Investigation note

Computer system under the PADPEEM methodology to estimate aerial carbon in coffee

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Abstract

The research aimed to design a Web-App computer system for data recording *in situ* and for estimating aerial carbon storage in coffee plots in Huatusco, Veracruz, Mexico. This was raised by the needs of producers to automate calculations of CO_2 capture that serve in contributing to climate change mitigation. The software was developed in the Montecillo Campus of the College of Postgraduates from February to October 2020 through the proposal of the PADPEEM methodology and was tested with the data obtained in some coffee crops in Huatusco in January 2020. The results showed the CarbonoCafé system, its architecture, navigation map and interfaces. The CarbonoCafé system will have an impact on the reduction of human, economic and time resources for the calculation of aerial carbon *in situ*. In addition, it contains databases that can be consulted from any computer or mobile phone.

Keywords: App, climate change mitigation, web system.

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Bazan *et al*. (2017) explained that in recent years the use of information and communication technologies (ICT) has become part of the daily life of a large number of people, which has caused users to have software and applications (App) that allow them to interact for the exchange of contents, education, research, use of services, agricultural technification and collaboration in various joint tasks from different sites.

Bakht (2018) expressed that the above would not have been achieved without the development of computing science distributed through computer networks, web pages, cross-platform systems and applications (App) that work with different operating systems and that can be interconnected with each other. Currently, there is a diversity of software that allows the collection of information in the field through mobile devices, facilitating the work of researchers and other professionals who require these tasks.

These systems contribute to various areas of knowledge, especially to those supporting agroforestry and environmental services focused on mitigating the effects of climate change caused mainly by the accumulation of carbon dioxide (CO_2) molecules. In the search for these systems, software and App that work with agroforestry information, aerial carbon capture and biomass *in situ* were searched, but little information was detected. Later, a review of crops that help mitigate the greenhouse effect and that can capture CO_2 was carried out.

As suggested by Isaza and Cornejo (2015), coffee was chosen because it captures a large amount of the molecule, in addition, due to its commercial, social and cultural interest. Afterwards, a coffee zone was sought in Mexico and the Huatusco region in the state of Veracruz was highlighted as one of the areas with the highest agroforestry volume with production under shade. Another aspect that was considered for the choice of the region is that it is possible to access the plots of the producers who support researchers from educational institutions of higher education and who are participating for the improvement of their crops.

There are several methodologies for the estimation of carbon stored in coffee plantations, but the highlighted ones are those of Tinoco and Escamilla (2017) and Rojas-García *et al*. (2015), who do so considering five reservoirs: shade perennials, coffee trees, leaf litter, herbaceous plants and soil. The way to evaluate shade perennials and coffee trees is by measuring the normal diameter and total height of individuals, and then allometric equations are applied to relate these variables to the dry weight of plant biomass. Regarding the reservoirs of leaf litter, herbaceous plants and soil, samples are collected to analyze them in the laboratory.

All this process is carried out by researchers, professors, students and producers collecting data *in situ*, which causes a large investment of time to do it because it is done manually filling out different forms. The information is then captured in spreadsheets and the different allometric formulas are applied. This process can cause errors from the recording of information, the capture of data, to the results by misapplication of allometric formulas. For this reason, it was thought of a software that helps to carry out all these activities and that also has the ability to take data in the field through mobile devices and that are recorded in databases.

For the construction of the software, a research on applications distributed over computer networks was carried. Bazan *et al*. (2017) explained that these networks work under the client-server model supported by the transmission control protocol/internet protocol (TCP/IP), which allows the communication of desktop and mobile computers, with different operating systems, connected to the network. The applications are designed under a Web-App architecture following different structures such as the LAMJ+G for its acronym of a web server using the Linux Operating System, Apache Server, MySQL database manager, JavaScript and Geomatic technologies under QGis (GNU-General Public License) and dynamic maps.

For all the above, the following question was reached: what hybrid methodology can be used for the design of a computer system that records, *in situ*, data on vegetation, soil and indicators for the diagnosis of the productive structure of coffee plots and that also considers the aerial carbon capture in coffee agroecosystems in Huatusco, Veracruz, Mexico? To answer the question, a research was proposed to design a Web-App computer system for the recording of data *in situ* and the estimation of aerial carbon storage in coffee plots in Huatusco, Veracruz, Mexico.

The proposed hypothesis was that the development of a computer system supported by a hybrid methodology allows the recording, *in situ*, of data on plants, trees and coffee trees, as well as the estimation of the aerial organic carbon storage in agroecosystems in the area. For the development of the system, it was proposed to use free software tools and the internet that allow the recording of data in the field and the estimation in real time of the aerial carbon capture in agroforestry coffee systems of the Huatusco region, Veracruz, Mexico and that can also be used by academics, students, forestry specialists, producers, among others. Also, that it manages databases and generates reports through documents, information on screen or dynamic maps.

The system is expected to have a scope for the Huatusco coffee region. One limitation is that the software only works for the selected region, the reason is that for a different geographical area, adjustments have to be made in the programming of the algorithms of allometric formulas according to the characteristics of each region and of the agroecosystems for the calculation of aerial carbon capture.

To answer the research question and achieve the objective, the construction of the computer system was proposed as a part of the materials and methods, based on good practices of Software Engineering, the PADDIEM methodology (Meráz *et al*., 2019) and the Mobile-D methodology (Amaya, 2013).

PADDIEM was used for the design of educational software and consisted of seven different phases: planning, analysis, design, development, implementation, evaluation and maintenance. Mobile-D was based on different agile models such as extreme programming (XP) and its main purpose was to obtain very fast development cycles so that the computer package is finished in a short time, it consisted of five stages: exploration, initialization, production, stabilization and testing of the system.

Later, it was necessary to propose a hybrid methodology that would integrate both PADDIEM and Mobile-D in the development of the system. The reason is that the characteristics of each one, separately, were not in line with what is intended in this project. The planning, analysis, evaluation and maintenance phases of PADDIEM were considered. The phases of Mobile-D that were considered were those of production and stabilization, which allow the rapid development of small products and the release of small segments of the system evaluating their operation. The resulting methodology took the name PADPEEM. The flowchart in Figure 1 shows the proposed methodology, where each stage is highlighted by rectangles and the different evaluations by rhombuses.

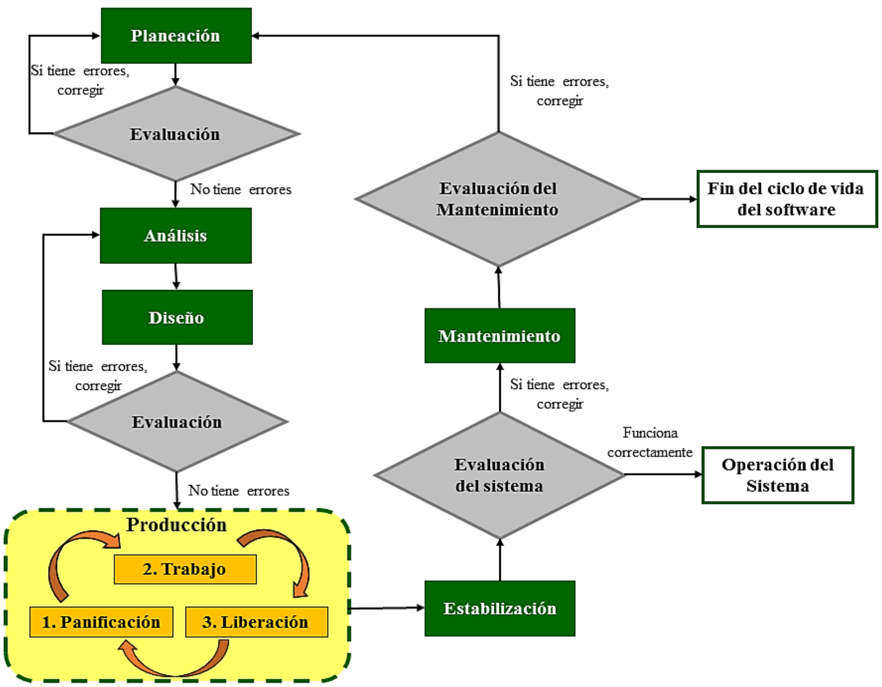

Figure 1. Proposal of hybrid methodology PADPEEM.

After selecting the PADPEEM methodology, the development of the software started, which was programmed in the Montecillo Campus of the College of Postgraduates from February to October 2020. Each stage of PADPEEM was followed as explain below:

Planning

The need of the project was identified, which was the design of a computer system for the recording of data *in situ* and the estimation of aerial carbon storage through the methodologies of Tinoco and Escamilla (2017), as well as that of Rojas-García *et al*. (2015) in coffee agroecosystems in Huatusco, Veracruz. Later, a feasibility study of the project was conducted by analyzing strengths, opportunities, weaknesses and threats (SWOT).

After this, the economic resources that were available for both hardware and software were identified. In addition, the time for the development of the system was considered. Also, the technological and human requirements were proposed by establishing multidisciplinary teams and the activities to be carried out in each stage of PADPEEM (Figure 2). A schedule of activities was also made.

Equipos multidisciplinarios de expertos	Etapas	Actividades a realizar
* Equipo de cómputo * Equipo de sustentabilidad en café * Equipo de diseño gráfico	P	1. Problemática y Necesidades 2. Propósito 3. Estudio de viabilidad 4. Requerimientos tecnológicos y humanos 5. Cronograma
* Equipo de cómputo * Equipo de sustentabilidad en café * Equipo de diseño gráfico	A	1. Propuesta del sistema 2. Ámbito del sistema 3. Especificación general tanto de usuarios como de los requisitos del software 4. Especificación detallada de los requerimientos del sistema. 5. Elección de la arquitectura, tipo de aplicación, lenguajes de programación y software a utilizar
* Equipo de cómputo * Equipo de diseño gráfico	D	1. Arquitectura general del sistema. 2. Mapa de navegación y permisos de usuarios 3. Propuesta de base de datos 4. Propuesta de diseño de interfaces.
* Equipo de cómputo	P	1. Creación del servidor web local 2. Elaboración de base de datos 3. Elaboración de interfaces 4. Programación de algoritmos para la estimación de biomasa y carbono 5. Generación de reportes
* Equipo de cómputo	E	1. Alojamiento de la base de datos en un servidor web remoto 2. Construcción de metadatos 3. Primera versión del sistema 4. Instalación 5. Pruebas piloto 6. Capacitación para el uso del sistema
* Equipo de cómputo * Equipo de sustentabilidad en café * Equipo de diseño gráfico	E	1. Evaluación de la etapa de Planeación 2. Evaluación de la etapa de Análisis y Diseño 3. Evaluación de la etapa de Producción y Estabilización 4. Evaluación de la opinión de los usuarios 5. Evaluación de la etapa de Mantenimiento
* Equipo de cómputo * Equipo de diseño gráfico	M	1. Corrección de errores detectados en la evaluación de cada etapa 2. Mejorar la implementación de las unidades del sistema 3. Incrementar los servicios del sistema conforme se descubren nuevos requerimientos. 4. Eliminar el sistema cuando finalice su ciclo de vida

Figure 2. Multidisciplinary teams and their participation in each stage of PADPEEM.

Analysis

At this stage the proposal of the system, the scope, general specifications, requirements, selection of architecture, type of application and software to be used was made. To fulfill the purpose of the software, two types of applications were proposed, a web and a hybrid mobile (Web-App). Also, six types of users who can access the system were established: administrator, researcher, specialized technician, student, support of specialized technician and producer. Each of them with a specific permission or role to enter the system and access certain views.

In addition, the system was projected with six main modules located in the menu of the main screen: user guide, user management, catalog management, sampling planning, field sampling and reports. Likewise, the need to find a remote web hosting service that adjusted to the LAMP +G structure to host the databases and software to be used was detected, because the laptop that was available did not meet the necessary technological requirements and did not have a fixed internet address (domain). For this reason, the hosting service 'hospedando.mx' that met the requirements for the project was contracted.

Design

The structure of databases was raised: a relational one and others called NoSQL. Also, the different interfaces and their different components for the App were projected through Visual Studio Code (Massachusetts Institute of Technology, License), as well as the programming languages JavaScript, CSS, HTML and React Native. Later, the algorithms that provided the calculations for the estimation of biomass and aerial carbon capture by means of the allometric equations of Rojas-García *et al*. (2015) were designed, especially the most representative species of the coffee plots of that area.

In addition, it was considered that the App can store information in JSON files on the mobile phone and can create reports in PDF files (Acrobat license) or in a dynamic map. It was also considered that information can be obtained on the website through a database management system or through a geographic information system such as QGis.

Production

Remotely, within the contracted web server, the relational database was developed, for which the MySQL database management system and the SQL language, which includes general data of the property, sampling and its georeferencing. In addition, in the computer equipment available (laptop with Intel Core i5, 8 RAM, 1 TB of hard disk), a NoSQL database was developed using the JavaScript programming language and the AsyncStorage storage of the React Native CLI framework.

Also, 97 interfaces with its different components were programmed. Later, the programming of the source code was performed for the algorithms that provided the calculations for the estimation of biomass and aerial carbon capture. Finally, the App was adapted to store information on the mobile phone, the reports were programmed, and the information was displayed on a dynamic map. In addition, the website where information can be obtained through QGis was programmed. As a result of the design and production stages, Figure 3 shows the architecture of the hybrid system based on LAMJ+G.

The architecture consists of three sections: client: where users have communication with the system through the interfaces, either in an App on mobile phones or through a website accessible from personal computers. Web access: the internet is the communication route of all the elements of the system, taking advantage of the benefits of the TCP/IP communication protocol, communication to databases, the different web services and the sending and receiving of JSON files for App. Server: remote computer built under the LAMJ+G structure. The client can access the system, various web resources and different software by making requests to the server.

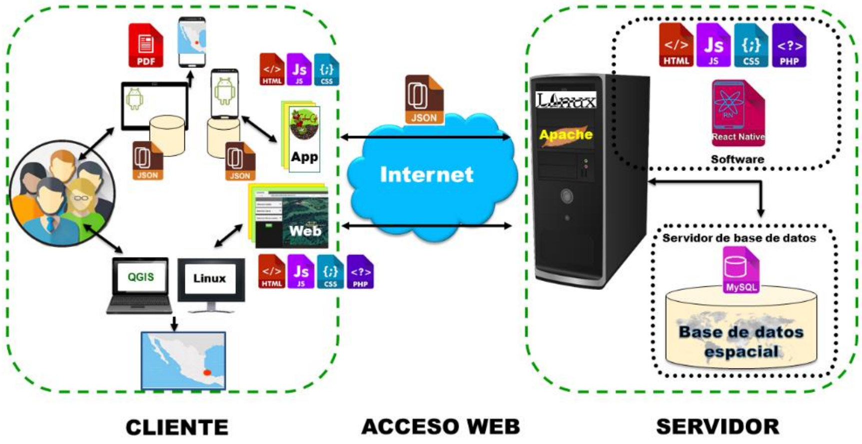

Figure 3. Architecture of the system based on web services using LAMJ+G.

Also, the server functions as a repository of the relational database that contains user information, sampling sites, geo-references and carbon retention calculations. In addition, it allows data access from the QGis to analyze spatial information. Likewise, the navigation map and permissions for each user were designed (Figure 4).

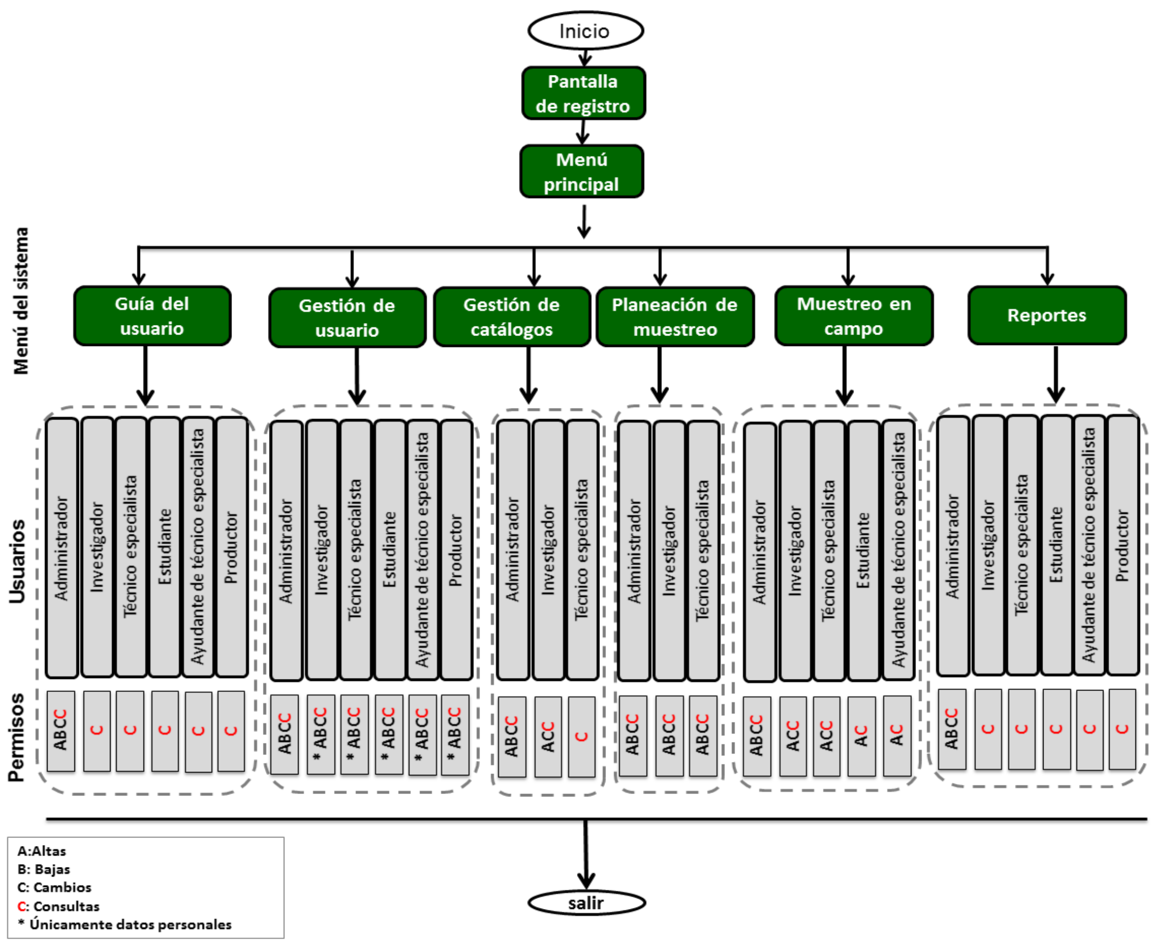

Figure 4. System navigation map and user permissions.

For a user to enter the system, they must be registered, otherwise, they must fill out a form with their data. Later, they go to the main menu. The user can only access the menu sections and some functions according to the assigned permissions of the registration profile (professor, researcher, student, producer, etc.).

Information from the user register and catalogues of sampling sites are recorded in databases. Likewise, data collected *in situ* is stored on the mobile phone and can be sent to the system as soon as there is an Internet connection. Figure 5 shows some of the interfaces made in the system and seen on the cell phone.

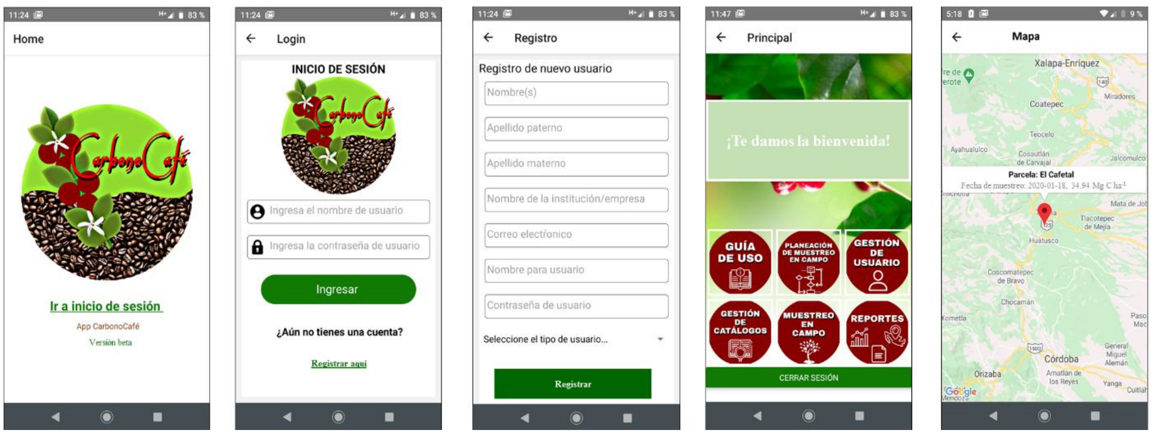

Figure 5. App interfaces.

Stabilization

All system tests were done using data obtained in the field in January 2020 with producers from Huatusco. Emphasis was placed on the proper functioning between the relational database hosted on the remote web server and the App, which allowed good communication between the software, databases, requests for reports, dynamic maps, etc. After this, the metadata was developed using the Dublin Core model and placed on the main page of the CarbonoCafé website with the address https://carbonocafe.tecnologiasgis.com.mx. Then, the pilot tests were conducted between September 22 and November 5, 2020. The CarbonoCafé App was installed on different smartphones. The installation did not fail and works properly.

Evaluation

The stages of planning, analysis-design, production-stabilization and maintenance were evaluated in accordance with what is established in Figure 1 using rubrics and questionnaires prepared for this system by the multidisciplinary teams.

Maintenance

The evaluations detected errors, changes or modifications in the system. The requests of the four types of maintenance were followed: corrective, evolutionary, adaptive and perfective. First, the maintenance request was recorded to diagnose the type of maintenance and the experts responsible for each process of the evaluation stage were assigned. The problem was then analyzed, and the possible solution was raised. After this, the implementation of the modification was prepared, where a list of priorities was made, the sequence to meet them and the delivery date and cost were established. Finally, the changes were monitored and evaluated until acceptance by the team of experts.

As a discussion, the CarbonCafé system was contrasted with other initiatives. CBP is a mobile application to quantify soil organic carbon in the United States of America that stores information in a database managed through a web system (Chotte *et al*., 2019). The application developed in this research also works with both an App and a Web system, but with a different approach since aerial organic carbon is calculated especially in coffee crops, but for a specific site in Mexico.

CO2Land based on CO2FIX that works under different operating systems that estimates the captured carbon and allows its changes to be determined annually using Geographic Information Systems (GIS) in different countries (Ruiz-Guevara *et al*., 2020). The system of this research works with a Web system with georeferenced data, in addition, it calculates biomass and aerial organic carbon through an App, the information is sent to the web server when there is access to an Internet connection.

In accordance with the above, it was demonstrated that CarbonoCafé is different from the systems described, since it is focused on the estimation of aerial carbon capture in coffee agroecosystems of Huatusco, Veracruz, uses allometric equations to estimate biomass in species specifically of the region and is based on the methodology of carbon quantification in agroforestry systems of coffee under shade proposed by Tinoco and Escamilla (2017); Rojas-García *et al*. (2015).

Conclusions

The general objective of this work was achieved. The hypothesis is not rejected because a computer system was developed under a hybrid methodology called PADPEEM. The CarbonoCafé system will have an impact on the reduction of human, economic and time resources for the calculation of aerial carbon *in situ*, which also allows having databases that can be consulted. The information presented in the reports will be useful to improve the quality of life of coffee producers, because, although currently the carbon credit market has not fully transcended, this information can be used by coffee producer organizations to technically and formally demonstrate the estimate of the carbon captured by their plots and thus aspire to payments for environmental services.

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