain on popularity, as regular QR Codes offer sufficient storage space for typical usage.

A 2015 study emphasizes the importance of perceived usefulness in determining QR Code usage rate [34]. The research found that users engaged in product-related tasks, like gathering product information or making purchases, tend to use QR Codes more often than those who use QR Code for socializing and entertainment purposes. Furthermore, it was observed that individuals with a higher number of electronic devices are more frequent users of QR Codes. A notable finding is that there is no statistically significant correlation between QR Code usage and either knowledge of the latest electronic devices or their perceived usefulness.

The most recent paper reviewed as a part of this project argues that QR Codes create a new infrastructural gateway [15]. The research looks at the QR Code's global evolution, studying patents, corporate records, ads, conducting observations, and expert interviews. It explores how data encoding standards, mobile tech, machine vision, and platform ecosystems have created a new element in computational systems acting as a bridge, enabling communication between different systems, people, and processes. The paper further claims that QR Codes are "becoming more and more the standard way of communicating with potential clients through print media" and "key element in the articulation of digital infrastructure".

QR Codes have been around since the last century, therefore the existing studies concerning the use of QR Codes are very outdated. No recent major studies have been published exploring the effects of innovative QR Codes or QR Codes generated using Stable Diffusion described in the next section.

There exists a significant divergence of opinions regarding the innovation of QR Codes. Like other technological domains, some researchers claim that innovation could increase usage, while others assert that it might deter users. I argue that most of the existing studies on QR Code usage are considerably outdated. The rapidly evolving landscape of current technology trends, along with users' increasing adaptability to new technologies, renders the findings of papers published several years ago unreliable.

2.3 Generative Artificial Intelligence

The performance of image generation has recently improved dramatically with the release of several Generative AI Diffusion Models (DMs) such as Open AI's DALL-e[6], Google's Imagen[20] or Midjourney[23] that have garnered global attention.

2.3.1 *Stable Diffusion: The Art of Noise Crafting*

Released in August 2022, Stable Diffusion (SD) is arguably the most famous DM today. SD produces unique photorealistic images using technology with processing power requirements that allow for running on any computer equipped with GPUs. New, personalised models can be efficiently trained and implemented on existing, high-quality SD models. This makes image generation widely available to the masses and contributes to its increasing global popularity.

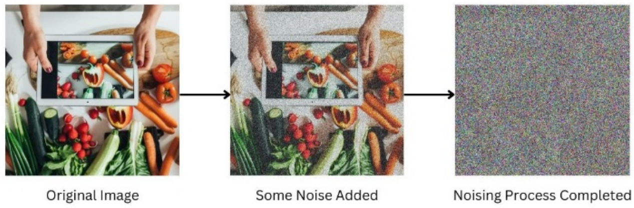


Figure 3: Forward diffusion generation process example. [45]

Predecessors of Diffusion Models, including Generative Adversarial Networks (GANs), Variational Auto-encoders (VAEs) and Flow-based Deep Generative Models, have shown great success in generative tasks. GAN models, for example, are exceptional at creating realistic images, natural language, and music [48]. However, training these models has proven to be problematic and unstable. Moreover, there is little evaluation metric to inform about the training status, making the training difficult to trace.

The concept of DMs was based on non-equilibrium thermodynamics and first introduced by Stanford research team [42] [49]. It consists of a chain of diffusion steps, gradually introducing random Gaussian noise to the data (reverse diffusion), and subsequently reversing the diffusion process to generate desired data samples from the noise (forward diffusion, see Figure 3). Training of DMs is more stable compared to GANs. Moreover, the generation process offers finer control over the outcome at each diffusion step. A study performed by researchers at OpenAI [16] found DMs superior to other generative models particularly in image synthesis. This is achieved by carefully choosing the model architecture and classifier guidance.

Stable Diffusion is an open-sourced DM developed by the CompVis group at the University of Munich[30]. The problem of high computational cost in DMs was addressed in SD by using the latent space of robustly pretrained auto-encoders [39]. This approach struck a near-ideal equilibrium between reducing complexity and retaining detail. Furthermore, SD incorporates cross-attention layers, enhancing the model's flexibility and enabling it to process a variety of conditioning inputs, such as text or bounding boxes.

OpenAI's CLIP (Contrastive Language-Image Pretraining) is a neural network trained on a large set of image and text pairs, enabling it to understand and connect images and their descriptions [37]. CLIP encoders are being increasingly integrated into the models, and their embeddings are processed by the DMs used including Stable Diffusion. CLIP can understand and connect images and text, while diffusion models can generate high-quality images from text prompts.

By combining CLIP's understanding of images and text with DMs' image generation capabilities, it is possible to create a system that can generate images from text descriptions with high fidelity and accuracy.

2.3.2 ControlNET

The generative SD model introduced earlier in this section can produce outcomes based on random Gaussian noise. The diffusion process creates images from this random noise guided by a text prompt. ControlNet introduced by a Standford research group provides an additional conditional layer to a pre-trained diffusion model allowing to guide the image creation to a larger extent as opposed to just a text prompt [51]. This unlocks a new level of generative AI potential and opens up countless new use cases, one of which is QR Code generation.

SD models can be interacted with through various means, including text prompts (text-to-image), image inputs (image-to-image), or a combination of both. The output generated from these models is inherently based on the random noise created using the generation seed [8]. While input images can guide the generative process, they do not determine the outcome. Similarly, text inputs offer specificity but also have limitations in guiding the output. ControlNet provides an additional layer of guidance for SD image generation, leveraging image-to-image translation models. These translators, such as edge extractors, are instrumental in extracting key features that are then fed into the generative process to influence the output. The state-of-the-art in text-to-image generation is facilitated by tools like CLIP, which are integrated into the SD models. Furthermore, these models allow for customization, including options for colour selection or inpainting [11]. Fine-tuning is another way of directing the model's output to some extent [18]. For example, one can fine-tune a pre-trained text-to-image model to bind a unique identifier with a specific subject done by DreamBooth [40].

ControlNet introduces an innovative and currently the only known approach utilized for AQR Code generation. ControlNet overlays additional neural network layers atop a latent diffusion model. In this architecture, a pre-trained SD model is locked and a trainable copy of a system layer is added (see Figure 4). This layer, consisting of a network block, transforms an input feature map x into another feature map y_c. Let $y = F(x; \Theta)$ represent the original transformation of a model (without adding ControlNet), where Θ are the parameters transforming the input y into x. To lock the model, the Θ parameters are left unchanged, and a trainable copy of these parameters, Θ_c, is introduced. The trainable layer of ControlNet, denoted as Z is added to SD and results in the following equation:

$$y_c = F(x; \Theta) + Z(F(x; \Theta_c))$$

Here, c represents the conditioning vector added to the equation as a form of control, which could be a sketch, depth map, edge map or a pose. This innovative structure allows for enhanced control and flexibility in the generative process of the model.

ControlNet is a way control input can be introduced into SD generation, which is a key instrument in the quest for QR Code generation. QR Code generation within the scope of this project relies on following conditional input in the form of a typical QR Code resulting in image-like output that transforms the QR Code structure into a visually pleasing output.

A novel ControlNet sibling, Uni-ControlNet, introduces a controllable simultaneous utilization of different local and global controls in a flexible manner within one model [52]. Uni-ControlNet incorporates new trainable adaptors to support the composition of local and global control inputs, compared to ControlNet which can only compose a single scope of control. Uni-ControlNet demonstrates its superiority over existing methods in terms of controllability, generation quality, and composability. Uni-ControlNet could provide an excellent basis for AQR Code generation, however, due to the lack of documentation and wider use adaptability, ControlNet was utilized for this project.

2.3.3 Generative AI & QR Codes

Building upon the foundational concepts of QR Codes and Generative AI discussed earlier, this section describes the innovative process of QR Code generation using ControlNet models. By leveraging an SD model for image generation and incorporating a ControlNet layer, it becomes feasible to guide the final output by inputting a QR Code as a source of guidance. ControlNet is an efficient way to tell a model which parts of an input image to preserve. QR Codes due to their visual nature are ideal adepts for inputs to guide ControlNet in image generation.

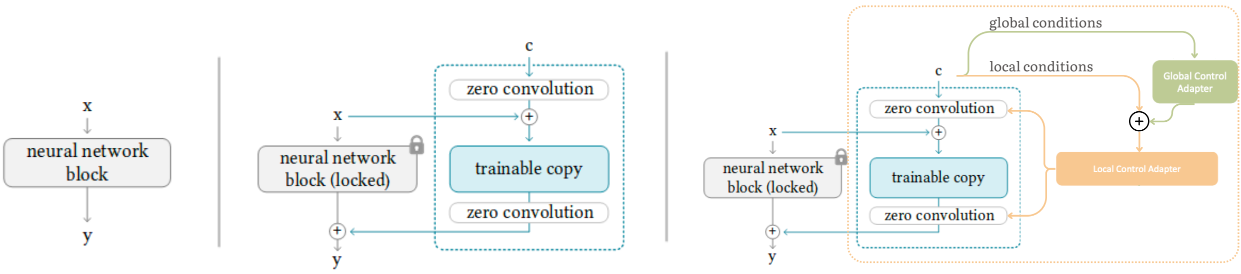
This concept was first published in a Reddit post [4] and was further developed by the QRBTF community, renowned for their work on artistic QR Codes [24]. While the QRBTF models remain unreleased, numerous tutorials, including one by Anthony Fu [17], offer insights into the process of generating artistic QR Codes using ControlNet. These manuals reference models such as QR Pattern [31], QR Code Monster [28], and IoC Lab ControlNet [22], explaining how varying the control weight parameters can impact the results. See Figure 5 for QR Codes generated by various ControlNet models.

The task of manually creating a dataset of visual QR Codes is highly challenging due to the extensive labour required for generating a single QR Code, necessitating an alternative approach for the development of a feasible dataset.

The QR Pattern model utilized a dataset available at [3], comprising 8,000 portraits with annotations. The selection of this dataset is somewhat debatable, as it predominantly consists of human portraits with annotations, which do not directly correlate with QR Code applications. In contrast, the QR IoC labs model was trained using the dataset found at [1], containing 3 million colour and grayscale images with annotations. Although this dataset appears more pertinent to QR Code generation, its suitability remains not entirely optimal. Regarding the QR Monster model, the dataset used for its training remains undisclosed.

A notable model, available at [2], was trained on a dataset created by converting images to grayscale. This approach seems most promising, as the image transformation process aligns closely with the reverse of QR Code creation, thus appearing to be the most logical choice.

The balance between creativity and scannability is a pivotal aspect of this process, as increased creative freedom often leads to reduced scannability. This pioneering approach, still in its infancy, lacks standardized frameworks and presents open questions regarding the inclusion of specific objects or features within the generated QR Codes. For instance, controlling the output in terms of human pose is



(a) Stable Diffusion (b) ControlNet (c) Uni-ControlNet

Figure 4: Model architecture of Stable Diffusion, ControlNet and Uni-ControlNet: (a) describes a model architecture of a standard diffusion system, (b) depicts an addition of ControlNet in form of a trainable copy of a network layer with zero-initialized convolution layers ensuring no harmful noise is added, (c) Uni-ControlNet architecture with additional global and local adaptors. [51].

(a) (b) (c)

Figure 5: Variations of SD generated QR Codes using various models: (a) GhostMix model, (b) QR Monster ControlNet, (c) QR Pattern ControlNet [9].

mentioned but not extensively explored. With no comprehensive studies focusing on user perception of these artistic QR Codes, questions linger about their practicality and recognizability in real-world scenarios.

3. IMPLEMENTATION

Initially, this project intended to produce QR Codes with a target image, such as an event mascot, embedded in a QR Code-like image to be used in a mobile app. This section explains the workflow that was followed to produce such outputs. The novelty and subjectivity in output quality present big challenges for this field. As of writing this dissertation, most of the models mentioned in this work are undergoing development and lacking detailed documentation. The implementation work done for this project relies on freely accessible information available at the beginning of the academic year 2023/2024.

The open-sourced "runwayml/stable-diffusion-v1-5" SD model trained on the "laion-aesthetics v2 5+" dataset is used for this project [41]. As an extension of this model, the "monster-labs/control_v1p_sd15_qrcode_monster" ControlNet model's version 2 by Monster labs [29] is used. This ControlNet extension was chosen due to showing the most promising results for both creativity and scannability criteria of produced QR Codes.

Python 3.10 was used for software development [36]. Some notable libraries used in this project are described in this section. Hugging Face's Diffusers were used to work with the SD and ControlNet models [47]. This library is a state-of-the-art standard for working with pre-trained diffusion models. It incorporates various repositories used for generating visual content and makes the widely used machine learning models accessible by providing an API for training and inference. Specifically, Diffusers provided the StableDiffusionControlNetPipeline used to interact with the chosen SD and ControlNet models.

To work with high-dimensional data representation of images and other number manipulations tensor libraries were used including PyTorch and numpy [35, 32]. Due to limited computational resources, float16 data representation was used for image generation. For this project, float16 provided a sufficient amount of image quality. However, float32 could potentially enhance the quality of generated images with additional resource costs.

The workflow implemented for AQR Code generation (see Figure 6) allows for optimising the regular QR Code being fed into the generation process. For the logic of the implemented workflow, see the Algorithm 2. These regular QR Codes are generated using the standard qrcode library [26]. Input optimisation includes changing the input image size, background colour, position and other parameters discussed further in this section. Pillow Image library [12] was used for further image processing.

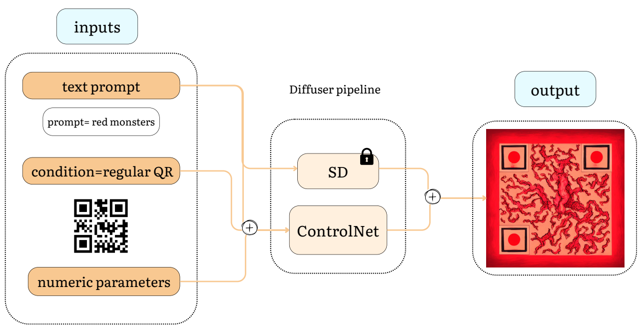


Figure 6: Diagram of workflow implemented in this project for AQR Code image inference.

Output results were verified manually at first and programmatically later for batch QR Code generation processes. Initially, output results from batch QR Code generation were checked for scannability using a manual approach with an iPhone SE 2020 camera and a QR Code reader app [14]. While this method closely mirrors actual user scanning and is highly reliable, it is time-consuming. Consequently, automated checks were introduced to expedite the verification process.

Two libraries were used to verify outputting artistic QR Codes. OpenCV's standard library with a built-in function for QR Code detection was utilised initially [27]. However, this library was found to perform significantly worse compared to the manual approach due to its focus on regular QR Code detection. A "qr-verify" tool in the form of a command line interface (CLI) was used to perform batch QR Code verification [10]. This CLI implements the same detection algorithm based on CNN models used by WeChat, is built on top of the OpenCV library, and has a higher performance compared to the standard OpenCV QR Code detection function. For a visual representation of the performance of both libraries, see Figure 9.

The majority of the project was developed using Jupyter Notebook in a Google Colab free-tier environment. This environment utilizes a T4 GPU with access to VMs with 25GB RAM. These resources provided a good starting point for the project in the initial experiments stage, however, due to limitations in available RAM, this environment was not suitable for running large-scale batch image generation and was causing issues in later stages of experimentation. For processing larger batches of images, a system with 6 hexacore AMD processors, an NVIDIA 6GB graphics card, and 16GB RAM was used.

Algorithm 2 : Image inference for batch generation.

1: Load models
2: Initialize the pipeline
3: Define inference parameters
4: **for** each combination of parameters **do**
5: Set the parameters
6: Initialize a QR Code
7: Perform image inference
8: Save the image and its metadata
9: **end for**
10: Clean up GPU resources

The performance of the generative model was evaluated and outputs were plotted and described in this paragraph. Model parameters explored in this project are described and the performance is visualised based on metrics consisting of these parameters. For the description of each parameter, see the Table 1 below. To visualize the effect each parameter has on the final image outputs from an experiment with varying parameters are captured in Figure 7. In another experiment, a batch of 2250 images was generated using variations of parameters: prompt, conditioning scale, size and position. The aim was to explore parameter correlation. The 2250 outputs were then evaluated based on the scannability. Increasing conditioning scale values led to an increase in scannability, as suggested by the research done as a part of the Background 2. An example of generated images with increasing conditioning scales can be seen in Figure 8. Note that maximising the conditioning scale solves the issue of output scannability, not the image quality. The correlation of the conditioning scale with various parameters is captured in heatmaps (see Figure 10).

Figure 7: This Figure demonstrates outputs generated using varying parameters. The first row was generated using QR Code inputs with varying sizes. It was observed that QR Code sizes around 16 produce the most visually pleasing outcomes, hence 16 is used as a fixed size across the experiments. The second row includes experiments with various seeds. The choice of seed influences the generation quite visibly. Due to the size of the seed space, experiments related to the seed choice are out of the scope of this project. The third row includes experiments with various guidance scale values. The guidance scale determines the extent to which the generation follows input prompts, and the ideal fixed value was determined to be around 7. Fixed parameters were: prompt ("Trees in a forest"), ControlNet conditioning scale (1.41), and model (QR Monster).

4. EVALUATION

This section contains a detailed breakdown of the experiments conducted during the course of this project. The main objective is to evaluate the human perception and engagement with Stable Diffusion-generated QR Codes compared to regular QR Codes. The majority of this study uses human subjects, and their opinions and observes their behaviour. As there is no previous similar work done at the time of writing, there are no known baselines that could be reused for this study. Therefore, baselines are established from the data collected.

Data was collected in multiple stages using various types of promotional media. One stage explored user interaction with QR Codes in a real-life setting, on a public display. Another two stages of the experiment were aimed at collecting insights into the user perception of QR Codes via questionnaires.

4.1 Objectives

This study is looking to answer questions regarding the usability, acceptance, and engagement of QR Codes generated

Parameter	Description	Values	Batch Generation
Text Prompt	The text that guides image generation.	String or List of Strings	Yes
Negative Prompt	This text prompt instructs the model on what not to include in the output.	String or List of Strings	No
Conditioning Scale	The chosen multiple of the ControlNet to be applied to the outcome, i.e., the strength with which the ControlNet condition is applied to the final image.	Float,[0.0, 2.5]	Yes
Guidance Scale	The closeness of the final output to the given text prompt, the higher the guidance scale, the more closely the output image aligns with the text prompt.	Integer, [0,25]	Yes
QR Code size	Specify the position and size of the input image, specify the spatial areas where the conditions are applied as well as the final output size.	Integer, [1,30]	Yes
Number of inference steps	The number of denoising steps, the higher the number of inference steps the higher quality image yields with additional time costs.	Integer, {20,40}	Yes
Seed	This value is an input of the Generator parameter, it makes the generation deterministic by specifying the base number for random noise generation.	Integer, [0,9999999]	No

Table 1: Description of input parameters for the inference pipeline combining SD and ControlNet models. The values column describes the type and range of the parameters used in the experiments conducted in this study, i.e. the interval of numbers taken into account. Batch Generation includes information about whether a batch generation experiment was conducted on a range of each parameter ('Yes' for most parameters except Negative Prompt and Seed. Exploring the Seed space and prompt engineering including the Negative Prompt is outside the scope of this project).

via Stable Diffusion. It assesses whether such QR Codes can be easily recognized by users, accepted as a standard by the community and whether they enhance user interaction. This research seeks to understand the potential of using advanced generative models to improve the creation, and application of QR Codes, focusing on user-centric outcomes.

4.2 Methodology

Data collection involved three different experiment stages. The set-up of each stage varies in context to allow for collecting data from a wider range of audiences. Overall, the intention was to explore user interaction in a real-life setting, complimented with more in-depth insights into user perception via collecting survey data. The study stages are described below.

The first stage comprised an experiment in the 'wild' conducted on the facilities of the University of Glasgow. This experiment aimed to objectively assess how people interact with various QR Codes on promotional media in public. A collaboration with university services was sought to create a campaign promoting the University of Glasgow Print Unit. Two kinds of promotional media were created- one type containing a regular QR Code, and one containing an AQR Code. Except for the QR Code area, the rest of the promotional material was the same for both types. There were two types of communication channels used for promotion:

- **Digital screens** displayed the posters in the James McCune Smith Learning Hub and the university's Main Library. A poster with each type of QR Code was displayed for 10 seconds every ±5 minutes during the opening hours on all promotional screens for 14 consecutive days. See the picture of a university screen featuring an AQR poster in Figure 11. Over 40000 enrolled students currently have access to the university premises [5]. However, there is no public information available regarding the number of students visiting or interacting with the campus screens, so further demographic data could not be provided.

- **Physical leaflets** were handed over to students around the university campus. Again, one type of leaflet contained a regular QR Code, and one type contained an AQR Code. The design of the leaflets was identical to the design of the digital posters but featured a different theme of an AQR Code. 60 leaflets in total, 30 of each type, were given away to students.

QR Code on each promotional media was linked to a website hosted on GitHub pages specifically designed for this study [44]. Each link contained parameters specific to the promotional medium and the type of QR Code used. The website

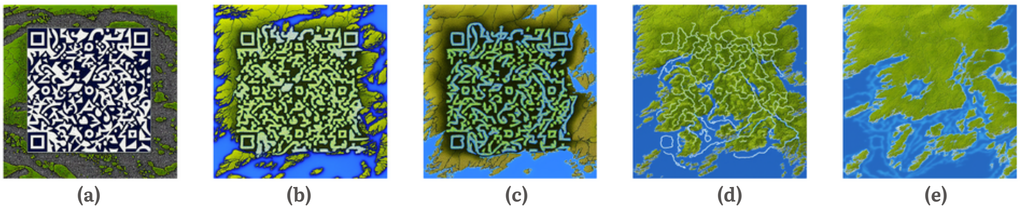


Figure 8: QR Codes generated using QR Code Monster model, using the prompt: "Earth, navigation, Scotland", negative prompt:"ugly, disfigured, low quality", guidance scale: 7, seed: 2313123, and the following ControlNet conditioning scales: (a) 2.3, (b) 1.55, (c) 1.41, (d) 0.91, (e) 0.75

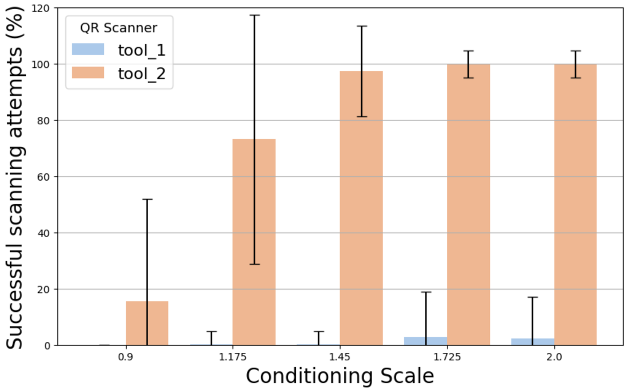


Figure 9: Percentage of scannable outputs plotted against the conditioning scale, evaluated via two different scanning tools. 'tool_1' corresponds to the OpenCV's standard QR Code detection, 'tool_2' corresponds to the 'qr-verify' CLI.

implemented Google Analytics for tracking user data [21]. This setup allowed for tracking the number of users scanning individual QR Codes and provided insights into user interaction with web pages linked to the displayed promotional materials. The page linked to the poster and leaflets with AQR additionally contained a survey with questions concerning the scanning experience and opinions on AQR Codes compared to regular QR Codes.

The second stage involved an email being dispatched to Level 4 and Level 5 Computing Science students at the university, totalling 268 individuals, aiming to gauge their engagement with AQR Codes versus standard QR Codes. The email highlighted promotional content for university services and invited students to partake in a survey. This survey explored preferences between AQRs and standard QR Codes, eliciting opinions on usability and practicality, aimed at further enriching the study with qualitative feedback. Despite a possible wide reach of the email notification, the Moodle post in question reported low visibility of 2 views from level 4 and 4 views from level 5 students.

The third stage of data collection involved surveying a poll of people to evaluate user engagement and preferences between regular and AQR Codes, focusing on their usability, design impact, and potential to enhance a brand's visual identity. The survey seeks to understand if and how AQRs could be integrated more effectively into marketing strategies to improve user interaction. The questions were aimed at understanding the challenges users face when scanning both QR Code types and subjectively assessing which type provides a quicker response. Additionally, it explores the importance of QR Code design in the decision to scan. 10 responses were recorded from 5 females and 5 males between the ages of 20 and 40.

4.3 Results

Data collected during the first stage of the study seen in Figure 12 suggest the following. No interaction with the promotional media displayed on the university's digital screen has been recorded. When it comes to interaction with printed media, 2 users interacted with leaflets containing the regular QR Code. No users interacted with the AQR Code contained on leaflets. Therefore, the only type of user interaction recorded during this stage is interaction with the regular QR Code on leaflets.

As the data collected is categorical and countable, a chi-square test was performed to accept or reject research question 2.: Does a Stable Diffusion generated AQR Code lead to increased user interaction? In this test, we assessed the relationship between the variables QR Code type and user interaction, which in this case translates into a user scanning a QR Code. No interaction was recorded with the promotional material on screens, therefore only interaction with promotional leaflets is taken into consideration. Let's take a null hypothesis "There is no difference between interaction with a regular QR Code and an AQR Code." We get the contingency table displayed in the Figure 3. As both types of QR Codes were displayed at once, we assumed the same number of people had the chance to interact with both QR Codes and we also assumed the number of such people to be 2000. Therefore, the number of people who did not interact with the displayed materials was 1000 for each of the QR Codes. These numbers give us $\chi^2 = 0.4985$ and a $p-value = 0.480$ with 1 degree of freedom. Setting the significance at 0.1, we cannot reject the null hypothesis and therefore cannot conclude there is a distinct difference between the two types of QR Codes in terms of user interaction.

During the second stage, no survey responses were recorded, therefore no data was collected. The third stage of the study revealed insights about user interaction and subjective opinions of AQR Code usability. The participants were asked about the challenges encountered when interacting with the two types of codes and the device used for scanning, experience with scanning different QR Codes in public, design importance, enhancement of brand or event identity and potential personal use of AQR Codes.

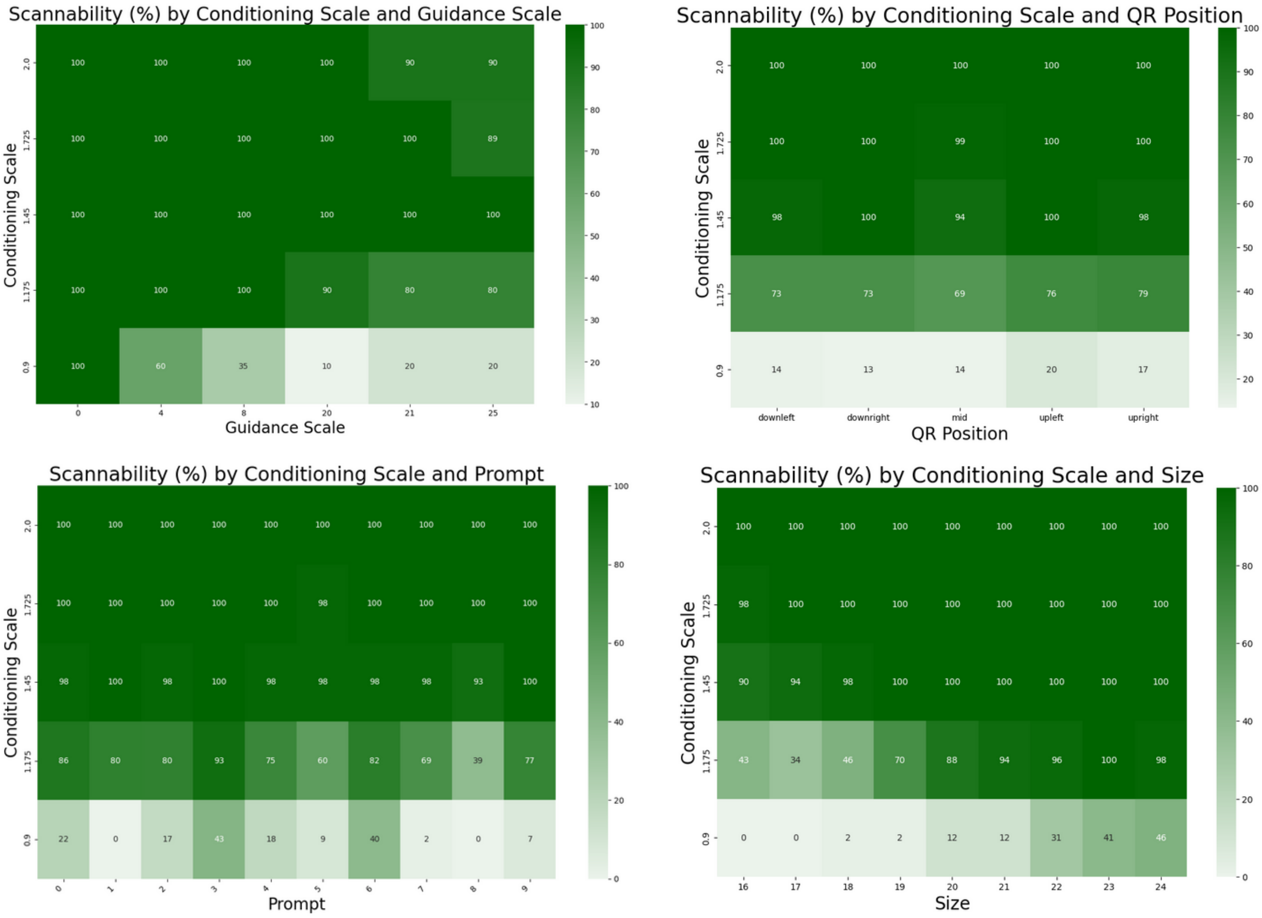


Figure 10: Heat maps are produced by plotting the conditioning scale by guidance scale, QR position, prompt, and size. A set of 2250 images was used to produce all heatmaps except the guidance scale one. The guidance scale heatmap was plotted based on 241 images. The images with varying guidance scales had to be generated separately due to limited computational resources. In contrast to the guidance scale and size, prompt and QR position seem to have little correlation with the conditioning scale when evaluated based on input scannability. With increasing guidance scale, a smaller range of conditioning scales yields 100% scannable outputs, meaning smaller guidance scales should be preferred when aiming for output scannability (for the rest of this study, due to computational resource limitation, the fixed value of 7 was used). Increased size seems to provide better scannable outputs for a wider range of conditioning scales.
Image prompts used to create the data for the above heatmaps:
'0': A bouquet of vibrant flowers with dewdrops on the petals, basking in the morning light.
'1': A chalkboard filled with intricate mathematical equations and geometric figures, with a vintage feel.
'2': A dynamic pose of a superhero with a flowing cape against a backdrop of a bustling cityscape at night.
'3': A gourmet, chef-prepared meal presented elegantly on a white porcelain plate.
'4': A scientist in a lab coat conducting an experiment with colorful bubbling test tubes.
'5': A sleek, modern computer setup with multiple monitors displaying code and 3D models.
'6': A steaming cup of espresso with a delicate foam art on top, on a rustic wooden table.
'7': A vibrant canvas showcasing a fusion of different art styles inspired by various famous artists.
'8': An abstract visualization of complex computing algorithms as neon structures in cyberspace.
'9': An adorable Pikachu enjoying a sunny day in a lush, green meadow, digital art.

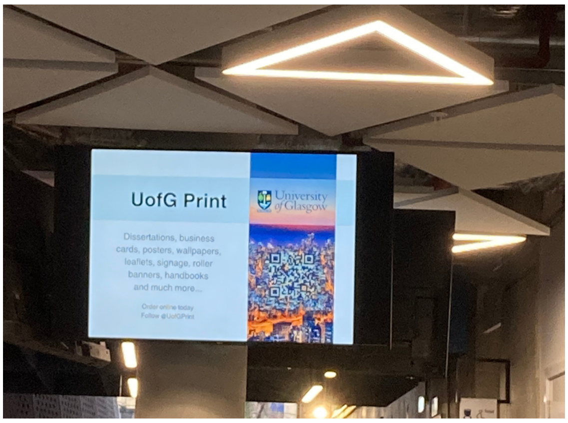


Figure 11: University screen featuring a poster during the first stage of the study.

The results showed that 100% of the participants subjectively stated regular QR Codes scanned faster than AQR Codes. This result is not surprising and points to AQR Code deficiencies in perceived scanning efficacy and consequently, user experience. Arguably, this result is influenced by the scanning device used and its software. The devices used by the participants and corresponding scanning attempts are summarized in Table 2. This indicates that some device types are better at scanning AQRs than others, which makes the functionality of AQRs dependent on the device being used for scanning. This means that the AQR Code field advancement is dependent not only on the development on the side of the AQR Code generators but also on scanning device manufacturers.

The study participants were asked to rate the design importance when deciding to scan a QR Code in public (results summarised in Figure 13). The participants were then asked to elaborate on their answers. Notable quotes from the answers collected include:

> I am generally unlikely to scan any QR Codes due to security reasons.

> AQR Codes could increase the likelihood for me to scan.

> I won't scan a QR Code just because it is pretty.

> AQRs have the potential to be missed by those not paying as much attention.

> I feel more tempted to scan an AQR Code due to knowing it takes more effort to prepare.

Among the explanations, 2 responses stated, that the nature of AQR Codes is making it more intriguing to scan compared to regular QR Codes due to intellectual curiosity. Another two participants found the visual appeal of AQR Codes to increase their likelihood of scanning. Conversely, six respondents emphasized that their decision to scan a QR Code is primarily influenced by its purpose or presentation. These insights present a contrast to the quantitative finding that a rating of 4 was most common for the question regarding design importance.

AQR Code scan result	Device Used
Success	iPhone 11 pro
	iPhone Xs
	iPhone (unknown type)
Failure	Google Pixel
	iPhone 12 mini
	Android
	iPhone 8
	OPPO Find X3

Table 2: Results from the third stage user survey concerning the scanning of an AQR Code and the device used. iPhone seems to provide a better success rate than other devices when it comes to QR Codes. This is arguably due to its hardware qualities.

QR Code type	People interacted	People not interacted	Total
Regular	2	1000	1002
AQR	0	1000	1000
Total	2	2000	2002

Table 3: Contingency table of results from the first stage of the study, used to calculate statistical significance and reject the null hypothesis. 2000 is the estimated number of people that have seen the displayed QR Codes. As both types of QR Codes were displayed on the same screens for the same amount of time, we estimated that each QR Code was seen by $2000/2 = 1000$ people.

9 participants stated they would like to see more Artistic QR Codes in advertising. When asked about the possibility of using an AQR themselves, 9 participants would opt for an AQR Code, with 4 participants mentioning certain conditions to be met by a potential AQR Code to be used. These conditions include efficient scannability, visual alignment with the promotional content, and response time equal to the response time of a regular QR Code. 1 participant would opt for a mix of both types of QR Codes.

Lastly, when asked about the potential of AQR Codes for enhancing a brand's visual identity, 9 participants expressed a positive outlook on this possibility. Here are some of the quotes collected from the response data:

> AQRs show creativity and it's something that can distinguish brands from other competitors.

> Yes, if they are well-designed.

> I think AQRs would provide an opportunity for the brand to be more recognizable.

Based on the numerical Likert Scale ratings we compared the likelihood of scanning a regular QR Code vs. AQR Code in public and considered the null hypothesis: "There is no difference in the likelihood of scanning QR Codes between regular and artistic QR Codes in public." Based on the Mann-Whitney U test, we got $p - value = 0.206$ and with the significance level of 0.1, we cannot reject the null hypothesis.

5. CONCLUSION

In summary, a workflow for image inference was presented and implemented. Experiments were conducted with vari-

	Session source	Landing page + query string	↓Active users	Sessions	Engaged sessions	Average engagement time per session	Engaged sessions per user	Events per session	Engagement rate	Event count
	Totals		5	6	3	12s	0.6	4	50%	24
1	(direct)	/print-unit-220001.html	3	3	2	18s	0.67	4.33	66.67%	13
2	regular qr leaflet	/print-unit-220001.html	2	3	1	7s	0.5	3.67	33.33%	11

Figure 12: Google Analytics data collected throughout the first stage of the study. This table captures all the data collected during this stage. The 'regular qr leaflet' total refers to users interacting with the leaflet containing a regular QR Code. '(direct)' refers to internal QR Code interaction outside the study, therefore it is not taken into consideration.

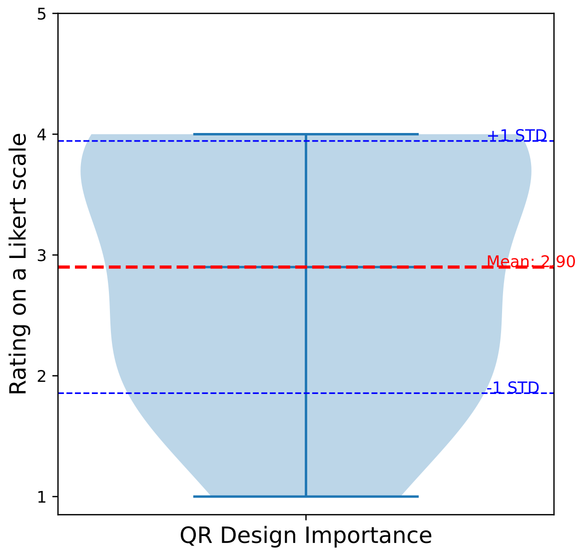


Figure 13: Summary of data collected concerning the design importance when scanning a QR Code in public. The average rating was 3 out of 5. The most common response was 4, stated by 4 out of 10 participants.

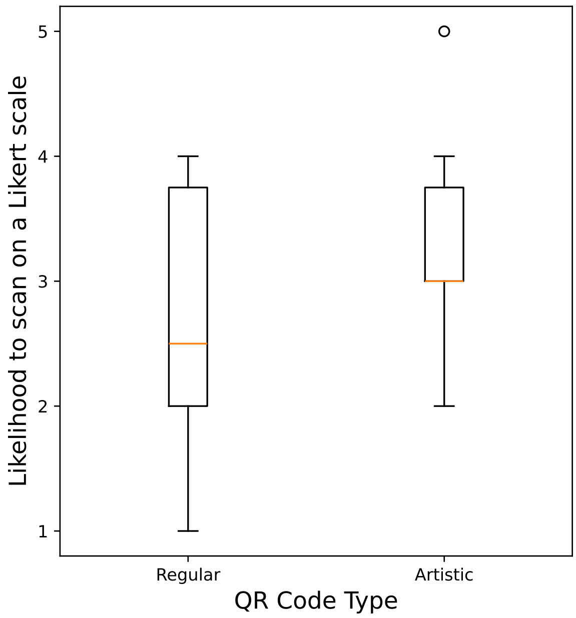


Figure 14: User reported likelihood to scan a QR Code by the type of QR Code. Average scores are 2.5 for the regular, and 3 for the AQR code, meaning users overall preferred AQR Codes.

ous input parameters. A batch of 2500 images was evaluated based on scannability, and the outputs were used to observe parameter correlations. A three-stage study was conducted to explore user engagement with the generated QR Codes in the 'wild'. This study evaluated how users perceived and engaged with AQR Codes, and is of a kind study aimed at understanding user perception of these QR Codes. Due to the small scale of generated images, study time frame and resource limitations, little data has been collected to reject or accept a research hypothesis. It cannot be confidently stated, whether AQR Codes lead to increased user interaction. However, this study arguably provides valuable information and a good starting point for further research in this field.

5.1 Future work

In future work, a larger-scale study could be conducted with larger amounts of data collected to reliably reject or accept a hypothesis. The security aspect of AQR Codes is another aspect to be explored. With the increased QR Code obscurity, security concerns could be raised regarding possible misuse of materials displayed in public.

A more reliable data set could be constructed that would closely align with visuals of AQR Codes and could be used to fine-tune a custom ControlNet model for QR Code generation. A couple of promising approaches have been mentioned in this study, such as grayscale image conversion using the HSV method, however, implementation and more thorough research into this is needed.

Evaluating output AQR images is a subjective task and there are no known metrics for a uniform rating of these outputs. This fact poses a challenge for possible automated solutions for AQR Code generations and would require further research and access to high-power computational resources for the development of such a system.

5.2 Reflection

This fruitful project journey provided many valuable lessons ranging from handling uncertain project goals, through looking beyond obvious ways of utilizing computational resources, to orchestrating a public user study.

Leaning on the knowledge gained in the course of this work, here are some of the things that could have been done differently. Taking publicly available datasets is not always a worthwhile solution. In the case of AQR Code generation, a custom data set could be crafted easily. Especially with access to available SD models and computer vision libraries, large numbers of images could be generated meeting the criteria for such dataset with minimal effort.

A greater effort could be put into broadening the public audience for a study in the 'wild' to gain more valuable data about interaction with QR Codes. Another aspect of the study design was the inconsistent device type used by participants to scan QR Codes. This could largely influence the responses collected in the surveys. A more controlled experiment with a consistent scanning device type could be designed to rule out the device's influence on the participant's perception of the use of AQR Codes.

Acknowledgments. I would like to thank my supervisor, Dr. Jonathan Grizou, who provided invaluable help, support, expertise and time during this project. I greatly appreciate his effort and the learning experience facilitated by him and am deeply grateful for being able to be his supervisee.

Additionally, I wish to express my heartfelt appreciation to my family and friends for their unwavering support and encouragement on my journey towards a Master's degree.

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APPENDIX

A. PARTICIPANT CONSENT

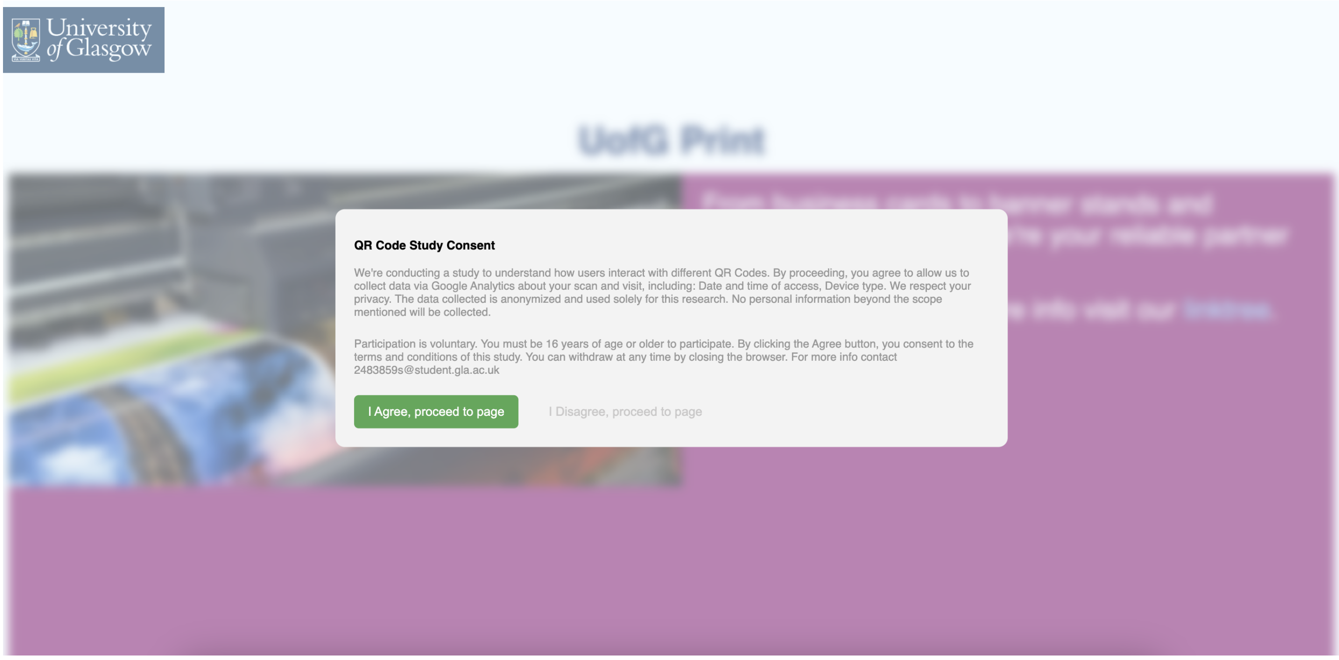

Figure 15: Consent pop-up window displayed on a web page linked to promotional materials used in the first stage of the study.

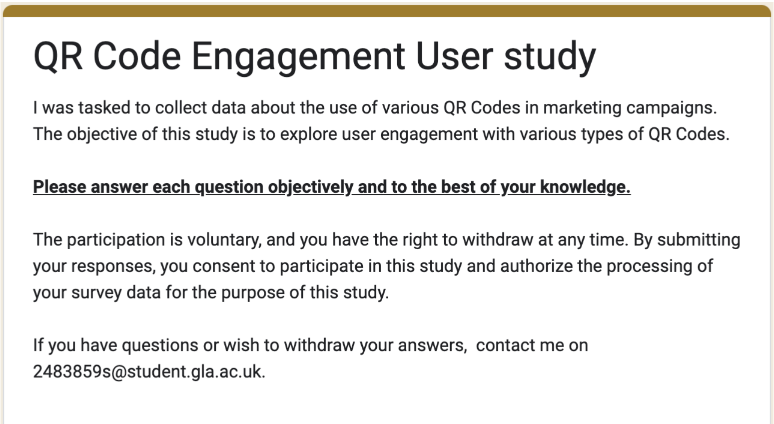

Figure 16: Consent message displayed to the survey participants in the third stage of the study.

School of Computing Science
University of Glasgow

Ethics checklist form for assessed exercises (at all levels)

This form is only applicable for assessed exercises that use other people ('participants') for the collection of information, typically in getting comments about a system or a system design, or getting information about how a system could be used, or evaluating a working system.

If no other people have been involved in the collection of information, then you do not need to complete this form.

If your evaluation does not comply with any one or more of the points below, please contact the Chair of the School of Computing Science Ethics Committee (matthew.chalmers@glasgow.ac.uk) for advice.

If your evaluation does comply with all the points below, please sign this form and submit it with your assessed work.

---

1. Participants were not exposed to any risks greater than those encountered in their normal working life.

   Investigators have a responsibility to protect participants from physical and mental harm during the investigation. The risk of harm must be no greater than in ordinary life. Areas of potential risk that require ethical approval include, but are not limited to, investigations that occur outside usual laboratory areas, or that require participant mobility (e.g. walking, running, use of public transport), unusual or repetitive activity or movement, that use sensory deprivation (e.g. ear plugs or blindfolds), bright or flashing lights, loud or disorienting noises, smell, taste, vibration, or force feedback

2. The experimental materials were paper-based, or comprised software running on standard hardware.

   Participants should not be exposed to any risks associated with the use of non-standard equipment: anything other than pen-and-paper, standard PCs, laptops, iPads, mobile phones and common hand-held devices is considered non-standard.

3. All participants explicitly stated that they agreed to take part, and that their data could be used in the project.

   If the results of the evaluation are likely to be used beyond the term of the project (for example, the software is to be deployed, or the data is to be published), then signed consent is necessary. A separate consent form should be signed by each participant.

   Otherwise, verbal consent is sufficient, and should be explicitly requested in the introductory script.

4. No incentives were offered to the participants.

   The payment of participants must not be used to induce them to risk harm beyond that which they risk without payment in their normal lifestyle.

5. No information about the evaluation or materials was intentionally withheld from the participants.
   Withholding information or misleading participants is unacceptable if participants are likely to object or show unease when debriefed.

6. No participant was under the age of 16.
   Parental consent is required for participants under the age of 16.

7. No participant has an impairment that may limit their understanding or communication.
   Additional consent is required for participants with impairments.

8. Neither I nor my supervisor is in a position of authority or influence over any of the participants.
   A position of authority or influence over any participant must not be allowed to pressurise participants to take part in, or remain in, any experiment.

9. All participants were informed that they could withdraw at any time.
   All participants have the right to withdraw at any time during the investigation. They should be told this in the introductory script.

10. All participants have been informed of my contact details.
    All participants must be able to contact the investigator after the investigation. They should be given the details of both student and module co-ordinator or supervisor as part of the debriefing.

11. The evaluation was discussed with all the participants at the end of the session, and all participants had the opportunity to ask questions.
    The student must provide the participants with sufficient information in the debriefing to enable them to understand the nature of the investigation. In cases where remote participants may withdraw from the experiment early and it is not possible to debrief them, the fact that doing so will result in their not being debriefed should be mentioned in the introductory text.

12. All the data collected from the participants is stored in an anonymous form.
    All participant data (hard-copy and soft-copy) should be stored securely, and in anonymous form.

Course and Assessment Name __COMPSCI5072P, COMPSCI5073P MSci - Level 5 Project - 2023-24___

Student's Name _____Alexandra Strompova______

Student Number _____2483859s_______

Student's Signature __ ________________

Date ___12/04/2024____

Education Use Consent

I hereby grant my permission for my Level 5 Project Final Research Paper and Interim Report to be distributed and shown to other University of Glasgow students and staff for educational purposes.

Name: Alexandra Strompova

Student Id: 2483859S

Signature:

Date: 12/04/2024