South American Development Society Journal

**Vol.:** 10 | **Nº.:** 29 | **Ano:** 2024 | **ISSN:** 2446-5763 | **DOI:** 10.24325/issn.2446-5763.v10i29p60-80
**Data de Submissão:** 09/04/2024 | **Data de Publicação:** 31/08/2024

# EVALUATING IOT HARDWARE PLATFORMS THROUGH FRUGAL INNOVATION

**William Aparecido Celestino Lopes** (Paulista University, São Paulo SP, Brazil)
**Marcelo Tsuguio Okano** (FATEC Barueri, Barueri SP, Brazil)
**Salvatore Binasco Lengua** (Paulista University, São Paulo SP, Brazil)
**Oduvaldo Vendrametto** (Paulista University, São Paulo SP, Brazil)
**João Carlos Lopes Fernandes** (Paulista University, São Paulo SP, Brazil)
**Marcelo Eloy Fernandes** (FATEC Barueri, Barueri SP, Brazil)

## Abstract

Digital technologies are revolutionizing the various areas of knowledge, providing features such as greater amounts of data, quantitative analyses, decision-making according to data content and programming of actions in response to the analyzed data. These technologies are being widely used in Industry 4.0 to capture data in real time (online) from a large number of sensors, process the data and activate the various actuators according to the captured and processed data, particularly the Electronic Prototyping Systems (EPBs) and Single Board Computers (SBCs) as affordable and versatile solutions, offering a cost-effective and easy-to-use option for agile and diverse prototyping. This research aims to analyze the various IoT hardware platforms such as EPB and SBC through the theoretical lens of Frugal Innovation, based on performance, core functionalities, and costs, to obtain the best solution for projects. From exploratory bibliographical research, families of electronic prototyping boards were identified. When considering the aspects involved in the context of Frugal and IoT innovation, electronic prototyping platforms are more likely to drive the creation of innovative, accessible, and connected technological solutions, meeting the specific needs of each project.

Keywords: IoT, Frugal Innovation, EPB, SBC, IoT, Hardware Platforms.

## Introduction

Digital technologies are revolutionizing various areas of knowledge, highlighting manufacturing, providing features such as greater amounts of data, quantitative analyses, decision-making according to data content, programming of actions in response to the analyzed data, a diversity of solutions to problems according to costs and creating conditions for understanding fundamental social developments [1].

In manufacturing, savings obtained through innovation are reflected in the reformulation of products and processes to reduce unnecessary costs. This type of innovation is called frugal innovation. Frugal innovation represents innovation in existing solutions with a focus on conserving resources [2].

Frugal innovation plays a vital role in Industry 4.0, which focuses on the development of advanced technologies aimed at achieving savings in processes, products, or services. The value of frugal innovation in Industry 4.0 represents the contribution of technology transfer to developing countries, with the aim of strengthening the competitiveness of companies and developing new forms of innovation through the impact on society as a form of savings that companies can achieve [2].

One of the digital technologies that stands out and can develop projects based on frugal innovation is the Internet of Things (IoT), which is a network of physical assets, actuators, and sensors that extends the reach of the Internet to devices traditionally connected to the Internet [1].

In the energy sector, the IoT facilitated the combination of sensing and intelligence with mobile payment technology (such as PAYG). This technology enabled the energy providers to minimize the risk of payment while still ensuring the financial viability of the service. The service was able to be turned off or on depending on the history of payment [1].

This technology is being widely used in Industry 4.0 to capture data in real-time (online) from many sensors, process the data, activate the various actuators according to the data obtained and implement intelligent solutions according to the technological need based on the project cost.

Presented by [26], a “frugal innovation approach” for a cheap and efficient IoT system solution in rural areas by connecting any type of sensor, such as environmental sensors for weather forecasting, chemical sensors, level sensors, image sensors, and so on.

onwards, and which includes an MQTT (Message Queuing Telemetry Transport) proxy to integrate low-cost, low-power generic sensor devices into a messaging system based on LoRa (Long Range) technology.

In this research we focus on IoT hardware platforms, the IoT hardware platform is composed of embedded hardware, a communication interface and a software development environment that provides all IoT resources [3]. These platforms are used to create practical and modern IoT projects [4] and allow the development and implementation of solutions with the characteristics of frugal innovation for manufacturing.

We selected two types of IoT hardware platforms, electronics prototyping boards (EPB), which offer an effective means for assembling and interconnecting electronic components, enabling practical validation and iteration of designs prior to large-scale production [5], and single board computers (SBC) which are compact, integrated systems that encapsulate the functionality of a complete computer on a single board [6].

Electronic Prototyping Board (EPB) and Single Board Computers (SBC) are affordable and versatile solutions, offering a cost-effective and easy-to-use option for agile and diverse prototyping. The adaptability of EPBs makes them suitable for a wide variety of projects. On the other hand, SBCs have greater processing power and advanced features, ac-companied by higher cost and complexity. Their robust performance makes them ideal for projects that require high capacity and complex functionality.

In this study, the use of IoT hardware platform stands out, which are typically used as tiny computers as they are cheap and applicable in different domains. So, this research reveals that the selection between EPB and SBC is determined by the specific needs of the project, aligning with the vision of frugal innovation that seeks effective and affordable solutions.

This diversity of types and models that differ in performance, functionality and costs can cause confusion when deciding on the correct IoT hardware platform for each project. In these cases, managers often prefer to decide in relation to the cost of the IoT hardware platform, which follows the frugal philosophy and generates frugal innovation (FI).

In this context, the choice of an IoT hardware platform for a manufacturing project should be made based on its technical performance, maximizing value, minimizing resource utilization [7] and in compliance with the frugal philosophy (do more with less) [8].

This research aims to analyze the various IoT hardware platforms such as EPB and SBC through the theoretical lens of Frugal Innovation, based on performance, core functionalities, and costs, to get the best solution for projects.

## Material and Methods

### 2.1. Frugal Innovation (FI)

In this article, we use the three criteria of [11] to characterize FI. The criteria are appropriate for all types of frugal innovation and aimed at emerging and developed markets:

- Cost reduction is characterized by a much lower price or significantly lower costs compared to conventional products and services.
- Core functionality implies a focus on core functionalities with the greatest customer benefits, directly targets user requirements, and in comparison, with current solutions available on the market; and
- Performance level must meet the level of performance required for its actual purpose and local conditions, compared to current solutions available on the market.

### 2.2. Methods

This topic discusses the research methodology adopted to meet the objective of this research, characterized as a combination of exploratory research, bibliographical research, qualitative analysis based on the three criteria of Weyrauch and Hestatt [11] to characterize FI, and survey using a specialist, allowed a comprehensive and in-depth understanding of the phenomenon under study.

The integration of these methods provided a solid basis for the conclusions and recommendations presented in the project, highlighting the importance of a multifaceted approach in conducting quality exploratory research.

The choice to adopt a qualitative analysis model based on [11] reflects the need to deeply understand the nuances and complexities of the phenomenon under study. The methodological procedure for quantitative analysis consisted of:

To carry out the bibliographical research, we chose to check the main characteristics of frugal innovation that best suit IoT hardware platform solutions and arrived at the following items:

- Existing solutions focused on resource conservation [2].
- Development of advanced technologies aimed at achieving savings in processes, products, or services [2].
- Contribution of technology transfer to developing countries, with the aim of strengthening the competitiveness of companies and developing new forms of innovation through the impact on society as a form of savings that companies can achieve [2].
- Frugal philosophy that incorporates "doing more with less" [8].
- Create greater value, even reducing the same resources necessary to generate that value, whether financial, natural, or temporal [7].

When selecting and evaluating the articles, it was checked whether they contained words according to the themes (frugal innovation, IoT and IoT Hardware Platform) and at least one of the characteristics of frugal innovation.

Based on the mentioned characteristics of frugal innovation, it was possible to correlate with the following characteristics of IoT hardware platform solutions:

- Cost reduction
- Main functionalities (resources)
- Performance

Therefore, it is possible to use the IF criteria from [11]. The study divided the main models used into three categories considering the following segments: performance, features and cost according to the criteria of [11] to characterize the FI.

Scientific research that involves collecting data through a survey of experts is a systematic approach that seeks to obtain the opinion and insights of a group of experts on a given subject.

The application of surveys allowed collecting primary data from relevant stakeholders. The ten selected experts are professionals who work with IoT, EPB and SBC in manufacturing and technical education companies, including four technical education teachers, a manufacturing manager, an automation technician, an instrumentation technician, a consultant, a tests and applications coordinator and an automation analyst.

One specialist has a secondary technical course and the others have completed higher education, five of whom have postgraduate degrees (3 specializations, one master's degree and one doctorate). The length of professional experience with IoT, EPB and SBC varies from 2 years (6 specialists), 3 years (2 specialists), 5 years (1 specialist) and 10 years (1 specialist).

The anonymity of experts was guaranteed for the confidentiality of survey participants in accordance with participants' requests. Based on bibliographical research, a questionnaire was prepared with open questions to be used in the survey. The purpose of this survey was to confirm or deny the concepts found in the bibliographic research in the opinion of experts. The survey responses were transcribed and analyzed.

Based on bibliographical research, a questionnaire was prepared with open questions to be used in the survey. The purpose of this survey was to confirm or deny the concepts found in the bibliographic research in the opinion of experts. The survey responses were transcribed and analyzed.

To analyze the experts' data, content analysis was used, which, according to Bardin [27], content analysis is an evolutionary set of methodological tools applicable to ex-tremely diverse discourses (content and continents). Content analysis is based on the be-lief that texts are a rich source of data that has a significant potential to reveal essential information about phenomena [28].

In Table 1 we present the domains and categories found in the content analysis.

**Table 1**. Domains and categories.

| Domain | Category |
|---|---|
| Costs, saving, reduction, less, more per less, economic, Frugal philosophy, doing more with less, frugality, cheapest | Costs reduction |
| Resource conservation, functionality, features, characteristics, competitiveness, create greater value, reducing the same resources, simplicity, value, resource. | Main functionalities (resources) |
| Performance, reducing the same resources, less, more per less | Performance |

## Results and Discussions

The bibliographical research presented the following EPBs and SBCs that suit the characteristics of Frugal Innovation according to the functional and performance qualities:

3.1 Characteristics From exploratory bibliographical research

Due to the constant evolution of the electronics market, three boards stand out in this scenario, being the Arduino Uno R3, Esp32, and Raspberry Pi Pico. The difference between these boards is their low commercial value and their versatility in use in initial projects [13].

The Arduino R3 Uno is electronics prototyping board developed by the Italian company Arduino LLC. Launched in 2012, it represents an improved iteration of the Arduino Uno series and is one of the most popular and widely used prototyping boards in the field of electronics and programming. The Arduino R3 Uno is known for its ease of use, flexibility, and active developer community [14].

With an Atmega328P microcontroller-based architecture, it offers several digital and analog input/output ports, allowing the interconnection and control of a wide variety of electronic components. Its importance in the electronic prototyping board scenario lies in its ability to democratize access to electronics and programming, allowing students, enthusiasts, and professionals to develop projects in an accessible and effective way, contributing to the popularization of the maker movement and the Internet of Things (IoT) [14]. Figure 1 shows the architecture of the Arduino R3 Uno [15].

The ESP32 is electronics prototyping board developed by the Chinese company Espressif Systems. Launched in 2016, it stands out for being equipped with a Tensilica LX6 dual-core microcontroller and integrated Wi-Fi and Bluetooth connectivity, in addition to offering digital and analog input/output ports and support for serial, SPI, and I2C communication interfaces. Its processing capacity, combined with wireless connectivity features, makes it ideal for Internet of Things (IoT) projects, home automation, and association with sensors, in addition to offering good cost-benefit, performance, and connectivity, thus allowing developers and enthusiasts to create innovative solutions [16]. Figure 2 shows the ESP32 architecture [17]

Figure 1. Arduino R3 Uno

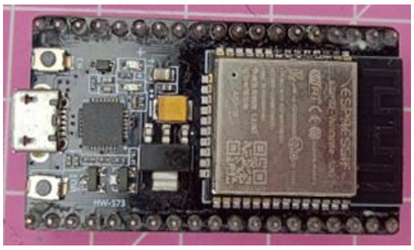

Figure 2. ESP32

The Raspberry Pi Pico is low-cost electronics prototyping board developed by the Raspberry Pi Foundation. It was launched in 2021 and is based on the RP2040 chip, has 40 GPIO pins, twenty-six of which are multifunctional, which makes it very versatile. It has a dual-core ARM Cortex-M0+ processor, 264kB of RAM, and 2MB of flash memory, making it a great option for those starting in the world of electronics prototyping, as it is cheap, easy to use, and has a large community of users and developers [18]. Figure 3 shows the architecture of the Raspberry Pi Pico [19].

In the SBC scenario, some examples stand out for their performance, functionality, and cost, such as Raspberry Pi 4 4GB - Model B, NVIDIA Jetson Nano 4GB, and Asus Tinker Board 2.

The Raspberry Pi 4 4GB - Model B is an SBC produced by the Raspberry Pi Foundation. Launched in June 2019, it features a Broadcom BCM2711 Quad-Core Cortex-A72 processor, 4 GB of RAM, USB 3.0 ports, dual HDMI video output, and Gigabit Ethernet connectivity. Enables a variety of applications, from productivity tasks to multimedia entertainment projects and software development with robust features, low cost, and accessibility, allowing individuals and communities to explore, prototype, and create a variety of technology solutions effectively and cost-effectively [20]. Figure 4 shows the architecture of the Raspberry Pi 4 4GB - Model B [21].

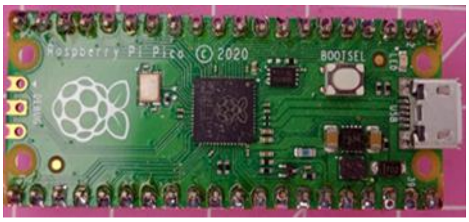

Figure 3. Raspberry Pi Pico

Figure 4. Raspberry Pi Pico 4GB

The NVIDIA Jetson Nano 4GB is an SBC developed by NVIDIA Corporation. Launched in October 2020, it features a Quad-Core ARM Cortex-A57 processor, 4 GB of RAM, NVIDIA Maxwell GPU with 128 CUDA cores, USB 3.0, Gigabit Ethernet, and GPIO. It is designed for computer vision, embedded AI, and robotics applications. Its importance in the Single Board Computer scenario lies in its ability to provide a powerful development environment for AI and computer vision projects in a compact format, facilitating the implementation of advanced solutions, as well as accelerating the development of intelligent and autonomous systems, opening opportunities for innovation in various industrial and research sectors [22]. Figure 5 shows the architecture of the Jetson Nano [23].

The Asus Tinker Board 2 is an SBC produced by Asus. Launched in 2021, it offers a Rockchip RK3399 quad-core processor, ARM Mali-T860 MP4 GPU, 4 GB of LPDDR4 RAM, and communication interfaces such as USB 3.2, Gigabit Ethernet and GPIO. It combines performance, connectivity, and expandability with features that suit a variety of applications, from IoT projects to software development and multimedia entertainment. Tinker Board 2 offers a versatile platform for enthusiasts, developers, and educators, promoting innovation and experimentation in the field of electronics and computing [24]. Figure 6 shows the architecture of the Asus Tinker Board 2 [25].

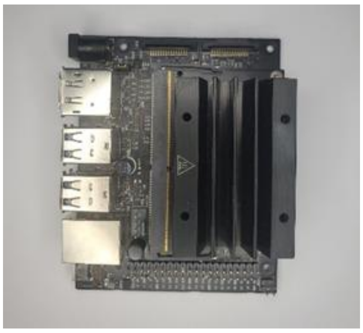

Figure 5. Jetson Nano

Figure 6. Asus Tinker Board2

The survey results showed that most experts (60%) are aware of SBCs, as they are more expensive IoT devices and are not present in the simplest projects. Unlike EPBs, which 100% of experts know and use in everyday projects involving IoT and manufacturing. The experts highlighted that the EPBs and SBCs found in the bibliographical research are the models most used in IoT and manufacturing projects.

3.2 Technical characteristics of EPB and SBC models

Electronic Prototyping Boards (EPB) - To understand the characteristics of each EPB board, the following models were used to develop the study: Arduino Uno R3, Esp32, and Raspberry Pi Pico. The variables studied in each EPB model were the processor, data bus, and clock speed used by each board, presented in Figure 7.

Another important variable identified based on performance is electronic prototyping board memory being divided into Flash and SRAM.

This distinction is important to understand how data is manipulated and processed, enabling efficiency in the practical application of projects. Information regarding these variables can be seen in Table 2.

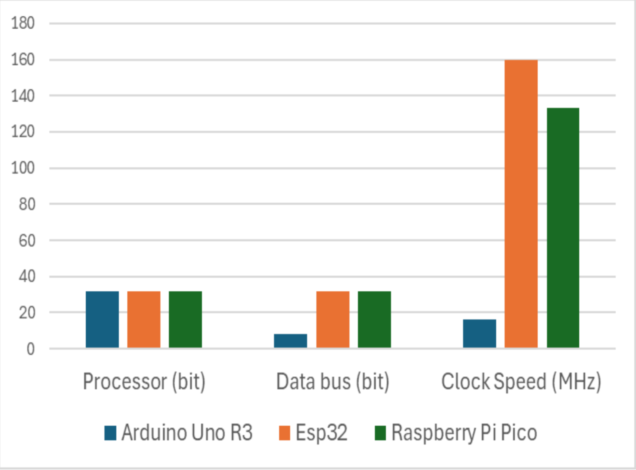


Figure 7. Features of EPB processing

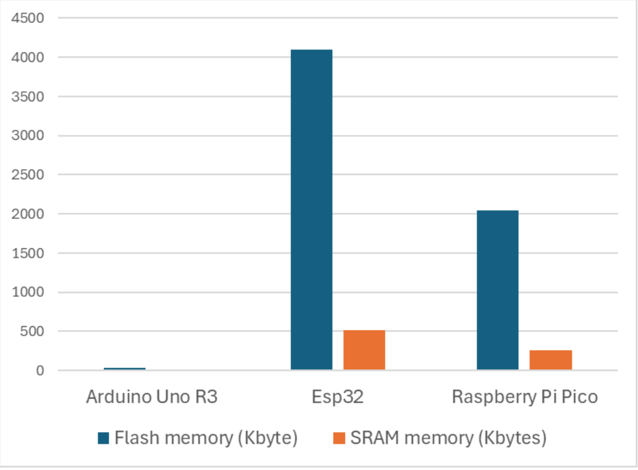


Figure 8. Characteristics of EPB memori

Knowing the functionalities of the Arduino Uno R3, ESP32, and Raspberry Pi Pico prototyping boards is essential to apply the concept of frugal innovation in projects. Each board offers several types of connectivity, such as Wi-Fi, Bluetooth, and other wireless protocols, allowing designs to communicate with other devices and integrate into connected systems efficiently.

The different connections and interfaces available on the prototyping boards offer flexibility in integrating peripherals and sensors. Choosing a board that offers interfaces suited to the project's needs can result in resource savings and facilitate the implementation of additional functionalities, promoting frugal innovation.

The size and dimensions of the boards are also key factors in applying the concept of frugal innovation, especially in projects with physical space limitations. More compact and lightweight boards, like the Raspberry Pi Pico, may be better suited for portable and wearable projects where size optimization is key.

Understanding the pinout of each board is crucial to ensuring compatibility and ease of use with other electronic components. By knowing the pinouts of prototyping boards, developers can avoid resource conflicts, connect peripherals appropriately, and optimize pin allocation to meet specific project demands. This allows the development of innovative and low-cost solutions, making the most of the functionalities offered by the boards and ensuring the viability of the concept of frugal innovation in electronic projects.

Given the functionalities presented by the EPB, the variables identified were the types of connectivity, connections, dimensions, pinout, and whether they have Bluetooth and Wi-Fi, presented in Table 2.

**Table 2.** Characteristics of EPB functionalities.

| Functionalities | Arduino Uno R3 | Esp32 | Raspberry Pi Pico |
|---|---|---|---|
| **Communication interfaces** | UART, I2C, and SPI | UART, I2C, SPI, and I2S | UART, I2C, and SPI |
| **Analog GPIO** | 6 pins | 18 pins | 3 pins |
| **Digital GPIO** | 14 pins | 36 pins | 23 pins |
| **Type of power** | via USB port or external power source | via USB port or external power source | via USB port or external power source |
| **Supply voltage** | from 7 to 12V | 3.3V | 5V |

| | | | |
|---|---|---|---|
| **Maximum supply current** | 20 mA per pin and 200 mA for the microcontroller | 500 mA | 100 mA |
| **USB port** | Yes | Yes | Yes |
| **Integrated Bluetooth** | No | Yes | Yes |
| **Integrated Wi-Fi** | No | Yes | Yes |
| **Height** | 14.3 mm | 3.1 mm | 3.6 mm |
| **Width** | 53.4 mm | 18 mm | 51 mm |
| **Length** | 68.6 mm | 25 mm | 21 mm |

Detailed analysis of the average prices of these boards allows the designer to understand the economic viability of each option when developing innovative solutions within a restricted budget. When considering the cost of the boards related to their functionalities and resources, the most appropriate options for applying frugal innovation in different contexts stand out, which can be seen in Figure 9.

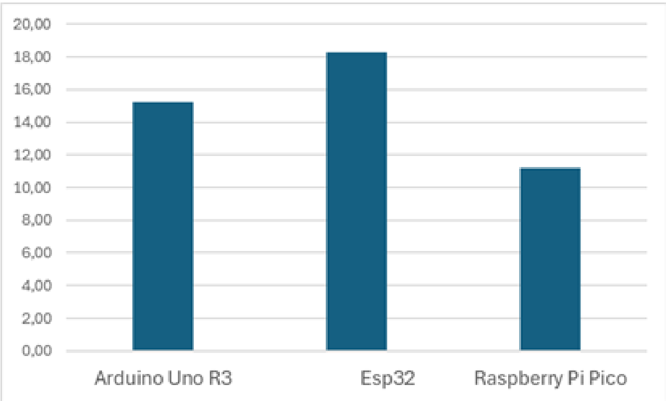


Figure 9. Analysis of prototyping boards based on costs.

Single-Board Computers (SBC) - The variables relating to each board containing the processor, architecture, and clock speed used by each SBC were also identified in the main types of SBC, presented in Table 3.

**Table 3.** SBC processing

| | Raspberry Pi 4 4GB - Model B | NVIDIA Jetson Nano 4GB | Asus Tinker Board 2 |
|---|---|---|---|
| **Processor** | Broadcom BCM2711, Quad core Cortex-A72 64-bit SoC @ 1.5GHz | NVIDIA Tegra X1+, quad-core Cortex-A57 @ 2.2 GHz + quad-core Cortex-A53 @ 1.4 GHz | Rockchip RK3399, quad-core Cortex-A72 @ 2.0 GHz + quad-core Cortex-A53 @ 1.5 GHz |
| **Architecture** | ARMv8-A | ARMv8-A | ARMv8-A |
| **Clock speed** | 1.5 GHz | 2.2 GHz | 2.0 GHz |
| **GPU** | Broadcom Video Core VI | NVIDIA Maxwell 128 | Mali-T860 MP4 |

Information regarding the types of memories and their performance in relation to the main SBC can be seen in Table 6.

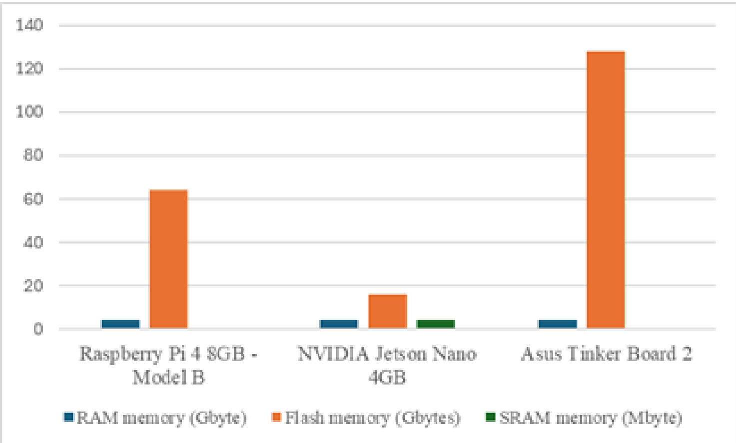


Figure 10. Characteristics of SBC Memories

The general features of the main SBC boards can be seen in Table 4.

**Table 4**. Characteristics of SBC functionalities

| Functionalities | Raspberry Pi 4 4GB - Model B | NVIDIA Jetson Nano 4GB | Asus Tinker Board 2 |
|---|---|---|---|
| Connectivity | WiFi 2.4 GHz and 5.0 GHz IEEE 802.11ac, Bluetooth 5.0, BLE and Gigabit Ethernet | Wi-Fi 802.11ac, Bluetooth 5.0 | Wi-Fi 802.11ac, Bluetooth 5.0 |
| USB Ports | 2xUSB 2.0, 2xUSB 3.0 | 4x USB 3.0, USB 2.0 Micro-B | 2 x USB 3.0, 4 x USB 2.0 |
| GPIO | 40 pins | 40 pins | 40 pins |
| MicroSD slot/capacity | 1 x MicroSD (up to 128 GB) | 1 x MicroSD (up to 2TB) | 1 x MicroSD (up to 256 GB) |
| Video Outputs | 2 Micro HDMI ports (4kp60 support) | HDMI 2.0, 2 x micro-HDMI 1.4 | HDMI 2.0, 2 x micro-HDMI 1.4 |
| Operational system | Raspbian, Ubuntu, Windows 10 IoT Core | Ubuntu, JetPack SDK | Ubuntu, Android |
| Peripherals served | keyboard, mouse, hard drive, printer, camera, sensor, etc. | keyboard, mouse, hard drive, printer, camera, sensor, etc. | keyboard, mouse, hard drive, printer, camera, sensor, etc. |
| Supply voltage | 5 V | 5 V | 5 V |
| Maximum supply current | 3A | 2A | 2A |
| Power supply | 5 V / 3 A | 5 V / 3 A | 5 V / 2 A |
| Height | 28 mm | 29 mm | 19.2 mm |
| Width | 56 mm | 80 mm | 56 mm |
| Length | 85 mm | 100 mm | 85.6 mm |

Detailed knowledge of the costs associated with each of these SBC board solutions is essential for an accurate analysis of the economic viability and potential for application in innovative projects. By understanding the costs involved, it is possible to compare different devices and identify which ones stand out as more affordable and efficient options.

Furthermore, market research allows savings opportunities to be identified, adjustments to the project scope, or even original approaches to the use of SBC, thus aligning with the concept of frugal innovation, which values economical but creative solutions and high impact. The values found can be seen in Table 8.

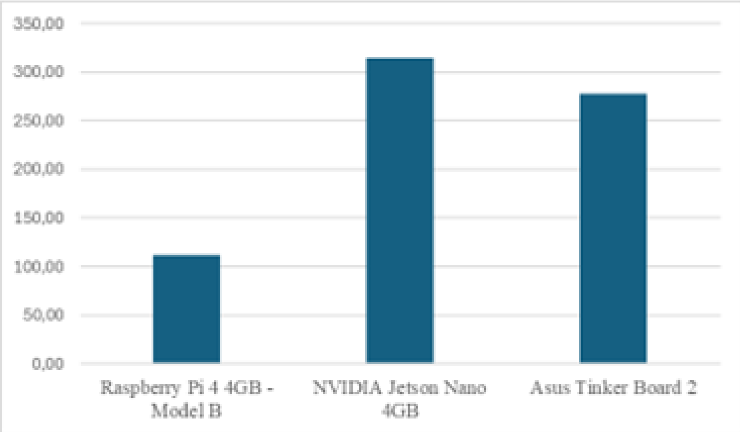


Figure 11. Costs of main SBC cards

The survey asked whether the experts had knowledge about the functionalities and performances of the EPBs and SBCs studied. In terms of performance, only one expert reported that they have no knowledge about the performance of EPBs and SBCs, but 90% of the experts reported that they have knowledge about some devices presented.

Regarding functionalities, 100% of experts know the functionalities of EPBs and SBCs. The experts validated the technical characteristics presented according to the bibliographical research.

3.3 Technical characteristics of EPB and SBC models

Performance - Comparative results between EPB boards and SBC single board computers based on performance and considering the variables Processor, Clock, Bus, GPU, RAM, and Flash memory.

In terms of performance, EPBs are less performant than SBCs due to the following main characteristics:

- The EPB has much lower clocks, in the MHz unit, and the SBC has clocks in the GHz unit, in other words, the higher the CPU clock rate increases performance and energy consumption. The highlight for the processing clock goes to the SBC NVIDIA Jetson Nano 4GB with 2.2 GHz.
- EPB has 8 and 32-bit buses while SBC has 64-bit buses. The main difference between 32-bit and 64-bit buses is the maximum amount of data that can be transferred and the memory addressing capacity. 64-bit computers are capable of processing larger volumes of data and addressing larger amounts of memory. These features are

beneficial in some situations, but not always necessary for all applications. The most effective use will depend on the specifics of the system and the tasks it needs to perform.

- EPB does not have RAM and the Flash and SRAM memories are smaller than memories of the same type as the SBC, in addition to the SBC having RAM to execute programs.
- Another important feature is the existence of a GPU in SBC, which does not exist in EPB. Several types of acceleration are worked on different computer systems, the most common being CPUs and GPUs. Central Processing Units, or CPUs, are the limitation of most electrical devices and are responsible for running software and applications. They are typically composed of multiple cores and their capacity is measured in gigahertz. Graphics processing units, or GPUs, are extremely specialized ones used for graphics rendering purposes. This allows devices to dedicate complex tasks, such as real-time object recognition, to graphics processing units.

These results indicate that EPBs are prepared for projects that do not require large processing power, on the other hand, SBCs are designed to have large processing power, compared to personal computer processors. Observing the performance of the EPB and SBC through the lens of Frugal Innovation, it can be deduced that the performance of the Arduino Uno R3 with a 16 MHz Clock and 8-bit Bus can perfectly meet the characteristics of Frugal Innovation, as most projects that collect data do not need a lot of processing power and at a lower cost.

But, if the performance evaluation is in relation to the best performance according to the characteristics of Processor, Clock, Bus, and Flash memory, the choice is the Esp32, because:

- It has a Dual-core processor with the highest clock rate of 160Mhz.
- The bus is 32 bits.
- Larger flash memory (from 4MB to 16MB) and SRAM (from 520KB to 520KB)

Functionalities- The comparative results between EPB boards and SBC single board computers based on the features considering the variables type of USB ports, GPIO, output voltage and integrated Bluetooth and integrated Wi-Fi. The key features observed were:

- USB port: all have at least one port, with SBC having more than one. USB ports are important to allow connection to other devices and services such as storage and networks.
- General Purpose Input/Output (GPIO) are programmable data input and output ports that are used to provide an interface between peripherals and microcontrollers: EPB has fewer ports than SBC.
- Output voltage: All EPB and SBC have pins for output voltage, which can be 5 V or 3.3 V. EPB has only one output voltage and SBC provides both voltages.
- Connectivity: An important feature is the connection to the Wi-Fi network to use cloud computing services, which is why it is important to have Wi-Fi built into the board, all SBC cards already come with Wi-Fi built in, in EPB only Esp32 has the functionality. Another important type of network is Bluetooth for connecting to sensors and local devices, only the Esp32 in the EPB has this connectivity and in the SBC only the Jetson Nano does not offer it built in.

Evaluating these features from the perspective of Frugal Innovation, it is worth highlighting that if the project is simple to apply without the need for connectivity, the Arduino Uno R3 ends up being the best choice. If the project requires an integrated Bluetooth and Wi-Fi connection, the ESP 32 becomes the best option.

Costs - The cost between the components based on market research indicated that the EPB presented values below US$ 20 and the SBC a much higher value, being above US$ 100, with emphasis on the maximum value obtained by the NVIDIA Jetson Nano 4GB of US$ 314.20.

## 4 Conclusions

This research achieved the objective of analyzing the various IoT hardware platforms, such as EPB and SBC, through the theoretical lens of Frugal Innovation, based on performance, main functionalities, and costs, to obtain the best solution for the projects.

EPB, with its economical nature and ease of use, has proven to be a solid choice for projects that require agility and rapid prototyping, enabling the materialization of ideas in an accessible and flexible way. On the other hand, SBC, despite a steeper learning curve and higher cost, offers increased computing power and a range of advanced features, making it ideal for initiatives that require robust performance and complex functionalities.

The disadvantage of SBCs is their high value compared to EPBs, so the lack of some functions such as Wi-Fi and Bluetooth in some EPBs are a disadvantage of their use in projects.

Six models of IoT hardware platforms were analyzed, based on the three characteristics of Frugal Innovation, to meet the frugal philosophy that is, "doing more with less", we excluded the SBC models due to excessive costs and kept the EPB models, the platform had the best result is Esp32. As for performance, the ESP32 has a 32-bit dual core processor, has the highest clock rate (160Mhz), Flash memory and SDRAM of the EPBs analyzed. The Esp32 has the key features such as Wi-Fi and Bluetooth built-in and the cost is not the lowest, it is 63% more expensive than the Raspberry Pi Pico board.

The research results and expert opinion are that these two complementary categories (EPB and SBC) enrich the development ecosystem, allowing innovators to choose the most appropriate IoT hardware platform for each scenario, ensuring effective results aligned with the demands of IoT solutions and frugal innovation.

For low complexity projects, the Arduino Uno R3 EPB model is the most used due to its popularity and low complexity in handling. However, they do not have an integrated Wi-Fi function, which puts the ESP 32 towards leadership in the use of projects that use IoT technology.

For projects that require greater processing capabilities, the SBC Raspberry Pi 4 4GB - Model B has the lowest cost and a greater number of applications in projects involving IoT, but the highest information processing speed is found in the NVIDIA Jetson Nano 4GB model.

For future projects, it is suggested that research and studies be conducted with SBCs with frugal innovation as the concept can be applied in areas such as AI and decision making that require robust platforms with high processing power, but at lower costs than excessive costs computer and servers.

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