A Novel Architecture for Community-Sustained Cultural Mapping System

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Abstract—**This paper presents a novel system architecture for implementing a cultural mapping system for the community of Buayan, a remote rural village in Sabah, East Malaysia. By considering various shortcomings of the local environment and the need for a community-sustained system, the cultural mapping system was designed to leverage a new set of architecture to achieve minimal implementation cost and higher reliability to survive the rural environment. The new architecture evolves from previous Telecentres' design and implementation experience that was targeted at larger scale ICT systems. This paper also highlights the critical influence of power provision on the digital system implementation in rural areas, which always incurs a significant amount of the overall implementation cost. An efficient ICT system architecture will significantly reduce the cost of its associated power provision. The implementation of the cultural mapping system using the new ICT architecture at Buayan is also being described.**

Keywords—Rural system architecture; telecentre; cultural mapping; sustainability

I. INTRODUCTION

Modern Information and Communication Technology (ICT) advancements have made thousands of online services possible, and the well-established cloud architecture has also enabled more and more highly accessible cloud-based services. The high speed and massive deployment of various means of communication networks, such as optical fibre and mobile cellular data networks, allow access to online systems anywhere and anytime. While the developed world moves rapidly to offer more comprehensive solutions by integrating different services, remote rural places in other parts of the world still struggle with basic amenities and communication access. The development of these remote places can never be treated as equal, as the same online services may not be practical for those living in these areas. The digital divide gap between the rural and urban areas can get more prominent, especially when infrastructure development is driven by commercial entities based on return-on-investment (ROI). The relatively small rural population can be a disadvantage in obtaining the same level of infrastructure development. Due to the different levels of readiness in basic infrastructure, deploying digital systems in remote rural areas would require a more rural-friendly architecture to achieve a more practical and sustainable system implementation in such an environment. In this paper, we describe our work on designing, prototyping, and deploying a custom-made cultural mapping system for the community of Buayan, a remote village in East Malaysia. The village is located at the edge of

mobile network coverage, where the overall network connectivity is relatively poor and slow. On top of that, the relatively inconsistent micro hydropower system used in the village adds a further challenge to deploying service hosting that requires a stable and consistent power source. Hence, we proposed an all-in-one architecture solution inclusive of power, ICT system, and cultural mapping software application that enables the local community to better self-sustain. The proposed architecture is tailored to the Buayan environment and is a smaller-scale version of our previous work on Telecentre design [3]. Apart from enjoying the common benefits of cultural mapping, the Buayan community has another more crucial intention: to inventory the local cultural heritage and community living continuously. These efforts enable the community to better inform the authorities in support of their fight to protect the local heritage and live against the planning of the mega-dam project in the same area. This paper is organised by highlighting the need for cultural mapping in Buayan in Section II, and followed by background on rural ICT system deployments for rural areas in Section III. Section IV summarises the important challenges of ICT system implementation in rural areas that lay the design foundation and consideration for the proposal of the cultural mapping system architecture in Section V. Section VI describes the actual system implementation in Buayan.

II. NEED FOR CULTURAL MAPPING

Cultural mapping is a systematic approach to identifying, recording, classifying, and analysing a community's cultural assets and resources [1]. A software system has been developed to assist with cultural mapping activities for the community of Buayan. Buayan is a remote village in the Ulu Papar region of Sabah in East Malaysia. Although the Dusun people have inhabited the area for at least six generations, the record of their cultural assets and resources has been minimal and incomplete. Access to Buayan requires going through the Crocker Range of a mountain on a bumpy drive. The journey during the monsoon season can be very challenging, even for the most powerful 4-wheel drive vehicles [2]. For the past ten years, the government has had plans to build a hydropower dam that would flood everything, including all cultural heritage within the area. Hence, the villagers have been working hard to convince the government to change the plan for the hydropower dam by justifying to the government agencies the rich heritage and the vast community activities within the sites. The cultural mapping system came in to ease the process of identifying and recording cultural assets of the Buayan community. The cultural mapping system is an

independent system that manages, maintains, and keeps all data locally for the community's sole interest. The community's concern for data privacy is one of the primary considerations of the cultural mapping system design to prevent a third party having ownership or access to the data that might be used against the community itself. As a result, the entire cultural mapping system will be hosted locally within Buayan and accessible only to the Buayan community. In order to achieve such a goal, a robust ICT system architecture must be designed and developed to support the cultural mapping system that is sustainable by the local community in such an environment.

III. BACKGROUND

For the past two decades, the most promising solution towards bridging the digital divide in rural areas has been to erect Telecentres in strategic locations to enable various computer and communication services to serve the surrounding populations. The development of telecentres enables ICT services in the middle of nowhere and acts as a social and economic development centre for the local communities. The complete computer systems, printers, and telephony connected through Very Small Aperture Terminal (VSAT) satellite communication links have made electronic communications such as the Internet and email possible for rural communities. The initial design of telecentres was simply to deploy existing urban computing and communication architecture into rural areas; thus, such deployment is typically very expensive because the telecentre architecture must include a complete power supply infrastructure solely to support the day-to-day operation of the entire telecentre. The eBario Telecentre, deployed in 2002 for the Bario community at the Kelabit Highland in East Malaysia [3], adopted this design. Its power supply infrastructure is a hybrid diesel power generator and a standalone solar power system. The overview of the eBario Telecentre architecture is shown in Fig. 1.

The solar power system was backed by the diesel power generator when it could not provide sufficient power to the Telecentre. As the cost of diesel and transportation rises year after year, more solar panels and batteries are added to compensate for the reduction in diesel power generators. The battery sub-system of the solar power system has also undergone replacement after five years due to wear and such replacement was very costly. The battery replacement could cost as much as 50% of the entire solar power system implementation due to the conventional solar power system using multiple high-capacity lower voltage modules to form the specific battery bank required by the solar power system. For example, a 24V solar system would require 12 units of 2V battery modules to form a 24V battery bank needed for the 24V solar system. For a 500Ah battery bank, 12 units of 500Ah deep cycle Seal Lead Acid (SLA) are required, and each battery unit can weigh up to 130kg. As a well-known fact, transportation into the rural area is already very costly, and Bario can only be accessed via air during deployment time. Transporting such batteries into Bario requires a Twin-Otter cargo plane into Bario. The biggest drawback of adopting the urban ICT architecture for rural deployment will be the overwhelming requirement for power supply. Table I shows how much the national grid and the standalone solar system cost for the same average daily energy use of 13 kWh.

TABLE I.   COMPARISON OF ENERGY COSTING FOR THE SAME AVERAGE DAILY USAGE OF 13KWH BETWEEN THE STANDALONE SOLAR POWER SYSTEM AND THE NATIONAL POWER GRID

| Estimated Energy Usage	
Daily usage: 13kWh (six 250W personal computers with eight daily hours of operation) Total usage for ten years: 46,800kWh	
Energy Costing	
Standalone Solar Power System	*National Power Grid*
First 5 years + initial installation (4kW Solar): RM180k	RM7k (based on RM0.30 per kWh)
Next 5 years (battery replacement): RM50k	RM12k (based on RM0.50 per kWh)
Total expenditure for ten years:	
RM230k	RM19k
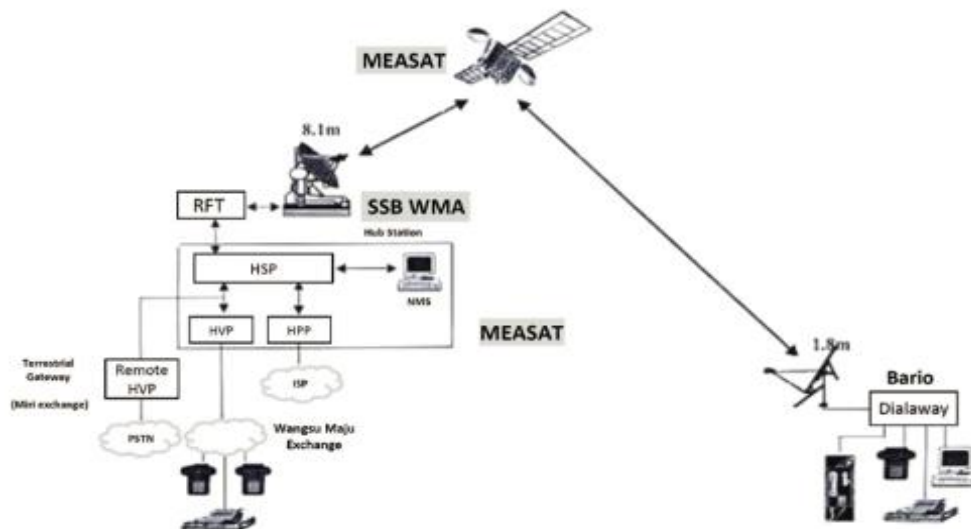
Fig. 1. The eBario Telecentre Architecture [3].

The above comparison shows that the energy cost for 10 years while using the national power grid is less than 10% of the total investment of deploying a standalone solar power system. The rural areas have no access to the national power grid, so the standalone solar system is the only viable power option. Therefore, power provision contributes to a significantly high percentage of the overall ICT implementation cost in rural areas. The overall cost of the solar system is determined largely by its designed power capacity. The higher the power requirements, the more expensive the system is. This includes the higher cost of transporting more solar panels, batteries, and supporting structures into rural areas. Hence, in order to reduce the overall rural ICT deployment cost, a more power-efficient ICT architecture is crucial.

The newer Telecentre model, deployed for rural sites such as Long Lamai, Ba'Kelalan, Buayan, and Larapan in East Malaysia in 2009 [4], has included an upgrade to a more power-efficient computing hardware platform. Instead of adopting conventional desktop computers with energy-hungry cathode-ray tube displays, the new Telecentre model adopted a mixture of energy-efficient desktop computers with liquid crystal displays (LCD) and laptop computers to strike a balance between energy efficiency and hardware cost. Fig. 2 shows the improved eLamai Telecentre computing platform. Portable computers, such as laptops, were still relatively expensive, and mobility of computers was not required by the Telecentres during the time of implementation. With the new computing platform, the average daily energy consumption was a mere 3kWh. This figure shows a significant reduction in energy consumption of about 10kWh per day compared to the previous Telecentre implementation. This reduction would bring down the standalone solar system deployment to as low as RM60k instead of RM230k, as shown in Table II. Hence, the overall maintenance cost could reduce almost three times compared to the previous eBario Telecentre. In the actual eLamai Telecentre implementation, a 4kW solar system was deployed instead of the estimated 3kW system to provide power for other appliances' usage.

TABLE II.   COMPARISON OF ESTIMATED OPERATING COST BASED ON THE NEW ELAMAI TELECENTRE'S SOLAR POWER SYSTEM AND THE NATIONAL POWER GRID

Estimated Energy Usage	
Daily usage: 2.88kWh (three 80Wdesktop computers and three 40W laptop with eight hours daily operation) Total usage for 10 years: 46,800kWh	
Energy Costing	
Standalone Solar Power System	*National Power Grid*
Approximate RM60k	RM4320 *(Based on RM0.30 per kWh for first five year, and RM0.50 per kWh for the second five year)*

In 2016, a new Telecentre architecture for the Orang Asli Telecentre programme (TPOA) was deployed [5]. The Telecentres consist of a mix of ICT systems with dedicated power supply modules and others that share the centralised power supply. The introduction of the dedicated power supply module for specific ICT systems, such as local content hosting and critical ICT appliance charging, was to further enhance the reliability of continuous service provision in the rural environment and compensate for the shortcoming of the power-sharing system that could be brought down by overwhelming usage and prolonged bad weather. The overall architecture for the Telecentre model is shown in Fig. 3.

The TPOA Telecentre architecture consists of two solar power systems: one for centralised power provision for non-critical but relatively high power consumption equipment such as VSAT modem/router, management desktop, networked projector, and lighting. Another solar power system is a modular design to support specific and more critical equipment such as content hosting servers, WiFi networks, and charging of tablets. By having a separate power provision architecture, service reliability of critical equipment could be achieved as a centralised power system can be brought down from time to time for many reasons, such as overwhelming usage and bad weather.

Unlike our design, the rural ICT implementations in other parts of the world were primarily focused on implementation strategies and models that did not consider the change in fundamental ICT system architecture that addressed the domestic problems of the rural environment. For example, a software-defined IPv6 network paradigm has been proposed for Nepal [6], but the context of the proposal is very much leveraging on the existing urban network efficiency paradigm for greener ICT. This proposal failed to take the local environment into account in its design considerations.

Most proposed models and strategies rely on existing urban technology building blocks to form solutions for rural implementation. The main research drivers for rural ICT deployment are still in the provision of better quality and cost-effective network accessibility to rural communities. For example, the VillageCell approach [7] focuses on enhancing the current mobile network provision to achieve a better voice call experience that does not address local limitations. In short, the system architecture should adapt to the implementation environment to achieve overall efficiency and minimise over-provision that could cause a hike in overall implementation cost. We are making reference to our previous works on green power architecture considerations for rural computing to customise a novel ICT system architecture for the application of cultural mapping in Buayan. Among the considerations are efficiency of power conversion, storage technology, and microprocessor power mode [8].

IV.   CHALLENGES OF ICT SYSTEM IMPLEMENTATION IN THE RURAL

Many factors influence the implementation of ICT systems in the rural environment. Usually, these factors determine the design of the system and also its associated power supply. The following challenges are to be addressed for the specific case of implementing the cultural mapping system for Buayan.
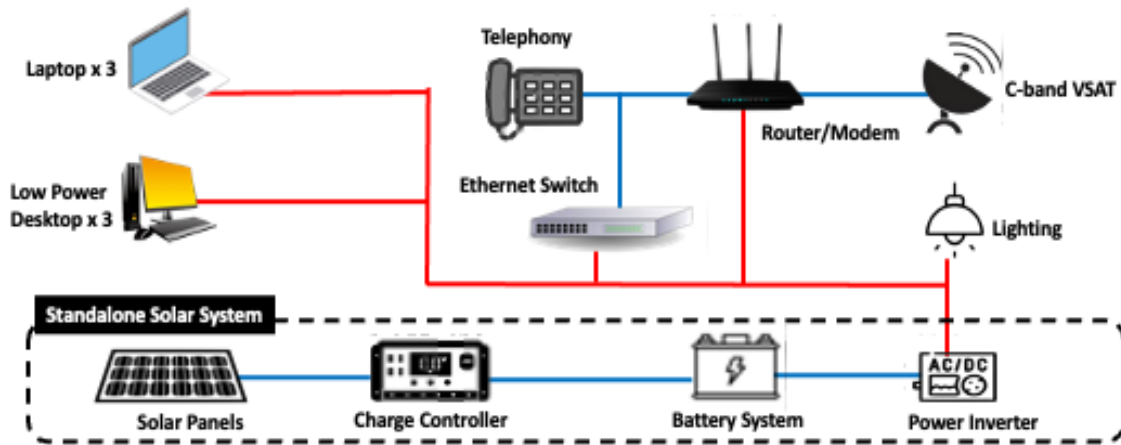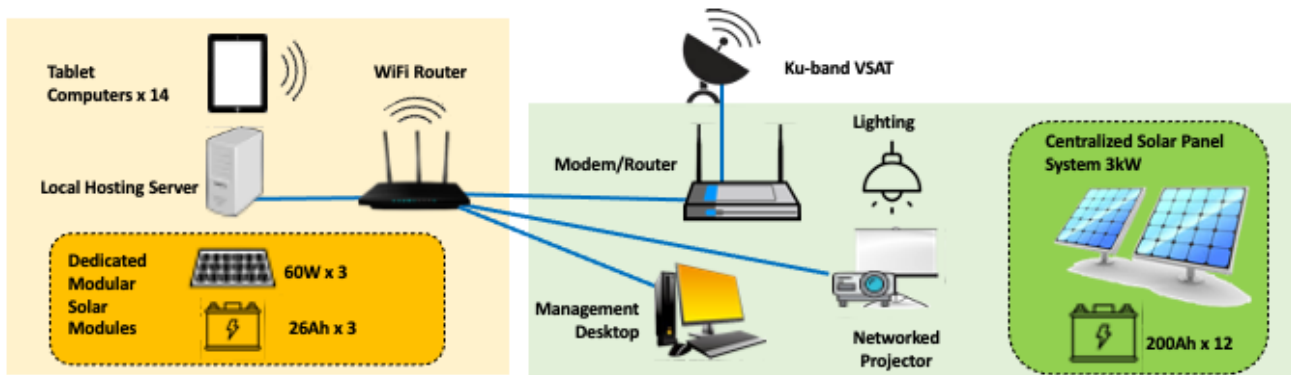
Fig. 2. The eLamai Telecentre Architecture.

Fig. 3. The TPOA Telecentre Architecture.

A. Reliability and Stability of the Local Electrical Power Supply

The village of Buayan is powered by a community-operated micro hydro system with limited capacity. The operation of the micro hydro system is greatly influenced by the change of seasons: during the drought season, the village will have an intermittent power supply. The intermittent power supply could last for days or weeks if the drought season is prolonged. Such an unreliable and unstable power supply is unsuitable for digital service hosting in the village, as the frequent power cuts could damage the system or corrupt the data. The micro hydropower supply system is community-operated; thus, the community also bears high maintenance costs, resulting in expensive per-kWh charges. Hence, it would be good to have a more reliable power supply module to power the cultural mapping system independently.

B. Difficult Physical Access to the Village

The limited accessibility to the village will lead to higher transportation costs for transporting goods and technical personnel. Hence, the entire digital system and its power supply module should be small enough to be carried easily by the 4-wheel drive vehicle. In such a remote rural area, it can be hard to get technical support for the digital system. Not only does transportation cost more, but it also depends on the weather and the state of the roads.

C. IT Literacy of the Local Community

The adoption of technology in the village is relatively slow due to patchy network connections via the cellular network. Hence, a software system with a steep learning curve is a no-go as any encountered technical problem will render the system useless because no one can resolve the issue. Furthermore, patchy communication access makes providing support over the phone even harder. The community may even have a problem reporting any issues encountered and technical difficulties could take weeks or months to resolve.

V. PROPOSED CULTURAL MAPPING SYSTEM ARCHITECTURE

New system architecture will be proposed that addresses all the shortcomings of the current implementation environment in Buayan. The new system architecture should have the following characteristics:

a) Highly Efficient in Power Consumption: The more efficient the system's power consumption, the smaller the power supply system can be used, resulting in a lower cost of maintaining the system and its associated power supply system. Hence, the system design uses an IoT-based CPU with extremely low power consumption (4W to 6W). NAND-based solid state drive storage is adopted for its energy efficiency as well.

b) Small System Footprint: The system's footprint should be as small as possible to facilitate transportation into the remote village. With a smaller power requirement, the power supply system can also be made smaller in its physical size. With less than 10W in mind, a renewable energy solar power system has been designed to support the system's operation for 24 hours a day, 7 days a week, and the size of the system is still relatively small for off-road transportation.

c) Low-Maintenance Software: Software glitches, such as those in the operating system and the software application for cultural mapping, should be kept to a minimum. A Linux-based command-line interface operating system environment has been used to eliminate graphical user interface-originated problems and to reduce the processing and memory requirements for the system. All services, such as web hosting, database, network sharing, secure socket shell, etc., were executed automatically without user intervention every time the system started. Whenever there is a power cut to the system, the system will be back online automatically once the power is restored.

The cultural mapping system hardware architecture is shown in Fig. 4. The integrated application hosting and the portal system consist of both the IoT computing system with its NAND storage appliance for cultural mapping applications and the solar power controller that provides power to both the IoT system and the external WiFi router that acts as the wireless network interface for user device access, such as an iPad. The renewable solar power system is an appropriate power source owing to the solar power availability in the Buayan region, which has direct normal irradiation of more than 3kWh/m2 daily [9]. The proposed solar power system design uses five sets of 30W panels and is configured for a 40Ah lead-acid car battery. The reason for adopting a car battery is that the battery is a consumable item and needs to be replaced every two years. Hence, to enable easy replacement by the community, the battery shall be the type that can be easily found in the nearby town. The solar system-specific battery is relatively more challenging to obtain. The adoption

of the solar power system with charging ports is to create a self-sufficient ecosystem where the same system can also charge the iPad used for accessing the cultural mapping system.

VI. System Implementation at Buayan

The system was successfully implemented in one of the households in Buayan in August 2022. Fig. 5 shows the proposed system's implementation, which includes an integrated application hosting and portal system module, a battery bank, and installed solar panels. Fig. 6 shows the community interacting with the cultural mapping system via the iPad.

The deployed system has been observed to be running well 24 hours a day. The solar power supply is consistent, and the hosted cultural mapping service is stable. Local communities have been using the system for cultural inventory every few hours a day. We look forward to further feedback from the users if any new system-related issues are discovered.

VII. Conclusion and Future Works

This paper presents the implementation of a new system architecture specifically designed to overcome local limitations to ensure a more reliable, cheaper, and community-maintainable system for the purpose of cultural mapping. The proposed architecture evolved from previous Telecentres design experience to address the community's need for a specific application. By being able to design and implement a system architecture that scales down significantly to minimise power requirements based on its application, the crucial renewable energy solar system design will also be designed into a smaller and portable system, which is critical for rural implementation. The significant costs incurred in digital system implementation in remote rural areas are the provision of power supply and transportation. Although cloud computing might not be suitable based on the patchy and slow network connection in Buayan, remote management will be a good initiative to provide technical support to the Buayan community remotely.
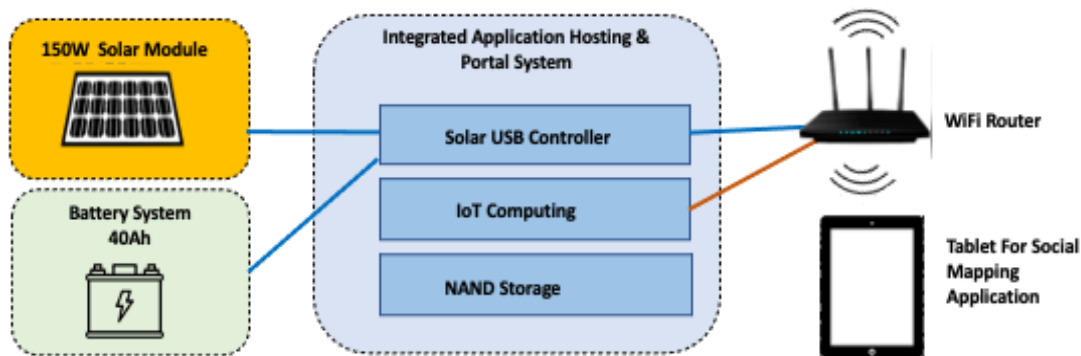

Fig. 4. The Cultural Mapping System Hardware Architecture.

(a)   (b)   (c)
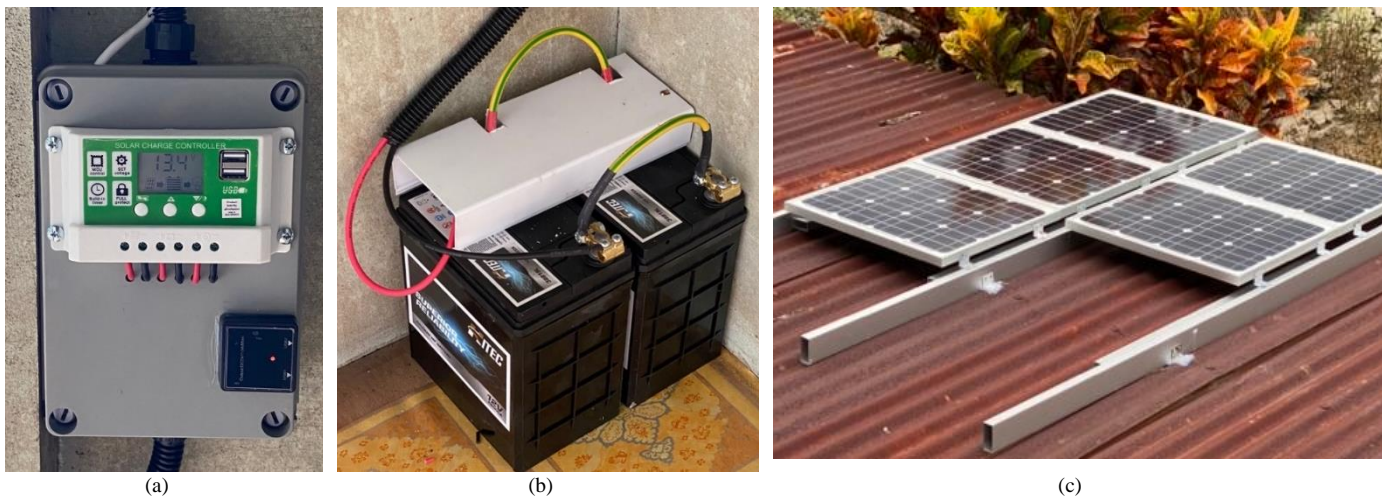
Fig. 5. The Hardware and Software Implementation of the Proposed System at Buayan. (a) The Housing for the Integrated Application Hosting, Portal System Module and Solar Power System with Charging Ports, (b) The Energy Storage System with Two Parallel Connected Car Batteries, and (c) the Five 12V 30W Solar Panels of the System.

Fig. 6. The Community Were Interacting with the Cultural Mapping System via the iPad.

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