

## **QR Code: Analysis in Depth**

**Ximena Ruiz Bermúdez and Manuel Molina Urbina**

**Department of Software Engineering**

**COT2104**

**Dr. Luis Morales**

**December 11, 2024**

## Table of Contents

<b>Abstract.....</b>	<b>4</b>
<b>QR Code: In-depth analysis.....</b>	<b>5</b>
<b>QR Code Structure .....</b>	<b>6</b>
Finder Pattern .....	6
Alignment pattern.....	7
Timing pattern .....	7
Quiet Zone.....	7
Data Area.....	8
Format and Version Information.....	8
<b>Key Features of QR Codes .....</b>	<b>8</b>
High Data Capacity .....	9
Free for Public Use.....	9
Automatic Link Access .....	9
Fast, 360° Scanning.....	9
Distortion Resistance.....	9
Error Correction .....	10
Efficient Encoding for Characters.....	10
Data Linking for Large Sets .....	10
Black-and-White Patterning.....	10

Optional Security.....	10
Direct Marking Ability.....	11
<b>Types of QR Codes .....</b>	<b>11</b>
Model 1 & 2 .....	11
Micro QR.....	11
rMQR .....	12
FrameQR .....	13
<b>Importance of QR Codes.....</b>	<b>13</b>
Medicine.....	13
Information Security .....	14
Archeology .....	15
<b>The future of QR Codes .....</b>	<b>15</b>
<b>Conclusion .....</b>	<b>16</b>
<b>References.....</b>	<b>18</b>

## Abstract

The focus of this research is to explore the history, structure, and characteristics of Quick Response (QR) Codes including types, encryption mechanisms, and the process behind their creation. QR codes have demonstrated the potential of becoming an essential tool for everyday processes and tasks, with their constant advancements and updates of the technologies behind. We also plan to discuss the future implementations of QR codes with emerging innovations like the inclusion of colors and images in their patterns.

**Keywords:** Quick Response Code, history, structure, process, emerging innovations, future implementations.

## QR Code: In-depth analysis

The binary number system is the foundation of every technological device we use today. Quick Response (QR) Codes can be considered a daily tool for people, ranging from publicity, utility, information sharing, legal documents, transport passage, among others. While people frequently interact with QR code patterns, few are aware of how they work, particularly the complex engineering processes that compose them.

To understand the motives of its creation, we should look back at the 1960's Japan. With the aftermath of World War II and the outbreak of the Korean War, a great market demand was experienced by Japan, increasing its economic rate. Consequently, supermarkets were in the middle of this booming economy, and cashiers were the ones who carried out the hard work, as they had to manually keep track of the ins and outs of goods. By the time, machine-readable codes were available for that task, however, they were not practical, and their maintenance costs were expensive.

In the 1970's IBM reinvented the Bull's eye code, a machine-readable code originally used by the automotive industry to track car parts. In its new model, the bull's eye code was adapted into a vertical one, known as the barcode (or Universal Product Code, UPC). This reinvention was successful, and the barcode started to be implemented across every industry but presented limitations over time due to its one-dimensional design, since they can only hold up to twenty digits, making it challenging to store the necessary data for tracking of products, often requiring more than two barcodes for a single item. To overcome these limitations a new solution was needed: The Quick Response Code.

The QR was developed in 1994 by Masahiro Hara, a DENSO WAVE Incorporated <sup>1</sup> employee who focused on the development of barcodes scanners and optical character recognition devices. The creation of this code came from the request of manufacturing sites looking for “the capability to code Kanji and Kana characters as well as alphanumeric ones” (DENSO WAVE, n.d.).

A QR Code is a two-dimensional symbol derived from the traditional barcode system. This matrix-based code consists of distinctive black square patterns on a white background; similar to the ones formed in a *go game*<sup>2</sup>. QR codes can handle various types of data formats including numeric and alphabetic characters, kanji, Kana, Hiragana, symbols, binary, and control codes; up to 7,089 characters can be encoded in a single symbol.

### QR Code Structure

A QR code consists of a matrix of black pattern blocks, where white spaces represent 0s and the black blocks represent 1s, encoding information in a binary format. This grid is divided into five main regions, each playing a crucial role in the code's functionality.

#### Finder Pattern

Seen at first sight, the finder pattern consists of three 5x5 squares, each containing a 3x3 white square with a black square in the center. These patterns are positioned in the upper left, upper right, and lower left corners of the QR code. This set of squares guarantees the code's size,




---

<sup>1</sup> Japanese company dedicated to the production of automobile parts.

<sup>2</sup> Strategic board game for two players that originated in ancient China.

position, and angle are detected from any orientation when scanned, providing 360-degree readability.

### Alignment pattern

The alignment pattern in a QR code helps to correct distortions that may happen when the code is viewed from an angle or applied to a curved surface. It includes a distinct black cell at the center, which makes it easier to locate the pattern's central point. By identifying this central point, any misalignment due to a distortion can be measured and adjusted.



Multiple alignment patterns are placed evenly across the QR code, allowing for accurate reading by correcting both linear and nonlinear distortions.

### Timing pattern

The timing pattern in a QR code is a sequence of arranged alternating black and white modules that helps establish the position of each cell within the QR code. Located in both the 6th row and the 6th column, it runs horizontally and vertically between the separators. This pattern helps correct spacing errors and provides a reference for determining cell pitch, symbol density, module coordinates, and version information area.



### Quiet Zone

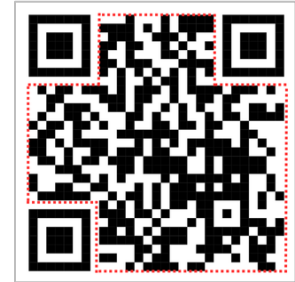
The quiet zone is an empty, 4-module-wide margin surrounding the QR code. This blank space separates the code from surrounding elements, ensuring that nearby text or markings



do not interfere with its readability. Providing a clear boundary, the quiet zone improves the accuracy of QR code detection and scanning.

### **Data Area**

The data area in a QR code is where the encoded information is stored. This area encodes binary values '0' and '1' into corresponding black and white cells, arranged according to encoding rules. Reed-Solomon error correction codes are embedded within this data area, enabling error correction and ensuring data reliability during scanning and decoding.



### **Format and Version Information**

The format and version information are important elements of a QR code, added in designated blank areas during the final stages of its creation. The format information encodes details about the error correction level and the mask pattern applied, ensuring the QR code can be accurately interpreted even if it is damaged or distorted. The version information is only included in larger QR codes, it provides data about the size and matrix dimensions of the QR code. These components are positioned to avoid interference with the encoded data while remaining easily accessible for scanning and decoding.



## **Key Features of QR Codes**

While QR codes may appear simple, their underlying complexity is remarkable. With the ability to store up to 2,953 bytes of data and robust error correction capabilities, QR codes boast several impressive features:



## **High Data Capacity**

QR codes can store far more information than regular barcodes, including complex characters like Kanji and Chinese. This allows QR codes to hold various data types, making them useful in different regions and industries.

## **Free for Public Use**

The QR code technology is available for anyone to use without licensing fees because its patent was released to the public. This makes it accessible for businesses, developers, and individuals for personal or commercial use.

## **Automatic Link Access**

In Japan and other places, most mobile phones can scan QR codes that link directly to websites. This feature makes it easy to share web links and quickly access online information without typing a URL.

## **Fast, 360° Scanning**

QR codes can be scanned from any direction because they have “finder” patterns (three squares) in their corners. These patterns help scanners detect the QR code’s position, size, and angle right away, making the scanning process fast and accurate without needing perfect alignment.

## **Distortion Resistance**

QR codes can be accurately scanned even if they’re on a curved surface or if the scanner is tilted. This is due to special alignment patterns that correct for any distortions, ensuring the code can still be read reliably.

## **Error Correction**

QR codes have error correction, meaning they can still be read if part of the code is damaged or dirty. Four error correction levels allow up to 30% of the code to be “reconstructed” even if damaged, so QR codes remain reliable in tough conditions.

## **Efficient Encoding for Characters**

QR codes were designed with Japanese Kanji and Kana in mind, making them efficient for storing complex characters. Compared to other 2D codes, QR codes can store these characters in less space, so they take up less room while holding the same amount of data.

## **Data Linking for Large Sets**

QR codes can divide large data into multiple smaller QR symbols, linking up to 16 individual codes. Each code segment has a “position marker,” so they can be scanned in any order, and the data will still be understood as a single, complete message.

## **Black-and-White Patterning**

QR codes are designed with a process called masking, which keeps black and white cells evenly arranged. This balanced pattern helps scanners read the data accurately and reduces the chances of mistakes during scanning.

## **Optional Security**

QR codes can be encrypted, meaning they can be set up with a unique mapping between characters and data for added security. This feature can make the data hard to read unless the user has the right key or information to decode it.

## Direct Marking Ability

QR codes can be printed or directly marked on items using laser or pin markers and still stay readable. They are easy to read on low-contrast surfaces, like metal or plastic, and can even be scanned from transparent materials like glass.

## Types of QR Codes

Since their invention, QR codes have evolved into various forms to enhance aesthetics or functionality. Here are some of the most notable types:

### Model 1 & 2

The original QR Code, known as Model 1, introduced a way to encode up to 1,167 numerals in a compact, square format with a maximum version size of 14 (73 x 73 modules). This foundational model made the way for QR Code Model 2, which was an improvement designed to ensure smooth readability even when the code was distorted. By adding an alignment pattern, Model 2 makes it possible to read QR Codes even on curved surfaces or from an angle. With Model 2, the encoding capacity increased significantly to hold up to 7,089 numerals, expanding the maximum version to 40 (177 x 177 modules).




### Micro QR

Micro QR Code was developed as a more space-efficient option, designed for small areas. It uses only a single position detection pattern, unlike the regular QR Code, which requires three detection patterns at the corners of the symbol. Additionally, Micro QR Codes need only a two-module margin around the code, rather than the four-module margin required by standard



QR Codes. This makes it suitable for printing in very small spaces, although it has a lower data capacity, with its M4 version capable of encoding a maximum of 35 numerals. Micro QR Code has been publicly available since it was approved as a Japan Industrial Standard in 2004, with DENSO WAVE waiving its patent rights.

## rMQR

rMQR Code (Rectangular Micro QR), offers a  solution for narrow spaces where a rectangular shape is preferable. It minimizes space by using “one and a half” finder patterns instead of the three required for traditional QR Codes, allowing it to fit into slimmer areas. This code can store anywhere from 12 to 361 numerals, with module configurations ranging from 7 x 43 to 17 x 139. rMQR Code received ISO approval<sup>3</sup> in May 2022, acknowledging its space-saving design and large storage capacity.

## SQRC

SQRC (Secure QR Code), introduces a method for nesting both public and private data within a single code. Private data is accessible only with a dedicated reader containing the cryptographic key, providing a safeguard against unauthorized access. Since SQRC codes look identical to regular QR Codes, they offer tampering and forgery prevention in environments such as event facilities, hospitals, and inter-company delivery services, making it an effective option for securely managing sensitive information.

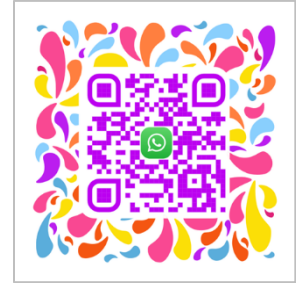



---

<sup>3</sup> Certification from the International Organization for Standardization (ISO) that demonstrates a company's commitment to meeting global standards.

## FrameQR

FrameQR was designed for visually appealing applications by incorporating a customizable frame around the code. This type allows companies to add images or logos, making QR Codes more noticeable and suitable for branding purposes. Frame shapes and colors can be set as desired; however, to maintain scannability, the contrast between the foreground (code) and background must remain high, and the QR Code must adhere to certain readability standards. FrameQR is popular for business cards and catalogs, as it can make a QR Code more engaging and memorable and is also useful in traceability and anti-forgery applications, where combining QR Codes with holograms can enhance security.



## Importance of QR Codes

QR codes are more than just a tool for marketing or linking to web pages; they serve a wide range of purposes across various sectors. In fields like medicine, security, and archaeology, QR codes provide essential data that enhances efficiency, traceability, and access to information.

### Medicine

QR codes have played a critical role during major global crises. In 2020, Canada Government implemented QR codes as the official certification of COVID-19 vaccines.

In 2002, the outbreak of bovine spongiform encephalopathy<sup>4</sup> (BSE), or mad cow disease, posed a similar challenge. People who consumed infected meat developed variant Creutzfeldt-

---

<sup>4</sup> Progressive and fatal disease of the nervous system in cattle. It results from infection by a "prion," an abnormal cellular protein found mostly in the brain.

Jakob disease<sup>5</sup> (vCJD), a human form of BSE. At that time, manufacturers used barcodes to monitor food safety. To improve traceability and help prevent the spread of vCJD, they began implementing QR codes.

Additionally, QR codes are now widely used in hospitals across Japan, Hong Kong, and Singapore. These codes appear on patients' wristbands, storing essential medical details like their medical history, treatments, and other critical information for quick, efficient access.

In Australia, QRs are used to label blood tests tubes, holding significant data in a reduced space. Once the QR-coded tubes are inserted into the tester, the system automatically reads and analyzes the samples.

## **Information Security**

Some researchers have explored the potential of implementing QR codes in banking processes. This approach involves two main steps: first, encrypting the data payload and generating a QR code from it; second, embedding the generated QR code within a colored image to enhance security.

Another proposal suggests using Steganography<sup>6</sup> with QR codes to conceal sensitive information. In this method, the QR code would display an unrelated public message that anyone could read, while only the intended recipient with the decryption key could access the hidden payment details. This added layer of encryption provides enhanced privacy for secure transactions.

---

<sup>5</sup> Creutzfeldt-Jakob disease is a prion disease characterized by progressive deterioration of mental function, leading to dementia, involuntary jerking of muscles (myoclonus), and staggering when walking. A variant form is acquired by eating contaminated beef.

<sup>6</sup> Practice of concealing information within another message or physical object to avoid detection.

## **Archeology**

QR codes have also proven valuable in archaeological research. During field analysis, important data may sometimes be overlooked, causing delays in results. In a study conducted at Telperion Shelter in Africa, archaeologists adopted QR codes to store contextual information, allowing for faster field recording, improved data presentation, and reduced recording errors. This approach streamlines the process and enhances the accuracy of archaeological documentation.

## **The future of QR Codes**

As AR (Augmented reality) and VR (Virtual Reality) Technology is implemented in devices such as apple vision, AR and VR could be implemented in QR codes so when this devices scan such codes the user can be sent to a custom experience or even used for marketing as seeing a store miles away from you in person, as well as offering a great experience for the user. QR codes linked to AR can enhance brand storytelling by allowing users to experience dynamic content like behind-the-scenes tours or interactive promotions. In cultural or entertainment settings, AR-enabled QR codes could provide virtual guides, display historical reconstructions, or offer interactive games related to a location or event. The success of AR/VR integration with QR codes depends on the widespread availability of compatible devices like Apple Vision and user familiarity with these technologies.

QR codes can also serve as an effective tool in education. By reducing paper usage, teachers can share class materials through QR codes, offering a sustainable alternative to printed handouts. Additionally, QR codes can be integrated into lectures, providing access to supplementary resources such as videos, conferences, or related websites. They also help

optimize space for record-keeping, enabling assignments, student data, and homework to be efficiently stored and accessed through QR codes.

QR codes have the potential to play a greater role in the health sector. For example, a hospital in Jerusalem, Israel, introduced QR codes into its anesthesia information management system to address gaps in record-keeping. Previously, only 52.2% of residents completed their case logs. After implementing QR codes for logging cases, the completion rate increased to 65.4%, demonstrating the effectiveness of QR codes in improving data collection and workflow efficiency in medical settings.

## **Conclusion**

QR codes have evolved from their origins as a tool for tracking automotive parts to becoming an indispensable part of modern life. Their versatility, efficiency, and ease of use make them a cornerstone in diverse fields such as medicine, archaeology, education, and beyond. By examining their history, structure, and various applications, this paper highlights how QR codes have adapted to meet the demands of an increasingly digital world.

The ongoing advancements in QR code technology, such as encryption for secure transactions, steganography, and the integration of augmented reality (AR) and virtual reality (VR), demonstrate their potential for future innovation. As industries continue to explore creative uses for QR codes; whether to streamline healthcare processes, enhance learning experiences, or revolutionize marketing and customer interaction. This technology can revolutionize the way we access, share, and protect information.

QR codes can be a model of how a simple, yet powerful innovation can continuously adapt, offering solutions to the challenges of a fast-paced, interconnected world. Their potential



is only limited by the imagination, making them an exciting subject for ongoing exploration and development.

## References

- Avidan, A., Weissman, C., & Levin, P. D. (2015). *Integration of QR codes into an anesthesia information management system for resident case log management*. International Journal of Medical Informatics, 84(4), 271–276. <https://doi.org/10.1016/j.ijmedinf.2014.12.007>
- Canadian Centre for Cyber Security. (2022, January). *Security considerations for QR codes* ITSAP.00.141. Government of Canada. <https://www.cyber.gc.ca/en/guidance/security-considerations-qr-codes-itsap00141>
- DENSO WAVE. (n.d.). *QR code development story*. DENSO. <https://www.denso-wave.com/en/technology/vol1.html>
- DENSO WAVE Incorporated. (n.d.). QR Code.com: *QR Code overview*. Retrieved November 19, 2024, from <https://www.qrcode.com/en/>
- Forssman, T., Jordaan, J., Forssman, K., Jordaan, G., & Louw, C. (2016). *The application of quick response (QR) codes in archaeology: A case study at Telperion Shelter, South Africa*. Antiquity, 90(353), 1363–1372. <https://doi.org/10.15184/aqy.2016.135>
- Joshi, P., & Patil, S. (2024). *The impact and potential of quick response (QR) codes in healthcare: A comprehensive review*. Proceedings of the Human Factors and Ergonomics Society Annual Meeting. <https://doi.org/10.1177/10711813241278266>
- Alajmi, M., Elashry, I., El-Sayed, H. S., & Farag Allah, O. S. (2020). *Steganography of encrypted messages inside valid QR codes*. IEEE Access, 8, 27861–27873. <https://doi.org/10.1109/ACCESS.2020.2971984>

Mathuria, M., & Mishara, A. (2017, April). *A review on QR code*. ResearchGate.

[https://www.researchgate.net/publication/316177848\\_A\\_Review\\_on\\_QR\\_Code](https://www.researchgate.net/publication/316177848_A_Review_on_QR_Code)

Pandey, D. (2008). *QR Code: An overview of its standardisation and applications*. Synthesis Journal, 2008, 059–067. Retrieved from

[https://www.academia.edu/31427962/Three\\_QR\\_Code](https://www.academia.edu/31427962/Three_QR_Code)

Paul, D. (2024, September 6). *QR code history—From 1994 to 2024—in under 10 mins*. Uniqode Blog. <https://www.uniqode.com/blog/qr-code-basics/qr-code-history>

Soon, T. J. (2008). QR code. Synthesis Journal, 2008, 59–78.

Tiwari, S. (2016). *An introduction to QR code technology*. 2016 International Conference on Information Technology, 39–44. <https://doi.org/10.1109/ICIT.2016.020>