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Tecnura

Tecnura

Tecnología y cultura, afirmando el conocimiento

Universidad Distrital Francisco José de Caldas
Facultad Tecnológica

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REVISTA *TECNURA*

La revista Tecnura es una publicación institucional de la Facultad Tecnológica de la Universidad Distrital Francisco José de Caldas de carácter científico-tecnológico, arbitrada mediante un proceso de revisión entre pares de doble ciego. La periodicidad de la conformación de sus comités Científico y Editorial está sujeta a la publicación de artículos en revistas indexadas internacionalmente por parte de sus respectivos miembros.

PERIODICIDAD

Es una publicación de carácter científico-tecnológico con periodicidad trimestral, que se publica los meses de enero, abril, julio y octubre. Su primer número apareció en el segundo semestre del año 1997 y hasta la fecha ha mantenido su regularidad.

COBERTURA TEMÁTICA

Las áreas temáticas de interés de la revista *Tecnura* están enfocadas a todos los campos de la ingeniería, como la electrónica, telecomunicaciones, electricidad, sistemas, industrial, mecánica, catastral, civil, ambiental, entre otras. Sin embargo, no se restringe únicamente a estas, también tienen cabida los temas de educación y salud, siempre y cuando estén relacionados con la ingeniería. La revista publicará únicamente artículos de investigación científica y tecnológica, de reflexión y de revisión.

MISIÓN

La revista *Tecnura* tiene como misión divulgar resultados de proyectos de investigación realizados en el área de la ingeniería, a través de la publicación de artículos originales e inéditos, realizados por académicos y profesionales pertenecientes a instituciones nacionales o extranjeras del orden público o privado.

PÚBLICO OBJETIVO

La revista *Tecnura* está dirigida a docentes, investigadores, estudiantes y profesionales interesados en la actualización permanente de sus conocimientos y el seguimiento de los procesos de investigación científico-tecnológica, en el campo de la ingeniería.

INDEXACIÓN

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TECNURA JOURNAL

Tecnura Journal is an institutional scientific-technological publication from the Faculty of Technology at District University Francisco José de Caldas, arbitrated by means of a double-blinded peer review process. The periodicity for its Scientific and Editorial committees line-up is subject to the publication of articles in internationally indexed magazines by its own members.

PERIODICITY

Tecnura journal is a scientific-technological publication with quarterly periodicity, published in January, April, July and October. Its first edition appeared in the second term, 1997 and its editions have normally continued from that year and on.

THEMATIC COVERAGE

The thematic areas of interest at Tecnura journal are focused on all fields of engineering such as electronical, telecommunications, electrical, computer, industrial, mechanical, cadastral, civil, environmental, etc. However, it is not restricted to those, there is also room for education and health topics as well, as long as they are related to engineering. The journal will only publish scientific and technological research, reflection and review articles.

MISSION

Tecnura journal is aimed at publishing research project results carried out in the field of engineering, through the publishing of original and unpublished articles written by academics and professionals from national or international public or private institutions.

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Tecnura journal is directed to professors, researchers, students and professionals interested in permanent update of their knowledge and the monitoring of the scientific-technological research processes in the field of engineering.

INDEXING

Tecnura is an academic publication indexed in the Regional Index Scielo Colombia (Colombia) and Redalyc (México); as wel as the following bibliographic databases: INSPEC of the Institution of Engineering and Technology (England), Fuente Académica Premier of EBSCO (United States), CABI (England), Index Copernicus (Poland), Informe Académico of Gale Cengage Learning (México), Periódica of the Universidad Nacional Autónoma de México (México), Oceanet (Spain) and Dialnet of the Universidad de la Rioja (Spain); it is also part of the following directories: Online Regional Information System for Scientific journals from Latin America, Caribbean, Spain and Portugal Latindex (México), bibliographic index Actualidad Iberoamericana (Chile), e-Revistas (Spain) , DOAJ (Sweden), Ulrich of Proquest (United States).

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SIGN UP

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El comité editorial de la revista *Tecnura* está comprometido con altos estándares de ética y buenas prácticas en la difusión y transferencia del conocimiento, para garantizar el rigor y la calidad científica. Es por ello que ha adoptado como referencia el Código de Conducta que, para editores de revistas científicas, ha establecido el Comité de Ética de Publicaciones (COPE: Committee on Publication Ethics) dentro de los cuales se destaca:

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En su calidad de máximos responsables de la revista, el comité y el equipo editorial de *Tecnura* se comprometen a:
- Aunar esfuerzos para satisfacer las necesidades de los lectores y autores.
- Propender por el mejoramiento continuo de la revista.
- Asegurar la calidad del material que se publica.
- Velar por la libertad de expresión.
- Mantener la integridad académica de su contenido.
- Impedir que intereses comerciales comprometan los criterios intelectuales.
- Publicar correcciones, aclaraciones, retractaciones y disculpas cuando sea necesario.

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Tecnura se compromete a asegurar la calidad del material que publica, informando sobre los objetivos y normas de la revista. Las decisiones de los editores para aceptar o rechazar un documento para su publicación se basan únicamente en la relevancia del trabajo, su originalidad y la pertinencia del estudio con relación a la línea editorial de la revista.

La revista incluye una descripción de los procesos seguidos en la evaluación por pares de cada trabajo recibido. Cuenta con una guía de autores en la que se presenta esta información. Dicha guía se actualiza regularmente y contiene un vínculo a la presente declaración ética. Se reconoce el derecho de los autores a apelar las decisiones editoriales.

Los editores no modificarán su decisión en la aceptación de envíos, a menos que se detecten irregularidades o situaciones extraordinarias. Cualquier cambio en los miembros del equipo editorial no afectará las decisiones ya tomadas, salvo casos excepcionales en los que confluyan graves circunstancias.

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Tecnura garantiza que el material remitido para su publicación será considerado como materia reservada y confidencial mientras que se evalúa (doble ciego).

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Cada vez que se tenga constancia de que algún trabajo publicado contiene inexactitudes importantes, declaraciones engañosas o distorsionadas, debe ser corregido de forma inmediata.

En caso de detectarse algún trabajo cuyo contenido sea fraudulento, será retirado tan pronto como se conozca, informando inmediatamente tanto a los lectores como a los sistemas de indexación.

Se consideran prácticas inadmisibles, y como tal se denunciarán las siguientes: el envío simultáneo de un mismo trabajo a varias revistas, la publicación duplicada o con cambios irrelevantes o parafraseo del mismo trabajo, o la fragmentación artificial de un trabajo en varios artículos.

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Tecnura establecerá los mecanismos necesarios para evitar o resolver los posibles conflictos de intereses entre autores, evaluadores y/o el propio equipo editorial.

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Cualquier autor, lector, evaluador o editor puede remitir sus quejas a los organismos competentes.

CODE OF ETHICS AND GOOD PRACTICE

The editorial board of Tecnura journal is committed to ethics high standards and good practice for knowledge dissemination and transfer, in order to ensure rigour and scientific quality. That is why it has taken as reference the Code of Conduct, which has been established by the Committee on Publication Ethics (COPE) for scientific journal editors; outlining the following:

General duties and responsibilities of the editorial board

As most responsible for the journal, *Tecnura* committee and the editorial board are committed to:

- Joining efforts to meet the readers and authors' needs.
- Tending to the continuous improvement of the Journal.
- Ensuring quality of published material.
- Ensuring freedom of expression.
- Maintaining the academic integrity of their content.
- Prevent commercial interests compromise intellectual standards.
- Post corrections, clarifications, retractions and apologies when necessary.
- Relations with readers
- Readers will be informed about who has funded research and their role in the research.

Relations with authors

Tecnura is committed to ensuring the quality of published material, informing the goals and standards of the journal. The decisions of publishers to accept or reject a paper for publication are based solely on the relevance of the work, originality and pertinence of the study with journal editorial line.

The journal includes a description of the process for peer evaluation of each received work, and has an authors guide with this information. The guide is regularly updated and contains a link to this code of ethics. The journal recognizes the right of authors to appeal editorial decisions Publishers will not change their decision in accepting or rejecting articles, unless extraordinary circumstances or irregularities are detected. Any change in the editorial board members will not affect decisions already made, except for unusual cases where serious circumstances converge.

Relations with evaluators

Tecnura makes available to reviewers a guide to what is expected from them. Reviewers' identity is protected at all times, ensuring anonymity.

Peer review process

Tecnura ensures that material submitted for publication will be considered private and confidential issue while being reviewed (double blind).

Claims

Tecnura is committed to respond quickly to complaints and ensure that dissatisfied claimant can process all complaints. In any case, if applicants fail to satisfy their claims, the journal considers that they have the right to raise their protests to other instances.

Promoting Academic Integrity

Tecnura ensures that the published material conforms to internationally accepted ethical standards.

Protection of individual data

Tecnura guarantees the confidentiality of individual information (e.g. participant teachers and/or students as collaborators or subjects of study in the presented research).

Tracking malpractice

Tecnura accepts the obligation to act accordingly in case of suspected malpractice or misconduct. This obligation extends both to publish and unpublished documents. The editors not only reject manuscripts with doubts about possible misconduct, but they are considered ethically obligated to report suspected cases of misconduct. From the journal every reasonable effort is made to ensure that works submitted for evaluation are rigorous and ethically appropriate.

Integrity and academic rigour

Whenever evidence that a published work contains significant misstatements, misleading or distorted statements, it must be corrected immediately.

In case of any work with fraudulent content is detected, it will be removed as soon as it is known, and immediately informing both readers and indexing systems.

Practices that are considered unacceptable and as such will be reported: simultaneous sending of the same work to various journals, duplicate publication with irrelevant changes or paraphrase of the same work, or the artificial fragmentation of a work in several articles.

Relations with owners and journal editors

The relation between editors, publishers and owners will be subject to the principle of editorial independence. *Tecnura* will ensure that articles are published based on their quality and suitability for readers, and not for an economic or political gain. In this sense, the fact that the journal is not governed by economic interests, and defends the ideal of universal and free access to knowledge, provides that independence.

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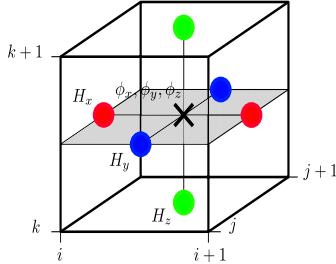
Tecnura will establish the necessary mechanisms to avoid or resolve potential conflicts of interest between authors, reviewers and/or the editorial board itself.

Complaints / allegations

Any author, reader, reviewer or editor may refer their complaints to the competent authorities.

Contenido

EDITORIAL

El Ministerio de Ciencia, Tecnología e Innovación, MINCIENCIAS, fue creado mediante la Ley 1951 de 2019 como el ente rector del Sistema de Ciencia, Tecnología e Innovación–CTeI, cuyo principal propósito es que el conocimiento generado a partir de la investigación y del desarrollo tecnológico nacional tenga un mayor impacto sobre el sistema productivo y contribuya a la solución de las problemáticas de la sociedad colombiana. Entre sus funciones, se encuentran las siguientes:

Diseñar, formular, coordinar, promover la implementación y evaluar la política pública, los planes, programas y estrategias que se encaminen a fomentar, fortalecer y desarrollar la Ciencia, la Tecnología y la Innovación, para consolidar una sociedad basada en el conocimiento; formular y coordinar el diseño, ejecución y evaluación del Plan Nacional de Ciencia Tecnología e Innovación; dirigir y coordinar el Sistema Nacional de Ciencia, Tecnología e Innovación; impulsar la formación e inserción de capacidades humanas, la cooperación internacional, la apropiación social de CTeI y la infraestructura, para el desarrollo científico, tecnológico y la innovación de la Nación.

Adicionalmente, es la entidad encargada de fomentar acciones y condiciones para que los desarrollos científicos, tecnológicos e innovadores se relacionen con los sectores productivo y social que favorezcan la equidad, la productividad, la competitividad, el emprendimiento, el empleo y el mejoramiento de las condiciones de vida de los ciudadanos; Por esta razón, debe establecer vínculos con otros sistemas administrativos, orientados al avance de la ciencia, la tecnología y la innovación, y orientar la creación de espacios y mecanismos para fomentar la coordinación, el fortalecimiento, la articulación y mutua cooperación de las entidades que integran el Sistema Nacional de Ciencia, Tecnología e Innovación.

Dada su naturaleza, también debe establecer los lineamientos que deben adoptar las entidades e institutos públicos y demás organismos para el desarrollo de actividades en Ciencia, Tecnología e Innovación, definir las áreas del conocimiento, su composición, organización, funcionamiento y las líneas temáticas, focos y misiones que orienten las acciones y los espacios de interfaz que permitan la articulación de los actores del Sistema Nacional de Ciencia, Tecnología

e Innovación y fomentar la creación y el fortalecimiento de instancias e instrumentos financieros, de diferentes fuentes, para el desarrollo de la Ciencia, Tecnología e Innovación, en el país.

Por su interacción con la academia debe consolidar las relaciones entre Universidad, Empresa, Estado y Sociedad para la generación de conocimiento, desarrollo tecnológico, innovación y la capacidad de transferencia de la tecnología y el conocimiento entre éstos, propiciando el fortalecimiento de las capacidades regionales en materia de ciencia, desarrollo tecnológico e innovación para el logro de los objetivos y de la Política Pública formulada por el Ministerio, promoviendo y articulando, las instancias regionales, departamentales y municipales de ciencia, tecnología e innovación SNCTI, para la coordinación de esfuerzos nacionales y regionales en CTeI.

Dentro de sus funciones también recae el promover la cooperación interinstitucional, interregional e internacional entre los actores del SNCTI, a través de políticas, planes, programas, proyectos y actividades, para la consecución de los objetivos y de la Política Pública formulada por el Ministerio; y administrar el Fondo Nacional de Financiamiento para la Ciencia, la Tecnología y la Innovación, "Fondo Francisco José de Caldas".

Para alcanzar este objetivo, se han implementado una serie de estrategias y acciones que pretenden, por una parte, acercar el sector productivo al aparato científico tanto nacional como internacional y, por otra, que los investigadores y las instituciones responsables de la producción, aplicación y apropiación del conocimiento sean más cercanas a las inquietudes y necesidades de la empresa y de la sociedad en general. Además de hacer énfasis en la generación de resultados para la sociedad, la Ley 1286 ha creado una serie de condiciones para que el desarrollo del conocimiento pueda extenderse a todas las regiones del país, de manera que las capacidades de Investigación y Desarrollo, que hoy se localizan en algunos centros de mayor desarrollo ayuden a cerrar las brechas, que limitan la posibilidad de dar respuesta a los problemas sociales y económicos a partir del conocimiento y la innovación.

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César Augusto García-Ubaque
Director

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EDITORIAL

The Ministry of Science, Technology and Innovation (MINCIENCIAS) was created by Law 1951 of 2019 as the governing body of the Science, Technology and Innovation System – ST&I. Its main purpose is to ensure that the knowledge generated from national research and technological development has a greater impact on the production system, and that it contributes to the solution of the problems of Colombian society. Some of its functions are listed below.

First, with respect to strategies and programs, the Ministry has the responsibility of designing, formulating, coordinating, and promoting and evaluating their implementation. This includes public policy, plans, programs, and strategies aimed at promoting and strengthening science, technology and innovation, in order to consolidate a society based on knowledge. In particular, the Ministry must be in charge of designing and executing the "National Plan for Science, Technology and Innovation;" direct and coordinate the "National System of Science, Technology and Innovation;" and to promote both human training in science and international cooperation, and the social appropriation of ST&I. All this in order to promote scientific, technological and innovation development in the country.

Second, with respect to the social integration of scientific and technological development, the Ministry has the responsibility of promoting the necessary conditions for scientific, technological and innovation developments to be related to the productive and social sectors. This in order to improve the living conditions of citizens: equity, productivity, competitiveness, entrepreneurship, and employment. For this reason, it must establish links with other administrative systems aimed at the advancement of science, technology and innovation. In other words, it must guide the creation of spaces and mechanisms to promote coordination, strengthening, and mutual cooperation of the entities that make up the National System of Science, Technology and Innovation (NSSTI).

Third, due to its nature as a governing body, the Ministry must establish the guidelines to be adopted by both public and private entities for the development of activities in Science, Technology and Innovation. This includes defining the areas of knowledge (composition, organization, functioning), thematic lines, focus, and missions that guide the actions. Additionally, it must promote the creation and strengthening of financial institutions and instruments (from different sources) for the development of science, technology and innovation in the country.

Fourth, due to its interaction with the academy, it must consolidate the relationships between University, Business, State, and Society, in order to generate knowledge, technological development, innovation, and the transfer of knowledge between them. In this way, it promotes the strengthening of regional capacities in science, technological development and innovation to achieve the objectives and public policies defined by itself. Its functions also include promoting inter-institutional, interregional, and international cooperation among SNCTI actors, which is achieved through policies, plans, programs, projects, and activities designed and executed by the Ministry.

Finally, its responsibilities also include managing the National Fund for Financing Science, Technology and Innovation, the "Francisco José de Caldas Fund."

In order to fulfill these responsibilities, a series of strategies and actions have been implemented and have two main objectives. On the one hand, to bring the productive sector closer to the national and international scientific system; on the other, to bring researchers and the institutions responsible for the production, application, and appropriation of knowledge closer to the concerns and needs of the company and society in general.

In addition to emphasizing the generation of results for society, the Law 1286 created a series of conditions so that the development of knowledge can be extended to all regions of the country. In this way, the research and development capacities that are located today in centers of greater growth use knowledge and innovation to help close the gaps that limit the possibility of responding to social and economic problems.

CÉSAR AUGUSTO GARCÍA-UBAQUE
Director

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INVESTIGACION

Seismic Inversion for the Calculation of Velocities Using the Generalized Inverse Linear Matrix, the Wave Equation, and a Non-Reflective-Boundaries Condition

Inversión sísmica para el cálculo de velocidades, usando la matriz lineal inversa generalizada, la ecuación de onda y fronteras no reflectivas

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Abstract

Objective: This work presents the results obtained in the development of a seismic velocity inversion model. The reference times recorded on the surface are taken and using the inversion model to obtain the initial reference model (hypocenters and velocities), starting from an unknown model.

Methodology: A hypothetical reference model is proposed containing 64 blocks with interval velocity, 16 recording stations on the surface, and 64 earthquakes in the center of each block. With this model, the reference arrival times are generated for each earthquake registered in each station. The inversion model is made up of two parts: the direct model, which allows calculating the arrival times of the signal registered on the surface according to the hypo-central location of the earthquake and the velocity of the P and S wave of the medium; and the inverse model, which estimates a model of the velocity of the environment and hypo-central locations of the earthquakes that are the input variables of the direct model. The direct model was developed with the wave equation, while the inverse model was developed by modifying the generalized inverse matrix by introducing a factor called "damping."

Results: The discretization model is based on the finite difference method. When estimating the values of velocity and hypo-central location with the inverse algorithm, the propagation of the wave is simulated with the direct model, and then compared with the data of reference times measured on the surface. Depending on the mean square error, we proceed to modify the mean velocities and hypo-centers of the earthquakes. This process repeates

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Seismic Inversion for the Calculation of Velocities Using the Generalized Inverse Linear Matrix

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iteratively until the calculated error is less than a tolerance of $2x10^{-3}s^2$.

Conclusions: It was found that the estimated values of velocity and hypocentral locations coincide well for regions closer to the surface, while for deep regions the error more significant compared to the hypothetical reference model.

Keywords: Attenuation, Non-Reflecting Boundary Conditions, Seismic Inversion, Wave Equation, Seismic Tomography.

Resumen

Objetivo: Se presentan los resultados obtenidos en el desarrollo de un modelo de inversión sísmico de velocidades. Se toman los tiempos de referencia registrados en superficie y mediante el modelo de inversión lograr obtener el modelo de referencia inicial (hipocentros y velocidades), partiendo de un modelo desconocido.

Metodología: Se propone un modelo hipotético de referencia que contiene 64 (4x4x4)) bloques con velocidad intercalada, 16 estaciones de registro en la superficie y 64 sismos en el centro de cada bloque. Con este modelo se generan los tiempos de arribo de referencia para cada sismo registrado en cada estación. El modelo de inversión se compone de dos partes: el modelo directo, que permite calcular los tiempos de arribo de la señal registrada en superficie según la localización hipocentral del sismo y la velocidad de la onda P y S del medio; y el modelo inverso, que estima un modelo de velocidad del medio y localizaciones hipocentrales de los sismos que son las variables de entrada del modelo directo. El modelo directo se desarrolló con la ecuación de onda, mientras que el modelo inverso se desarrolló mediante una modificación a la matriz inversa generalizada introduciendo un factor denominado "amortiguamiento".

Resultados: Ambos modelos fueron discretizados mediante el método de diferencias finitas. Al estimar los valores de velocidad y localización hipocentral con el algoritmo inverso, se simula la propagación de la onda con el modelo directo, y se comparan con los datos de tiempos de referencia medidos en superficie. Según sea el valor del error cuadrático medio, se procede a modificar las velocidades del medio e hipocentros de los sismos. Este proceso se repite iterativamente hasta lograr que el error calculado sea menor que una tolerancia de $2x10^{-3}s^2$.

Conclusiones: Se encontró que los valores estimados de velocidad y localizaciones hipocentrales coinciden muy bien para regiones más cercanas a la superficie, mientras que para regiones profundas el error es mayor en comparación con el modelo hipotético de referencia.

Palabras clave: Atenuación, Condiciones Fronteras no Reflectivas, Ecuación de Onda, Inversión sísmica, Tomografía sísmica.

INTRODUCTION

For decades, seismic tomography has been the main tool to know the inner structure of the Earth. Their origins go from characterization to seismic prospection of oil wells (Bois et al., 1971). The fundamental theory of inversion geophysics data begins with Backus & Gilbert (1967), and a decade later the first application of seismic tomography appears (Aki et al., 1977; Aki & Lee, 1976; Dziewonski et al., 1977). In Aki & Lee (1976), the arrival times of the P wave are inverted to produce velocities variation. For the purpose of this work, there are three main assumptions: a front wave plane arrives, the velocity variation can be adjusted for a regular grid, and the geometry of the rays entering each block of the grid is only affected by the velocity variation. This work is considered the first example of seismic tomography that assumes the simultaneous inversion of the hypo-central location and velocity.

During the first two decades after the work by Aki & Lee (1976), the arrival times were calculated using ray tracing. However, the wave phenomena as the dispersion of the diffraction affect the arrival times, especially in 3D models (Liu & Dong, 2012). Virieux (1986) suggests calculating arrival times simulating

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the seismic wave propagation through a 3D elastic medium. Tong et al. (2014) make a review of different forward model methods and conclude that the wave propagation method tends to decrease error, but better results are achieved when we use seismograms. Recently, some works have managed to invert the entire seismogram. Chen et al. (2007), Fichtner & Trampert (2011), and Tape et al. (2010) calculated the residuals of full synthetic seismograms against the observations, getting better results in different regions of study.

THEORETICAL FRAMEWORK AND ANALYSES

1. Direct Model

The wave equation (1) is classified as a hyperbolic differential equation (Burden et al., 2016) in three dimensions:

$$\frac{\partial^2 \phi(x,y,z,t)}{\partial t^2} - V^2 \nabla^2 \phi = 0, \tag{1}$$

where V is the velocity, which depends on spatial coordinates, and ϕ is the wave function. Considering some boundaries and initial conditions, such as:

$$\phi(\partial E, t) = 0, \qquad t > 0, \tag{2}$$

$$\phi(E, 0) = f(E), \tag{3}$$

$$\frac{\partial \phi}{\partial t}(E, 0) = g(E), \tag{4}$$

where E represents the spatial coordinates, and ∂E is the E boundary; also $f(E)$, $g(E)$ are the known functions in the entire domain. In Cartesian coordinates (x, y, z) and considering integers (i, j, k, n), so that

$$(x_i, y_j, z_k) = (i\Delta x, j\Delta y, k\Delta z) \tag{5}$$

$$t_n = n\Delta t, \tag{6}$$

with the soace and time discretized. Using Taylor series expansion with a fourth order approximation we obtain:

$$\frac{\partial^2 \phi(x_i,y_j,z_k,t_n)}{\partial t^2} = \frac{\phi(x_i,y_j,z_k,t_{n+1}) - 2\phi(x_i,y_j,z_k,t_n) + \phi(x_i,y_j,z_k,t_{n-1})}{\Delta t^2}, \tag{7}$$

$$\frac{\partial^2 \phi(x_i,y_j,z_k,t_n)}{\partial x^2} = \frac{\phi(x_{i+1},y_j,z_k,t_n) - 2\phi(x_i,y_j,z_k,t_n) + \phi(x_{i-1},y_j,z_k,t_n)}{\Delta x^2},$$

for the coordinates y and z we obtain analogous expressions. By replacing the equation system (7) in (1), solving $\phi(x_i, y_j, z_k, t_{n+1})$, and following the nomenclature proposed by Yee (1966), we obtain:

$$\phi_{i,j,k}^{n+1} = V^2 \Delta t^2 \left(\begin{array}{c} \frac{\phi_{i+1,j,k}^n - \phi_{i,j,k}^n + \phi_{i-1,j,k}^n}{\Delta x^2} + \\ \frac{\phi_{i,j+1,k}^n - \phi_{i,j,k}^n + \phi_{i,j-1,k}^n}{\Delta y^2} + \\ \frac{\phi_{i,j,k+1}^n - \phi_{i,j,k}^n + \phi_{i,j,k-1}^n}{\Delta z^2} + \end{array} \right) + \left(\begin{array}{c} 2\phi(x_i, y_j, z_k, t_n) - \\ \phi(x_i, y_j, z_k, t_{n-1}) \end{array} \right). \tag{8}$$

Equation (8) solves the wave equation if the values in the boundary and the initial conditions are known. The elements of the wave function in the time step $n + 1$ depend on the four nearest neighbors in a previous time step n and on the same component in a time step $n – 1$. The direct algorithm estimates the arrival time of a seismic wave (T_{dir}), with propagation from the source j to the station k. The theoretical wave time (P) is obtained aggregating T_{dir} with the time of the seismic event (T_f), as can be seen in (9):

$$T_P^{teo} = T_{dir} + T_f. \tag{9}$$

The theoretical calculation of wave time S assumes that the wave velocities S and P are proportional in the entire medium and behave like a Poison solid (10), with proportionality constant with $\alpha = \sqrt{3}$. Thus, $T_S^{teo} = \alpha T_{dir} - T_f$ and the difference of arrival times of waves S and P is:

$$T_{sp} = T_{dir} + T_f, \tag{10}$$

$$T_{sp} = (\alpha - 1)T_{dir}. \tag{11}$$

As the station locations are fixed, T_{dir} depends on the velocity distribution and the hypocenter of the seismic event. Therefore T_P^{teo} is the only variable that depends on the origin time.

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2. Generalized linear inversion

In the inverse algorithm, we compared data measured on the surface with the results obtained from the simulation. Thus, we quantify the difference between the simulated values and the measured observations in the field. Then, it is possible to modify the initial values of the P wave velocity parameters in the field and the coordinates of the hypocenter. With these new initial values, we simulate the arrival times of the P wave for each one of the seismic events and compare the new results with the measured data on the surface, obtaining a new error difference, which will allow us to recalculate the new initial parameters for the next simulation.

This new methodology iterates until the difference between the simulated and the observed data on the surface is lower than the set threshold, in order to invert the velocity, the hypocenter and the origin time simultaneously and the origin time (Crosson, 1976; Ramadan, 2016). In the same way, the hypocenters inversion method was generalized in a simultaneous inversion of velocities and hypocenters (Franco *et al.*, 2006).

In the model, we consider N seismic sources with hypocenters given by x_j = longitude, y_j = latitude, z_j = depth, and arrival times t_j, where $j = \{1,2,3...,N\}$. Additionally, we split the in L blocks space each block with velocity v_j, where $l = \{1,2,3...,L\}$. These variables compose the model m^0:

$$m^0 = (x_1^0, y_1^0, z_1^0, t_1^0, ..., x_N^0, y_N^0, z_N^0, t_N^0, v_1^0, ..., v_L^0), \quad (12)$$

where $4N + L$ represents the number of elements.

To determine m^0, we consider M stations ($k = 1,2,...,M$) located at (x_k, y_k, z_k, t_k) and the arrival time observed in the k-th position for the j-th source. A functional relationship $T(m^0)$ allows us to reproduce the observed times according to the model m^0. If this relation is linear, the sensitivity matrix defined as:

$$G = (C), \quad (13)$$

where A_j is a $MX4$ matrix given by:
$$A_j = (C) \quad (14)$$
and C is a $NMxL$ matrix, the i-th line of C is:

$$C_{il} = \delta_{jki}\left(\frac{\partial T_{jk}}{\partial V_l}\right), \quad (15)$$

with $i(j,k) = k + (j-1)M$ and δ_{jki} is.
$$\Delta T \cdot (m) = G\Delta m, \quad (16)$$

To find Δm (16), we need to invert G, but G is not necessarily a square matrix. Therefore, we use the least square method to determine m, which consists of multiplying the matrix by its transpose and then we invert the result. According to this, (16) is transformed into:

$$G^T \Delta T \cdot (m) = G^T G\Delta m,$$
$$(G^T G)^{-1} G^T \Delta T \cdot (m) = \Delta m, \quad (17)$$

where ΔT is the variation between the time observed (measured on the surface) and the time simulated:

$$\Delta T = T_{Obs} - T_{Simulado}. \quad (18)$$

The error between both times is calculated as follows:

$$error = \sqrt{\sum_{k=1}^{M} \Delta T_k}, \quad (19)$$

and Δm is the change of the model, thus:
$$\Delta m = m^{i+j} - m^i = (G^T G)^{-1} G^T \Delta T \cdot (m). \quad (20)$$

The matrix $G^T G$ may have determinant equal zero, in which case the matrix is not invertible; this is means that the system shown in (20) does not have a unique solution, and there is at least one null eigenvalue. As proved by Schwerdtfeger (Schwerdtfeger, 1960), there is a method to obtain the subspace solution to the highest likely dimension, known as Lanczos breakdown. This technique consists of decomposing G through matrices built with eigenvalues different from zero. The generalized inverse found with this method fits better the data on the model. However, the computational method cost makes it difficult when implementing real-world applications where matrices are bigger. Furthermore, there is difficulty to formally organize the eigenvalues, due to the data uncertainty because some of them may have

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values too close to zero to be significant. Therefore, we use a different approach to overcome this obstacle: a weight matrix $\epsilon^2 W_m$ is added to the $G^T G$ as shown in (21):

$$m^{i+j} = (G^T G + \epsilon^2 W_m)^{-1} G T \, \Delta T \cdot (m) + m^i, \quad (21)$$

where ϵ is the dampening factor. If ϵ increases, the error curve presents fewer fluctuations because it depends on the iteration. This factor is found empirically, so we obtained a reasonable fit between the theoretical and observed data, and we also found that the variations of the model during each iteration are small. The W_m matrix in the most straightforward cases is the identity matrix. The initial model m^0 is proposed randomly but within a range of values that make sense in the geological model. With this model, the arrival time is simulated with the direct model and is obtained the difference with the reference time ΔT^0.

It is possible to define the smoothing matrix (Stein & Wysession, s. f.) to modify the change rate of the velocity model. For a 3D geometry composed by a rectangle with several blocks $L = L_x \times L_y \times L_z$, the number of columns for D is L and has the following form:

$$D = (D_x \, D_y \, D_z), \quad (22)$$

where the sub-matrices $D_x, D_y,$ and D_z represent the first derivative in the directions x, y and z with the number of rows $(L_x - 1)L_y L_z, L_x(L_y - 1)L_z$ and $L_x L_y(L_z - 1)$, respectively. The smoothing is applied to the velocity distribution, so it does not affect the hypocenter and origin time model, hence:

$$W_m = (I \, 0 \, 0 \, D^T D), \quad (23)$$

where I is the identity matrix with dimensions $4N \times 4N$

$D_x, D_y,$ and D_z comprise the sub-matrices $B_x, B_y,$ and $B_{z'}$ defined as:

$$D_x = (B_x \, 0 \cdots 0 \, 0 \, B_x \cdots 0 \; \vdots \; \vdots \; \ddots \; \vdots \; 0 \, 0 \cdots B_x)_{(L_x - 1)L_y L_z \times L}$$
$$D_y = (B_y \, 0 \cdots 0 \, 0 \, B_y \cdots 0 \; \vdots \; \vdots \; \ddots \; \vdots \; 0 \, 0 \cdots B_y)_{L_x(L_y - 1)L_z \times L} \quad (24)$$
$$D_z = (B_z \, 0 \cdots 0 \, 0 \, B_z \cdots 0 \; \vdots \; \vdots \; \ddots \; \vdots \; 0 \, 0 \cdots B_z)_{L_x L_y(L_z - 1) \times L}$$

where,

$$B_x = (-1 \, 1 \, 0 \cdots 0 \, 0 \, 0 \, -1 \, 1 \cdots 0 \, 0 \; \vdots \vdots \vdots \vdots \vdots \vdots \; 0 \, 0 \, 0 \cdots -1 \, 1)_{(L_x - 1) \times L_x} \quad (25)$$

$$B_y = \begin{pmatrix} -1 \, 0 \cdots 1 \, 0 \cdots 0 \, 0 \, 0 \, -1 \cdots 0 \, 1 \cdots 0 \, 0 \\ \vdots \vdots \vdots \vdots \vdots \; \vdots \vdots \; 0 \, 0 \cdots -1 \, 0 \cdots 0 \, 1 \end{pmatrix}_{L_x(L_y - 1) \times L_x L_y} \quad (26)$$

Usually, $B_x, B_y,$ and $B_{z'}$ are equal, and the only difference is the separation of the columns between -1 and 1. For B_x there is no separation; for B_y the separation is L_x; and for B_z separation is $L_x L_y$.

3. CONDITIONS OF NON-REFLECTIVE BOUNDARY

The boundary conditions known as Dirichlet or Neumann are the most used in the solution of partial differential equations. These boundary conditions can reflect all the energy in the boundary. However, the algorithm determine this energy reflected from any seismic source directly, causing phantom seismic events. Thus, we propose to use non-reflective boundaries, described below.

3.1 Disconnected wave equation

Hastings et. al. (Hastings et al., 1996) proposed a method based on (Berenger, 1994a) that consists of defining potential and decompose the wave equation according to the formulation of (Yee, 1966), is used for the electromagnetic fields.

The wave equation (1) can be split in connected equations, assuming that V is constant. Potential is defined as $H = (Hx, Hy, Bz)$ so that:

$$\frac{\partial H_x}{\partial t} = V \frac{\partial(\phi_x + \phi_y + \phi_z)}{\partial x},$$
$$\frac{\partial H_y}{\partial t} = V \frac{\partial(\phi_x + \phi_y + \phi_z)}{\partial y}, \quad (27)$$
$$\frac{\partial H_z}{\partial t} = V \frac{\partial(\phi_x + \phi_y + \phi_z)}{\partial z},$$

also,

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$$\frac{\partial \phi_x}{\partial t} = V \frac{\partial H_x}{\partial x},$$
$$\frac{\partial \phi_y}{\partial t} = V \frac{\partial H_y}{\partial y}, \quad (28)$$
$$\frac{\partial \phi_z}{\partial t} = V \frac{\partial H_z}{\partial z},$$

where $\phi = \phi_x + \phi_y + \phi_z$.

Following the scheme used by (Yee, 1966), the following nomenclature for the indeces is defined as:

$$\vec{r}_{H_x} = \left(i, j + \frac{1}{2}, k + 1/2\right),$$
$$\vec{r}_{H_y} = \left(i + \frac{1}{2}, j, k + \frac{1}{2}\right), \quad (29)$$
$$\vec{r}_{H_z} = \left(i + \frac{1}{2}, j + \frac{1}{2}, k\right),$$
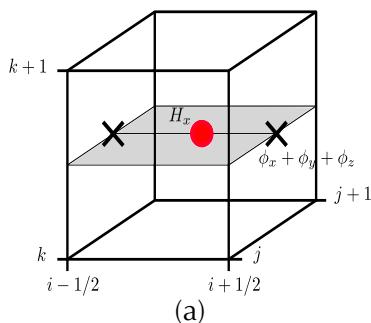
and,

$$\vec{r}_\phi = \left(i + \frac{1}{2}, j + \frac{1}{2}, k + \frac{1}{2}\right), \quad (30)$$

as suggested by Gonzalez (2012), the operators of centered difference are defined as:

$$\delta_x U(i,j,k) = U\left(i + \frac{1}{2}, j, k\right) - U\left(i - \frac{1}{2}, j, k\right),$$

$$\delta_x U(i,j,k) = U\left(i, j + \frac{1}{2}, k\right) - U\left(i, j - \frac{1}{2}, k\right), \quad (31)$$

$$\delta_x U(i,j,k) = U\left(i, j, k + \frac{1}{2}\right) - U\left(i, j, k - \frac{1}{2}\right),$$

According to the equations (30) to (32), the discretization of (27) in Taylor series with second order truncation error is:

$$H_x^{n+1/2}(\vec{r}_{H_x}) = \left[H_x^{n-\frac{1}{2}}(\vec{r}_{H_x}) + \Lambda_x \delta_x \left(\begin{array}{c} \phi_x^n(\vec{r}_{H_x}) + \\ \phi_y^n(\vec{r}_{H_x}) + \\ \phi_z^n(\vec{r}_{H_x}) \end{array} \right) \right],$$

$$H_y^{n+1/2}(\vec{r}_{H_y}) = \left[H_y^{n-\frac{1}{2}}(\vec{r}_{H_y}) + \Lambda_y \delta_y \left(\begin{array}{c} \phi_x^n(\vec{r}_{H_y}) + \\ \phi_y^n(\vec{r}_{H_y}) + \\ \phi_z^n(\vec{r}_{H_y}) \end{array} \right) \right], \quad (32)$$

$$H_z^{n+1/2}(\vec{r}_{H_z}) = \left[H_z^{n-\frac{1}{2}}(\vec{r}_{H_z}) + \Lambda_z \delta_z \left(\begin{array}{c} \phi_x^n(\vec{r}_{H_z}) + \\ \phi_y^n(\vec{r}_{H_z}) + \\ \phi_z^n(\vec{r}_{H_z}) + \end{array} \right) \right],$$

and the discretization for the system shown in (28) is:

$$\phi_x^{n+1}(\vec{r}_\phi) = \phi_x^n(\vec{r}_\phi) + \Lambda_x \delta_x [H_x^{n+1/2}(\vec{r}_\phi)],$$
$$\phi_y^{n+1}(\vec{r}_\phi) = \phi_y^n(\vec{r}_\phi) + \Lambda_y \delta_y [H_y^{n+1/2}(\vec{r}_\phi)], \quad (33)$$
$$\phi_z^{n+1}(\vec{r}_\phi) = \phi_z^n(\vec{r}_\phi) + \Lambda_z \delta_z [H_z^{n+1/2}(\vec{r}_\phi)],$$

Equations (32) and (33) show the evolution rule, as well as the relation between the potential and the wave function with their neighbors.

Each component of the potential contributed to the full wave function in the corresponding direction (Figure 1).

Figure 1. Spatial discretization diagram for the wave equation solution: Circles represent potential, *Hx* (red), *Hy* (blue) and *Hz* (green), and the cross shows the wave function. (a) Relation of *Hx* with its neighbors (the components of the wave function). (b) Association of ϕ_x, ϕ_y, and ϕ_z with its respective neighbors (the potential of each case). When the space split, and the disconnected wave function is in the semi-entire points and around the corresponding potential, which is going to help define its value.

Source: Authors.

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3.2. Attenuation factors

Assuming that the space formed by a square and covered by a shell of determined width, we define an *inside* region called *PML* and a contact region called *interface* (Figure 2). So that one wave will expand freely in the *interface* and will be absorbed in the *PML* region.
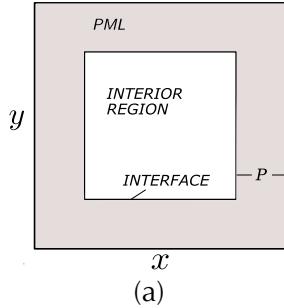
So that the wave attenuation occurs, (Berenger, 1994b) proposes attenuation factors Q_{s1} and Q_{s2} in the (33) and (34), so the potential is redefined as:

$$H_x^{n+1/2}(\vec{r}_{H_x}) = \begin{bmatrix} Q_{x1}(i) H_x^{n-\frac{1}{2}}(\vec{r}_{H_x}) + \\ +Q_{x2}(i)\delta_x \begin{pmatrix} \phi_x^n(\vec{r}_{H_x}) + \\ \phi_y^n(\vec{r}_{H_x}) + \\ \phi_z^n(\vec{r}_{H_x}) \end{pmatrix} \end{bmatrix},$$

$$H_y^{n+1/2}(\vec{r}_{H_y}) = \begin{bmatrix} Q_{y1}(j) H_y^{n-\frac{1}{2}}(\vec{r}_{H_y}) + \\ +Q_{y2}(j)\delta_y \begin{pmatrix} \phi_x^n(\vec{r}_{H_y}) + \\ \phi_y^n(\vec{r}_{H_y}) + \\ \phi_z^n(\vec{r}_{H_y}) \end{pmatrix} \end{bmatrix}, \quad (34)$$

$$H_z^{n+1/2}(\vec{r}_{H_z}) = \begin{bmatrix} Q_{z1}(k) H_z^{n-\frac{1}{2}}(\vec{r}_{H_z}) + \\ +Q_{z2}(k)\delta_z \begin{pmatrix} \phi_x^n(\vec{r}_{H_z}) + \\ \phi_y^n(\vec{r}_{H_z}) + \\ \phi_z^n(\vec{r}_{H_z}) \end{pmatrix} \end{bmatrix},$$
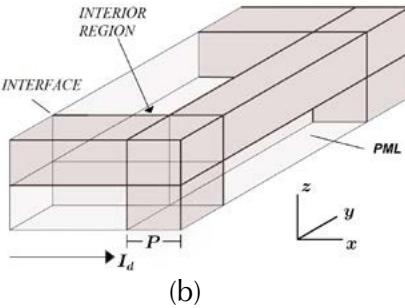
and for the disconnected wave function:

$$\phi_x^{n+1}(\vec{r}_\phi) = \left[Q_{x1}(i+1/2)\phi_x^n(\vec{r}_\phi) + +Q_{x2}(i+1/2)\delta_x \left(H_x^{n+1/2}(\vec{r}_\phi) \right) \right],$$
$$\phi_y^{n+1}(\vec{r}_\phi) = \left[Q_{y1}(j+1/2)\phi_y^n(\vec{r}_\phi) + +Q_{y2}(j+1/2)\delta_y \left(H_y^{n+1/2}(\vec{r}_\phi) \right) \right], \quad (35)$$
$$\phi_z^{n+1}(\vec{r}_\phi) = \left[Q_{z1}(k+1/2)\phi_z^n(\vec{r}_\phi) + +Q_{z2}(k+1/2)\delta_z \left(H_z^{n+1/2}(\vec{r}_\phi) \right) \right],$$

The attenuation factors:

$$Q_{s1}(\beta) = e^{-q_s(\beta)\Delta tV}, \quad (36)$$

$$Q_{s2}(\beta) = \frac{1 - e^{-q_s(\beta)\Delta tV}}{q_s(\beta)\Delta s}, \quad (37)$$

where $s = \{x, y, z\}$ and $\beta = \{i, j, k\}$, respectively, and

$$q_s(\beta) = \left(\frac{r(\beta)}{P} \right)^4, \quad (38)$$

where P is the length of the *PML* region and $r(\beta)$ is the depth from the *interface* to the outside edge as shown in Figure 2(a) and 2(b).

3.3. Complete solution

There is a slight change in the *interface* between the two regions, and the wave is slowly absorbed depending on the length P. Given the calculated limit in (38), when $r \to 0$ then $q \to 0$. So, from the (36) and (37) it is obtained that $Q_{s1} \to 1$ and $Q_{s2} \to \Lambda_s$ thus the same (32) and (33) are reproduced. Then, we use the standard solution in the *inside* region by using finite differences (8) and redefining the indices following the diagram in (Kane Yee, 1966):

$$\phi^{n+1}(\vec{r}_\phi) = \begin{pmatrix} 2(1 - \Lambda^2)\phi^n(\vec{r}_\phi) + \Lambda_x^2\delta_x\phi^n(\vec{r}_\phi) + \Lambda_y^2\delta_y\phi^n(\vec{r}_\phi) + \\ \Lambda_z^2\delta_z\phi^n(\vec{r}_\phi) - \phi^{n-1}(\vec{r}_\phi) \end{pmatrix}, \quad (39)$$

Figure 2. Wave space expansion. (a) The cube is cut in the z axis and forms a plane (known as a slice). A dark color represents the PML region. (b) Upper right edge of the cube.

Source: Authors.

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In the PML region, we use the solution of the disconnected wave equation (35), as well as the following equation in the *interface*:

$$H_x^{n+\frac{1}{2}}\left(I_d, j+\frac{1}{2}, k+\frac{1}{2}\right) == \begin{pmatrix} Q_{x1}(I_d)H_x^{n-1/2}\left(I_d, j+\frac{1}{2}, k+1/2\right) + \\ Q_{x2}(I_d)\begin{pmatrix} \phi_x^n\left(I_d+1/2, j+\frac{1}{2}, k+1/2\right) + \\ +\phi_y^n\left(I_d+\frac{1}{2}, j+\frac{1}{2}, k+\frac{1}{2}\right) + \\ +\phi_z^n\left(I_d+\frac{1}{2}, j+\frac{1}{2}, k+\frac{1}{2}\right) - \\ \phi^n\left(I_d-\frac{1}{2}, j+\frac{1}{2}, k+\frac{1}{2}\right) \end{pmatrix} \end{pmatrix}, \quad (40)$$

where I_d is the value that the index i takes in the right-side *interface* (Figure 2). Similarly, the equation of potential Hx is obtained in the left *interface* and for the rest of the potentials Hy and Hz. In other words, we have both the potential and the disconnected wave function in the *PML* region. In the *interface* we have only the potential and only the wave function in the inside (Figure 3). In most outer boundaries, we can use the Dirichlet or Neumann conditions (2).

3.4. Scope and limitations

There are three possible limitations in the proposed model. First, the velocity blocks, hypocenters, and stations must be located; then it is possible to define the space and its limits based on those locations. Additionally, the space should be small for a short computational time; conversely, ample space contains the location of elements and stations of the model and allows achieving an equilibrium. Second, it is better to have many blocks for the tomography in order to be more detailed; however, there is a limit to the information available. Finally, since the stations are located on the surface and the hypocenter is distributed in the sub-surface, there is significant uncertainty of the velocity solution the larger the distance between the stations and the hypocenter.
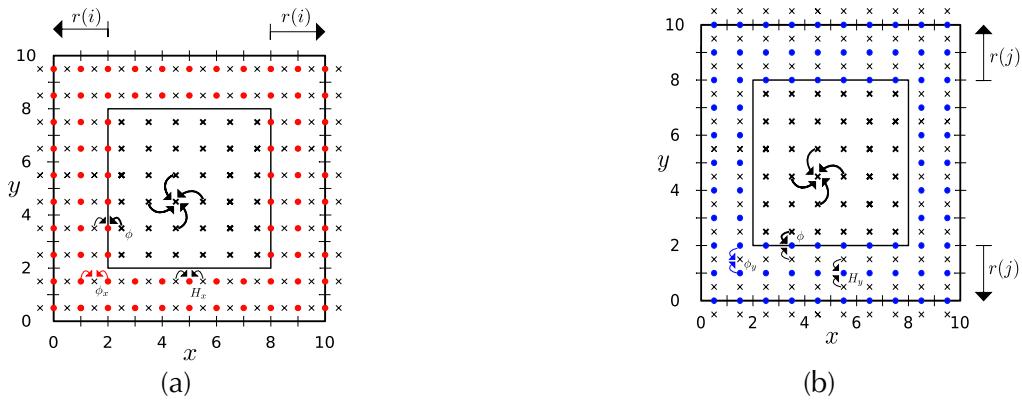
Figure 3. Slices of the cube for the complete solution of the wave expansion with a non-reflective boundary: Circles represent H_x (red) and H_y (blue), while crosses represent ϕ_x in (a), ϕ_y in (b) and ϕ (bold cross). Also, the arrows symbolize which neighbor feeds each term and $r(\beta)$ is the depth of the PML region from the interface to the edge. (a) Discretization for ϕ_x and H_x. (b) Discretization for ϕ_y and H_y.

Source: Authors.

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4. SPACE OF THE MODEL

The model validation comprised 54 seismic events, registered in Urabá, Colombia. We developed a model in which the limits are formed by a cubic surface with height h_z, width h_x in heading West-East, and length h_y heading South-North (Figure 4). It represents a part of the surface and sub-surface of this region, where the hypocenters of seismic events, the stations, and the velocity blocks are determined by the user. Furthermore, h_x and h_y are given by the location of the stations and epicenters of the seismic events (superficial projection of the hypocenters), while h_z is limited by the distribution of these events.

4.1. Number of elements in the model

There is a limit for the number of elements considered in the model depending on the information available. According to the number of seismic events ($N = 54$), 403 observed times are determined (number of equations), including the arrival time of the P wave (TP) and the difference between the arrival times of the P and S waves (TSP). To have a better adjustment of the convergence of the generalized inversion corresponding to the observed information, the number of equations cannot exceed the number of unknown factors; otherwise, we obtain unexpected solutions. The unknown factors are the elements of the model; for every seismic event there are 4 (location *x; y; z* of the hypocenter and origin

time), that is 4 x *N* = 216. They reduce the number of blocks to consider:

$$403 - 4 \times N = 187$$

So, the maximum number of blocks is 187. If h_x, h_y, and h_z split up in L_x, L_y, and L_z intervals, then a matrix forms a $L = L_x \times L_y \times L_z$ total blocks, so that $L_x \times L_y \times L_z < 187$.

4.2. Uncertainty of the velocity with depth

The last limitation is the uncertainty of velocity with depth. The trajectory between the hypocenter and the station is named ray according to the Fermat principle: the way taken by a wave expanding from one point to the other is such that the time used to cover it is minimum. The more significant the depth, the littler the ray density; so, the deepest cubes have a lower possibility of being crossed by a ray; furthermore, the uncertainty of velocity is more significant.

5. DIRECT ALGORITHM VALIDATION AND THE NON-REFLECTIVE BOUNDARIES

A region built with dimensions 200*km* x 40 *km* x 40*km* and seven stations on the surface, 10*km* apart towards *x* starting from *x* = 20*km* and the seismic source at $(100, 25, 25)$ *km*, with velocity $V_p = 5km/s$ as shown in Figure 5(a).

Figure 5(a) shows the wave reflecting on the boundary, while in figure 5(b) the wavefield is like
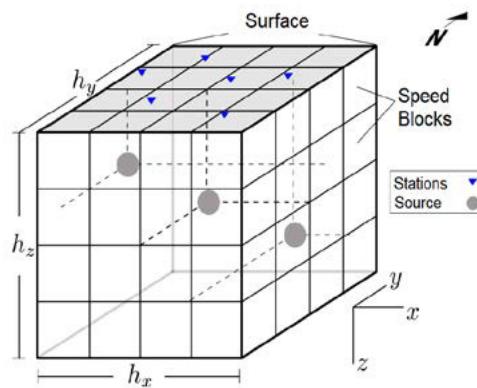
Figure 4. Spatial limits of the model formed by one cube split into blocks *L* with *N* sources and *M* stations.

Source: Authors.

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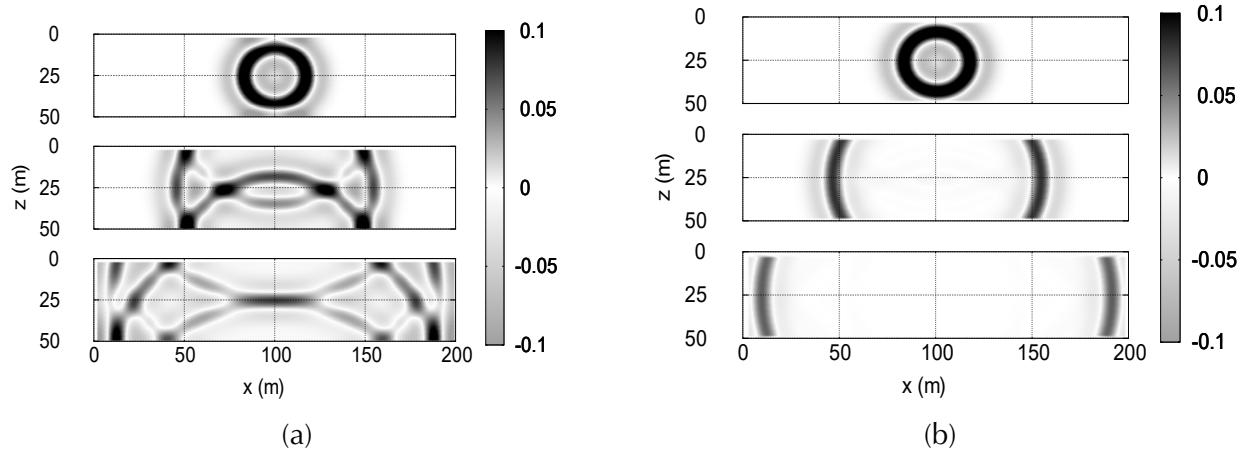
Figure 5. Plane view *y = 25 km*. **(a)** Without boundaries *PML*. **(b)** With boundaries *PML*. **Source:** Authors.

an open frontier. These reflections to the inside of the region in the study do not appear.

6. VALIDATION OF THE INVERSION PROGRAM

We built a synthetic model considering a region with dimensions 48*km* x 48 *km* x 48*km* divided into 64 blocks, each one characterized by velocity. The distribution is analogous to the checkerboard, with the alternate velocity *5.5 km/s* and *6.5 km/s*. In each block, a seismic source is at the center, and 16 stations in the center of the upper face of the superficial blocks as shown in Figure 6(a).

Using the direct algorithm, we simulate seismic events and determine the arrival times for each one (T_{obs}).

We run the initial inverse algorithm assuming an initial model with a uniform velocity of 5 *km/s* and hypocenters located in the center of the region (24 x 24 x24) *km* (Figure 6(b)). As expected, the initial error is significant. Figure 7(a) shows the result of 69 iterations where the error given by (21) converges after a certain number of iterations and the model does not change significantly. It was comparing the synthetic model in Figure 6(a) with the final model in Figure 7(b), it is possible to see that the difference is minimal on the surface but increases in deep parts and even more in the corners (Figure 8). Similarly, the error related to the velocity distribution increases
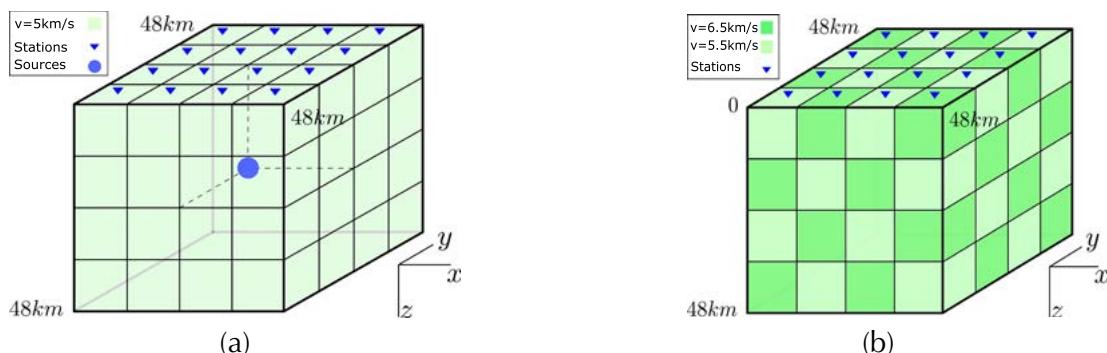
Figure 6. (a) Reference synthetic model containing 64 blocks with alternate velocity 5.5km/s and 6.5 km/s, 16 stations in the surface (blue triangles), and 64 seisms in the center of each block. **(b)** Model with homogeneous velocity of (5km/s) and initial location of the sources in the center of the cube.

Source: Authors.

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the deeper the hypocenter is located (Figure 7). This distribution means that a deep block has less chance to be sampled by the wave of any sources, and it will weigh less in the solution of the inversion. Therefore, a deep source location error because of the velocity error of a deep block.

Figure 7(c) shows the the hypocenters in the plane *xy* (*Slice z = 0*). They are located approximately in the center of the block,like the reference model. In Figure 7(d), we have the projections of the locations over the plane *xz* (*y = 0*), where the

hypocenters are approximately in the center of each block, except for the deepest blocks. The black dots show a more significant error.

A lack of information produces errors in the locations as well as errors in the estimation of velocity. This error is due to the ray paths coming to form seismic events that cut the blocks in the surface, while deeper rays only cuts deepest blocks. This lack of information from the deepest blocks creates an error in the source location of the sources, as well as higher velocities (Figure 8). In Figures 8(a) to 8(c),

(a)

(b)

(c)

(d)
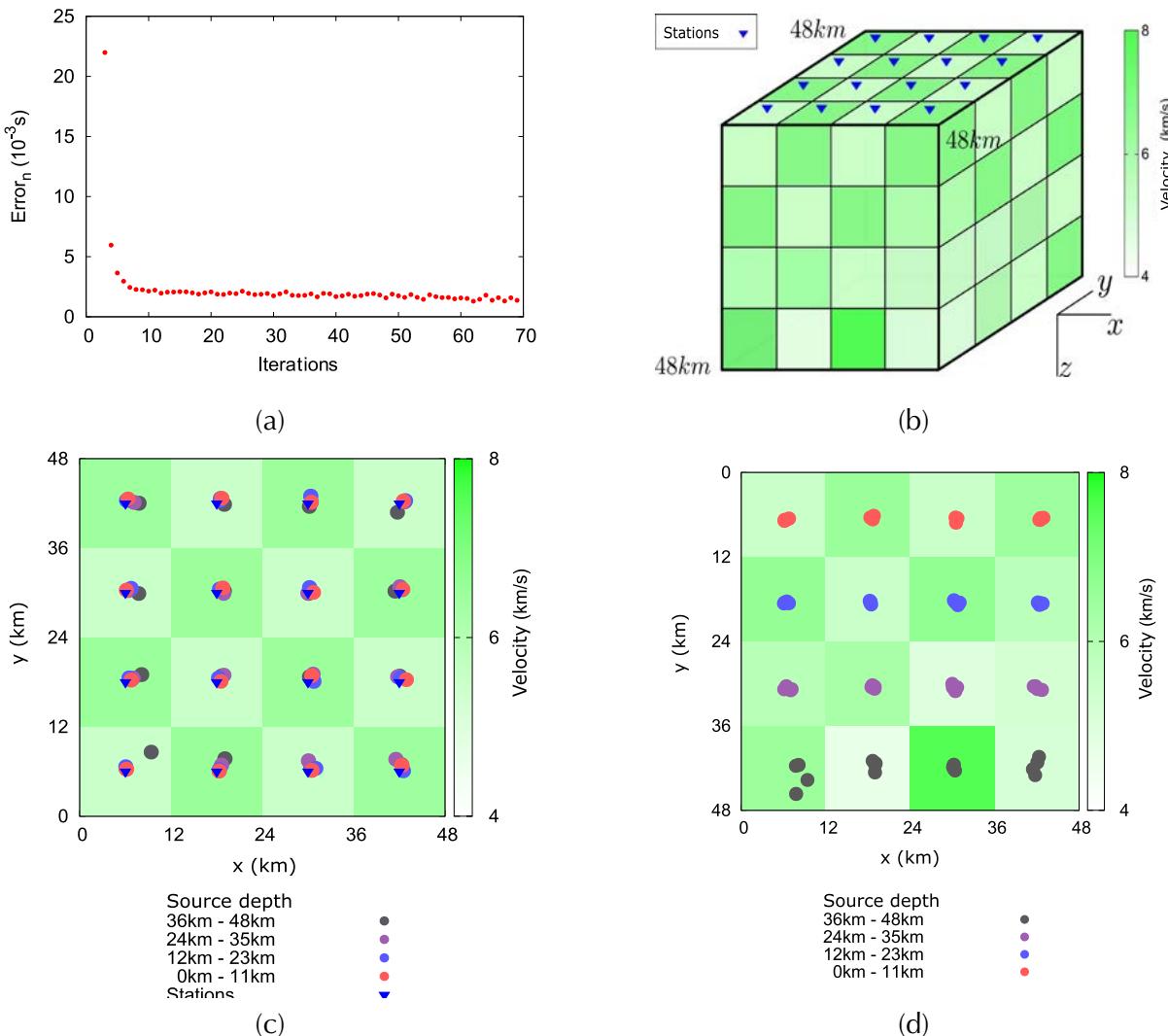
Figure 7. (a) Error variations depending on the iterations for a model with constant velocity. **(b)** Final model after the inversion containing 64 blocks, 16 stations in the surface, and 64 hypocenters (one per each block). **(c)** Slice of the hypocenters projections on the *xy* surface (*z = 0*). **(d)** View of the hypocenters projections in the *xz* plane (*y = 0*).

Source: Authors.

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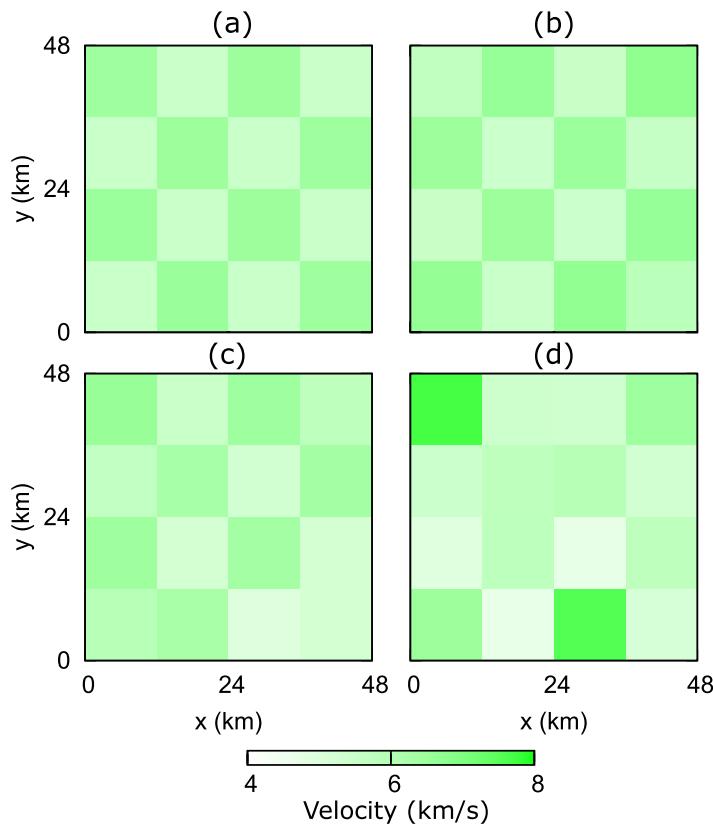
Figure 8. Velocity Slice section to different depths **(a)** 0 *km*, **(b)** 12 *km*, **(c)** 24 *km* and **(d)** 36 *km*.

Source: Authors.

the slices of the more superficial layers show that the velocity value is close to the value calculated by the reference model (Figure 6(a)), but Figure 8(d) represents a deeper layer, and the values show a more significant error.

CONCLUSIONS

An inversion program was created using inverse and direct models of an algorithm with the following contributions: the inverse algorithm considers the smooth velocity variations found in the geological models, while the direct algorithm works with finite differences and non-reflective PML boundaries, which offers a useful tool to make high-quality synthetic seismograms.

In order to prove the direct algorithm, we suggest making the solution of the wave equation by finite differences with non-reflective boundaries and

truncation error of grade 4 or higher. This reduces the error of the theoretical arrival time without damaging the computational time.

Multiple sources run simultaneously; this would represent a significant advance. For this reason, we proposed that the sources be distinguished by their frequency, as is the case with FM radio stations. Then, the simulated stations must discriminate frequencies, so that the computational time decreases.

Better results may be achieved if the acquisition time had been more significant. Therefore, we propose to install stations in the zone for over a minimum of 5 years. We also recommended the inversion program in real-time, with this work as an initial model, and obtaining a better resolution of the velocity and a reinforce the understanding of the tectonics of the region. The inversion program can be used for stations without synchrony.

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Drone Design for Monitoring Volcanic Areas

Diseño de Drones para monitoreo de zonas volcánicas

Juan Vorobioff[1] , Norberto Boggio[2] , Marcelo Gutierrez[3] ,
Federico Checozzi[4] , Carlos Rinaldi[5]

Abstract

Objective: Volcanic eruptions are a serious threat to the environment. In order to assess more accurately the state of a volcanic zone, spatially distributed measurements are required.

Methodology: An electronic nose (eNose), a quadcopter drone with gas, temperature, and humidity sensors was developed. The drone was assembled with 3D printed parts and tested for properties like structural rigidity. The eNose samples gases, manages a sensor array, acquires data, extracts features, and classifies them with suitable classification algorithms.

Results: The eNose drone system provides a versatile technology for autonomous monitoring of diverse environments. A logarithmic calibration curve was observed for the CO sensor.

Conclusions: The implementation of a eNose drone system and its application to the detection and study of gases in volcanic areas would be innovative in Argentina. The system can access remote dangerous areas and is versatile. Different gas sensors like H_2S or SO_2 can be added.

Resumen

Objetivo: Las erupciones volcánicas son una grave amenaza para el ambiente. La ceniza de un volcán puede contaminar el agua, la vegetación, el ganado y a las personas. Con el fin de evaluar con mayor precisión el estado de la zona volcánica, se requiere la aplicación de mediciones distribuidas espacialmente.

Metodología: Se desarrolló una nariz electrónica (eNose) y un dron cuadricóptero con sensores de gas, temperatura y humedad. El dron fue ensamblado con una estructura realizada con impresora 3D y se comprobó su correcta rigidez. La nariz electrónica toma muestra de gases, controla el array de sensores, adquiere datos, extrae características de los datos y clasifica las muestras con los algoritmos correspondientes.

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Resultados: El sistema de dron eNose provee una tecnología flexible para el monitoreo de diferentes entornos. Para el sensor de gas de CO se observó una curva de calibración logarítmica.

Conclusiones: La implementación de un sistema *drone eNose* y su aplicación a la detección y estudio de gases en áreas volcánicas resultaría innovador en Argentina. El sistema puede acceder a zonas remotas y peligrosas, y es muy flexible. Se pueden agregar diferentes sensores de gas como por ejemplo H_2S o SO_2.

INTRODUCTION

Currently, volcanic eruptions act as triggers for a series of processes that endanger the population. They constitute a serious threat and are responsible for many problems, which is why air quality must be monitored in volcanic areas (Malvina, 2019; Vargas, 2018). Gases released by a volcanic eruption will be highly toxic depending on their concentration, volume, and time in the environment. The follow-up and monitoring of these emissions must be carried out continuously throughout the whole process of a volcanic eruption in order to diagnose anomalies and prevent accidents (Amelung, 2007). Additionally, since wind and rain disperse the gases, it is essential to carry out spatially distributed direct readings to obtain a true representation of gas concentration. However, installing a fixed sensor network is not necessarily a reasonable solution due to economic and logistical reasons; thus, a mobile measuring device would be more useful and efficient (Vargas, 2018).

According to official information from the National Geographic Institute (IGN) in Argentina, there are around 37 active volcanoes in the Andes mountain range. So, this work presents the development and assembling of a drone for gas monitoring in volcanic areas.

Drones are very useful in this area since they allow control in dangerous environments. Sensing devices such as an electronic nose (eNose) can be used to take samples, interact with other systems, and provide useful markers to manage system operators. (Vorobioff, 2018) Also, drones can carry out continual measurement procedures over long time periods, so they can carry out space-time measurements with higher point density (Rodionova, 2005). Additionally, the use of an automated observation platform can minimize human intervention and minimizes gas exposure (e.g., to hydrogen sulfide).

Using a drone would make it possible to locate the emission sources of the pollutants and carry out the monitoring required by volcanologists in a faster and less expensive way. The development and implementation of a complete equipment, an eNose drone, could be used for an in-situ detection of pollutants and their source, and then take direct action measures when necessary. The complete development of this technique would allow an early diagnosis of volcanic eruptions and a preventive control over the nearby population (Hanisch, 1998). The drone would have built-in sensors able to find the exact location of volcanic eruptions and would have the computational capability to calculate gas and temperature distribution, for example (Hein, 2009). This would allow deciding the places that according to the model should be observed. (Wold, 2001) A drone must be able to perform three main tasks: It must serve as a flexible and autonomous system to explore large areas to measure gas concentrations (e.g., H_2S and CO_2); it must be able to provide useful information such as distribution maps and gas leak locations from the acquired data; and it must take measurements, take images, and pass on this information in real time (Neumann, 2010).

Therefore, the prediction of eruptions from location and on-site monitoring of gas emission sources could be possible in a faster and less expensive way.

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The environmental impact could be rapidly reduced by improving the quality of the management system (Vega-Posada, 2017). The complete development of this technique would allow the diagnosis of soil quality as well as sanitary control (Becken, 2011).

In the bibliography there are also numerous examples of this kind of applications. For instance, the Federal Institute for Materials Testing and Research in Germany designed a drone with different sensors (Neumann, 2010). Gas sensitive drones are valuable instruments to address these issues such as gas leak detection, monitoring, or exploration of dangerous regions (Massacane, 2010)

METHODOLOGY

Drone manufacture

The implemented methodology aimed to perform the following: to develop a drone (mobile robot) with an eNose system; and to test the analytical capabilities of the assembled system by conducting studies in semi-field conditions (small spaces under controlled conditions). Once these objectives are met, an area or region of interest may be explored to sample pollutants and to obtain their distribution map. Results in different project stages contribute to the development of new technologies relevant to environmental chemistry; in each of the stages of this work, different human resources are trained in order to apply these new technologies to different areas (Márquez 2012).

Drone structure parts were manufactured using a 3D printer, and the drone's arm rigidity was tested. The weight of each arm must be constant; and since the tubular arms oscillate less than the rectangular ones, the tubular were chosen to improve the structural rigidity of the drone. Furthermore, parts were printed with filaments composed of different materials to obtain a robust frame. Motors and propellers were selected according to the drone load capacity, sensors, stability control, and the tele-transmission system. The flight can be controlled manually by

remote control or autonomously by a programmed flight plan.

The electronic controller was compensated to avoid vibrations because it was essential to have more rigidity. The selected design of the drone allowed printing without support material and can accommodate 3-cell 6000 mAh or 4-cell 4200 mAh LiPo battery. It was possible to put camera and/or sensors in their compartments. Four Readytosky model 2212 of 920 kV motors and suitable propellers were selected. A Pixhawk PX flight controller was chosen because it has the following benefits: real-time operating system (RTOS), multiple communication interfaces, a backup power system, manual and automatic flight modes, and the ability to record flight data on an SD card. The chosen kit also includes a GPS module and telemetry, and a Radiolink AT9S 2.4G 9CH transmitter allowed the connection with the drone. In the following section, different parts of the drone and its characteristics are described in detail.

Motors and propellers
Four Readytosky 2212 920 kV motors and the most suitable propellers have been selected for the drone (Figure 1). Their main characteristics are described below:

Model RS 2212, Weight: 56 g, Size: 24 x 12 mm
Propellers: model 1045

Electronic speed controller

Figure 1. Motor RS 2212 and propellers model 1045.

Source: AliExpress (https://www.aliexpress.com/i/4000560376991.html).

Drone Design for Monitoring Volcanic Areas

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The selected Electronic Speed Controller (ESC) model is Simonk 30A (Figure 2). Its main characteristics are:

Brand: Readytosky, Cont.Current:30A, Burst Current(10sec): 40A, BEC (Battery Elimination Circuit): 3 A, recommended battery: Lipo:2-3S LiPO, with dimensions LxWxH: 45 x 24 x 9 mm, and weight: 24 g.

Flight controller

The Pixhawk PX flight controller (Figure 3) has been chosen for its multiple advantages. It has a real-time operating system (RTOS), multiple communication interfaces, backup power system, manual and automatic flight modes, and the ability to record flight data on an SD card. This model also includes a GPS and telemetry module.

Features:

1. Ultra-fast microcontroller of 32 bits with real-time systems
2. 14 output PWM
3. Interface UART and I2C

Remote control system

The link with the drone is done through a Radiolink AT9S for RC quadcopters (Figure 4)

Features:

- Dimensions: for AT9S: 185 x 105 x 183mm
- Weight: 0.88 kg
- Modulation: QPSK
- Bandwidth: 6 MHz and 250 kbps
- Distance: 950 meters above ground, 1400 meters in the air.
- Channels: 8
- Screen: 2.7 ″230 x 320 pixels, 16 colors.

Figure 2. Electronic Speed Controller (ESC) Simonk 30A.

Source: Authors.

Figure 3. Pixhawk Flight Controller.

Source: Authors

Figure 4. left). RadioLink AT9S transmitter, **right)**. RadioLink R9DS receiver.

Source: Authors.

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Drone structure

To implement the drone structure, parts were manufactured using a 3D printer. 3D printers make replicas of 3D designs, creating pieces with any type of complexity. For the drone shell, a Thingiverse design was used. This online community is managed by the 3D printing company Makerbot, which is a site for sharing object designs that can be 3D printed. In this case, there are many models available to print, but the structures have to be selected correctly to obtain better rigidity and guarantee low weight.

Two quadcopter arm models are shown in Figure 5; a weight is placed on each arm and they sway. At the same weight, the tubular arm oscillates less than the rectangular arm, so the tubular arms are chosen to improve structural rigidity because the electronic controller has to compensate for arm vibrations.

The selected design can be printed without support material, and it can accommodate a 3-cell 6000 mAh or 4-cell 4200 mAh battery. Furthermore, it is possible to house camera and/or sensors in their compartments.

Figure 6 shows the different 3D printed parts used to assemble the drone structure. The complete structure of the drone weighs 480g without the electronics. Special care has been taken so that the 4 drone arms have similar weights.

The characteristics that had to be selected for the drone in order to develop this work are:

- The correct structure of the drone so that it has low weight and good rigidity.
- Medium kV motors.
- Optimal battery for 12 minutes of flight.
- Propellers.
- Required current from the ESC controller.
- Flight controller.
- Autopilot.

Figure 7 shows a typical quadcopter connection diagram with ESC controllers' interface between motors, control logic, and battery. The battery powers the ESC that powers the motors. Three signals compose the ESC control logic: ESC signal, telemetry signal (which is optional), and the ESC signal ground connection. In this case, the ESC signal from each drive is controlled by a PWM pin on the system and the ground signals can be connected to the control system ground.

Figure 5. Rigidity test of the drone arms: Tubular (blue) and Rectangular (violet) arms.

Source: Authors.

Piece	Time	Layer height	Filling	Material
x4	01h36m	0.35 mm	20 %	ABS
	10h04m	0.35 mm	20 %	ABS
	02h58m	0.35 mm	20 %	ABS
	01h36m	0.35 mm	20 %	ABS
x4	06h01m	0.20 mm	50 %	PLA
	03h48m	0.35 mm	20 %	ABS

Figure 6. Printed parts of the drone and their printing features.

Source: Authors.

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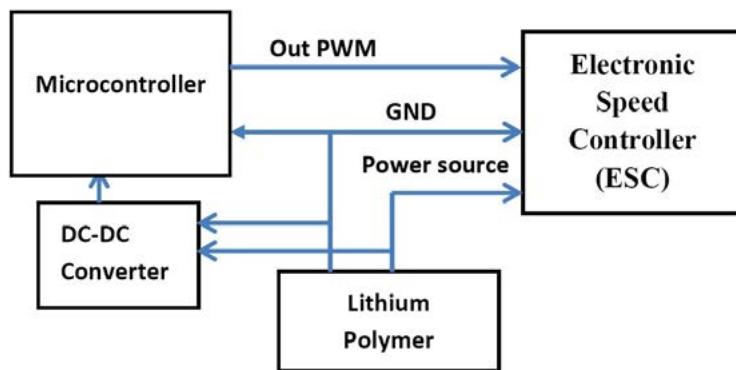
Figure 7. Connection diagram of the motors and ESC to the drone.

Source: Authors.

Gas detection system

The gas detection system (eNose) to be mounted on the drone consists of a plate containing the gas sensors, the electronics to process measurements, and an Arduino Nano 3.0 microcontroller. Data is analyzed on a PC with a user-friendly pattern recognition software which has a GUI that allows to pick between PCA, Fisher, and linear classifiers.

The sensor array consists of 6 Microsens MOS type gas sensors, and part of this arrangement consisted of three MSGS-3000i sensors. The MSGS-3000i Gas Sensor detects CO, ethanol, and volatile organic compounds (VOC) emissions. The remaining part of the arrangement consisted of three

MSGS-3007i sensors, which detect NO_2 in 0.05 to 5 ppm range. Due to the integrated sockets that the eNose possesses, sensors could be easily changed to detect different compounds. Figure 8 shows the ENose board with the 6 gas sensors.

Detectable gases:
- CO: 2 – 1000 ppm
- C_2H_5OH: 20–500ppm
- H_2: 1–1000ppm
- NH_3: 1–600ppm
- CH_4:> 2000ppm

Drone system integration with the eNose
An electronic nose (eNose) is attached to the drone. An eNose is an instrument that can "smell" and is
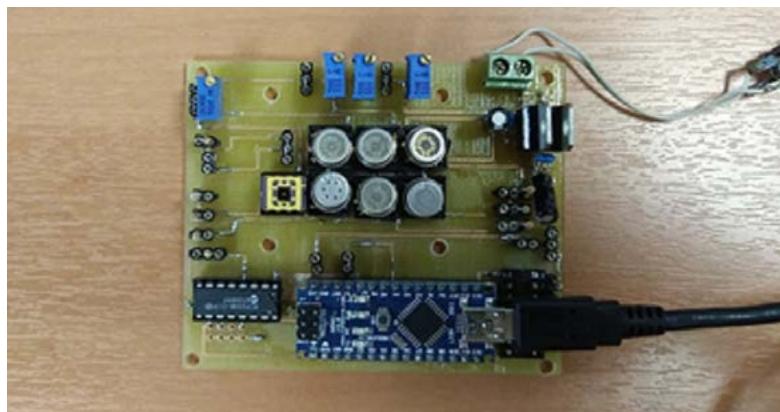
Figure 8. eNose board.

Source: Authors.

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able to execute analyses of a mixture of gases, vapors, and odors. It is an artificial smell instrument that allows distinguishing and recognizing aromas using gas sensors (Rodríguez, 2019). This device has 4 subsystems: one that samples and evaluates the quality of the gas mixture, the gas sensor array that detects the gas mixture, the control electronics that manages the sensor array and signal quality, and the data acquisition and processing system that extracts characteristic features or "traces" of each aroma and reports the results to the user. Each function must be integrated into the drone and tested in flight. The compact eNose design can be used both in R&D laboratories and in field work with the addition of batteries. The data is processed with a versatile and friendly-interfaced recognition software that uses one of the following algorithms to process the data: PCA, Fisher and Linear Classifiers (Scott, 2006), (Webb, 2011).

Integration by parts

Since the eNose has its own hardware with a data acquisition system, this equipment should preferably be mounted on top of the drone. The system is powered by LiPO batteries that consist of 3 packs with 5200 mAh cells. Also, a GPS system must be installed in order to temporarily geolocate and synchronize the eNose measurements, so the measurements results will be correlated with the physical position of the drone and the measuring time. The drone's trajectory will be programmed according to different measurement needs and areas of interest. Once the characterization stage of the different systems is completed, the area of interest will be analyzed.

RESULTS

The implementation of an eNose drone system has the advantage of being a flexible system. This project was carried out with the objective of studying the negative environmental impacts arisen from volcanic eruptions, but the technological innovations of this project could be applied to other fields of monitoring. For example, controlling high-toxicity-risk areas due to the emission of gaseous pollutants, inaccessible for humans. Figure 9 shoes the assembled.

a)

b)

Figure 9. Assembled drone. **(a)** Top view. **(b)** Side view.

Source: Authors.

Gas sensor system

The eNose board tests were performed to verify the correct operation of the gas sensors. Different gases were injected using a Gas Bank. A Mass Flow Controller (MFC) generates different concentrations of gases to perform the calibration curve of the sensors.

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For example, the response of a sensor for different CO concentrations is shown below, and figure 10 presents the logarithmic response. The normalized resistance of the sensor is plotted: Rs/Ro, where Rs is the resistance measured in the presence of gas, and Ro is the resistance in the presence of air.
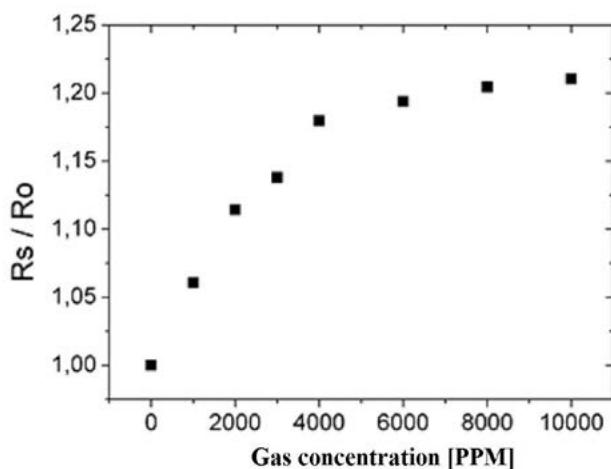
Figure 10. Normalized sensor response for different CO concentrations.

Source: Authors.

CONCLUSIONS

The implementation of an eNose drone system and its application to the study and detection of gases in volcanic areas would be innovative in Argentina. It was designed for the prevention and minimization of negative environmental impacts arising from volcanic eruptions. The technological innovation on this work could be used on other monitoring applications, like controlling areas with a high risk of toxicity due to the emission of gaseous polluting substances, inaccessible by human contact, such as industrial effluent treatment plants, areas close to toxic spills, and volcanic formations. Furthermore, it contributes to reducing the risk of accidents to volcanologists from a human-safety point of view.

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Evaluation of Mechanical Properties of Composites Manufactured from Recycled Tetra Pak® Containers

Evaluación de propiedades mecánicas de compuestos manufacturados a partir de contenedores de Tetra Pak® reciclados

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Abstract

Context: Tetra Pak® is a common material used for the production of food containers. Currently, those containers are recycled by physical separation of the cellulose fibers through a hydro pulped process, but sometimes separating the individual components is not economically viable. This work evaluates an alternative process to obtain composites from recycled Tetra Pak®.

Methodology: Tetra Pak® used containers were collected and cut into small pieces at the laboratory. Then, the containers were hot-pressed to obtain sheets in a manual hydraulic press by using different configurations. Samples were cut, and their tensile strength was evaluated (ASTM D3039). Failure analysis of samples was carried out by FE-SEM to identify issues related to processing and to understand the differences in mechanical properties.

Results: The results showed that the lowest tensile strength was 9.5 MPa (type I sample) and the highest tensile strength was 37.4 MPa (type III sample).

Conclusions: The results of mechanical tests show that this material can be used for non-structural purposes in the building industry. Failure analysis shows that fiber pull-out and delamination are the most important failure mechanisms in type I samples. For type III sample, failure was produced by a sequence of intralaminar fractures.

Financing: Instituto Tecnológico Metropolitano de Medellín

Keywords: composites, hot-pressing, mechanical properties, recycled, Tetra Pak®.

Resumen

Contexto: Tetra Pak® es un material común que se utiliza para recipientes de alimentos. Actualmente, esos contenedores se reciclan mediante la separación física de las fibras de celulosa a través de un proceso de hidropulpeado, pero a veces no es económicamente viable separar los componentes individuales. En este trabajo, se evaluó un proceso alternativo para obtener materiales compuestos de Tetra Pak® reciclado.

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Metodología: Inicialmente, los contenedores de Tetra Pak® usados se recolectaron y cortaron en trozos pequeños en el laboratorio. Después, los contenedores se prensaron en caliente para obtener laminados en una prensa hidráulica manual utilizando diferentes configuraciones. Después de obtener los materiales compuestos, se cortaron las muestras y se evaluó su resistencia a la tracción (ASTM D3039). El análisis de fallas de las muestras fue realizado por FE-SEM para identificar problemas relacionados con el procesamiento y para comprender las diferencias en las propiedades mecánicas.

Resultados: Los resultados mostraron que la menor resistencia a la tracción era de 9,5 MPa (muestras de tipo I). La mayor resistencia a la tracción fue de 37,4 MPa para muestras de tipo III.

Conclusiones: Los resultados de las pruebas mecánicas permitieron concluir que el material se puede utilizar para fines no estructurales en la industria de la construcción. El análisis de fallas mostró que el desprendimiento de la fibra es el mecanismo más importante en las muestras de tipo I. Para las muestras de tipo III, la fractura se produjo por una secuencia de fallas interlaminares.

Financiamiento: Instituto Tecnológico Metropolitano de Medellín

Palabras clave: compuestos, prensado en caliente, propiedades mecánicas, reciclado, Tetra Pak®.

INTRODUCTION

Current efforts in material science aim to reduce the use of primary materials as wood (Ayrilmis et al. , 2013; Hidalgo et al., 2013a). Composites made from waste seems to be a good option and have gained increasing attention (Souza et al., 2018; Moreno & Saron, 2017). Tetra Pak® is a material used for food packaging and consists of three layers: carton, polymer, and aluminum. Those containers are recycled by physical separation of the cellulose fibers through three main processes: incineration, aluminum recovering by pyrolysis, and processing in an extruder (Lopes & Felisberti, 2006). However, in most of cases it is not economically viable to separate the individual components because although composites have been obtained, there is still a lack of knowledge to identify the variables required to process them and turn them into something functional.

Ali & Nystrom (1995) used Tetra Pak® in their work and performed a physical separation of polyethylene and aluminum (PEA) from the cellulose fibers through a hydro pulped process. In their work, the authors used water and shook the Tetra Pak® containers for several minutes (30-45 min). After an appropriate shaking time, the cellulose phase and PEA were partially separated from each other.

The authors also added an accelerator (NaOH) to remove hydrogen bonds and recover more fibers. A similar procedure was done by Turrado et al. (2012). However, at the end of the process PEA still contained some cellulose.

Recycling of containers is possible using different processes. Hidalgo et al. (2013b) indicated several methods used to manufacture polyethylene aluminum (PEA), such as hot plates compression, extrusion, injection, and rotational molding. The authors showed several applications for the PEA such as plastic wood and automobile applications, among others. However, they did not use 100% of the containers but developed the products using the PEA in all cases. On the other hand, Paula et al. (2005) used PEA with recycled HDPE/LDPE and virgin PolyEthylene (PE) resin to get materials with improved mechanical properties, but increased the water absorption by the polyamide presence in the HDPE and LDPE recycled. However, all the mixtures had excellent chemical resistance. Salamanca & Vaca (2017) have reported the effect on mechanical properties (tensile and flexural strength) of a thermoformed composite (90 wt% Tetra Pak® and 10 wt% LDPE). Galvis & Villabona (2016) have studied the feasibility of using 100 wt% Tetra Pak® for structural applications. Bekhta et al. (2016) made thermoformed panels using several types of containers

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(including Tetra Pak® and candy packing) and they found that the new product has improved mechanical properties when it was compared to virgin resin of PE.

Recent studies (Kaseem et al., 2017) indicated that small wood particles used as reinforcements (in sizes 100 μm and 600 μm) improved the adherence between the particles and the polymeric matrix. Valim et al. (2015) analyzed the possibility of using polyethylene aluminum (PEA) composite in buildings. However, the composites were affected significantly by exposure to UV light, thus degrading mechanical properties like impact resistance and strain resistance. So, the authors concluded that PEA might be used but not in structural components of civil constructions. New uses and modifications for the PEA were also reported by Caraschi & Leão (2003). In their work, the authors showed that chopped Tetra Pak® might be used as reinforcement in a polypropylene matrix since the natural fibers in the container increased the tensile strength if the content of recycled material is near to 15%wt. In another study Ebadi et al. (2016) evaluated Tetra Pak® wastes as a reinforcement in polymers. The authors found that tensile strength of composites increased 26% after including Tetra Pak® wastes. In another application of Tetra Pak®, Silva et al. (2015) fabricated several types of roofs, made from 100% PEA using zinc and PEA. The authors evaluated the tensile strength and the sheets capability for use as thermal and sound insulators. In another work, Rhamin et al. (2013) concluded that recycled panels made from Tetra Pak® might be used for internal or external applications.

In summary, several authors are trying to manufacture composites from recycled Tetra Pak®. So, this work aims to assess the mechanical properties of composite materials manufactured from 100 wt% recycled Tetra Pak® containers and to avoid the extensive use of water and resins. The premise is that the preparation of raw material must be done without extensive labor and water would not be used to separate or modify the containers to obtain a most sustainable process. Several samples were prepared by modifying the size of raw

material and the manufacturing parameters. After obtaining the samples, the mechanical properties and water absorption tests of the composites were evaluated. Also, the fracture surface of the samples was analyzed by FE-SEM in order to understand the main failure mechanism. The results were compared with other materials used in non-structural applications to demonstrate the capabilities of the composites obtained in this article.

EXPERIMENTAL METHODOLOGY

Materials Processing

Commercial Tetra Pak® containers with dimensions 4.6 mm L x 3.6 mm W x 11.85 mm H were collected. The containers are composed of several layers of low-density polyethylene (LDPE) 20%wt., Aluminum (Al) 5%wt. and cellulose 75%wt., according to the manufacturer. Three different samples were prepared to develop this experiment. The samples were prepared in order to obtain composites without additives or reinforcements, and by using a scalable process to obtain sheets. Initially, the containers were disassembled and stacked manually. Fifteen as-received containers were stacked in 5 layers to obtain a final composite without cutting the containers and create Type I samples; Type II samples were prepared by cutting the containers into slices of 10 mm x 15 mm; and type III samples, by cutting containers into pieces of 5 mm x 5 mm. After positioning the layers in a mold of 250 mm x 120 mm x 7 mm and applying several cycles of pressure and temperature in a manual hydraulic press with hot plates, the composites were obtained. The processing parameters used in this work were selected according to the literature (Sun & Zhang, 2013), and the limitations of the equipment available in the polymers laboratory of the Metropolitan Technological Institute (ITM, in Spanish). After cutting, samples were hot-pressed without any additional binder to form the composite, so the final composite is obtained using 100% recycled materials.

The procedure C recommended in ASTM D4703-03 was used: a suitable working method

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for thermoforming polyethylene sheets with a working pressure higher than 8 MPa. Figure 1 outlines the procedure, as well as the pressure, temperature, and time during the sheets manufacturing.

Mechanical properties

The composite sheet (200 mm x 120 mm x 7 mm) was cut manually to obtain the samples, which were prepared according to the ASTM D3039 standard (Standard Test Method for Tensile Properties of Polymer Matrix Composite Materials) by aligning the test specimens by the sheets' longest dimension (200 mm). The mechanical tests were done in a Shimadzu AGX-100 KN Universal testing machine

available in polymers laboratory of the ITM. All samples were tested at a testing speed of 5 mm/min at 25 °C. In all cases, for every type of material, three samples of each type were tested, and the results were averaged.

Analysis of fractured surfaces

After performing mechanical tests, the samples were analyzed to understand the main failure mechanism and to determine how the manufacturing process could be improved. The samples were observed in a LEICA EZ4D stereomicroscope and in a FE-SEM 7100F available in the microscopy laboratory of
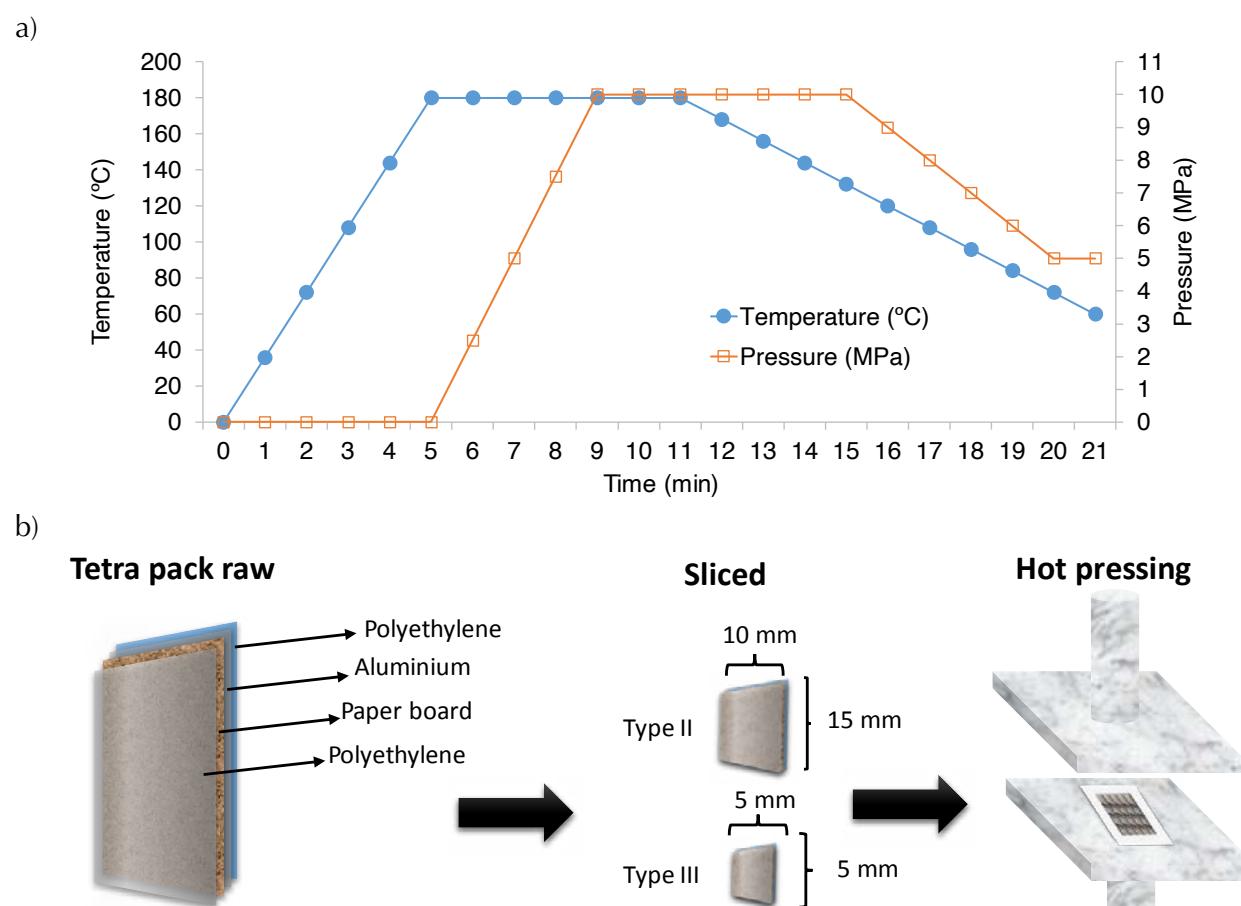
Figure 1. (a) Pressure, temperature, and time during the sheets manufacturing. (b) Details about the mold and the slices used during the manufacturing.

Source: Authors.

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ITM. The samples were covered with a thin layer of gold to avoid surface charging.

Water absorption tests

Water absorption tests were done according to the ASTM D570-98 (2005) standard. The samples weight was recorded before and after soaking them in water for 24 hours. Both weights were compared to obtain the water absorption. The dimensions of samples were 76 mm x 24.5 mm x 7 mm (length, width, and thickness, respectively). The procedure described in numeral 7.1 of the ASTM D570 standard was used: immersing the specimen in distilled water during 24 h at 23 ° C ± 1 ° C.

RESULTS AND DICUSSION

Mechanical properties

Figure 2 shows the average and standard deviation of tensile strength of the manufactured samples. The lowest resistance was found in Type I samples and the highest was found in Type III samples. Type I

samples had even lower resistance than that of the LDPE matrix (13.3 – 26.4 MPa) (Barcelona, n.d.). In this case the low resistance of the composites can be explained by the lack of preparation of Type I samples since the samples were hot pressed without cutting the container.

Type II samples showed an intermediate resistance (24.1 MPa) and the standard deviation of the results shows that the manufacturing process is uniform. Conversely, Type III samples (chopped material) report the highest tensile strength, but they also have the highest standard deviation, so the processing conditions did not provide uniform materials.

This behavior can be explained by the different orientations of the chops used for the manufactured composites. Since the orientation of the chops was not controlled during the manufacture, the fibers randomly oriented can affect the tensile strength measured in just one direction. Table 1 lists different materials investigated by other authors or commercial materials and shows the maximum tensile strength possible. It is observed that the resistance of the materials investigated in this work is similar to that observed by other authors. Moreover, the resistance
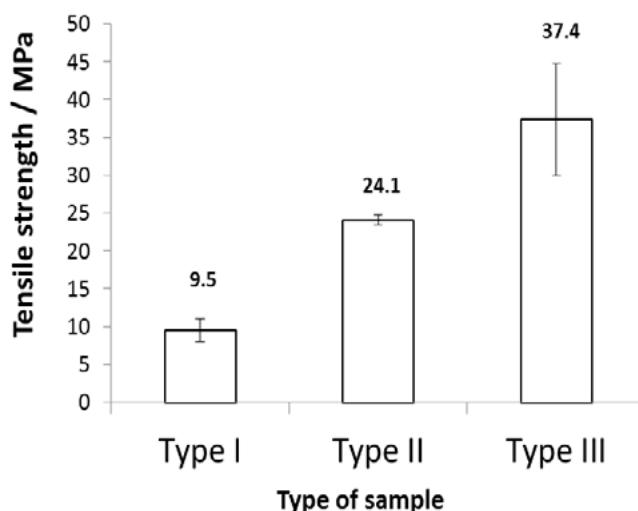
Figure 2. Results of tensile tests.

Source: Authors.

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of the prepared recycled Tetra Pak® composites without any further modification is similar even though those reported in the Table 1 were modified with resins and polymers. Also, some authors have studied the mechanical properties of materials for non-structural purposes in the construction industry. The values reported in this work are comparable with those found in literature for Short Pineapple-Leaf-Fiber (PALF)-LDPE Composites (10.2 MPa–13.0 MPa, and 16.3 MPa–22.5 MP, for randomly and longitudinally oriented fiber, respectively) (George et al., 1995), and for Wood-plastic board (WPB), sugarcane bagasse particleboard (SBpb), Plywood board (PB), and Sugarcane bagasse fiberboard (SBfb), whose values are 28.20 MPa, 14.35 MPa, 15.20 MPa, and 31.45 MPa, respectively (Martínez-López et al., 2014) for non structural purposes.

Hitchon & Phillips (1979) reported that the fiber strength decreases as the length of the fiber increases; and Pamungkas et al. (2018) showed that the fiber length increases the mechanical properties of a composite of Zalacca Midrib Fiber (ZMF)/HDPE. This article does not include tests for the effect of the fiber length, but the size of the chops can be interpreted as an indirect evaluation of the fiber length. The results of this article show that the shorter the chops, the tensile strength increases. However, some authors have found ambivalent results, so there is no clear trend about the effect of fiber length on tensile strength (Amuthakkannan et al., 2013).

On the other hand, when the fibers are perpendicular to the direction of the applied stresses, they act as stress raisers, but it is worth noticing that the fibers in the fragments of the samples had a random orientation and their effect was not studied. When the fibers are cut into small pieces, there is a higher probability of finding fibers perpendicular to the load application direction, which would imply a lower resistance of the compounds in this order: Type III < Type II < Type I. However, the behavior of the tests for this research was contrary leading to the phenomenon associated with the direction of the fibers being negligible. A similar behavior has been reported in the literature by other authors (Xia et al., 2002).

Analysis of fractured surfaces
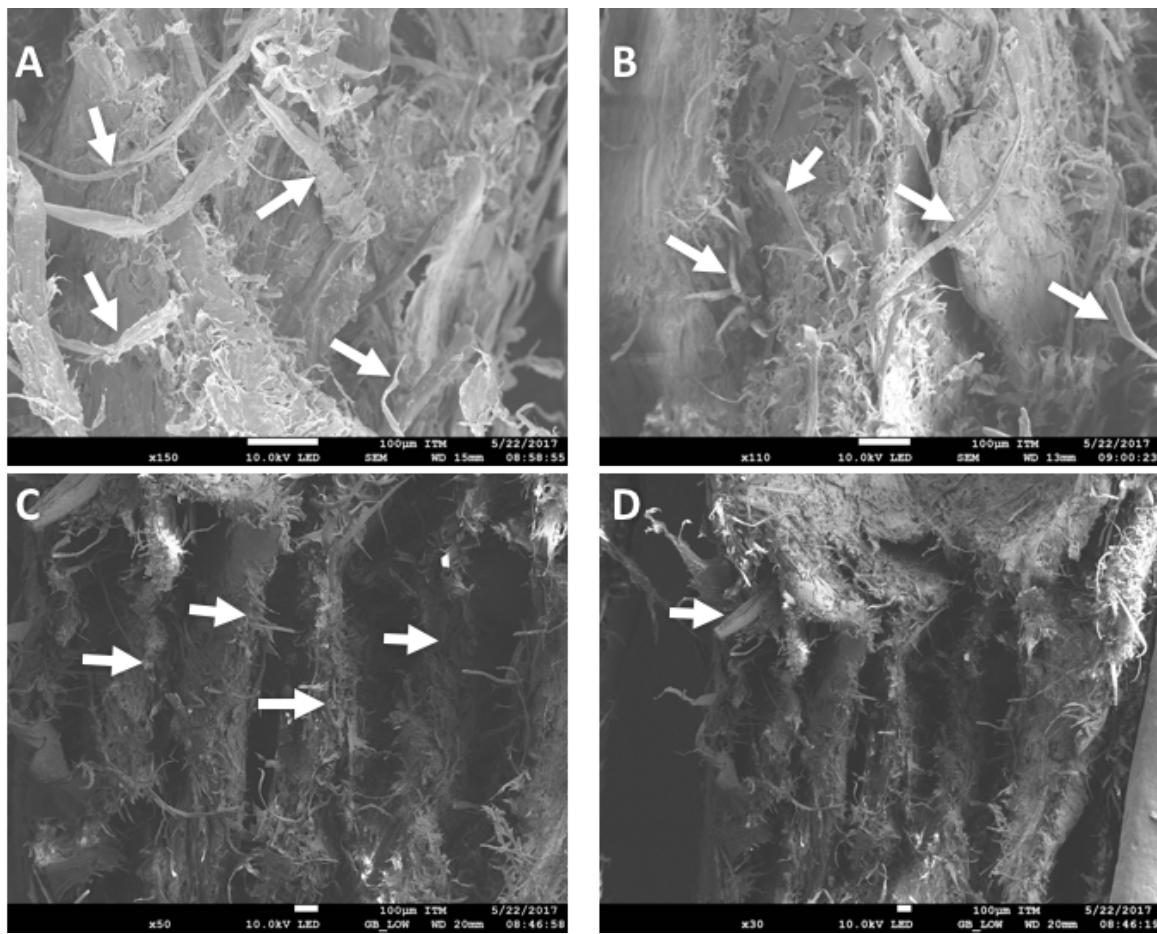
Figure 3 shows the SEM images of fractured Type I sample. They indicate that there is a fiber pull-out after the mechanical tests. Some fibers were found to be coated with LDPE and adhesive layers, as indicated by the rows in Figures 3a and 3b.

Also, it is possible to observe that LDPE fibrils stretched resulting in a ductile failure of the material. Most of the fibers did not show a separation from the matrix, which mean that the processing parameters can melt the polymer around the fibers. Also, uncoated fibers were observed and most of them were released from the matrix (Figures 3a and 3b). Figures 3c and 3d show that the delamination of some layers and the empty spaces between them (see arrows). Thus, it can be concluded from Figure 3 that pull-out and

Table 1. Materials reported in the literature with similar properties.
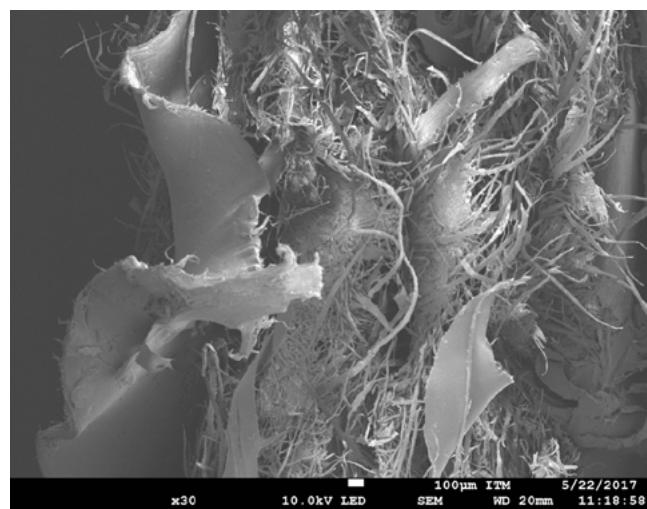
Material	Tensile strength (MPa)
Virgin LDPE (Barcelona, n.d.)	13.30 – 26.40
Recycled Tetra Pak®-Based Boards (RTPBB) (Quintero et al., 2017)	≈ 5.67 – 6.60
LDPE-AL reinforced with 2-dimensional disposable fibers (Hidalgo et al., 2012)	24.86
Non-reinforced plastic wood board (Martínez-López et al., 2014)	28.20
Plastic wood reinforced with 2.5%wt. of clay nanoparticles (Yadav & Yusoh, 2015)	32.04
LDPE-AL reinforced with 50%wt. of fique fibers (Hidalgo et al., 2011)	67.26

Source: Authors.

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Figure 3. SEM images of failed Type I sample.

Source: Authors.

delamination are the common failure mechanisms in Type I sample.

The surface analysis of Type III samples showed that the composite did not fracture in a transverse plane form (Figure 4). These failures are characterized by being staggered and are caused by separation of layers. Figure 4 also shows the detail of the failure observed in the SEM. Additionally, it was observed that the fracture has been produced by a sequence of intralaminar fracture in cellulose fiber layers. Greenhalgh (2009) reported that the intralaminar fracture is intrinsically linked to fiber-dominated failure. This work also identified fiber failures since there is a reduction in the cross-section area of the fibers.

Figure 4. SEM image of the failed Type III sample.

Source: Authors.

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For Type II, sheets of cellulose are separated by low density polyethylene and polypropylene. Since those materials have different thermoforming temperatures, the inner layers were not melted during the process, leading to interlaminar failure around the polypropylene layers. Although there are some differences in the fusion temperature for the polymer components of the Tetra Pak® containers (polypropylene and polyethylene) and these differences can decrease the mechanical anchorage, the same differences can be found for all the configurations studied in this work.

Figure 5 shows the fractured surfaces of Types II and III samples observed through a stereomicroscope. Type II evidenced interlaminar failures (see arrows in Figure 5a) while Type III showed intralaminar failures inside the cellulose layers instead of polypropylene layers (see arrows in Figure 5b).

Water absorption tests

Table 2 shows the results of water absorption tests for all samples. Chopped material favors water absorption. When the material is cut into small pieces the exposed area increases and so does the absorption of water (Zawadiak *et al.*, 2017). Inks and the polymers (PP and PE) in the samples are hydrophobic and can act as water barriers. On the other hand, the fibers (cellulose) and porous clays boos the water absorption properties (Yilgor *et al.*, 2014).

At the end of the tests (after 24 hours), the water infiltrated the entire transverse area of the samples since the polymer did not completely cover the fibers. Also, for Type III the polymer did not cover all the chopped material, so the water absorption caused by cellulose layers was higher.

Figure 5. Fractured surfaces of Type II (a) and Type III (b) samples in stereomicroscope.

Source: Authors.

Table 2. Results from water absorption tests.

Type Material	Water Absorption (%)	Standard Deviation (%)
I	9.96%	0.01%
II	11.35%	0.04%
III	14.45%	0.03%

Source: Authors.

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CONCLUSIONS

The properties of samples obtained from recycled Tetra Pak® were studied and the following results were found:

- The lowest tensile strength was found for Type I sample (9.5 MPa), and the highest was found for Type III sample (37.5 MPa). Thus, when the recycled containers are chopped into small pieces (5 mm x 5 mm) the composites obtained by hot-pressing showed the best mechanical performance.
- Type III sample showed the highest water absorption (around 15% wt.). The water absorption is caused by the hydrophilic condition of cellulose fibers and clay on the containers.
- Two different failure mechanisms with the highest mechanical strength were identified in the samples. Type II showed interlaminar failure between cellulose and polyethylene layers, while Type III samples showed intralaminar failures in cellulose layers.
- Samples obtained using recycled Tetra Pak® containers may be applied for non-structural purposes in the building industry.

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Hybrid Optimization Strategy for Optimal Location and Sizing of DG in Distribution Networks

Estrategia de optimización híbrida para ubicación y dimensionamiento óptimo de GD en redes de distribución

Oscar Danilo Montoya[1] , Walter Gil-González[2] , Luis Fernando Grisales-Noreña[3] , Carlos Alberto Ramírez Vanegas[4] y Alexander Molina-Cabrera[5]

Abstract

Objective: This paper presents a hybrid optimization methodology for the optimal location and sizing of distributed generators (DG) in electrical distribution networks. We propose a mixed-integer nonlinear problem (MINLP) model for the mathematical formulation, whose objective function is the minimizing of power losses due to the Joule effect in conductors. The constraints we considered include active and reactive power balance, voltage regulation, percentage of penetration of DG into the distribution network, and the total amount of DG allowed in such network.

Methodology: To solve the MINLP model, we employed a master-slave strategy that uses the Chu-Beasley genetic algorithm (CBGA) and the optimal power flow (OPF) model as the master and slave algorithms, respectively. This hybrid technique helps reduce the complexity of the MINLP model

by eliminating binary variables through the master algorithm and then solving the resulting nonlinear problem (NLP), which corresponds to the OPF model, and uses a classical interior-point method available in MATLAB's *fmincon* toolbox.

Results: We tested the efficiency and robustness of the proposed methodology in 33- and 69-node radial distribution networks. The results show its high performance in terms of power loss reduction and final sizing of DG.

Conclusions: The results obtained in the test systems under analysis reveal that there is a direct and proportional relationship between technical losses, the percentage of distributed generation penetration, and the number of generators available.

Keywords: Chu-Beasley genetic algorithm, distributed generation, hybrid optimization, master–slave algorithm, optimal power flow, radial distribution networks

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Resumen

Objetivo: En este documento se presenta una metodología de optimización híbrida para la ubicación y el tamaño óptimos de generadores distribuidos (DG) en redes de distribución eléctrica. Se propone un modelo de problema no lineal de enteros mixtos (MINLP) para la formulación matemática, cuya función objetivo es la minimización de las pérdidas de potencia debido al efecto Joule en los conductores. Las restricciones incluyen el equilibrio de potencia activa y reactiva, regulación del voltaje, porcentaje de penetración de las DG en la red de distribución y las DG totales permitidas en dicha red.

Metodología: Para resolver el modelo MINLP, se emplea una estrategia maestro-esclavo que utiliza el algoritmo genético Chu-Beasley (CBGA) y el modelo de flujo de potencia óptimo (OPF) como algoritmos maestro y esclavo, respectivamente. Esta técnica híbrida ayuda a reducir la complejidad del modelo MINLP al eliminar las variables binarias a través del algoritmo maestro y luego resolver el problema no lineal resultante (PNL) que corresponde al modelo OPF, utilizando un método clásico de punto interior disponible en la caja de herramientas *fmincon* de MATLAB

Resultados: Se prueba la eficiencia y la solidez de la metodología propuesta en redes de distribución radial de 33 y 69 nodos. Los resultados muestran un alto rendimiento en términos de reducción de pérdida de potencia y dimensionamiento final de DG.

Conclusiones: Existe una relación directa y proporcional entre las pérdidas técnicas, el porcentaje de penetración de generación distribuida y el número de generadores disponible.

Palabras clave: Algoritmo genético Chu-Beasley, generación distribuida, optimización híbrida, algoritmo maestro-esclavo, flujo de potencia óptimo, redes de distribución radial.

Acronyms

CBGA:	Chu-Beasley genetic algorithm
CG:	Conventional generation
DG:	Distributed generation
OPF:	Optimal power flow
NLP:	Nonlinear programming
MINLP:	Mixed-integer nonlinear programming
DS:	Distribution system

Nomenclature

Sets

Ω_N	Chu-Beasley genetic algorithm

Parameters and sub-indexes

i, ij	Sub-indexes associated with network nodes and segments in the DS, respectively
N_{dis}^{DG}	Maximum number of DGs allowed in the DS
$P_i^{DG,\max}$	Maximum active power that can be generated by a DG [W]
P_i^D	Active power demanded at node *i* [W]
Q_i^D	Reactive power demanded at node *i* [VAr]
$V_i^{\max}$	Maximum permissible voltage at node *i* [V]
$V_i^{\min}$	Minimum permissible voltage at node *i* [V]
Y_{ij}	Magnitude of the admittance associated with network segment *ij* [S]
α	Factor associated with the permissible percentage of DG penetration into the DS [%]
ϕ_{ij}	Angle of the admittance associated with network segment ij [rad]

Variables

P_i^{CG}	Active power generated at node *i* by a CG [W]
P_i^{DG}	Active power generated at node *i* by a DG [W]
Q_i^{CG}	Reactive power generated at node *i* by a CG [VAr]
Q_i^{DG}	Reactive power generated at node *i* by a DG [VAr]
V_i, V_j	Magnitude of the voltage at node *i* or j [V]
x_i	Decision variable that takes a value of 1 if the DG is located at node *i* or 0 if it is not
θ_{ij}	Magnitude of the voltage at node *i* or *j* [V]
	Angle difference of the voltages associated with nodes *i* and *j* [rad]

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INTRODUCTION

Electrical systems have evolved from conventional electrical networks that used traditional power generation technologies including hydraulic and thermal plants (coal, diesel, natural gas, etc.) (Gómez-Expósito, Conejo, & Cañizares, 2017) to systems that take advantage of high penetration of distributed energy resources—mainly wind and solar photovoltaic power generation (Hernandez, Velasco, & Trujillo, 2011; Jain, Singh, & Srivastava, 2014).

This paradigm shift in the structure of power systems has been driven mainly by the growing global concern over the harmful consequences of the greenhouse effect, as evidenced in the agreement to combat climate change signed in Paris in 2015 (Montoya, Grajales, Garces, & Castro, 2017). In this regard, a great number of governments worldwide have made a commitment to gradually replace the use of fossil fuels with renewable resources for power generation because power systems along with transportation systems are the largest producers of greenhouse gases into the atmosphere (Ellabban, Abu-Rub, & Blaabjerg, 2014). Therefore, to combat the harmful effects of fossil fuel-based power generation, various alternative technologies have been developed—mainly, distributed solar and wind energy resources along with battery-based long-term energy storage systems (Gil-González, Montoya, Holguín, Garces, & Grisales-Noreña, 2019; Montoya et al., 2017).

Several studies have proposed solutions to incorporate renewable energies into power systems, improve the technical aspects of the network, and reduce the environmental impact caused by conventional power generation processes (Balamurugan, Srinivasan, & Reindl, 2012). In particular, the authors in (Kaur, Kumbhar, & Sharma, 2014) used the sequential quadratic programming technique and the branch and bound algorithm for the location and sizing of DG; also, they proposed the minimization of system power losses during peak hours as the objective function.

In (Keane & O'Malley, 2005), an analytical method was implemented for the optimal location of multiple DG and an optimal power flow (OPF) model for their sizing. In that case, the objective was to reduce active power losses during a peak demand scenario. The authors in (Keane & O'Malley, 2005) developed a linear programming-based methodology to determine the optimal location and sizing of DG. The objective function in such study was the maximization of the power supplied by such generators, considering the classical operating limitations of DS. In (Kansal, Kumar, & Tyagi, 2013), a methodology that integrated three different types of DG into a DS was presented; its objective function was power loss reduction. To solve the problem, the authors proposed the use of a metaheuristic algorithm known as particle swarm optimization (PSO).

In (Kefayat, Ara, & Niaki, 2015), a hybrid optimization strategy combined two algorithms: ant colony optimization and artificial bee colony optimization. The first algorithm was responsible for the location of the DG, and the second for their sizing. The objective function was a linear combination that reduced active and reactive power losses, CO_2 emissions, investment costs in DG, and an index associated with voltage stability. The authors in (Kansal, Kumar, & Tyagi, 2016) presented a hybrid approach for locating multiple DG. To solve the problem, they combined the PSO technique with an analytical method for sizing said generators, using the reduction of power losses in the DS as the objective function. Moreover, in (Grisales-Noreña, Gonzalez Montoya, & Ramos-Paja, 2018), the authors proposed a hybrid metaheuristic algorithm to locate and size DG in radial distribution networks with a master-slave strategy. In the master stage, a population-based incremental learning (PBIL) method was responsible for the optimal location of DG, while a PSO algorithm was used for their sizing in the slave stage. In said work, the objective function was the minimization of active power losses and the improvement of the voltage profile.

In this state-of-the-art review, we found that the problem of optimal integration and sizing of DG in electrical networks using metaheuristic optimization techniques is divided into two stages. The first stage is in charge of their location, and the second one

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of their sizing. Also, we determined that one of the best alternatives to solve this problem is to combine different optimization strategies that exploit the nature of both subproblems (the discrete nature of the location problem and the continuous nature of the sizing problem).

Therefore, this paper presents a master-slave hybrid optimization technique, where the master problem defines the location nodes of DG by means of a combinatorial optimization metaheuristic method known as the Chu-Beasley genetic algorithm (CBGA) (Chu & Beasley, 1997), whereas the slave problem is responsible for sizing such generators for each configuration provided by the master stage. This is achieved by solving an OPF problem using the interior-point method available in MAT-LAB's *fmincon* optimization package. We propose the reduction of active power losses as the objective function, while the constraints evaluate typical characteristics in the operation of DS, such as active and reactive power balance, voltage regulation limits, and generation capacities, among others.

The main contribution of this hybrid method, which combines the CBGA with the *fmincon* optimization package, lies in the ability of the CBGA to solve discrete problems together with the OPF that ensures the efficient sizing of DG. Additionally, unlike in studies in the specialized literature, our proposed master-slave technique can be used to analyze different percentages of active power in the penetration of DG, as well as to modify the number of DG to be located. As a result, this strategy is a flexible tool that may be used in problems regarding the planning and expansion of electrical networks.

An important new aspect of this study is the possibility of analyzing multiple distributed generation scenarios, which allow us to identify sensitivities between the number and capacity of DG with respect to the reduction of active power losses. This proves that solving the problem is still a work in progress, and multiple studies should be conducted to find better solutions in reasonable computational times.

The rest of this paper is structured as follows. Section 2 introduces the mathematical formulation of the problem. Section 3 describes the proposed master-slave optimization methodology. Section 4 presents the 33- and 69-node test systems employed here. Section 5 details the parameterization of the CBGA and the OPF model, as well as the simulation scenarios. Section 6 reports the results. Section 7 draws some conclusions. Finally, a list of references is provided at the end of this paper.

MATHEMATICAL FORMULATION

To mathematically describe the problem of optimal location and sizing of DG in DS, we used a MINLP model, whose objective function was the reduction of the DS' active power losses during peak hours [6, 19]. The constraints included the traditional operating characteristics of power flow in DS, the allowed DG penetration percentage in the DS, and the number of DG available. The complete mathematical model is presented in equations (1) to (8).

Objective function:

$$\min z = \sum_{i \in \Omega_N} V_i \left(\sum_{j \in \Omega_N} V_j Y_{ij} \cos\left(\theta_{ij} - \phi_{ij}\right) \right) \tag{1}$$

Constraints:

$$P_i^{CG} + P_i^{DG} - P_i^D = V_i \sum_{j \in \Omega_N} V_j Y_{ij} \cos\left(\theta_{ij} - \phi_{ij}\right), \quad \left\{\forall i \in \Omega_N\right\} \tag{2}$$

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$$Q_i^{CG} + Q_i^{DG} - Q_i^{D} = V_i \sum_{j \in \Omega_N} V_j Y_{ij} \sin\left(\theta_{ij} - \phi_{ij}\right), \quad \left\{\forall i \in \Omega_N\right\} \tag{3}$$

$$V_i^{\min} \leq V_i \leq V_i^{\max} \left\{\forall i \in \Omega_N\right\} \tag{4}$$

$$0 \leq P_i^{DG} \leq x_i \cdot P_i^{DG,\max} \left\{\forall i \in \Omega_N\right\} \tag{5}$$

$$\sum_{i \in \Omega_N} x_i \cdot P_i^{DG} \leq \alpha \cdot \sum_{i \in \Omega_N} P_i^{D} \tag{6}$$

$$\sum_{i \in \Omega_N} x_i \leq N_{\text{dis}}^{DG} \tag{7}$$

$$x_i \in \{0,1\} \quad \left\{\forall i \in \Omega_N\right\} \tag{8}$$

The objective function in equation (1) corresponds to the active power losses in the distribution lines as a function of the magnitudes and angles of the voltages across all the system busbars and the parameters of the conductors. Constraints equations (2) and (3) determine the balance of active and reactive power at each node in the system, respectively. Equation (4) presents the maximum and minimum voltage regulation conditions at each node; equation (5), the maximum and minimum active power values that can be supplied by each DG located at node i; equation (6), the percentage of penetration in terms of active power generated by the DG; and equations (7) and (8) present the maximum number of DG allowed in the system and the binary nature of the decision variables associated to the location of the DG, respectively.

The mathematical formulation presented from equations (1) to (8) reveals that the binary nature of the decision variables associated with the location of the DG makes this a non-differentiable model; therefore, traditional derivative-based optimization techniques are not applicable (Grisales-Noreña et al., 2018). This proves that hybrid models should be used to separate the binary location problem from the continuous OPF problem associated with the sizing of DG. The next section details our CBGA-*fmincon* method used to address this problem using a master-slave strategy.

PROPOSED SOLUTION METHODOLOGY

To solve the problem of optimal location and sizing of DG in DS, we propose a master-slave strategy (referred to as hybrid optimization technique in literature) (Grisales-Noreña et al., 2018). This strategy involves dividing the MINLP model into two optimization sub problems: the first one corresponds to the master algorithm; the second one, to the slave problem (Su, 2017; Sun et al., 2015).

Master problem

In the master problem, we define the location of the DG nodes by means of the combinatorial optimization metaheuristic technique known as the Chu-Beasley genetic algorithm (CBGA). Said technique is very efficient in solving binary optimization problems (Mahmoud, Yorino, & Ahmed, 2016), such as placing a DG at node i. However, to define the adaptation function of the CBGA, we first need to find the optimal solution to the slave problem.

Mathematically speaking, the CBGA is responsible for determining the location of the DG. In other words, regarding the mathematical formulation presented from equations (1) to (8), the CBGA solves equations (5) to (8).

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To calculate the decision vector $x = [x_1, x_2, ..., x_n]$ by means of the CBGA, we consider the following basic aspects:

a. The initial population is randomly generated when there are more than two DG. Its size should not exceed ten individuals who must be different.

    Define the set of variables x_i to be enabled so that the binary nature required by equation (8) is maintained, validate that the maximum number of distributed generators to be installed is not exceeded (equation (7)), and enable constraints equation (5) and equation (6) in the nodes where distributed generation will be installed.

b. When one or two distributed generators are to be located, all possible combinations are created in the initial population. In other words, an exhaustive search is performed, and all the individuals are evaluated in the slave algorithm; then, the optimal solution would be the individual with the lowest losses. In this case, the optimization process ends at this point.

c. Every individual in the population generated in step a is evaluated using the slave algorithm.

d. To select the descendant, four randomly selected individuals in the population participate in a tournament that produces two winners. We use a single-point crossover and a mutation rate with a probability above 90%.

e. If the individuals created in the previous stage have a number of generators different from that assigned for location, a reconstructive algorithm is applied to remove extra nodes from individuals and to add generators to those that need them.

f. The individual with the best adaptation function from the previous step is selected. Furthermore, if its adaptation function is better than that of the worst individual in the population and is different from all the others,

it is admitted into the population. Otherwise, the generational cycle does not alter the population.

g. The individual with the best adaptation function in the population is selected as the incumbent.

h. The process goes back to step d, and the procedure is repeated until all the generational cycles are completed or the adaptation function of the best individual does not change for at least ten continuous generations.

It should be noted that the adaptation function corresponds to the technical losses stated by equation (1) and obtained through the solution proposed by the slave algorithm.

Slave problem

After obtaining the locations of the DG in the DS during the master stage, the MINLP mathematical model presented on equations (1) to (8) is reduced to a nonlinear problem (NLP)—referred to as optimal power flow (OPF) problem in literature—for distribution networks, where the expressions on equations (7) and (8) have already been guaranteed during the generation of individuals in the master stage. The mathematical model that must be solved in the slave stage is presented is as follows

    Minimizing equation (1) corresponds to the value of the adaptation function that is subject to the set of constraints defined from equations (1) to (6).

The previous description presents the generic mathematical model of an OPF problem, solved using MATLAB's optimization package for nonlinear programming problems known as *fmincon*. This tool uses the interior-point optimization method to retrieve an optimal feasible solution to said problem.

The DG considered in this study do not have the sufficient capacity to control the voltage in the busbars to which they are connected; therefore, they are modeled as PQ nodes, where the generation of active and reactive power varies and depends on

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the capacity of the distributed energy resource and the electronic power converter.

To clarify the type of problems that the *fmincon* package solves, equation (9) provides an overview of all the mathematical models that this tool can address.

$$\min_{y} f(x) \ so \ that \begin{cases} c(y) \leq 0 \\ c_{eq}(y) =| 0 \\ Ay \leq b \\ A_{eq}y \leq b_{eq} \\ y_{\min} \leq y \leq y_{\max} \end{cases} \quad (9)$$

Where y is the set of variables of the problem, i.e. $y = \left[V_i, \theta_i, P_i^{CG} P_i^{DG}, Q_i^{CG}, Q_i^{DG} \right]$, $i \in \Omega_N$, being $f(y)$ the objective function (1); $c(y)$, the set of nonlinear inequalities (null for the OPF problem under study); $c(y)$, the set of nonlinear equations that represent the balance of active and reactive power (equations (2) and (3)); $Ay \leq b$, the set of linear inequalities (equation (6)); $A_{eq}y \leq b_{eq}$, the set of linear equations of the optimization problem that generates an empty set for the OPF problem; and $y_{min} \leq y \leq y_{max}$, the upper and lower limits of the decision variables as presented in equations (4) and (5).

Finally, the syntax for the *fmincon* package in MATLAB is

$$y = fmincon\left(fun, y0,| A, b, A_{eq}, b_{eq}, y_{\min}, y_{\max}, nonlcon \right)$$

where y_0 is a feasible point in the solution space, and *nonlcon* is the set of nonlinear constraints. For more details about the implementation of NLP problems in MATLAB, see (MATLAB, n.d.).

Flow diagram

The flow diagram in Figure 1 summarizes the master-slave methodology we propose to solve the problem of optimal location and sizing of DG in DS using a hybrid optimization strategy, referred to here as CBGA-*fmincon*.

In this type of hybrid optimization strategies, the master algorithm is completely dependent on the slave algorithm because the latter guides the former in the search for the best solution (Grisales-Noreña et al., 2018). Hence, the same master stage with

different slave strategies might find potentially different solutions (mainly in nonconvex NLP problems). This demonstrates that hybrid optimization is still an open field of study with great research potential.
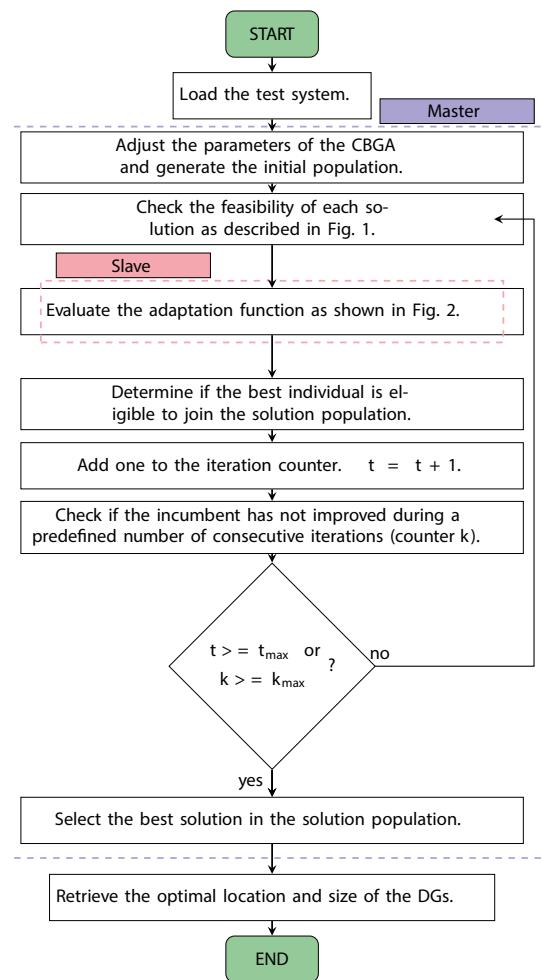
Figure 1. Proposed master-slave methodology combining the CBGA and MATLAB's *fmincon* package.

Source: Authors.

TEST SYSTEMS

In order to evaluate the proposed methodology to solve the problem of optimal location and sizing of DG in DS, we employed two test systems implemented in the specialized literature (Sahoo & Prasad, 2006): a 33-node test system and the classical Baran & Wu 69-node test system.

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Test system 1

This feeder—whose topology is shown in Figure 2, has a single conventional generator (slack node in busbar 1), 33 nodes, and a radial nature. It operates at 12.66 kV and has an active and reactive power demand of 3715 kW and 2300 kVAr, respectively. Table 1 details the line parameters and the demand at each node (Grisales-Noreña *et al.*, 2018).

Test system 2

This test system—whose topology is shown in Figure 3, has a single conventional generator (slack node in busbar 1), 69 nodes, and 68 feeders. It operates at 12.66 kV (Sultana & Roy, 2016) and has an active and reactive power demand of 3890.67 kW and 2693.6 kVAr, respectively. Information about its parameters can be consulted in (Grisales-Noreña *et al.*, 2018).
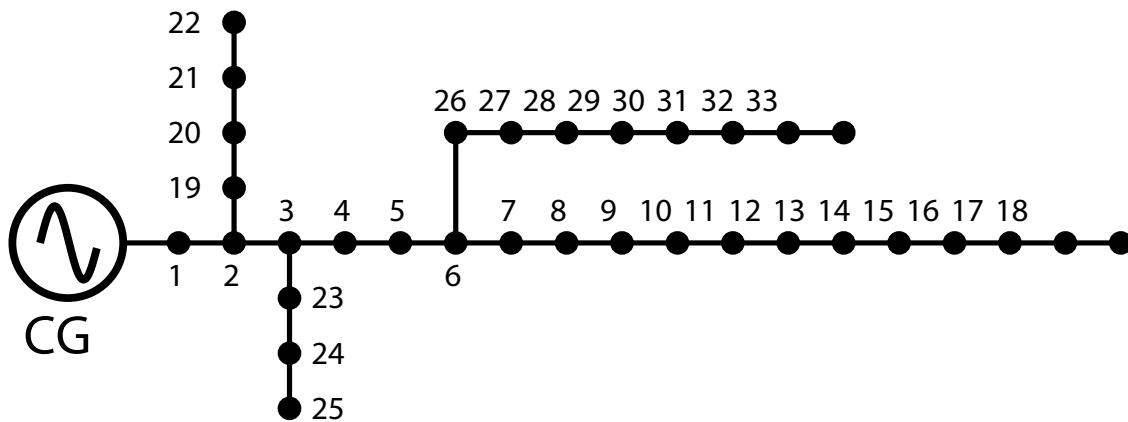
Figure 2. Topology of test system 1.

Source: (Sahoo & Prasad, 2006).
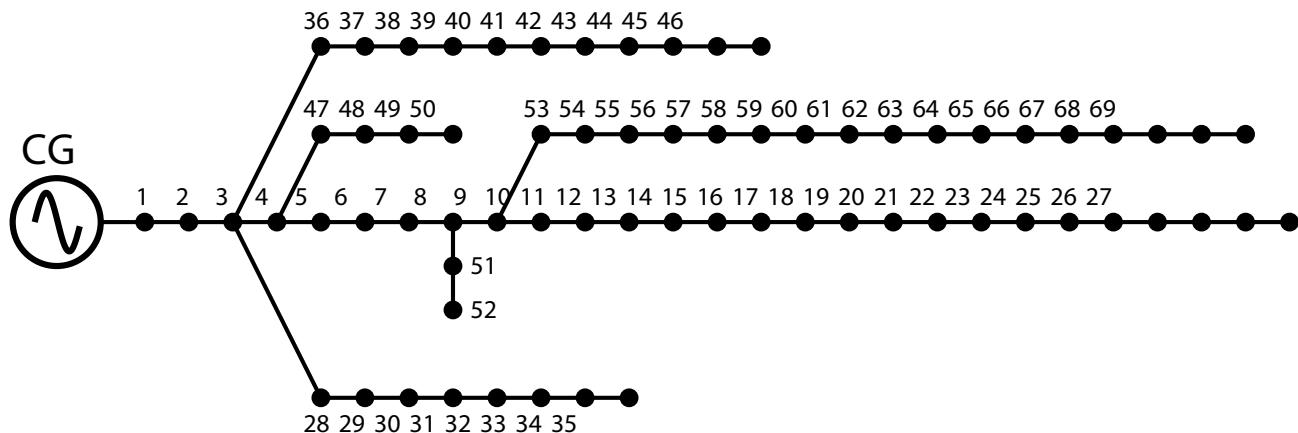
Figure 3. Topology of Test system 2.

Source: (Sahoo & Prasad, 2006).

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PARAMETERIZATION OF THE CBGA–OPF METHODOLOGY AND SIMULATION SCENARIOS

This section presents the parameters employed to solve the problem of optimal location and sizing of DG in DS using the master-slave strategy described in Section 3, as well as the simulation scenarios.

Table 1. Information about network segments and demand of Test system 1.

Node i	Node j	R_{ij} [Ω]	X_{ij} [Ω]	P_j [Ω]	Q_j [Ω]
1	2	0.0922	0.0477	100	60
2	3	0.4930	0.2511	90	40
3	4	0.3660	0.1864	120	80
4	5	0.3811	0.1941	60	30
5	6	0.8190	0.7070	60	20
6	7	0.1872	0.6188	200	100
7	8	0.7114	0.2351	200	100
8	9	1.0300	0.7400	60	20
9	10	1.0400	0.7400	60	20
10	11	0.1966	0.0650	45	30
11	12	0.3744	0.1238	60	35
12	13	1.4680	1.1550	60	35
13	14	0.5416	0.7129	120	80
14	15	0.5910	0.5260	60	10
15	16	0.7463	0.5450	60	20
16	17	1.2890	1.7210	60	20
17	18	0.7320	0.5740	90	40
18	19	0.1640	0.1565	90	40
19	20	1.5042	1.3554	90	40
20	21	0.4095	0.4784	90	40
21	22	0.7089	0.9373	90	40
22	23	0.4512	0.3083	90	50
23	24	0.8980	0.7091	420	200
24	25	0.8960	0.7011	420	200
25	26	0.2030	0.1034	60	25
26	27	0.2842	0.1447	60	25
27	28	1.0590	0.9337	60	20
28	29	0.8042	0.7006	120	70
29	30	0.5075	0.2585	200	600
30	31	0.9744	0.9630	150	70
31	32	0.3105	0.3619	210	100
32	33	0.3410	0.5302	60	40

Source: Authors.

Parameterization of the CBGA-OPF methodology

Parameterizing the CBGA is an essentially heuristic process that adjusts the parameters of the optimization process by trial and error (Chu & Beasley, 1997). In this paper, we selected the parameters presented in Table 2.

Table 2. Parameters of the CBGA.

Parameter	Value
Population size	10
Crossover rate	100%
Mutation rate	90%
Individuals for the tournament	4
Generational cycles	100
Stop due to incumbent	10

Source: Authors.

The CBGA considers a single-point crossover, and the dimension of each individual in the population is equivalent to the number of nodes in the system under study except for the slack node. Moreover, the tournament to select the parents is held with the information from the objective function of each individual; the two winning individuals (selected as parents) will be entitled to produce offspring through crossover and mutation. At this point, note that the two resulting offspring are compared in terms of the objective function, and only the one with the best performance will be able to join the population provided that it meets the diversity criteria and outperforms the worst solution contained in the population.

For the OPF model, we used the parameters shown in Table 3, which served to implement the interior-point method used by the *fmincon* package, as well as its stopping criteria.

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Table 3. Parameters of the CBGA.

Parameter	Value
Number of iterations	3000
Tolerance to change in the objective function	$1 \times 10-9$
Tolerance to equality constraints	$1 \times 10-9$
Initial voltage value	1 p.u.
Initial angle value	0 rad
Initial power value at the DG nodes	0 p.u.

Source: Authors.

We used the *fmincon* package, available in MAT-LAB (2017a version)(MATLAB, n.d.), to solve the OPF problem.

Simulated scenarios and considerations

To evaluate the proposed methodology for the optimal selection of DG in DS with the CBGA-*fmincon* master-slave algorithm, we applied the following criteria:

a. Three scenarios were simulated. The first scenario (**S1**) considers a DG penetration rate at 20% of the active power demand; the second scenario (**S2**) at 40%; and the third scenario (**S3**) at 60%.

b. The maximum active power generation capacity of each DG is below or equal to the total distributed generation penetration allowed in each scenario.

c. In every simulation scenario, all the DG operate with a unity power factor, i.e. they can only generate active power $Q_i^{DG} = 0, \quad i \in \Omega_N$.

d. Regarding permissible voltage regulation, the voltage at each node after locating the DG is 5%. If the problem is not feasible due to voltage, this limit is extended to 10%.

e. The maximum number of DG considered is equal to three.

f. The voltage and power base values used for both test systems are 12.66 kV and 1 MVA, respectively.

APPLICATION AND RESULTS

For the implementation of the CBGA-OPF master-slave strategy, we used MATLAB (2017a version) on a computer with an AMD A10-8700p Radeon R6 processor, 8 GB of RAM, and Windows 10 (Single Language).

Results in test system 1

The base case of this test system presents active power losses of 210.98 kW, and its lowest voltage is 0.908 p.u. at node 18. Table 4 presents the active power losses obtained after the proposed methodology was applied to Test system 1 in each simulation case described in the previous section. Figure 4 illustrates the voltage regulation of this system in S1, and Table 5 lists the location and size of each DG.

The results in Table 5 indicate that the percentage of DG penetration and the number of generators allowed have a direct impact on the minimization of the active power losses in the DS.

Table 4. Active power losses in Test system 1.

Scenario	Losses [kW] Number of DGs		
	1	2	3
S1	139.14	130.75	129.94
S2	120.60	94.19	93.70
S3	112.78	87.88	81.33

Source: Authors.

Table 5. Distributed generation in Test system 1.

Scenario	Number of generators						Location and size
	1	2		3			
S1	14	16	32	14	17	32	Node
	743	351	392	235	214	294	Cap. [kW]
S2	8	14	31	9	16	33	Node
	1486	667	819	516	398	573	Cap. [kW]
S3	7	12	30	15	24	30	Node
	2281	1028	1201	581	896	752	Cap. [kW]

Source: Authors.

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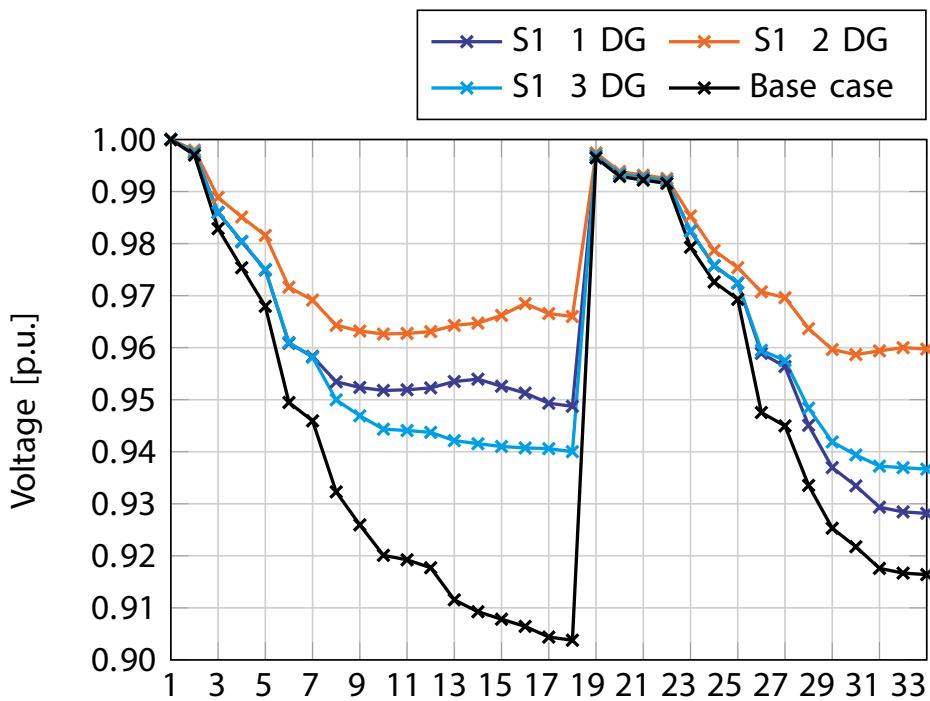
Figure 4. Voltage regulation behavior in Test system 1 in S1.

Source: Authors.

Therefore, if we consider the active power losses of the system without DG (i.e., 210.98 kW) to be the base case, S1 shows a reduction in losses equivalent to 34.05% with a single generator, while S3 produces a reduction of 61.45% with three generators. These percentages suggest that there is a direct and proportional relationship in Test system 1 between the percentage of DG penetration, the number of generators allowed, and the reduction in technical losses in the system.

Furthermore, Figure 4 presents the behavior of the voltage profiles of all the system nodes in S1. Note that the voltage regulation of several nodes in the base case is above 5%. However, when a 20% DG penetration is allowed, the system's voltage profiles can be improved.

It should be noted that the number of generators allowed in the system has a significant impact on voltage profiles. For instance, when one or three DG

are employed, voltage regulation is not achieved. This occurs because a 20% of active power injection at a single node of the system cannot affect the behavior of the voltages across the entire network in the case of a single generator. This also happens with three generators because the average injection falls below 8%, which does not help modify substantially the local voltage profiles. However, when two generators are used, their average injection at each node is around 10%; that and their location (nodes 16 and 32) allow them to modify all the network voltage profiles until the whole system presents a regulation below 5%.

Finally, the sizes of the DG in Table 5 suggest that the capacities of the DG are evenly distributed depending on the scenario under analysis and the number of generators allowed. In particular, note that in S2 a single generator is assigned a net power generation capacity of 1486 kW; two generators,

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667 kW and 819 kW, respectively; and three generators, 516 kW, 398 kW, and 573 kW, respectively. Nevertheless, when the combined capacities of the two and three generators add up, we obtain a net installed capacity of 1486 kW, which clearly shows that the net installed capacity corresponds to 40% of the total power demand regardless of the number of generators available.

Results in test system 2

The base case of this test system presents active power losses of 242.14 kW, and its lowest voltage is 0.9029 p.u. at node 69.

Table 6 presents the active power losses obtained after applying the proposed methodology to Test system 2 in each simulation case described in the previous section. Figure 5 details the voltage profile of this system in S2, and Table 7 shows the location and size of each DG.

Table 6. Active power losses in Test system 2.

Scenario	Losses [kW] Number of DGs		
	1	2	3
E1	139.06	137.95	138.27
E2	91.90	91.88	91.87
E3	91.08	91.20	84.43

Source: Authors.

Table 7. Active power losses in Test system 2.

Scenario	Number of generators						Location and size
	1	2		3			
S1	62	61	64	62	63	68	Node
	778	398	380	272	269	238	Cap. [kW]
S2	61	61	62	61	62	65	Node
	1556	780	777	535	532	489	Cap. [kW]
S3	61	59	61	15	60	62	Node
	2334	1208	1129	788	784	762	Cap. [kW]

Source: Authors.
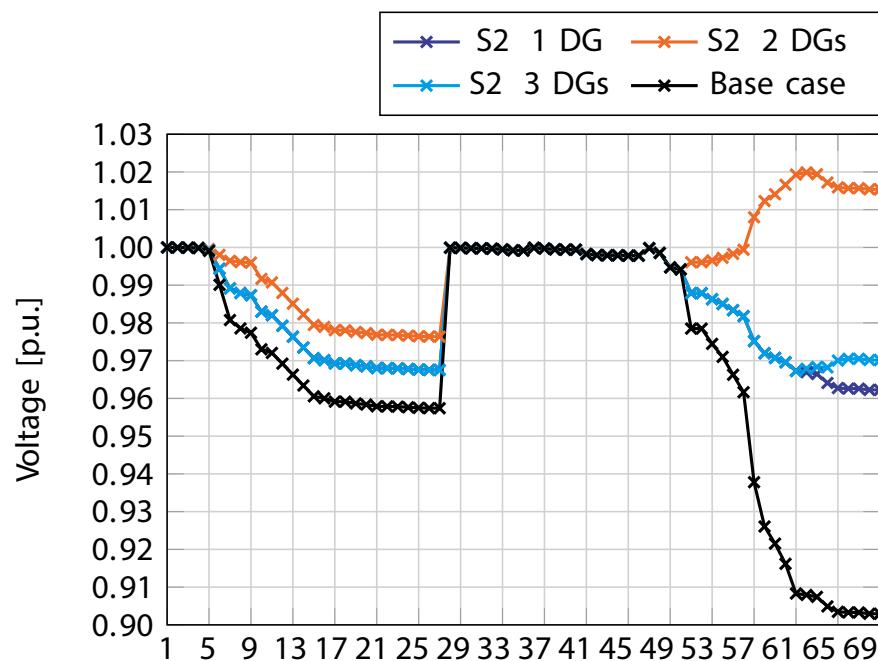
Figure 5. Voltage regulation behavior in Test system 2 in S2.

Source: Authors.

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We conclude from Table 6 that taking as a reference the base case mentioned above, S1 with a single generator shows the lowest reduction in active power losses (42.57%), while S3 with three generators exhibits the highest reduction (65.13%).

However, Table 6 also suggests that the best solutions are found in S2 because they lead to an average reduction in technical losses of 62.05% with a DG penetration of 40% regardless of the number of generators that are installed; nodes 61 and 62 (see Table 7) are the most preferred nodes for DG location.

Figure 5 presents the voltage profiles of S2 considering one to three available DG. Note that the base case violates the voltage regulation constraints from node 57 onward. Nonetheless, the rest of the cases ensure that voltage regulation remains within the allowed limits. Additionally, the voltage profiles are above 1 p.u. from node 57 onward in the case of two generators, which does not occur in the two other cases. Finally, the cases with one and three generators have very similar voltage profiles and only differ from node 61 onward. This is evidence that the positive effect of DG integration on voltage profiles, as it keeps them within the allowed ranges in all scenarios.

Comparative results

To validate the performance of the proposed master-slave methodology, which integrates the CBGA and the nonlinear optimization package (*fmincon*), this section compares it with the methodology proposed in (Grisales-Noreña *et al.*, 2018), where the population-based incremental learning (PBIL) algorithm is combined with the particle swarm optimization (PSO) algorithm to solve the problem of optimal location and sizing of DG in radial networks. The authors of that study recommend for the base case a distributed generation penetration equivalent to 40% of the power injected by the slack node and a maximum capacity of 1200 kW for each DG that is installed.

Figure 6 shows the results of the comparison between the PBIL–PSO method and the methodology proposed here in Test system 1. Note that our proposed hybrid algorithm exhibits superior performance regarding the minimization of power losses in each scenario under analysis. In particular, Figure 6(a) reveals that there was a reduction in power losses of 4.1 kW with one DG, while such reductions were 1.6 kW and 0.9 kW, respectively for two and three DG. Therefore, these results prove that the CBGA-*fmincon* method is numerically superior to the PBIL-PSO reported in (Grisales-Noreña *et al.*, 2018) for the IEEE 33-node system.

Regarding Test system 2, Figure 6(b) indicates that the CBGA-*fmincon* method is numerically equivalent to the PBIL-PSOin the case of two and three DG because both methods produced the same objective function. However, in the case of one DG, our proposed method exhibited a slight improvement of 0.5 kW in the objective function. This can be considered a positive result because the CBGA-*fmincon* method usually exceeds or matches the results reported by the specialized literature. The locations of the DG were not included in this section because they correspond to those previously reported in (Grisales-Noreña *et al.*, 2018).
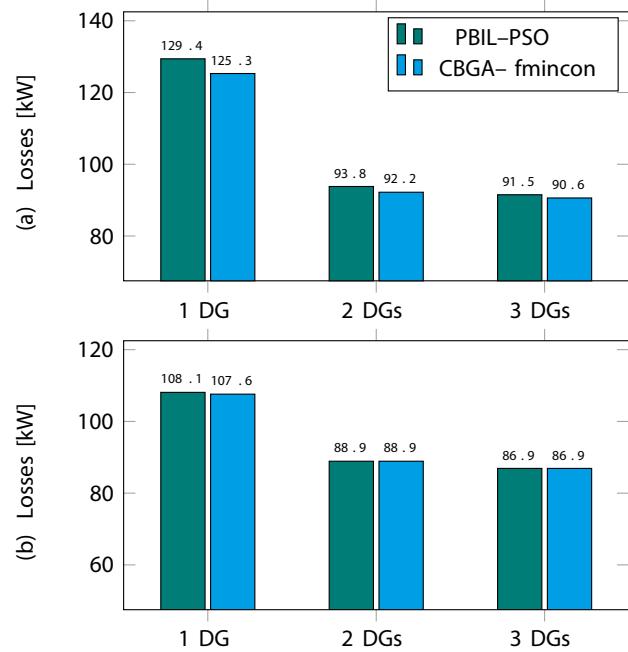
Figure 6. Comparison between our proposed method and its PBIL-PSO counterpart: (a) Test system 1. (b) Test system 2.

Source: Authors.

CONCLUSIONS AND FUTURE WORK

We proposed a hybrid optimization technique that combines the Chu-Beasley generic algorithm (CBGA) and the optimal power flow (OPF) model to solve the problem of optimal location and sizing of distributed generators (DG) in distribution systems (DS). This technique divides the original mixed-integer nonlinear programming problem into two sub-problems that are then sequentially solved using a master-slave methodology.

The results obtained in the test systems under analysis reveal that there is a direct and proportional relationship between technical losses, the percentage of distributed generation penetration, and the number of generators available. Therefore, our proposed integration methodology may be very useful for companies in the electricity sector that are interested in maximizing the economic benefit of using distributed energy resources to improve the quality, reliability, and continuity of the service they provide to end-users. This happens because our methodology is flexible and can be easily adapted to the specific conditions and requirements of each distribution company.

Future work can explore economic analyses to establish the minimum temporal relationship between the profits obtained from technical loss reduction and the costs associated with the installation, operation, and maintenance of distributed generation units considering different demand scenarios.

The integration of distributed generators using electronic power converters that control the flow of active and reactive power between the electrical network and the generator may also be considered. This could lead to greater reductions in technical losses and a significant improvement in the voltage profiles at each busbar.

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Hybrid Optimization Strategy for Optimal Location and Sizing of DG in Distribution Networks

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Fusion of Hyperspectral and Multispectral Images Based on a Non-locally Centralized Sparse Model of Abundance Maps

Fusión de imágenes hiperespectrales y multiespectrales basado en un modelo de escacez no local centralizado de mapas de abundancias

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Abstract

Context: Systems that acquire hyperspectral (HS) images have opened a wide field of applications in different areas, such as remote sensing and computer vision applications. However, hardware restrictions may limit the performance of such applications because of the low spatial resolution of obtained hyperspectral images. In the state-of-the-art, the fusion of a HS image with low spatial resolution panchromatic (PAN) or multispectral (MS) images with high spatial resolution has been efficiently employed to computationally improve the resolution of the HS source. The problem of fusing images is traditionally described as an ill-posed inverse problem whose solution is obtained assuming that the high spatial resolution HS (HR-HS) image is sparse in an analytic or learned dictionary.

Method: This paper proposes a non-locally centralized sparse representation model on a set of learned dictionaries to spatially regularize the fusion problem. Besides, we consider the linear mixing model that decomposes the measured spectrum into a collection of constituent spectra (endmembers) and a set of corresponding fractions (abundance) maps to take advantage of the intrinsic properties and low dimensionality of HS images. The spatial-spectral dictionaries are learned from the estimated abundance maps exploiting the spectral correlation between abundance maps and the non-local self-similarity in the spatial domain. Then, an alternating iterative algorithm is employed to solve the fusion problem conditionally on the learned dictionaries.

Results: After using real data, the results show that the proposed method outperforms the state-of-the-art methods under various quantitative metrics: RMSE, UIQI, SAM, ERGAS, PSNR, and DD.

Conclusions: This paper proposes a novel fusion model that includes a non-local Sparse representation of abundance maps by using spectral unmixing. The proposed model obtains better fused images than traditional fusion approaches based on sparcity.

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Keywords: Image fusion, dictionary learning, non-local sparse representation, spectral unmixing, abundance maps.

Resumen

Contexto: Los sistemas de adquisición de imágenes hiperespectrales (HS) son comúnmente usados en un rango diverso de aplicaciones que involucran tareas de detección y clasificación. Sin embargo, la baja resolución de imágenes hiperespectrales podría limitar el rendimiento de las tareas relacionadas con dichas aplicaciones. En los últimos años, fusionar la información de una imagen HS con imágenes multiespectrales (MS) o pancromáticas (PAN) de alta resolución espacial ha sido ampliamente usado para mejorar la resolución espacial de la imagen HS. La fusión de imágenes ha sido formulada como un problema inverso cuya solución es una imagen HS de alta resolución espacial, la cual se asume escasa en un diccionario analítico o aprendido. Por otra parte, el desmezclado espectral es un procedimiento en donde el espectro medido de un píxel mezclado es descompuesto en una colección de firmas espectrales que hacen referencia a las firmas puras de la imagen y mapas de abundancia que indican la porción de cada firma pura presente en un píxel especifico.

Método: Este trabajo propone un modelo de representación escasa, centralizado y no local sobre un conjunto de diccionarios aprendidos para regularizar el problema de fusión convencional. Los diccionarios son aprendidos a partir de los mapas de abundancia estimados para explotar la correlación entre mapas de abundancia y la auto-similitud no local sobre el dominio espacial. Luego, condicionalmente sobre los diccionarios aprendidos, el problema de fusión es solucionado por un algoritmo numérico iterativo y alternante.

Resultados: Después de usar datos reales, los resultados muestran que el método propuesto supera los métodos del estado del arte bajo diferentes métricas cuantitativas.

Conclusiones: Este modelo permite incluir la redundancia no local en el problema de fusión de imágenes hiperespectral y multiespectral sobre los mapas de abundancia usando desmezclado espectral, mejorando los resultados de los métodos de fusión basados en el modelo de escasez tradicional.

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Palabras clave: Fusión de imágenes, aprendizaje de diccionarios, representación escasa no-local, desmezclado espectral, mapas de abundancias.

INTRODUCTION

Hyperspectral (HS) imaging acquires a real scene in hundreds of spectral bands, each associated with a specific wavelength (Medina *et al.*, 2017). The analysis of spectral signatures of these images has allowed the advancement of many applications in the fields of medical imaging (Panasyuk *et al.*, 2007; Lu and Fei, 2014), remote sensing (Schaepman *et al.*, 2009; Bioucas-Dias *et al.*, 2013; Velasco *et al.*, 2016), and astronomy (Schreiber *et al.*, 2009; Hege *et al.*, 2004). However, due to hardware restrictions, HS images are limited by a low spatial resolution (Shaw and Burke, 2003). For example, the Hyperion imaging spectrometer has a spatial resolution of 30 meters-per-pixel (Middleton *et al.*, 2013) that can degrade the performance for practical applications.

In order to increase the spatial resolution of HS images, a usual approach is to merge the HS image with high spatial resolution images. An example appropriate for this paper consists of merging the HS image (that has high spectral resolution) with a multispectral (MS) image (that has high spatial resolution) (Wei *et al.*, 2015; Simoes *et al.*, 2015). Another well-known example is HS pan-sharpening, which addresses the fusion of panchromatic and HS images (Loncan *et al.*, 2015).

Image fusion is essential to find a suitable model considering the prior knowledge of natural images due to the ill-posed nature of the inverse problem. Thus, some effective regularizers that restrict the solution space have been employed in the state-of-the-art for image restoration (IR) problems with encouraging results (Dong, Zhang and Shi,

2011; Chan *et al.*, 2015; Oliveira, Bioucas-Dias and Figueiredo, 2009; Vargas *et al.*, 2018). In detail, under a super-resolution approach, employing previous total variations have achieved state-of-the-art performance for fusing HS and MS images (Simoes *et al.*, 2015). Additionally, it has been demonstrated that assuming the sparcity of the signal of interest is a suitable regularization method in image restoration problems such as image deblurring, image denoising, and image super-resolution (Dong *et al.* 2011, Wei *et al.*, 2015; Yang *et al.*, 2010). Formally, a sparce representation states that a signal $\mathbf{x} \in \mathbb{R}^{N_p}$ can be represented as a linear combination of a few atoms via $\mathbf{x} = \mathbf{\Phi}\alpha_x$ on the dictionary $\mathbf{\Phi}$ (Cardon *et al.*, 2015). If the target signals reconstructed are multi-dimensional images, the representation of smaller patches on an over-complete dictionary learned from the data successfully determines the underlying structure of the images (Mallat, 1999).

On the other hand, restoring the image $\mathbf{x}$ from a degraded image $\mathbf{y} = \mathbf{Hx} + \mathbf{n}$ under sparcity is challenging due to degradation during the acquisition process. The estimation of the sparce coefficient α_x employing common optimization algorithms as Bayesian frameworks, iterative shrinkage/thresholding, Lasso, and basis pursuit (Tibshirani, 1996; Tropp and Wright, 2010; Beck and Teboulle, 2009; Bruckstein, Donoho and Elad, 2009; Chen, Donoho and Saunders, 2001) may not be an optimal estimation of the original sparce coefficient α_x. Thus, the reconstruction $\hat{\mathbf{x}} = \mathbf{\Phi}\alpha_y$ may lead to an inaccurate estimation (Mairal *et al.*, 2009; Dong et al., 2012).

According to this limitation, we are interested on improving the estimated sparce representation, so non-local redundancy properties in natural scenes are studied to enhance the representation model. For instance, non-local self-similarities of natural scenes have been included in approaches for super-resolution or denoising leading to state-of-the-art performance (Elad and Aharon; 2006; Dian, Fang and Li, 2017; Mairal *et al.*, 2009; Fu *et al.*, 2017). Similarly, to enhance the accuracy of IR methods based on sparsity, a centralized non-local sparce representation (CNSR) model has been proposed in

(Dong et al., 2012). Specifically, this representation intends to increase the quality of the reconstructed image $\hat{\mathbf{x}}$ by reducing the error $\mathbf{v}_\alpha = \alpha_x - \alpha_y$ known as sparce coding noise (SCN). This goal is achieved by centralizing the sparce coefficient α_y to α_x that is estimated from the non-local redundancies in $\mathbf{x}$.

On the other hand, research on IR literature has included the unmixing spectral model on several IR problems to find a treatable connection between the distorted measurements and the original image, and to take advantage of intrinsic properties such as spectral non-local similarity (Wei *et al.*, 2016; Vargas, Arguello and Tourneret, 2019; Zhao, Yang and Chan, 2013). Even sparcity assumptions in abundance (Vargas *et al.*, 2018, Ghasrodashti *et al.*, 2017; Zhao et al., 2014) and spatial non-local similarity (Zhao, Yang and Chan, 2013) have been taken into account on the hyperspectral image super-resolution and fusion problems showing promising results. Nonetheless, prior unified knowledge of spatial-spectral non-local similarity and sparcity has not been considered on the abundances.

This work introduces a multispectral and hyperspectral image fusion model that assumes a CNSR of abundance maps in a learned dictionary. More precisely, local and spectral non-local similarity assumptions on the abundances are included in the model by the spectral unmixing decomposition and the spatial non-local estimation from α_y now associated with the sparse representation of the abundances α_a, respectively. Additionally, the abundances are supposed to be sparce on an over-complete dictionary, which is constructed from available abundance and HS-MS data. The dictionary consists of several sub-dictionaries learned from groups of similar patches. Then, all patches of a cluster are sparsely represented and centralized to a good estimation of α_a under its corresponding sub-dictionary (each cluster associates with a single sub-dictionary). Therefore, both the construction of a composite over-complete dictionary and the centralization are performed to exploit non-local redundancies in the abundances.

In the global optimization problem, the sparse codes and spatial-spectral dictionary are estimated

jointly under an alternating approach. Once the dictionary has been updated, an iterative nonlinear shrinkage algorithm solves the resulting multi-band image fusion problem; this algorithm consists of projecting the solution of a quadratic problem on the thresholding operator in each iteration (Daubechies, Defrise and De Mol, 2004). Moreover, the regularization parameters underlying the optimization problem are adaptively adjusted from a Bayesian formulation (Dong et al. 2012). Non-local similarity and sparcity assumptions are favorable on abundance maps due to the large presence of soft regions. Additionally, the burden load decrease by data reduction compared to the original image. Considering experimental scenarios with real HS images, we show that the proposed fusion approach outperforms and achieves the performance of the competitive approaches gaining up to 1[dB] under the peak signal-to-noise ratio (PSNR) metric.

PROBLEM STATEMENT

For modeling the MS and HS images, it is commonly assumed that there is a linear degradation in the spectral and spatial domain of a HS image with higher resolution denoted by the vector $\mathbf{x} \in \mathbb{R}^{N_p}$ with $N_p=NML$ (Wei et al., 2016; Wei, Dobigeon and Tourneret, 2015; Simoes et al., 2015). The acquired HS image denoted by the vector $\mathbf{y}_H \in \mathbb{R}^{N_H M_H L}$ is assumed to be a blurred and down-sampled version of the high full-resolution image $\mathbf{x}$. In contrast, the MS image $\mathbf{y}_M \in \mathbb{R}^{NML_M}$ is obtained from a spectral degradation of the target image (Wei et al., 2015). Thus, the sensing models for the MS and HS images are given as

$$\begin{aligned} \mathbf{y}_H &= \mathbf{PBx} + \mathbf{n}_H \\ \mathbf{y}_M &= \mathbf{Rx} + \mathbf{n}_M \end{aligned} \tag{1}$$

Where $\mathbf{P} \in \mathbb{R}^{N_H M_H L \times N_p}$ represents the down-sampling matrix, $\mathbf{B} \in \mathbb{R}^{N_p \times N_p}$ is a circular convolution operator described as blurring matrix, $\mathbf{R} \in \mathbb{R}^{NML_M \times N_p}$ denotes the transfer function of the MS sensor, and the vectors $\mathbf{n}_M \in \mathbb{R}^{NML_M}$ and $\mathbf{n}_H \in \mathbb{R}^{N_H M_H L}$ represent additive Gaussian noise for the MS and HS images.

For notation convenience, the spatial-spectral tensor $\boldsymbol{\mathcal{X}} \in \mathbb{R}^{N \times M \times L}$ (L is the number of spectral bands and $N \times M$ represents the spatial dimension) is represented by the vector $\mathbf{x} = [\overline{\boldsymbol{x}}_1^T, \cdots, \overline{\boldsymbol{x}}_L^T] \in \mathbb{R}^{NML}$, where $\overline{\boldsymbol{x}}_i$ contains all the image intensities associated with the i-th spectral band on $\boldsymbol{\mathcal{X}}$. Likewise, we can exploit intrinsic properties of the spectral unmixing model for the fusion problem in which each spectral signature of a multi-band image can be associated to a linear mixture of several pure spectral signatures known as endmembers. Under this model, the image $\mathbf{x}$ is decomposed as $\mathbf{x} = \mathbf{Ma}$, where $\mathbf{a} = [\overline{\mathbf{a}}_1^T, \cdots, \overline{\mathbf{a}}_L^T] \in \mathbb{R}^{N_L}$ with $N_L=NML$ are the P abundane maps in a vector form denoting $\overline{\mathbf{a}}_i^T \in \mathbb{R}^{NM}$ as the i-th abundance map. The matrix $\mathbf{M} = \mathbf{I} \otimes \overline{\mathbf{M}} \in \mathbb{R}^{N_p \times N_L}$ is a block-diagonal matrix on the endmembers' matrix $\overline{\mathbf{M}} \in \mathbb{R}^{L \times P}$ with P the number of materials. Thus, the acquisition models in equation (1) can be rewritten as

$$\begin{aligned} \mathbf{y}_H &= \mathbf{PBMa} + \mathbf{n}_H \\ \mathbf{y}_M &= \mathbf{RMa} + \mathbf{n}_M \end{aligned} \tag{2}$$

Considering the observation models in equation (2), the optimization problem formulated in this paper consists of estimating the vector of abundances from the observed measurements y_M and y_H. Since the resultant problem is ill-posed, this work proposes that the regularization strategy employed for the fused solution be a centralized non-local sparce model on the abundance maps.

METHODOLOGY

In this section, we describe the methodology for the fusion of hyperspectral and multispectral images based on the non-local sparse representation model. First of all, consider that the abundance data $\mathbf{a}$ is decomposed into overlapping image cubic patches. Dividing images in patches has obtained effective results in the image domain in many image processing applications (Tosic and Frossard, 2011). We start by defining $\mathbf{W}_i \in \mathbb{R}^{S^2 L \times N_L}$ as the matrix extracting cubic patch at location i, $\mathbf{a}_i = \mathbf{W}_i \mathbf{a} \in \mathbb{R}^{S^2 P}$ as the vectorized abundance cubic patch with dimensions $S \times S \times P$, and i indicating the position of the central pixel. Then, considering a sparce representation of

the cubic patch in a fixed dictionary, i.e., $\mathbf{a}_i = \mathbf{\Phi} \, \boldsymbol{\alpha}_{a,i}$, where $\boldsymbol{\alpha}_{a,i}$ is a sparce vector. Finally, considering the collection of sparce coefficients $\{\boldsymbol{\alpha}_{a,i}\}$, the recovery of the abundances $\mathbf{a}$ can be computed by averaging all the patches

$$\hat{\mathbf{a}} = \left(\sum_i \mathbf{W}_i^T \, \mathbf{W}_i\right)^{-1} \sum_i \mathbf{W}_i^T \, \mathbf{\Phi} \boldsymbol{\alpha}_{a,i} = \mathbf{\Phi} \circ \boldsymbol{\alpha}_a \qquad (3)$$

For notation simplicity, the estimated abundance $\hat{\mathbf{a}}$ aforementioned is denoted as $\hat{\mathbf{a}} := \mathbf{\Phi} \circ \boldsymbol{\alpha}_a$, where $\boldsymbol{\alpha}_a$ represents the collection of the set of sparce codes $\boldsymbol{\alpha}_{a,i}$.

Non-local sparce representation model

In literature, different IR problems have employed sparsity-based regularization approaches to handle its ill-posed nature (Dong *et al.* 2011; Yang *et al.*, 2010; Yin, Li and Fang, 2013). However, since the observed images are a degraded version of the target image, the obtained sparce coefficient $\boldsymbol{\alpha}_y$ is a degraded estimation of the sparce coefficient $\boldsymbol{\alpha}_a$ of the abundance maps, resulting in a degradation of the recovered image quality. To improve the sparce recovery results, an effective solution consists of employing non-local similarities of natural scenes (Mairal *et al.*, 2009; Dong et al., 2012). Furthermore, this assumption of non-local similarity could also be satisfied with abundance maps since similar spatial structures in the image domain are present on the abundances. Therefore, the assumption of this work is that non-local similarities of the abundance maps could benefit the fused image results. Specifically, this work proposes a centralized non-local representation (Dong et al., 2012) of abundance maps to regularize the underlying high-resolution HS image. Based on the observation models in equation (2) and the CNSR model, the fusion problem is formulated as the following optimization problem

where the quadratic functions correspond to the data fidelity of the MS and HS images, the last function represents the CNSR prior model, $\boldsymbol{\beta}_i$ is a close estimation of the sparce representation $\boldsymbol{\alpha}_{a,i}$ associated to the i-th abundance patch $\mathbf{a}_i$, and λ is a regularization parameter. The Term associated with the prior sparcity in equation (4) is removed because of the dictionary structure that implicitly promotes sparcity, this will be addressed later. Additionally, a ℓ_1-term is included to centralize $\boldsymbol{\alpha}_{a,i}$ to the non-local estimation $\boldsymbol{\beta}_i$ suppressing the SCN $\boldsymbol{\alpha}_y - \boldsymbol{\alpha}_x$ (Dong et al., 2012). Based on the non-locality of the abundances, the enhanced estimate $\boldsymbol{\beta}_i$ of $\boldsymbol{\alpha}_{a,i}$ is computed as a weighted sum of sparse coefficients $\boldsymbol{\alpha}_{y,p}$, so that $p \in \Omega_i, \Omega_i \subseteq \{1, 2, \cdots\}$. In particular, the coefficients $\boldsymbol{\alpha}_{y,p}$ are the sparce vectors of non-local cubic patches similar to $\hat{\mathbf{a}}_i$ obtained from the abundance maps. Thus, $\boldsymbol{\beta}_i$ can be computed as

$$\boldsymbol{\beta}_i = \sum_{p \in \Omega_i} \omega_p \, \boldsymbol{\alpha}_{y,p},$$

$$\omega_p = \frac{1}{\varphi} \exp\left(\frac{-\left\| \hat{\mathbf{a}}_i - \hat{\mathbf{a}}_p \right\|_2^2}{h}\right) \qquad (5)$$

where ω_p is the corresponding weight of the patch p, φ is a normalization factor, and h is a fixed constant. To distinguish the current patch and its similar neighboring patches, we employed the indexes i and p, respectively.

Bayesian interpretation

We developed a Bayesian analysis of the MS and HS image fusion based on the prior CNSR in order to provide an alternative to calculate the regularization parameter $\boldsymbol{\lambda}$ in equation (4). We define an auxiliary variable $\boldsymbol{\theta} = \boldsymbol{\alpha} - \boldsymbol{\beta}$ to obtain the relationship between maximum a posterior (MAP) estimator, and the SCN estimation. Thus, the MAP estimator of $\boldsymbol{\theta}$ is given by

$$\hat{\boldsymbol{\alpha}}_y = \underset{\boldsymbol{\alpha}}{argmin} \frac{1}{2} \left\| \mathbf{y}_H - \mathbf{PBM}(\mathbf{\Phi} \circ \boldsymbol{\alpha}) \right\|_2^2 + \frac{1}{2} \left\| \mathbf{y}_M - \mathbf{RM}(\mathbf{\Phi} \circ \boldsymbol{\alpha}) \right\|_2^2 + \lambda \sum_i \left\| \boldsymbol{\alpha}_i - \boldsymbol{\beta}_i \right\|_1 \qquad (4)$$

$$\boldsymbol{\theta}_y = \underset{\boldsymbol{\theta}}{argmax}\ \log P\left(\boldsymbol{\theta}\,|\mathbf{y}_H, \mathbf{y}_M\right)$$

$$\boldsymbol{\theta}_y = \underset{\boldsymbol{\theta}}{argmin} - \left(\log P\big(\mathbf{y}_H|\boldsymbol{\theta}\big) + \log P\big(\mathbf{y}_M|\boldsymbol{\theta}\big) + \log P(\boldsymbol{\theta})\right) \tag{6}$$

The likelihood terms $P(\mathbf{y}_H|\boldsymbol{\theta})$ and $P(\mathbf{y}_M|\boldsymbol{\theta})$ are characterized by the Gaussian distribution, and the prior probability term is characterized by the Laplacian distribution. According to the CNSR model for fusion in equation (4), the likelihood terms are formulated as

$$P(\mathbf{y}_H|\boldsymbol{\theta}) = P(\mathbf{y}_H|\boldsymbol{\alpha}, \boldsymbol{\beta}) = \frac{\exp\left(-\frac{1}{2}\big(\mathbf{y}_H - \mathbf{PBM}(\boldsymbol{\Phi} \circ \boldsymbol{\alpha})\big)^{\mathrm{T}} \boldsymbol{\Lambda}_H^{-1}\big(\mathbf{y}_H - \mathbf{PBM}(\boldsymbol{\Phi} \circ \boldsymbol{\alpha})\big)\right)}{2\pi^{\frac{(N_H M_H L)}{2}} |\boldsymbol{\Lambda}_H|^{\frac{1}{2}}} \tag{7}$$

$$P(\mathbf{y}_M|\boldsymbol{\theta}) = P(\mathbf{y}_M|\boldsymbol{\alpha}, \boldsymbol{\beta})$$

$$= \frac{\exp\left(-\frac{1}{2}\big(\mathbf{y}_M - \mathbf{RM}(\boldsymbol{\Phi} \circ \boldsymbol{\alpha})\big)^{\mathrm{T}} \boldsymbol{\Lambda}_M^{-1}\big(\mathbf{y}_M - \mathbf{RM}(\boldsymbol{\Phi} \circ \boldsymbol{\alpha})\big)\right)}{2\pi^{\frac{(NML_M)}{2}} |\boldsymbol{\Lambda}_M|^{\frac{1}{2}}} \tag{8}$$

$$P(\boldsymbol{\theta}) = \prod_i \prod_j \frac{1}{\sqrt{2}\boldsymbol{\gamma}_{i,j}} \exp\left(\frac{-|\boldsymbol{\theta}_{i,j}|}{\boldsymbol{\gamma}_{i,j}}\right) \tag{9}$$

where $\boldsymbol{\Lambda}_H = diag\big([\sigma_{H,1}^2 1_{(N_H,M_H)}, \cdots, \sigma_{H,L}^2 1_{(N_H,M_H)}]\big)$ is the covariance matrix for the band-vectorized HS image with standard deviation per band $\sigma_{H,l}$ $(l = 1, \cdots, L)$, (1_a) denoting the vector of ones of size $1 \times a$, $\boldsymbol{\Lambda}_M = diag\big([\sigma_{M,1}^2 1_{(N,M)}, \cdots, \sigma_{M,L_M}^2 1_{(N,M)}]\big)$ is the covariance matrix for the band-vectorized MS image with standard deviation per band σ_{M,l_m} $(l_m = 1, \cdots, L_M)$, $\boldsymbol{\theta}_{i,j}$ is the j-th element of the sparce code $\boldsymbol{\theta}_i$, and $\boldsymbol{\gamma}_{i,j}$ is the standard deviation of $\boldsymbol{\theta}_i(j)$. Now, substituting the $P(\mathbf{y}_H|\boldsymbol{\alpha}, \boldsymbol{\beta})$,, $P(\mathbf{y}_M|\boldsymbol{\alpha}, \boldsymbol{\beta})$ and $P(\boldsymbol{\theta})$ in equation (6) we obtain the MAP estimator of $\boldsymbol{\theta}$ given by the following optimization problem

$$\widehat{\boldsymbol{\alpha}}_y = \underset{\boldsymbol{\alpha}}{argmin}\ \frac{1}{2}\left\|\boldsymbol{\Lambda}_H^{-\frac{1}{2}}\big(\mathbf{y}_H - \mathbf{PBM}(\boldsymbol{\Phi} \circ \boldsymbol{\alpha})\big)\right\|_2^2 + \frac{1}{2}\left\|\boldsymbol{\Lambda}_M^{-\frac{1}{2}}\big(\mathbf{y}_M - \mathbf{RM}(\boldsymbol{\Phi} \circ \boldsymbol{\alpha})\big)\right\|_2^2$$

$$+ \sum_i \sum_i \frac{2}{\boldsymbol{\gamma}_{i,j}}\left|\boldsymbol{\alpha}_{i,j} - \boldsymbol{\beta}_{i,j}\right| \tag{10}$$

By observing equations (10) and (4) on the third term, we can see by comparison that the regularization parameter can be calculated as $\boldsymbol{\lambda}_{i,j} = \frac{2}{\boldsymbol{\gamma}_{i,j}}$.

Dictionary learning

Basis functions extracted from learned or analytical dictionaries are able to represent basic structures of natural image and define sparcity domains. Let a given cubic patch $\mathbf{a}_i$ be represented as a matrix $\mathbf{A}_i \in \mathbb{R}^{S^2 \times P}$ where the rows are the abundance coefficients. Under a sparce model of the abundances, $\mathbf{A}_i$ can be described by few atoms (Fu *et al.*, 2017)

$$\mathbf{A}_i = \sum_m \alpha_m \boldsymbol{\Phi}_m, \tag{11}$$

where $\{\Phi_m\}$ denotes a collection of atoms, α_m are the corresponding sparce codes, and $m \ll S^2 P$. The selection of the dictionary elements is a relevant issue of sparcity-based methods. In this work, we propose a dictionary with tridimensional atoms that are constructed using separable abundance and spatial components as follows

$$\Phi_m = \mathbf{v}_d \mathbf{u}_r^T \qquad (12)$$

where $\{\mathbf{u}_r\}_1^P$ and $\{\mathbf{v}_d\}_1^{S^2}$ are orthonormal basis spanning the abundance maps and spatial subspace, respectively. Under this factorization of the dictionary, we are able to exploit the correlation in the abundances as well as in the spatial domain. Specifically, the basis for the abundance subspace domain $\mathbf{U}$ and the spatial domain $\mathbf{V}$ are extracted from the abundances data allowing to construct the atoms in equation (12) with correlation information between abundance maps and spatial information simultaneously. In the abundance subspace domain, the estimated abundance vector $\hat{\mathbf{a}}$ is reorganized as a P x NM matrix via PCA the abundance basis $\mathbf{U} = [\mathbf{u}_1, \cdots, \mathbf{u}_P]$. Similarly, the spatial basis $\mathbf{V} = [\mathbf{v}_1, \cdots, \mathbf{v}_{S^2}]$ is calculated using PCA from spatial patches extracted along all the abundance maps.

In the spatial domain, we learn different dictionaries for different clusters of the abundance training patches (Dong et al., 2011; Dong et al., 2012). Thus, the patches are clustered by spatial similarity of $\hat{\mathbf{a}}$ pooled along with all the abundance maps employing the K-means method. This methodology lies on grouping patches spatially in different clusters $\mathcal{C}_K$, with $k = 1, \cdots, K$, by using the high frequency components of the abundance maps. This strategy is more suitable since clustering by intensity presents low performance discriminating images (Fu et al., 2017). The high frequency patterns $\tilde{\mathbf{a}}$ of $\hat{\mathbf{a}}$ can be calculated as

$$\tilde{\mathbf{a}} = \hat{\mathbf{a}} - \mathbf{G}\hat{\mathbf{a}} \qquad (13)$$

where $\mathbf{G}$ is a low pass filtering operator. It is worth noting that the high frequency of the abundance maps $\tilde{\mathbf{a}}$ is employed only for clustering and the resultant clusters $\mathcal{C}_K$ associates with a spatial basis $\mathbf{V}^k = [\mathbf{v}_1^k, \cdots, \mathbf{v}_{S^2}^k]$ extracted from the estimated

abundance maps $\hat{\mathbf{a}}$. Composing the PCA abundance and spatial basis following equation (12), the proposed structured spatial-spectral dictionary for a given abundance cubic patch $\mathbf{a}_i$ in $\mathcal{C}_K$ can be written as follow

$$\overline{\Phi}_k = \mathbf{V}_k \otimes \mathbf{U}, \qquad (14)$$

where $\overline{\Phi}_k = [\phi_1^k, \cdots, \phi_{S^2P}^k]$, and $\otimes$ denotes the Kronecker operator. It is important to note that $\mathbf{a}_i$ only can be associated with a single spatial-spectral dictionary $\overline{\Phi}_k$. A schematic representation of the spatial-abundance structure of the proposed adaptive dictionary is shown in Figure 1.
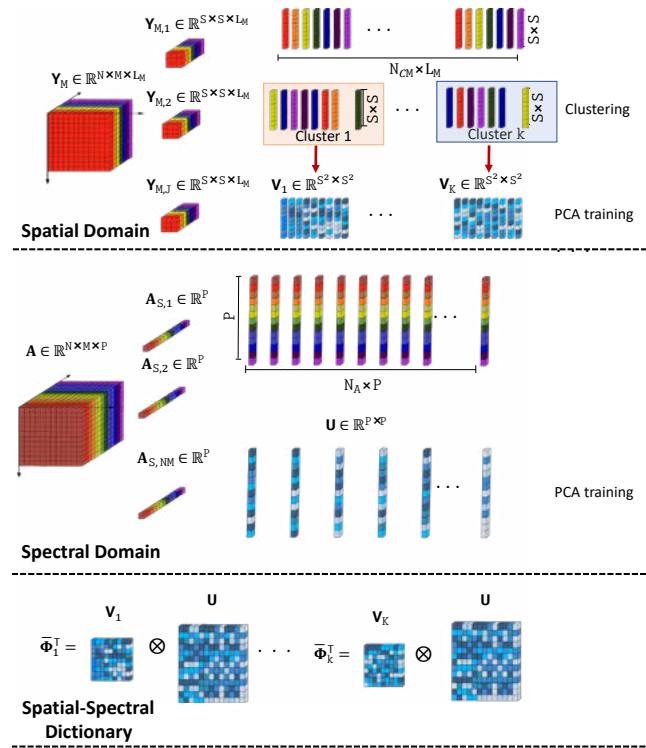
**Figure 1.** Schematic representation of the proposed adaptive spatial-spectral dictionary learned from the abundance maps.

Source: Authors.

Fusion algorithm based on a CNSR model

The strategy to solve the MS and HS image fusion problem based on a non-local sparce representation of the abundance maps in equation (4) is an iterative scheme that employs a shrinkage step in

every iteration (Dong *et al.*, 2012). The proposed algorithm is summarized in Algorithm 1.

Algorithm 1: MS and HS Image Fusion based on CNSR

Input: $\mathbf{y}_H$ $\mathbf{y}_{M'}$ and endmember matrix $\mathbf{M}$
Output: Abundance maps with high spatial resolution

Initialization: $\hat{\mathbf{x}}^{(0)} = bicubic(\mathbf{y}_H)$, $\hat{\mathbf{a}}^{(0)} = sunsal(\hat{\mathbf{x}}^{(0)}, \mathbf{M})$, $\mathbf{x}_M^{(0)} = \mathbf{y}_M$ and $\mathbf{x}_H^{(0)} = \mathbf{y}_H$

1:   **for** $t = 0$ **to** iterations **do**

2:   Compute the spatial basis $\mathbf{V}_k^{(t)}$ via PCA and K-means from $\mathbf{x}_M^{(t)}$

3:   Compute spectral basis $\mathbf{U}^{(t)}$ using PCA from $\hat{\mathbf{a}}^{(t)}$

4:   Construct the spectral-spatial dictionary $\overline{\boldsymbol{\Phi}}_k^{(t)}$ using equation (14)

5:   **for** $q = 0$ **to** Q **do**

6:   $\hat{\mathbf{x}}^{(q+1/2)} = \hat{\mathbf{x}}^{(q)} + \delta \mathbf{B}^T \mathbf{P}^T \big(\mathbf{y}_H - \mathbf{P}\mathbf{B}\hat{\mathbf{x}}^{(q)}\big) + \delta \mathbf{R}^T \big(\mathbf{y}_M - \mathbf{R}\hat{\mathbf{x}}^{(q)}\big)$ δ is a constant

7:   Compute the abundance maps from image $\hat{\mathbf{x}}^{\left(q+\frac{1}{2}\right)}$ and endmembers matrix $\mathbf{M}$ with a regularization parameter $\mu = 0.1$.

7:   $\hat{\mathbf{a}}^{(q+1/2)} = sunsal\left(\hat{\mathbf{x}}^{\left(q+\frac{1}{2}\right)}, \mathbf{M}, \mu\right)$

8:   $\hat{\boldsymbol{\alpha}}_y^{(q+1/2)} = \left[\overline{\boldsymbol{\Phi}}_{k,1}^{(t)}\mathbf{W}_1\hat{\mathbf{a}}^{(q+1/2)}, \cdots, \overline{\boldsymbol{\Phi}}_{k,npat}^{(t)}\mathbf{W}_{npat}\hat{\mathbf{a}}^{(q+1/2)}\right]$, where $\overline{\boldsymbol{\Phi}}_{k,m}^{(t)}$ is the dictionary of the m-th patch and $npat$ is the number of patches.

9:   Compute $\hat{\boldsymbol{\alpha}}_{y,i}^{(q+1)}$ using equation (15)

10:   Update β_i using equation (5)

11:   Update abundance maps: $\hat{\mathbf{a}}^{(q+1)} = \overline{\boldsymbol{\Phi}}_{k,1}^{(t)} \circ \hat{\boldsymbol{\alpha}}_y^{(q+1)}$ using equation (3)

12:   Compute high resolution image: $\hat{\mathbf{x}}^{(q+1)} = \mathbf{M}\,\hat{\mathbf{a}}^{(q+1)}$

13:   **end for**

14:   Compute abundances and MS image: $\hat{\mathbf{a}}^{(t)} = \hat{\mathbf{a}}^{(q+1)}$ and $\hat{\mathbf{x}}_M^{(t)} = \mathbf{R}\hat{\mathbf{x}}^{(q+1)}$

15:   end for

The algorithm consists of two main iterative loops. The external loop (whose iterations are indexed by t) is implemented to update the spatial-abundance dictionary $\overline{\boldsymbol{\Phi}}_k$. Once the dictionary $\overline{\boldsymbol{\Phi}}_k$ is computed, the internal loop (whose iterations are indexed by q) estimates an approximation of the abundances $\hat{\mathbf{a}}$ by employing an alternating strategy of three steps. First, the solution of the problem associated with the forward model or the image fidelity term is found by a gradient descent algorithm. Second, a rough estimation of the abundance maps is obtained by the sparce unmixing algorithm via variable splitting

and augmented Lagrangian (SUnSAL) introduced in (Bioucas *et al.*, 2010). Third, a shrinkage operator (Dong *et al.*, 2012; Daubechies, Defrise and De Mol, 2004) is employed to compute the sparce co-efficients $\hat{\boldsymbol{\alpha}}_y$. Thus, the solution $\hat{\boldsymbol{\alpha}}_y$ in the $q + 1$-th iteration is given by

$$\hat{\boldsymbol{\alpha}}_{y,i}^{q+1} = \mathcal{H}_\tau\big(\hat{\boldsymbol{\alpha}}_{y,i}^{q+1/2} - \beta_i\big) + \beta_i \qquad (15)$$

where $\mathcal{H}_\tau(\cdot)$ is the soft-thresholding proximal solution of the ℓ_1 norm with a threshold parameter τ.

EXPERIMENTAL RESULTS

This section presents the performance of the proposed method on two target hyperspectral images fixed as ground truth for the simulations. The experimental scenarios are conducted on both data sets: the Pavia image with spatial resolution 128 x 128 and 93 spectral bands, and the Moffett image with spatial resolution 128 x 128 and 93 spectral bands. The high-resolution ground-truth images are degraded by spectral and spatial distortion operators to obtain the MS and HS images, respectively. Particularly, the HS image is obtained from the target image by filtering every band with a 5 x 5 filter sampled from a Gaussian distribution followed by a down-sampling operation on the vertical and horizontal directions with a scale factor d = 4. The MS image was calculated by applying a spectral filtering of the high-resolution ground-truth images with the LANDSAT $_8$ spectral response leading to a MS image with L_M = 4 bands. Then, both degraded MS and HS images are perturbed band-by-band with additive Gaussian noise. The HS image is contaminated with SNR 30 = [db] in the last 50 bands and SNR 35 = [db] for the bands remaining while for the MS image is contaminated with a SNR 30 = [db]. The setting parameters for the fusion algorithm were selected as follows: K = 60 clusters; spatial patch size 6 x 6, 12 similar neighbors cubic

patches are extracted to calculate β_i (i.e., $|\Omega i|$) in a neighborhood size of 50 x 50; the parameter δ is set on 1.25 while the thresholding for sparce representation is set on τ = 1.841. In order to compare the proposed method, three different approaches known as (HMIF-SR), (HySure), and (HyMuXNol) (Wei *et al.*, 2015; Simoes *et al.*, 2015; Arias, Vargas and Arguello, 2019) are simulated on the same fusion scenario.

The MS and HS images and the full-resolution reconstructed images for the Pavia and Moffett images are shown in Figures 2 and 3. The results from the proposed fusion strategy show a better-quality estimation of the target image. Furthermore, the fused resultant images of adversary methods depict greater spectral and spatial degradation compared to the Pavia and Moffett ground-truth images.

The evaluation of the proposed fusion method is performed employing the PSNR (Peak Signal-to-Noise Ratio), UIQI (Universal Image Quality Index), RMSE (Root-Mean-Square error), ERGAS (Relative Dimensionless Global Error in Synthesis), SAM (Spectral Angle Mapper), and DD (Degree of Distortion) image fusion metrics (see (Wei *et al.*, 2015) for more details). Tables 1 and 2 summarize the computed quantitative metrics of the proposed strategy compared to the competitive fusion strategies whose numerical values clearly favor the restored images from the suggested fusion method.

Table 1. Quantitative fusion results of the proposed method and the competitive algorithms on the Pavia image: PSNR [dB], UIQI, RMSE (10^{-2}), ERGAS, SAM [degrees], DD (10^{-3})

Methods	PSNR	UIQI	RMSE	ERGAS	SAM	DD
Hysure	36.214	0.978	1.511	1.313	2.682	11.131
HMIF-SR	39.684	0.991	0.947	0.847	1.495	7.011
HyMuXNol	40.632	0.992	0.863	0.764	1.345	6.105
Proposed	41.129	0.995	0.825	0.712	1.223	5.737

Source: Authors.
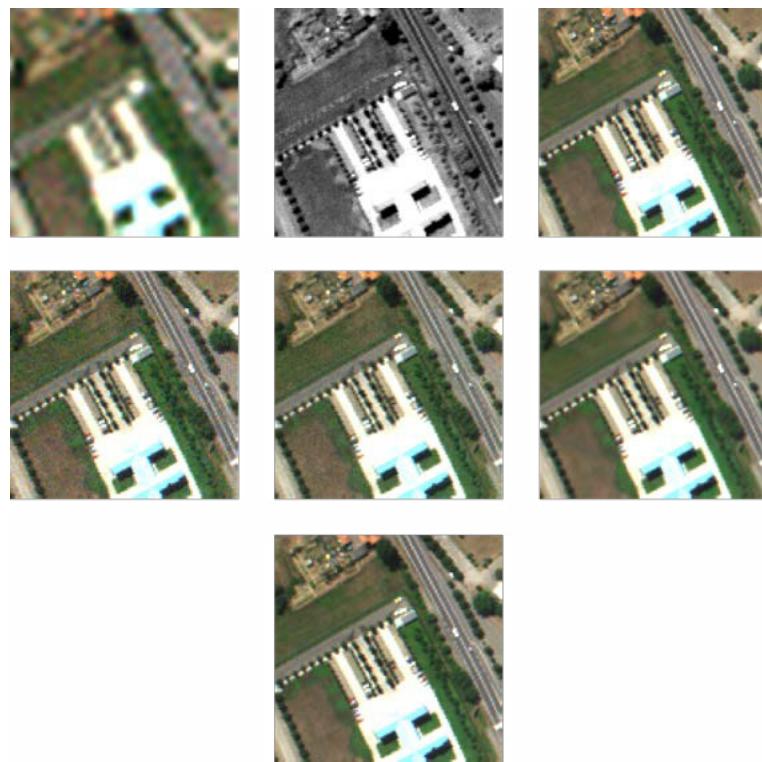
Figure 2. Qualitative fused images (Pavia image). (Row 1, left) MS image. (Row 1, middle) MS image. (Row 1, right) Ground truth. (Row 2, left) HySure. (Row 2, middle) HMIF-SR. (Row 2, right) HyMuXNol. (Row 3) Proposed.

Source: Authors.

Table 2. Quantitative fusion results of the proposed method and the competitive algorithms on the Moffet image: PSNR [dB], UIQI, RMSE (10^{-2}), ERGAS, SAM [degrees], DD (10^{-3})

Methods	PSNR	UIQI	RMSE	ERGAS	SAM	DD
Hysure	37.994	0.987	1.246	1.486	3.232	9.082
HMIF-SR	40.578	0.993	0.867	1.037	2.103	6.429
HyMuXNol	41.448	0.994	0.852	0.994	1.948	6.191
Proposed	41.924	0.996	0.758	0.915	1.167	5.953

Source: Authors

To further show the advantage of the proposed solution compared to the best method in the state-of-the-art HyMuXNol, we randomly extracted four spectral signatures on the Pavia and Moffett ground-truth images and evaluated them qualitatively (Figure 4). It is possible to see that the recovered spectral signatures using the prior CNSR on the abundances are closer to the ground-truth spectral signatures, indicating that the spectral information of the scenes is better fitted with the proposed model than the underlying model in the HyMuXNol method, and this happens for all the selected images.
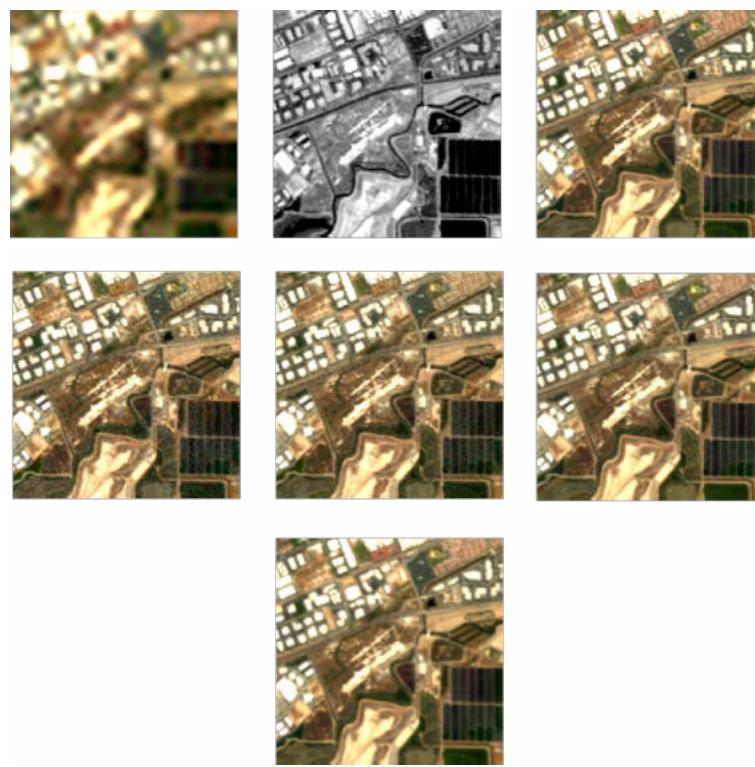
Figure 3. Qualitative fused images (Moffet image). (Row 1, left) MS image. (Row 1, middle) MS image. (Row 1, right) Ground truth. (Row 2, left) HySure. (Row 2, middle) HMIF-SR. (Row 2, right) HyMuXNol. (Row 3) Proposed.
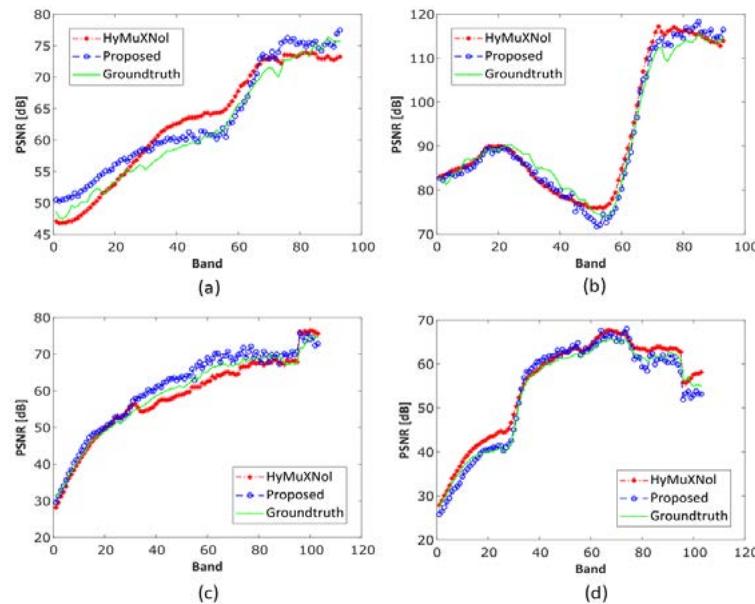
Source: Authors.

Figure 4. Evaluation of the spectral performance: (Row 1) Ground-truth and recovered spectral signatures on the Pavia data set. (Row 2) Ground-truth and recovered spectral signatures on the Moffett data set.

Source: Authors.

CONCLUSIONS

This work proposed a MS and HS image fusion model solved under a sparce model on a set of learned dictionaries. By using the spectral unmixing decomposition, this model includes a non-local sparce representation of abundance maps on the fusion problem while taking advantage at the same time of the low dimensionality of the HS data. The estimated sparce representation is centralized for a better estimation obtained from the non-local redundancy of the abundances. These considerations lead to enhance the quality of fused images of state-of-the-art fusion methods based on sparce regularization. Additionally, a spatial-spectral dictionary is adaptively constructed, exploiting the low dimensionality of the abundance maps. The dictionary structure consists of K sub-dictionaries, each one estimated from a cluster of similar spatial features of abundance maps. Thus, an abundance patch is then sparcely represented in the appropriate dictionary. In order to obtain the full resolution image, the employed numerical strategy includes two main steps alternated iteratively: shrinkage thresholding operator for sparse regularization is used to solve the ℓ_1 norm, and the execution of a gradient descent method to solve the quadratic fidelity problem. Restoration results show that the proposed image fusion model based on the abundance map analysis outperforms the competitive fusion methods based on sparse regularization in terms of the quantitative metrics PSNR, UIQI, RMSE, ERGAS, DD, and SAM.

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Applying MULTIPOL to Determine the Relevance of Projects in a Strategic IT Plan for an Educational Institution

Determinación de la pertinencia de proyectos de un plan estratégico informático en una institución educativa aplicando MULTIPOL

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Abstract

Objective: To determine the relevance of the projects defined in a strategic IT plan for an educational institution through the application of MULTIPOL.

Methodology: The research was quantitative with a descriptive non-experimental design. Interviews were conducted with teachers and administrators of the educational institution called "Cuarta Poza de Manga," as well as a documentary review, in order to determine the parameters required to apply MULTIPOL and evaluate the more relevant projects of the institution.

Results: It was established that the most relevant projects for the institution were the following: Improving the computer infrastructure; incorporating an online learning management system to support teaching processes; using social media to broadcast relevant information to the educational community of the institution.

Conclusions: The application on MULTIPOL allowed finding the most relevant projects the institution should take into account to leverage its development.

Keywords: strategic IT plan, educational institution, MULTIPOL, decision-making, pertinence.

Resumen

Objetivo: La presente investigación tuvo por objetivo determinar la pertinencia de los proyectos definidos en un plan estratégico informático de una institución educativa mediante la aplicación de MULTIPOL

Metodología: La investigación realizada fue de tipo cuantitativo con diseño no experimental transeccional descriptivo, donde se aplicó una revisión documental y entrevistas a docentes y administrativos de la Institución Educativa Cuarta Poza de Manga, con el fin de determinar los parámetros requeridos para aplicar MULTIPOL y evaluar los proyectos con aspectos relevantes a la institución.

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Applying MULTIPOL to Determine the Relevance of Projects in a Strategic IT Plan for an Educational Institution

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Resultados: Se estableció que los proyectos con mayor pertinencia para la institución fueron: el mejoramiento de la infraestructura de computadores, la incorporación de un sistema de gestión de aprendizaje en línea para apoyar los procesos de enseñanza, y la utilización de redes sociales para difundir información relevante a la comunidad educativa de la institución.

Conclusiones: Aplicar MULTIPOL permitió definir los proyectos de desarrollo más relevantes para la institución educativa, es decir, aquellos a los cuales debería prestar más atención para promover su desarrollo.
Palabras clave: plan estratégico informático, institución educativa, MULTIPOL, toma de decisiones, pertinencia.

INTRODUCTION

Companies require the use of computational tools that facilitate the fulfillment of organizational objectives to allow entering into competitive economies (Panetto and Cecil, 2013). In particular, organizations such as educational institutions use information systems and other aligned technologies, in order to develop strategies that encourage the competitiveness of the company and help them face the challenges of the current context (Sanchez-Puchol, Pastor-Collado, and Borrell, 2017). Taking into account that educational institutions support the development of society, it is essential to increase their level of business and academic knowledge. For this reason, these organizations are implementing information systems capable of establishing a transversal integration for communication, acquisition, and production of information (Martins, Branco, Gonçalves, Au-Yong-Oliveira, Oliveira, Naranjo-Zolotov and Cruz-Jesús, 2019).

These information systems are implemented according to the needs of the institution. For example, administrators use them in the collection and processing of information to support strategic decision-making, whereas the faculty staff need them for managing the students' learning process and the interactions required during the educational process. The application of these systems facilitates accessing, managing, and spreading information throughout the institution, and it also helps reduce work times and guarantee quality reports of different academic dependencies (Shah, 2014). Therefore, the development of

strategies focused on improving the management of this resource has become fundamental and required to both achieve a higher level of competitiveness and to improve sustainability practices (Ariani, Gholamzadeh, Mukhtar, Sahran, Abdul and Jaromír, 2017).

Strategic planning is carried out continuously, so that the institution guarantees linking organizational and academic processes with technological growth present in the market. Also, it is possible to align the mission and objectives with the demands of the competitive environment, while having an efficient management among the dependencies (Ariyanto, Budiyanto, and Joko, 2017). However, this planning may lead to projects that exceed the economic, infrastructure, or human resources of the institution because each one entails different duration, complexity, amount of work required, and budget (Zavadskas, Vilutiene, Turskis and Šaparauskas, 2014). Moreover, it is necessary to take into account the uncertainty that comes from a changing market environment and inflexibility that a strategic plan could impose for the organization (Dibrell, Craig and Neubaum, 2014).

One of the methods that help determine the relevance of a project is MULTIPOL. This methodology has been used in research related to decision making. For example, a study carried out in 2018 applied MULTIPOL in the evaluation of the proposals made by the candidates for mayor of Cartagena (Colombia). The work took the proposals related to the promotion of education in the city and evaluated them in order to define which ones were most relevant, and in this way help citizens make the

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best decision regarding the next mayor (Martelo, Hamdan, Jaramillo, 2018). Likewise, other research defines the strategies with the greatest impact to reduce student dropouts, which allows universities to effectively address this phenomenon (Martelo, Herrera, Villabona, 2017). Furthermore, another work analyzes the projects defined in a programmatic proposal of the Program Director of a public university in order to help determine the highest priority projects to be executed in the academic unit and obtain the greatest benefit (Martelo, Jimenez-Pitre, Jaramillo, 2017).

Therefore, the objective of this research is to help determine the relevance of projects defined in a strategic IT plan for its application in the academic and administrative processes of educational institutions. This analysis of projects can be carried out by applying MULTIPOL, which allows supporting decision-making through the evaluation of actions, projects, or strategies in relationship with constraints defined as criteria and policies and taking into account the context of the institution.

METHODOLOGY

This was a quantitative research, with a descriptive non-experimental cross-sectional design: non-experimental because the variables were studied without manipulation, but only their behavior was observed (Garson, 2013); cross-sectional because the information was collected in a defined and fixed-timed place, based on an established sample (Lee and McKinney, 2013). In addition, the strategic IT plan of the educational institution was detailed in order to determine the relevance of the projects proposed (Babbie, 2011).

The population evaluated consisted of 30 teachers, 3 coordinators, and the rector of the institution named "Cuarta Poza de Manga," located in Turbaco, Bolívar (Colombia). The sample involved the entire population because when applying the collection instrument was access to all participants.

The collection technique was a documentary review where the files contained in the strategic plan were consulted in order to detail the projects included, as shown in Table 1.

Table 1. Projects included in the strategic IT plan of "Cuarta Poza de Manga" Educational Institution.

Projects	Description
Formal planning of the structure of the academic unit	The organizational structure of the academic unit in the institution allows organizing formal information flows and achieving harmony among employees, specifying roles and responsibilities to coordinate and fulfill the strategic objectives of the institution.
Improving computer infrastructure	Having the computational infrastructure align with what the academic community needs helps increase the use of IT for the training process; it also helps develop skills related to digital literacy. Likewise, the operational activities benefit from the acquisition of equipment for the development of responsibilities, also reducing the consumption of paper.
Implementing a software for the management of academic activities in the institution	The implementation of a system to manage information and communication between academic processes within the institution streamlines the activities and procedures of the employees and reduces response times.
Incorporating an online learning management system to support teaching processes	This provides advantages, such as facilitating the preparation of students, enhancing transmission of knowledge, obtaining information about the student learning process, applying modular and flexible technology that can be adapted to the needs of each teacher, enhancing digital literacy in students, and having a direct communication channel between students and teachers to solve doubts and share information.
Using social media to broadcast relevant information to the community within the institution	The use of social media as an alternative to support organizational communication and broadcast information allows the institution to announce student acceptance policies, generate channels to encourage parent participation, keep academic calendars updated, and share multimedia content. In addition, it helps in the propagation of the institutional image.

Source: Authors.

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On the other hand, interviews were the instrument applied to obtain information on criteria and policies. This information was used as parameters for the MULTIPOL technique. The approach established in the strategic plan was also taken into account in order to define these parameters. Tables 2 and 3 show this.

MULTIPOL was used as a data analysis method. This method consists of a process of evaluating actions or strategies based on criteria and policies, while taking into account the consensus of a group of experts. In this particular case, the projects established in the strategic plan are analyzed through criteria and policies defined by the directors of the institution in order to rate the relationship between them and define the more relevant projects according to the context of the institution.

A guide model was established to explain the phases of the investigation (Figure 1).

Table 2. Criteria for the evaluation of the projects in the strategic plan.

Criteria	Description
Higher educational quality	To provide better educational quality shown in how the teachers teach.
Technological appropriation	To acquire and adapt technological tools within study lessons and administrative processes.
Systematization of administrative processes	To organize administrative processes of the institution to efficiently coordinate academic management activities.
Available resources	According to the number of resources at the economic, infrastructural, and human level of the educational institution.
Broadcasting information	To communicate information related to academic activities and resources within the institutional work, as well as the impact the institution has on the municipality, the region, and the country.

Source: Authors.

Table 3. Policies that define constraints on the projects of the strategic plan.

| Policies	Description
Continuous improvement of the quality system	To establish standard activities that allow growth in the quality of academic and administrative processes.
Continuous teacher training	To define strategies that support the pedagogical and professional development of teachers on an ongoing basis.
Information and communication technology support in teaching	To incorporate information and communication technologies in the academic activities of teachers in order to improve the teaching methodologies applied in class.
Association with organizational processes	The strategies must be consistent with the academic and administrative activities and processes of the institution in order to support achieving the organizational objectives.

Source: authors.

Figure 1. Conceptual model proposed to define the phases of the investigation.

Source: Authors.

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Phase 1: Selecting the group of experts. People with academic and administrative expertise within the educational institution were asked to participate in order to define the parameters required for using MULTIPOL. The teachers and administrative staff of the institution "Cuarta Posa de Manga" were chosen as a group of experts for the study because they are the actors involved in the management and teaching-learning processes.

Phase 2: Gathering information. The opinion of the group of experts was taken into account, and the data relevant to their knowledge of the strategic plan was consulted in order to define the criteria and policies that would serve to evaluate the projects contained in the plan and establish their relevance with the objectives and resources of the institution. Therefore, the actions were determined according to the requirements of the MULTIPOL technique, which contains the following variables: short name, long name, and description (Table 4).

Likewise, the criteria and policies were established based on the same parameters of the actions, but MULTIPOL requires that these variables contain an attribute of weight, which determines the relevance of the criteria for the projects assessed. Tables 5 and 6 show this new attribute.

Table 4. Actions adjusted to the parameters of the MULTIPOL technique.

Long name	Short name	Description
Formal planning of the organizational structure of the academic unit	FPSU	The organizational structure of the academic unit in the institution allows organizing formal information flows and achieving harmony among employees, specifying roles and responsibilities to coordinate and fulfill the strategic objectives of the institution.
Improving of the computer infrastructure	ICI	Having the computational infrastructure align with what the academic community needs helps increase the use of IT for the training process; it also helps develop skills related to digital literacy. Likewise, the operational activities benefit from the acquisition of equipment for the development of responsibilities, also reducing the consumption of paper.
Implementing a software for the management of academic activities in the institution	ISMA	The implementation of a system to manage information and communication between academic processes within the institution streamlines the activities and procedures of the employees and reduces response times.
Incorporating an online learning management system to support teaching processes	ISMT	This provides advantages, such as facilitating the preparation of students, enhancing transmission of knowledge, obtaining information about the student learning process, applying modular and flexible technology that can be adapted to the needs of each teacher, enhancing digital literacy in students, and having a direct communication channel between students and teachers to solve doubts and share information.
Using social media to broadcast relevant information to the community within the institution	SNIE	The use of social media as an alternative to support organizational communication and broadcast information allows the institution to announce student acceptance policies, generate channels to encourage parent participation, keep academic calendars updated, and share multimedia content. In addition, it helps in the propagation of the institutional image.

Source: Authors.

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Table 5. Criteria adjusted to the parameters of the MULTIPOL technique.

Long name	Short name	Weight	Description
Higher educational quality	HEQ	1	To provide better educational quality shown in how the teachers teach.
Technological appropriation	TA	1	To acquire and adapt technological tools within study lessons and administrative processes.
Systematization of administrative processes	SAP	1	To organize administrative processes of the institution to efficiently coordinate academic management activities.
Available resources	AR	1	According to the number of resources at the economic, infrastructural, and human level of the educational institution.
Broadcasting information	DI	1	To communicate information related to academic activities and resources within the institutional work, as well as the impact the institution has on the municipality, the region, and the country.

Source: Authors.

Table 6. Policies adjusted to the parameters of the MULTIPOL technique.

Long name	Short name	Weight	Description
Continuous improvement of the quality system	CIQS	1	To establish standard activities that allow growth in the quality of academic and administrative processes.
Continuous teacher training	CTT	1	To define strategies that support the pedagogical and professional development of teachers on an ongoing basis.
Information and communication technology support in teaching	ICTT	1	To incorporate information and communication technologies in the academic activities of teachers in order to improve the teaching methodologies applied in class.
Association with organizational processes	AOP	1	The strategies must be consistent with the academic and administrative activities and processes of the institution in order to support achieving the organizational objectives.

Source: Authors.

Phase 3: Definition of the relevance of the projects. MULTIPOL was applied to the projects contained in the strategic plan of the institution, and the criteria and policies served as constraining factors for each situation. This process resulted in tables and graphs that show the relationship between actions and the other variables, their compatibility, and the probability to succeed.

Phase 4: Analysis and selection of projects. The results obtained after applying MULTIPOL are examined with the institution administrative staff since they are in charge of selecting the projects to be executed for improving efficiency of academic and administrative processes. MULTIPOL presents graphs that show the behavior of the actions concerning the criteria and policies to determine their relevance for the institution.

RESULTS

To define the relevance of the projects, the variables required were submitted, and the resulting tables and graphs were displayed. Table 7 shows the relationship between actions and policies.

The average obtained for each project is shown and indicates the impact of its implementation on the institution's processes. Likewise, a graph called Profile Map was obtained, which presents the behavior of the relationship between actions and policies in order to establish priorities regarding the projects that are more closely related to the policies that govern the institution (shown in Figure 2).

On the other hand, MULTIPOL also provided a graph known as Sensitivity Classification Map, which represents the success probability of the

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Table 7. Evaluation of actions regarding the policies of the institution.

| Actions/Policies	CIQS	CTT	ICTT	AOP	Average	Standard deviation
FPSU	14,3	14,4	14,4	14,9	14,5	0,2
ICI	16,1	16,4	16,1	16,1	16,2	0,1
ISMA	15,2	15,4	15,3	15,2	15,3	0,1
ISMT	16,4	16,9	16,5	16,5	16,5	0,2
SNIE	15,8	16	16	15,6	15,9	0,2

Source: Authors.
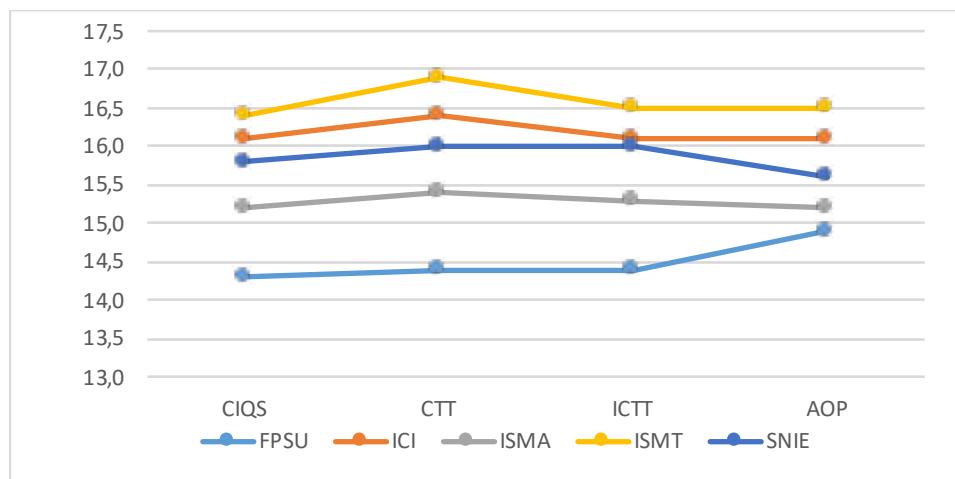
Figure 2. Profile Map of action evaluation in relationship with policies.
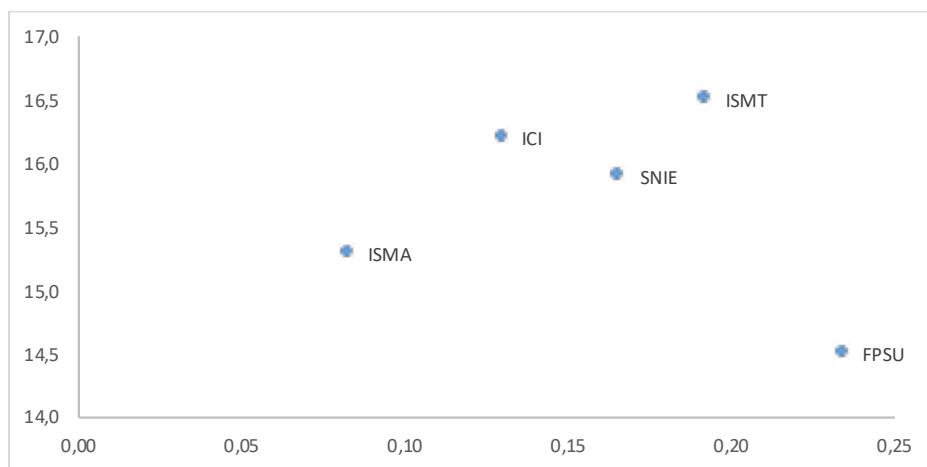
Source: Authors.

Figure 3. Sensitivity classification map of the evaluation of actions in relationship with policies.

Source: Authors.

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projects based on the effectiveness of their implementation in "Cuarta Posa de Manga." The one furthest left is the one with greatest probability to succeed, while the projects with high effectiveness are those located highest on the graph, as shown in Figure 3.

As seen in the previous graph, the most effective projects for the institution are ISMT and ICI, while those with the highest probability of success are ISMA and ICI. Thus, the project most favorable for the institution is ICI (Improvement of computing infrastructure), followed by ISMT (Incorporating an online learning management system to support teaching processes), SNIE (Using social media to broadcast relevant information to the community within the institution), ISMA (Implementing a software for managing the academic area of the institution), and FPSU (Formal planning of the organizational structure of the academic unit). This result is similar to the study carried out by (Pucciarelli and Kaplan, 2016), where it is stated that social networks and viral marketing are essential for the development of educational institutions, so that they can obtain greater visibility, reputation, and prestige with which compete with other organizations, as well as focus their efforts on developing technology to eliminate barriers that may arise in the inclusion of new forms of teaching.

ICI is established as the project with the greatest relevance because it supports the effective fulfillment of the other projects. In addition, it satisfies the needs of appropriation of information and communication technologies in the academic and administrative processes of the institution "Cuarta Poza de Manga," since having a computational infrastructure with sufficient characteristics would guarantee an improvement in the activities carried out by teachers and administrative staff.

This result is similar to the research carried out by Bozalek, Ng'ambi, and Gachago (2013), which determined that in order to achieve the acceptance and use of technology, the institution must define strategies focused on the creation of propitious spaces for this purpose; furthermore, it is necessary to implement policies that promote continuous improvement of information technologies in educational establishments.

CONCLUSIONS

The most relevant project for the educational institution was the "Improvement of the computer infrastructure" because it supports the effective fulfillment of other projects and guarantees the optimization of academic and administrative processes.

Other projects that are taken into account for the development of the institution were "Incorporating an online learning management system to support teaching processes," "Using social media to broadcast relevant information to the community within the institution," "Implementing a software for the management of the academic area," and "Formal planning of the organizational structure of the academic unit," which are organized by their positive impact on the educational institution.

The project with the highest probability of success was "Implementing a software for the management of the academic area." This should be taken as the first project to implement if an anomaly with any resource or process in a specific area occurs.

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Estudio de caso

Guided Models for Teaching Students Research in Science and Engineering

Modelos guiados para la investigación en ingeniería y ciencias básicas

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Jaime Duván Reyes Roncancio[3]

Abstract

Context: This article presents the arguments that support the formulation of a research model from the idea of "guided models," which allows the designing of routes and methodologies for the approaching, formulating, and solving problems in the training of technologists and engineers.

Method: The methodology used was based on grounded theory, which allows solving problems and develop innovative research through theoretical and methodological categories.

Results: It was possible to organize the model with a special emphasis on the generation of monitoring and contrasting matrices as a control mechanism and guide for the researcher.

Conclusions: The implications of the incorporation of this model are analyzed in relation to the training purposes of engineering and technology professionals, articulated through a progression hypothesis as a reference every researcher will be able to get when analyzing and reviewing their own research processes regardless of the methodology developed.

Keywords: models, methodology, informed theory, investigation, training.

Resumen

Contexto: En este artículo se presentan los argumentos que fundamentan la formulación de un modelo de investigación desde la idea de "modelos guiados," que permite el diseño de rutas y metodologías para el planteamiento, formulación y resolución de problemas en la formación de tecnólogos e ingenieros.

Método: La metodología utilizada se basa en la teoría fundamentada, la cual permite por medio de categorías teóricas y metodológicas resolver problemas y desarrollar investigaciones innovadoras.

Resultados: Se obtuvo la organización del modelo, con especial énfasis en la generación de matrices de seguimiento y contrastación, como mecanismo de control y guía para el investigador.

Conclusiones: Las implicaciones de la incorporación de este modelo se analizan en relación con los propósitos de formación de profesionales de la ingeniería y de la tecnología, articulándose mediante una hipótesis de progresión como referencia que puede tener todo investigador al momento de analizar y revisar sus propios procesos de indagación, independientemente de la metodología que se desarrolle.

Palabras clave: modelos, metodología, teórica fundamentada, investigación, formación.

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Guided Models for Teaching Students Research in Science and Engineering

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INTRODUCTION

This work aims to contribute to research training in initial and continuing teaching of methodological processes in three main areas. First, by formulating guided models for the construction of theories both in the practice and implementation of strategies, as well as in routes for the resolution of research problems (Gallego-Badillo R. , 2004). Secondly, with the foundation of methodological designs that help guide research in engineering and science with the purpose of understanding scientific research processes. Third, by formulating the bases for the constitution of methodological guides, specifically dedicated to the training of researchers (Giraldo, 2011) (Gangoso, 2016).

From this perspective, this work is based on four guidelines. In the first place, the need to start from the construction of guided models, in other words, the methodological definition of the models as part of the construction of knowledge, which could be applied both in the training of researchers and for school science. Second, an epistemological foundation from the formulation and construction of theoretical categories. Third, a methodological proposal in accordance with said paradigm from grounded theory, whose starting point is the approach of a guided model of the phenomenon under investigation. This proposal is especially operative when it comes to building master's theses. And finally, methodological routes and hypothesis of progression to conclude with an example of construction and application of the proposal.

METHODOLOGICAL PERSPECTIVE IN RESEARCH TRAINING

Throughout the history of natural science, the importance of formulating models that explain everything from natural phenomena to the structure of the universe itself has been widely documented. From this perspective, we propose a work oriented to research processes. This work is developed from two strategies: formulating models and establishing methodologies that allow configuring a work route in order to generate new and better ways of building knowledge (Niaz, 2016) (Da Rochaa, 2019).

From the importance of science education and model-based teaching arises the need to build a proposal of guided models for research training in Technology, Engineering, and Basic Sciences. Therefore, a guided model is proposed accompanied by a systematic review of both theoretical references and scientific production (Gómez and Garduño, 2020), in order to establish a solid support for the system (Chamizo-Guerrero & Ríos-López, 2017) (Arraiz, 2014). In other words, it is necessary to generate conceptual structures in students within a system framed in a model that would grant them several advantages. For example, the model will allow them both to understand the problem and to postulate hypothetical scenarios for the solution; that is, it will give them tools for the construction of innovative methodological designs that give them a guide to solve the problem and generate new ways of approaching science and technology education (Acevedo-Díaz & al, 2017) (Bosque-Pérez & al, 2016) (Sánchez-Robayo & Torres-Duarte, 2017). Additionally, it allows them to construct a representation of the degree work within an epistemological framework.

This proposal is based on the concept of model proposed by Ingham and Gilbert (1991). They argued that a model is a simplified representation of a system that focuses attention on specific aspects of it (Peralta, 2016). Furthermore, models allow aspects within the system (i.e. objects, events, or ideas) that are complex or that are on a different scale than the system itself. Models are important for scientific research in the formulation of hypotheses to be tested, as well as in the description of scientific phenomena (Ingham & Gilbert, 1993).

In summary, this proposal seeks to contribute to the development of the next generation of researchers. In particular, the objective is to help the development of skills that allow them, on the one hand, to pose problems and evaluate them, and on the other, to provide solutions with an emphasis on the construction of models to guide research and innovation processes.

Guided Models for Teaching Students Research in Science and Engineering

Gallego–Torres ., A.P. Bustos–Velazco., E.H. y Reyes–Roncancio., J.D.

FROM GROUNDED THEORY TO THE ESTABLISHMENT OF MODELS IN RESEARCH AS A WORK ROUTE

In order to formulate a theory of guided models for research training, we turn to what is stated by Strauss and Corbin called "Grounded Theory," understood as the possibility of innovating with the generation of models that allow explaining a phenomenon (Glaser & Strauss, 1967). In particular, this research focuses on two types of phenomena related to the natural sciences and technology (Weiss, 2017) (Ovalle, 2019): on the one hand, those phenomena linked to the daily action of human beings; on the other, to those generated by nature itself.

Finally, it is important to take into account what is called "the four phases of all hermeneutical research." These phases are a) instrument validation; b) implementation; c) methods and tools for the collection and systematization of information; and d) the qualitative or quantitative analysis of the information (i.e. triangulation and analysis) (Carrero, 2012).

Grounded theory

The grounded theory was initially defined by Glaser and Strauss, who in 1967 published a book called "The Discovery of Grounded Theory" where they developed it (Glaser & Strauss, 1967). After this publication, many researchers have adopted this proposal whose purpose is to construct concepts that are derived from the registered and systematized information of experiences in which social researchers live experiences with communities (Hernández, Herrera, Martínez, & Páez, 2011). Grounded Theory (or "research training" in this case) adopts a mixed methodological paradigm (Medina, Arguello & Gómez, 2017) that allows the construction of guided models, which is the modeling of research proposals according to the intentions of every investigation. In this way, the conceptualization becomes an abstract and simplified perspective, as knowledge of the lived world and that the researcher wants to represent through the construction of models that, in the case of this investigation, is applied to the teaching of science (Arraiz, 2014) (Bonilla-García & López-Suárez, 2016).

Our proposal to work on guided models based on grounded theory for the training of researchers is structured around five moments:

1. Formulation of the model: systems of questions, objectives, and hypotheses posed as a system.
2. Presentation of theoretical categories by induction as a guide for mapping bibliographic information and conceptual foundation of research (Contreras Accounts, 2020). As many categories as concepts that are formulated in the problem will be proposed.
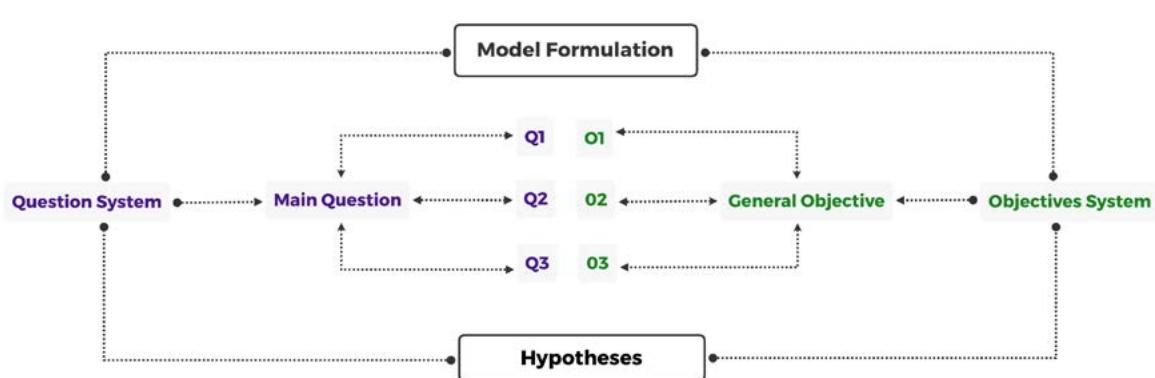

Figure 1. Formulation of the model.

Source: Own.

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Table 1. Category matrix.

RESEARCH PROBLEM	GENERAL OBJECTIVE	SPECIFIC OBJECTIVES	CATEGORIES	CATEGORY DEFINITION	SUBCATEGORIES

Source: Own

3. Design of the methodological route: Construction of methodological designs, and the validation process of the instruments and activities that constitute the researcher's field work (Cisterna, 2005). This validation is carried out by entities, which are three differentiated actors, in order to give ownership and reliability to the research. These three actors are: a) academic peers of the researcher, b) experts, and c) a similar population group (Paramo-Bernal, 2018).

4. Implementation: The proposed designs are applied, the data obtained is systematized, and the information is triangulated (Richards, 2018). The systematization process can be qualitative or quantitative, with the need to go through writing techniques and semantic codes configured in the interpretation of the validated instruments (phase two). In this sense, it is important to use specialized software for the qualitative and quantitative analysis of information (e.g. MAXQDA®, Atlas-Ti®, N-Vivo®, SPSS®) (Chandra & Shang, 2019)

5. Modeling and Analysis. In this last phase, the researcher validates his hypotheses and tests the solution to the problem from the initial model. This process allows either a reconfiguration of the initial model or the reconfiguration of the initial approach and conclusions (Campeón, Becerra, & Villa, 2018).
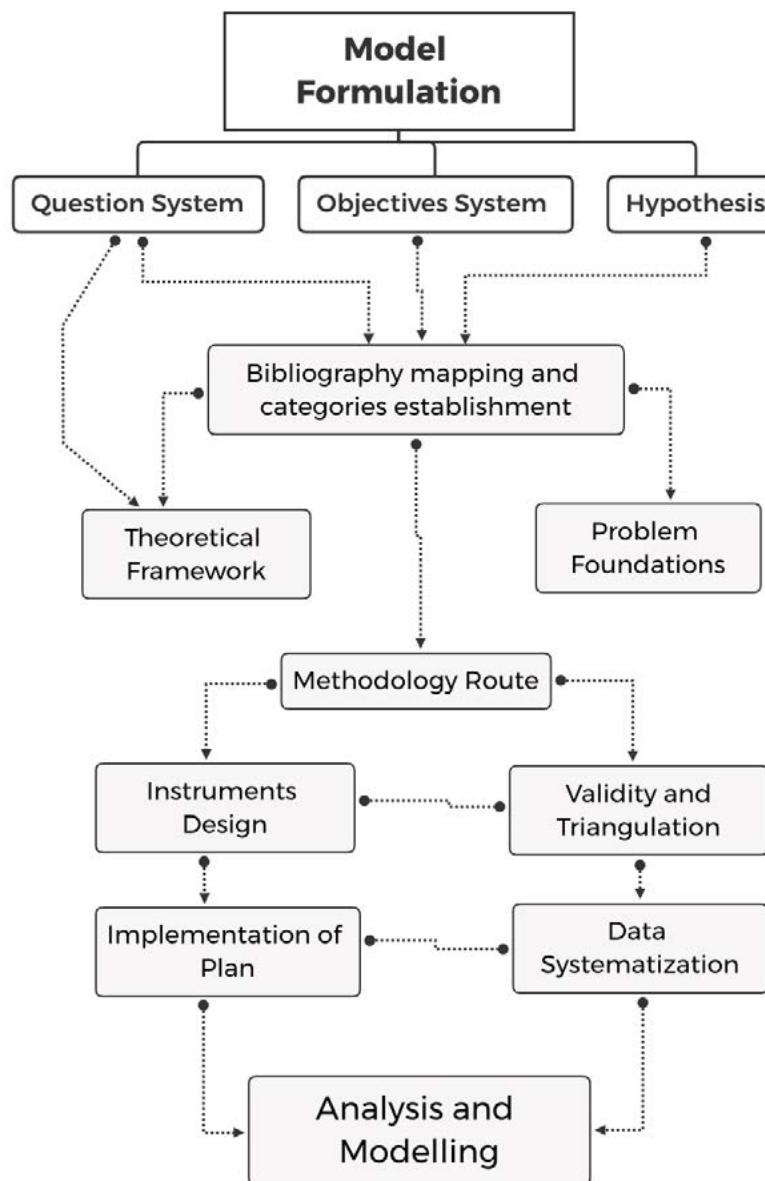
The follow-up to this methodological process, shown in Figure 2, secures the development of a systematic and reliable work, which will guarantee that the obtained results contribute to the scientific community dedicated to education. This greatly benefits future researchers who pursue a hermeneutical education.

THE DESIGNING AND IMPLEMENTING OF GUIDED MODELS IN THE INVESTIGATIVE PROCESS

In this section we will address an interpretive approach to the idea of guided models for research training in a dynamic and reflective sense. Thus, the concept of model is presented in association with factors that enhance its dialogic-reflective character. These factors also serve to structure a trajectory as a form of argued representation of the methodological route, via specific representations of maps of the process (Gutierrez, 2016). A generic example of representation of models and methodological maps is distinguished.

This organization helps to consolidate a new look at what is done when researching in science education because it questions the monitoring of phases (stages) and the mechanical use of techniques (methods), without reflecting on the events of the research process. Additionally, this option positions the conception of the reflective researcher, who is epistemologically aware of the differences between the application of research methods (from their various enunciations) and the design and implementation of problem-solving routes. This awareness of the difference applies even in cases in which mixed-cut methodological alternatives that dialogue with the construction of models and progression hypotheses are developed (Gallego-Badillo, Pérez, & Gallego-Torres, 2020).

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Figure 2. Guided Model for Research Training.

Source: Own.

Guided Models for Research Methodologies

The concept of "guided model" in research acquires relevance insofar as it allows understanding the process of solving the research problem from a dynamic, active, reflective, and also changing and complex approach. However, these characteristics do not imply that the process is difficult or impossible. Another characteristic feature of the concept is the validation of the research in a praxiological sense; this favors the construction of meaning in actions, based on the reflection over the experiences of researchers and their work team (Arango-Londoño, 2016). For this reason, the guided model is enriched by the

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contexts of reflection, the researcher's learning and the validation and feedback processes from experts.

Consequently, when the research process is beginning, the design of methodological models from the aforementioned approach is appropriate for the case of epistemological and hermeneutical perspectives. This is due to the constructive nature of knowledge that is produced and is applicable, for example, in the field of science education.

Factors that enhance the guided model

According to the researcher's reflected experience on his own inquiry processes, research actions are consolidated as elements or factors of the investigative process. For the first case, the researcher can assume that the methodology consists of considering relevant aspects that are added or achieved as they solve their research problem question. For the second case, it can be assumed that the aspects associated with the methodology are like turning points in their maximum potential, that is, they are capable of reconstructing different paths to follow; these alternatives are proposed from a qualification perspective, not a denial, of those initially proposed. Thus, in the case of methodological trajectories, it is necessary to consider dynamic factors rather than disconnected elements.

A guided model can be designed with the following factors in mind:

1. _The epistemological perspective on the nature of knowledge that is produced_. It is necessary to consciously assume whether the knowledge that is produced obeys the researcher's particular philosophical views (e.g. realism or relativism), since this also gives value to the researcher's own knowledge.

2. _The organization of threads_. These are usually understood as phases of the investigation and are designs of possible routes of inquiry associated with the objectives of the investigation.

3. _The constitution of meaning for the threads_. What are they developed for? What do they contribute? Why are they necessary?

4. _The progressive approach to the process through the threads_. The researcher's actions must be continually reflected in such a way as to build a progressive awareness of the process. Therefore, it is not about developing the threads like a recipe in which predetermined steps are followed; on the contrary, each reflected investigative action contributes to the indicated meaning. Thus, the reconstruction processes of the corresponding methodological experiences are facilitated.

It is worth noting that this description does not refer to specific investigative techniques. This is because the techniques are selected or constructed to the extent that their characteristics enhance particular actions of the researcher. Although this is not an obstacle to consider them in the planning of the sub-processes, it should never be assumed in a dogmatic sense as it would be contradictory with the dynamic approach that we have presented.

Guided models and progression hypotheses as a reference map

When organizing the research design from guided models, it is possible to establish a progression hypothesis as a reference map. In this sense, the progression hypothesis acquires relevance to contrast and reflect on the coherence of the methodological path (Figure 2). The factors are considered as criteria and in each of these it is convenient to analyze the "places" of reference. As a synthesis, it is possible to deduce a map that reveals a state of the guided model; In addition, it is possible to make maps at the beginning, during, and at the end of the investigative process. In this way, not only would there be evidence of the methodological transformation route as a product, but also the progression hypothesis would be fed back.

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Table 2. Reference progression hypothesis for the representation of methodological routes.

	Progression hypothesis in a guided model		
	A	**B**	**C**
[E] **Epistemological perspective of the knowledge that is produced**	A1: mainly positivist, A2: realistic approach associated with the explanation of the subject-object relationship.	B1: transitional, in process of reflection, B2: argues with positivism in the construction of explanations.	C1: a perspective of construction of reality is assumed for the object of study, C2: analyze the role of epistemological relativism.
[SP] **The organization of threads**	A3: isolated steps of the process are distinguished, A4: phases are listed as steps to develop.	B3: some thread relationships are built, B4: some factors distinguished (dynamic perspective of some threads).	C3: Consistent relationships are established between threads C4: factors are characterized C5: Threads are related to the research question C6: dynamic perspective of threads is displayed
[ADV] **The constitution of meaning for the threads**	A5: sense associated with following plans or recipes (mainly positivist approach).	B5: sense in relation to some threads, B6: reflective approach in negotiation with the alternative epistemological gaze.	C7: sense of thread in correspondence with the alternative epistemological gaze, C8: the dynamic sense is evidenced in the reflective processes developed.
[PRG] **The progressive approach to the process through the threads.**	A6: an additive perspective of progression prevails	B7: a thoughtful look at the progression for some threads B8: reflective tendency to maintain additive focus in some cases	C9: reflective-critical approach to the progression of all threads, C10: factor qualification complex approach C11: development of enrichment processes for research categories.

Source: Own
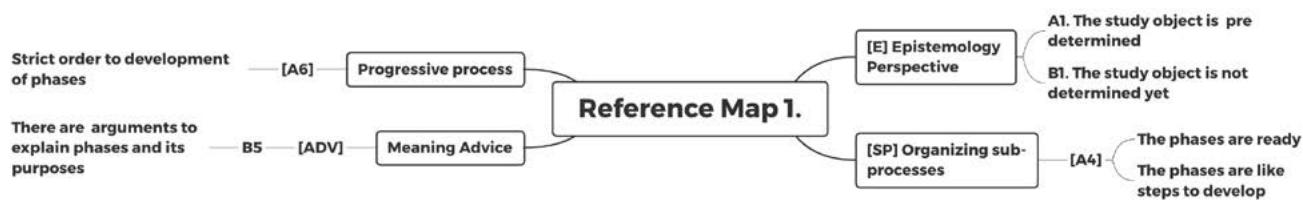
Examples of Guided Model as Synthesis

Regardless of the stage of development of the methodological process, it is possible to construct a representation as a reference map (Figure 3). This allows identifying the state of the process or reflecting and redirecting actions in order to qualify the methodological route as such. Thus, the route acquires meaning for the researcher and her work team (a dynamic, critical and reflective sense) instead of being addressed as a set of instructions or rigid steps.
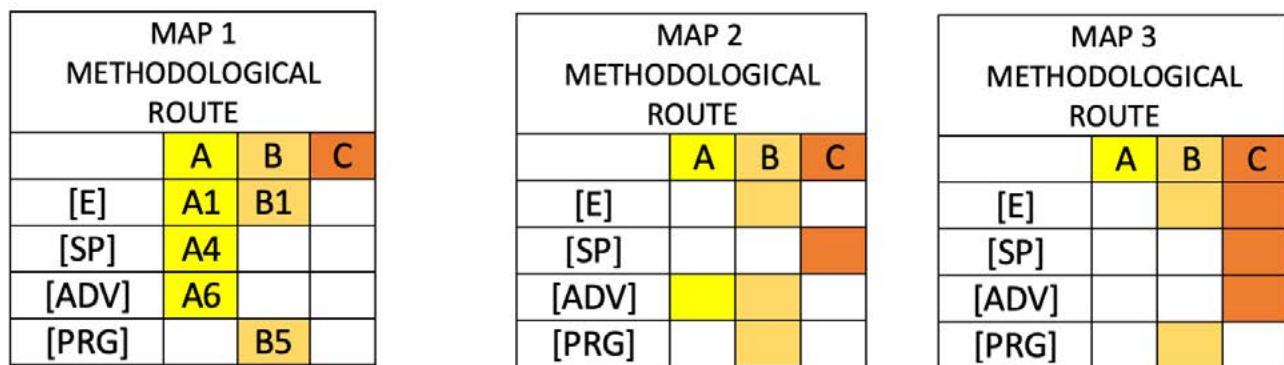
When representing the guided model from the elaboration of reference maps based on the hypothesis of progression, consider the following example. Figure 3 shows the organization and state of

reflection on the design and development of a hypothetical methodological process. From this, it is possible to recreate a way to orient ourselves in our own methodological path.

From the categories of the progression hypothesis, levels A, B, and C have been selected. In these, the researcher has reflected and is in a moment of reflection both personally and with his team. This yields the representation of maps (Figure 4) that are represented as a methodological route given that the process is dynamic and reflective. As shown, the example has three maps corresponding to three moments (review, reflection, discussion), based on the factors of the progression hypothesis. With this, it is posible to give an account of the methodological route developed.

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Figure 3. Reference Map.

Source: Own.

Figure 4. Methodological routes.

Source: Own.

CONCLUSIONS

The guided model is an alternative for the collective and autonomous monitoring of inquiry processes, and it requires the construction of conceptual references such as progression hypotheses.

It is worth highlighting that this is the first of several works that have been prepared within the line of emphasis on research, and we hope to continue deepening and presenting results to the community of specialists.

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Decision Support Systems (DSS) Applied to the Formulation of Agricultural Public Policies

Sistemas de soporte de decisiones (SSD) aplicados a la formulación de políticas públicas agrarias

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Abstract

Objective: The process of formulating agricultural public policies is complex due to the large number of variables involved in it. However, there is a methodology that helps the process: the development of decision support systems (DSS). This article shows the results of reviewing the developments made on implementing DSS on the formulating agricultural public policies.

Methodology: A bibliographic review was carried out in various scientific databases by looking for implementations of SSD on the process of formulating agricultural policies. After finding out the SSD systems developed, qualitative and descriptive analyzes of the systems were carried out.

Results: Thirty DSS systems applied to the formulation of agricultural policies were found, and the majority is focused on the agricultural production process and its relationship with the environment.

Conclusions: When developing potential agricultural policies, there is a fundamental need to generate

DSS that determine possible future behavior of stakeholders. These DSS also need to be adjusted to the characteristics of the countries located in the tropical zone.

Financing: Universidad Distrital Francisco José de Caldas, Universidad Militar Nueva Granada.

Keywords: Decision Support Systems, DSS, Public Policy, Policymaking, Agriculture, Agricultural Sector.

Resumen

Objetivo: El proceso de formulación de políticas públicas agrarias es altamente complejo por la gran cantidad de variables que intervienen en el proceso. Por eso, el desarrollo de sistemas de soporte de decisiones (SSD) ayudan a mejorar dicho proceso. El artículo revisa los desarrollos que se han realizado con respecto al tema.

Metodología: Se realizó una revisión bibliográfica en varias bases de datos científicas, buscando desarrollos de sistemas SSD aplicados al proceso de formulación de políticas agrarias. Al determinar cuáles

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sistemas SSD se han desarrollado, se procedió a realizar un análisis cualitativo y también descriptivo de los sistemas.

Resultados: Se encontraron 30 sistemas SSD aplicados a la formulación de políticas agrarias, donde la mayoría están enfocados al proceso de producción agrícola y su relación con el medio ambiente.

Conclusiones: Al formular posibles políticas agrarias, es muy necesario generar sistemas SSD que predigan el futuro comportamiento de las partes involucradas. Adicionalmente, estos sistemas deben ser ajustados para que tengan en cuenta las características de los países localizados en la zona tropical.

Financiamiento: Universidad Distrital Francisco José de Caldas, Universidad Militar Nueva Granada.

Palabras clave: Sistemas de Soporte de Decisiones, SDD, Política Pública, Formulación de Políticas, Agricultura, Sector Agrario.

INTRODUCTION

The process of formulating agricultural policies is complex by definition. This complexity starts because of the many variables the process entails: public policy makers should use their region's political, economic, social, cultural, and environmental needs as inputs for the process (Cárdenas & Vallejo, 2016; Morgan, Marsden, Miele, & Morley, 2010; Rodríguez Espinosa, Ramírez Gómez, & Restrepo-Betancur, 2016; Sánchez, Rincón, & Lugo, 2013). Additionally, they must aim for the development of these policies to promote sustainable development, such as that proposed by the United Nations Development Program (PNUD, 2019). Therefore, the results of the policies must generate economic growth, poverty reduction, food security, negative environmental impact reduction, decent work, inequality reduction, production, and responsible consumption (Boza, 2013; Firbank, Les G; Petit Sandrine, Smart Simon; Blain, Alasdair; Fuller, 2008; Guanziroli, 2014; Suárez, 2015; Temprano, 2013; Vargas, Boada, Araca, Vargas, & Vargas, 2016). All these elements make it a highly complex process which Olson called "Organized Anarchy." He explains that the complexity is directly related to the integration of many agents and actions that intervene the process (Vergara Varela, 2016).

Furthermore, it is worth highlighting that the limited rationality of the human being restricts the decision-making process during the formulation of public policies. Helbert Simon, Nobel Prize in Economics, explains that limited rationality is the decision-making process done in a partially irrational way due to cognitive, information, or time restrictions during the process (Capra, 2014).

All these factors cause unexpected results from public policies generated, which go against sustainable development and the objectives set by the policy when formulated. For example, in Colombia the implementation of agrarian policies has triggered an increase in production and also generated an increase in social inequality by concentrating land ownership in a few people (Baudasse & Calderón, 2009; Gómez, 2016; Morales, Morales, & Rizo, 2017; Ospina, 2017; Soto, 2003).

On the other hand, systems that help make the decision-making process easier have been developed in recent decades. They are called Decision Support Systems (DSS) and are computational solutions that can be used to support complex decision making and problem solving. The traditional design of a DSS system is made up of three components. The first component consists of robust database management capabilities. The second component consists of powerful modeling functions that are accessed by a model management system. Finally, the third component consists of the system having a user friendly graphical interface (Shim et al., 2002).

Therefore, DSS propose an alternative to reduce the uncertainty that possible results can generate when implementing agricultural policies. For this reason, there have been several researches around the world that have developed DSS for the formulation of agricultural public policies in order to foresee possible future results depending on the

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implementation of the policies formulated. This article reviews different DSS applied to the formulation of agricultural public policies throughout the world during recent years.

METHODOLOGY

The applied methodology is descriptive in nature with a qualitative approach. First, a search for publications related to the topic was first performed on scientific databases such as IEEE, SpringerLink, Science Direct, Scopus, and Web of Science. In these databases, the following words were used when searching: "Decision Support Systems," "Public policy," "Policymaking," "Farming," and "Agriculture". Once the results were obtained, a manual review was carried out to determine the relationship between the documents and the objective of the investigations, and to analyze the relevance and the use of each DSS during the formulating of agricultural policies. Thirty DSS applied to agricultural policies were found.

RESULTS

Table 1 presents the summary of the DSS that were found after the search and debugging process. The first column shows the year of creation of the system (i.e. each system's first version) since several of the oldest systems have been continuously updated. The second column is the name the creators called each system. In some cases there was no name assigned to the DSS; in those cases, the indicative "Not Registered" was placed.

The third column briefly describes the application of the DSS when formulating agrarian public policy, although a deeper explanation of each system is better explained below Table 1. The fourth column refers to the country for which each system was design and implemented.

EPIC (Erosion/Productivity Impact Calculator) is a system that determines the relationship between soil erosion and soil productivity in the United States. It continuously simulates the processes associated with erosion. EPIC is made up of components based on hydrology, climate simulation, erosion-sedimentation, nutrient cycling, plant growth, tillage, and soil temperature. It also uses calculations to assess the economic cost of erosion, and to determine optimal management strategies (Sharpley & Williams, 1990).

CropSyst is a system written in C++, and its first version was developed in 1992. This System is used to analyze the effect of crop management on productivity and the environment. It simulates the use of water in the soil, the level of nitrogen in the soil plant, the growth of crops and roots, the production of dry matter, yield, the production and decomposition of residues, and the erosion. Management options include crop selection, crop rotation, irrigation, nitrogen fertilization, tillage operations, and residue management (Stöckle, Nelson, & Kemanian, 2019).

LUPAS (Land Use Planning and Analysis System) was designed as a DSS for strategic land use planning. The system includes Crop Simulation Models, Expert Systems, SIG, and Multiple Objective Linear Programming (MGLP) models for land evaluation and optimization. LUPAS has three main parts: first, land assessment, which includes assessing resource availability, land suitability, and yield estimation; second, construction of scenarios based on policy opinions; and third, the optimization of land use (Roetter et al., 2005).

AgClimate is a web-based weather forecasting and information system. AgClimate was implemented in a Linux environment with specific applications and Perl modules installed. Dynamic tools were developed using the PHP web programming language that interacts with FLASH movies and MySQL databases. The system has two main components: the front-end interface and a set of dynamic tools. The main navigation menu includes weather forecast tools and management options for crops, forestry, pastures, and livestock. It also includes a section on climate and "El Niño" phenomenon with background information. The tools section contains two applications that allow the user to examine the weather forecast for individual counties based on the ENSO phase and assess the yield potentials for certain crops (Fraisse et al., 2006).

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Table 1. Decision Support Systems in Formulating Agricultural Public Policies.

Year	Name SSD	Application	Countries
1990	EPIC	To determine the relationship between soil erosion and soil productivity.	United States
1992	CropSyst	Analysis of the effect of crop management on productivity and environment.	United States
2005	LUPAS	Land use planning.	Netherlands, Philippines, Germany
2006	AgClimate	Weather information and forecast.	United States
2007	APSIM	Simulates biophysical processes in agricultural systems.	Australia, New Zealand
2008	LWIDSS	Land use and impact on water.	Canada
2008	PERFECT	Predict runoff (water flow over land), soil erosion, and crop production.	Australia, Canada, China
2009	Water for Tomorrow	Land use and water resources management.	China
2009	EDSS	Water resources management.	China
2009	MedAction	Hypothetical analysis of various policy alternatives.	Netherlands
2009	DeSurvey	To support policy decisions related to sustainable agriculture, water resource management, and land degradation.	Netherlands, United Kingdom
2009	IWM	Water resources management.	Australia, Bangladesh
2009	AQUATOOL	Water resources management.	Spain
2009	Not Registered	Land use and sustainable management.	Vietnam
2010	MAFIC-DSS	Selection of alternative crops.	Greece
2010	LUMOCAP	Land use.	Netherlands, Poland, Belgium, Spain, Italy, Denmark
2010	MPMAS	Water use.	Germany
2010	MicroLEIS	Multifunctional evaluation of the biophysical quality of the soil.	Spain
2011	FARMERS	Manure management as fertilizer and reduction of soil contamination.	Denmark
2011	IPAD DSS	Assessment of world agricultural production.	United States
2012	Not Registered	Soil and water conservation within an agricultural basin.	United States
2013	PAU_TRACPWR	Crop machinery management.	India
2013	Not Registered	Protection of vineyards against the plague called "Oídio."	France
2015	ARIES	Simulation and evaluation of human impact on nature.	Peru, Denmark, United Kingdom
2015	VULPES	Environmental risk assessment of pesticides.	Italy
2015	ALL_WATER_gw	Groundwater management.	Tunisia, United States, Germany.
2016	SmartScape™	Strategic planning of crop change.	United States, Denmark, Iran
2017	DSSAT	Evaluation and application of crop models.	United States
2018	DESTISOL	Assessment of the ecosystems planned for the soils.	France
2019	NitroShed	Simulates farmers' decision-making process and how policies might affect adoption rates of best management practices.	United States

Source: Authors.

The APSIM (Agricultural Production Systems Simulator) is a system that simulates biophysical processes in agricultural systems, and specifically determines the possible economic and ecological results of management practices against climate risk. It also analyzes food security, and adaptation to climate change. APSIM is structured around plant, soil, and management modules. The creators, Queensland University (Australia), started developing it in 2007 (APSIM, 2019).

The LWIDSS (Land and Water Integration Decision Support System) simulates land use scenarios

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characterized by different assumptions about management practices. The results are presented in the form of SIG spatial layers. These can be incorporated into other components, such as non-point source pollutant models to assess the impact of soil quality on water. Land use scenarios are integrated with watershed hydrology models to develop flow, sediment, and nutrient performance standards in streams to protect aquatic biodiversity (Wong et al., 2008).

PERFECT (Productivity Erosion and Runoff Functions to Evaluate Conservation Techniques) is a system that was designed to predict runoff (water flow over the land), erosion, and crop production to determine the sequences of planting, harvesting, and management of residues under different tillage practices. This model has been used widely in the agricultural areas of Australia, China, and India, among others (Li, Tullberg, Freebairn, McLaughlin, & Li, 2008).

The "Water for Tomorrow" DSS is designed to assist policymakers in making decisions about land use and water resource management, taking into account human use, preservation, and restoration of the ecosystem. Users can locate the watershed of interest, view summary data on that watershed, view and compare model results, and generate reports (Eckman, West, Barford, & Raber, 2009).

They developed a web-based regional agricultural industry structure optimization tool in China, using AJAX (Asynchronous JavaScript and XML) technology and a suite of decision support tools for agricultural policymakers. The system provides a configuration method that allows applying sensitivity analysis, data use, and analysis results of comparative advantage, and a component that can solve the linear programming model and its double problem by the simplex method (Huang & Zhu, 2009).

The Integrated Environmental Decision Support System (EDSS) was designed to help policymakers and other stakeholders gain a clearer understanding of key factors in water resource management. The system is made using MATLAB and a geographic information system (SIG). The model considers the social, economic, ecological, environmental system of water, and water resources as its interrelated

subsystems, and integrates them into an organic whole to analyze. The system provides a visual simulation environment, and analysis and management capabilities of water resources for different scenarios (Leng & Haimid, 2009).

The MedAction Policy Support System (PSS) aims to support policymakers in arid and semi-arid regions in understanding the impacts of autonomous developments within a region, such as demographic and economic growth, or change climate. The system allows hypothetical analyzes of various policy alternatives; policy indicators can measure impact such as agricultural sector gains, forest area, water use and availability, land degradation, and changes in land use. The system is made up of several sub-modules, which are integrated into a single model that simulates regional developments up to thirty years in the future (H. Van Delden, 2009).

The DeSurvey Integrated Assessment Model (DeSurvey IAM) is a policy formulation support system. The system aims to support political decisions related to sustainable agriculture, water resource management, and land degradation. The system contains twenty models that include climate, hydrology, water management, erosion, salinization, vegetation growth, land use, macroeconomics, crop choice, and irrigation, among others, and they work with different spatial and temporal resolutions. Depending on the issue at hand and the data available, a region-specific application can be configured to contain a proper combination of built-in models (H. Van Delden, Kirkby, & Hahn, 2009).

Researchers from the Institute of Water Modeling (IWM) developed a Water Resources DSS that uses mathematical models to simulate and predict likely impacts in sectors such as agriculture. The DSS has been designed to be an educational tool for non-technical users and stakeholders. Thus, users can obtain information about the risks associated with climate change and also the effectiveness of different adaptation options (Zaman, Rahman, & Khan, 2009).

AQUATOOL is a DSS for basins and water resource planning and management (Andreu, Pérez, Paredes, & Solera, 2009). The system consists of

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several modules. The SIMGES module is a general model for the Simulation of Watershed Management, in which there are elements of regulation, storage, collection, transport, and consumption. The GESCAL module was developed to determine the quality of the water. The OPTIGES module defines the monthly distribution of water. The SIMRISK module is for watershed management and risk measurement. The EVALHID module (Evaluation of water resources) is used to develop Precipitation-Runoff Models (Andreu Álvarez, 2019).

Researchers from Vietnam developed a decision support system for agricultural land use planning and sustainable management. The system is made up of the following components: the optimal problem-solving component helps the decision maker to solve the optimal problem; the expert opinion component helps the decision maker to establish the necessary requirements and expert data in order to combine it with expert opinions using the Delphi method; the reporting and Implementation Component helps to report the final option selected on the planning map. The system was developed using Microsoft Visual Studio together with MapInfo MapXtreme and was designed based on three main objectives: economic efficiency, land suitability, and sustainable environment (Huy, 2009).

The MAFIC-DSS (Major Field Crops Decision Support System) is web-based and supports farmers in the selection procedure of appropriate alternative crops. The system provides the necessary information and supports the farmer throughout the growing period. The system has seven modules: The user profile module stores information for each farmer; the SIG module contains the necessary spatial information and stores data such as land use, cadastral information, soil characteristics, and climatic characteristics; the agricultural policy module contains all the national and EU agricultural policies and directives necessary for each crop of interest; the market profile module maintains the market information and the cultivation cost for each product, which refers mainly to market prices, national and international demand for each product, prices and specifications of fertilizers and pesticides, means

of transportation, and energy costs; the interaction module is a chat-like application enriched with image upload facilities that allows farmers to send inquiries to experts using text and photos of their fields; and finally, the crop module, which consists of two submodules. The first sub-module contains different knowledge bases related to the main crops, such as soil and climate cultivation requirements and cultivation techniques, including needs for fertilization and irrigation. The second sub-module is a system for the chemical and organic management of pests and diseases (Antonopoulou, Karetsos, Maliappis, & Sideridis, 2010).

The LUMOCAP System (dynamic land use change modeling for CAP impact assessment on the rural landscape) aims to assess how different political scenarios will affect land and landscape use in the 27 member States of the European Union. Due to the inherent complexity of land use change processes, agricultural policies at European level have their effect not only on the evolution of the agricultural sector, but also on the regional ecological coherence and socio-economic dynamics of rural areas. The system allows the following up of relationships between EU policies, agricultural economy, land suitability, and land use dynamics through simulation (Hedwig Van Delden et al., 2010).

MPMAS (Mathematical Programming-based Multi-Agent Systems) is a system developed by the Hohenheim University. It was implemented using C++, and its user interface offers two modes. The first mode is the single agent mode, which simulates a decision problem for a single agent. The second mode is the complete agent, where decision making and actions of all agents like production, investment and consumption decisions, agent-agent interactions, and all relevant biophysical processes are simulated generally for several years. The system was used to predict the behavior of farmers in the use of water when building a dam (Berger, Schilling, Troost, & Latynskiy, 2010).

The decision support system MicroLEIS (Mediterranean Land Evaluation Information System) was designed for the multifunctional evaluation of the biophysical quality of the soil, using the

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characteristics of the soil such as place, climate, and cultivation as input data, and it is particularly applied to the peculiarities of the Mediterranean region. This DSS was designed to have a toolkit that integrates databases, statistical models, expert systems, neural networks, web and GIS applications, and other information technologies (De la Rosa & Anaya-Romero, 2010).

Fertilizing by Application and Reuse of Manure Environmental Risk Software (FARMERS) is a decision-making system for the safe and sustainable management of livestock manure as a fertilizer in order to control and limit the accumulation of metals in the soil and to reduce metal bio-transference from the floor to other compartments. The system was developed based on a multi-compartment model for evaluating environmental risks. The tool was implemented in Visual C++ and is structured in a database (MS Access®) where all the required data is stored and the risk assessment model, a GIS module for the visualization of the scenario, and the results are obtained. The decision support system allows you to choose between three estimation options depending on the needs, which provide information to both farmers and policymakers. The first option is useful for evaluating the suitability of the current management practices of the different farms, and the others provide information on the measures that can be taken to carry out a fertilization plan without exceeding the risk to human health (Río, Franco-Uría, Abad, & Roca, 2011).

The IPAD DSS (International Production Assessment Division decision support system) was developed by NASA and aims to assess world agricultural production. The system takes global data, model input sources, and analysis tools to estimate crop production. The multiple data and results of the model are the basis for processing, analysing and visualization techniques that lead to an evidence convergence approach to the monthly estimates of production of specific products in each country (Van Leeuwen et al., 2011).

A decision support system for soil and water conservation within an agricultural basin was designed and used to generate alternative decision support scenarios to facilitate integrated watershed management concepts in an interactive and holistic way (Lal, 2012).

A decision support system called PAU_TRACP-WR for crop machinery management in India was developed. Detailed data information on the production parameters of the main crops, such as tractor prices, crop values, workloads, and the level of adoption of various agricultural technologies were used for designing the system (Bector & Singh Surendra, 2013).

A DSS for the protection of vineyards against the plague called "Oídio" ("blanquilla" or "cenicilla") because this plague must be treated before any symptoms appear. The system simulates the entire life cycle of the pathogen, including sexual and asexual reproduction modes, while estimating the area of the diseased leaf. The system is modeled after mathematical equations and expert knowledge (Garin, Houlès, & Jallas, 2013).

A Decision Support System to identify land strategically located for the agrarian reform that developed in South Africa was developed in 2014. The system was built from geographic information systems (GIS), Earth Observation (EO) data, and multi-criteria decision making (MCDM). An index to identify the land was created, expert workshops to determine the criteria for land identification were conducted, and the analytical hierarchy process (AHP) was used to weight the criteria (Musakwa, Makoni, Kangethe, & Segooa, 2014).

ARIES is a dynamic modeling platform that uses artificial intelligence techniques to simulate and evaluate the impact of human intervention on nature. The system integrates a set of process- and agent-based models to identify the changes in flows of ecosystem services as a response to changes in land use and weather, as well as the impact and scope of future land use scenarios in the region (Francesconi, Pérez Miñana, Willcock, Villa, & Quintero, 2015).

VULPES ("Vulnerability to Pesticide") is a system based on GIS, client-server type designed for groundwater. The system aims to transfer scientific knowledge for evaluating environmental risks from

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pesticides, which allows to apply consolidated models and methodologies used in standardized scenarios for regulatory purposes and to identify vulnerable areas to pesticides. It is a system intended to help those responsible for public policies investigate sensitive areas to specific substances and propose limitations of use or mitigation measures (Di Guardo & Finizio, 2015).

ALL_WATER_gw was developed for groundwater management within the framework of the WEAP-MODFLOW DSS. The system takes into account water demand, minimization of water cost, maximum reduction, and compliance with water salinity restrictions. The system uses a multi-objective genetic algorithm (MOGA) and PARETO optimization approaches to handle the formulated problem (Nouiri, Yitayew, Maßmann, & Tarhouni, 2015).

The SmartScapeTM DSS is a system with an interactive web-based environment for strategic crop change planning, which allows users to create and evaluate a crop change scenario. This system has three main components: A terrain selection panel; a scenario panel that allows stakeholders to make a crop change and run multiple environmental models; and a comparison scenario panel that allows users to compare the outcome of crop change scenarios in various ecosystem services using various visual analyzes and highlight the tradeoffs between multiple ecosystem services (Tayyebi, Arsanjani, Tayyebi, Omrani, & Moghadam, 2016).

The DSSAT is a comprehensive system that helps the evaluation and application of crop models for a variety of agricultural and environmental uses, such as yield predictions and water use (Salazar et al., 2012). This serves as support for agricultural planning and regional policy. The DSS contains various crop and soil simulation models, as well as climate, soil and crop databases, and evaluation programs (Wolfe & Richard, 2017).

The DESTISOL DSS is based on an integrative approach that links the indicators of soil characteristics: quality (i.e. physicochemical and biological characteristics, fertility, and contamination), functions, and ecosystem services. With this linking, the system also semi-quantitatively evaluates the

ecosystem services that are provided by the soil as food production, air quality, flood mitigation, or climate regulation (Anne et al., 2018).

NitroShed is a system that was developed using agent-based modeling in Python. The system simulates the decision-making process of farmers in the Mississippi Basin and the Mexico Gulf. Additionally, it presents a simulation of how policies might affect adoption rates of best management practices affecting also the repercussions that farming activities may have on the soil. For example, the implementation of best practices could reduce the contamination produced by nutrients released by the farms located in the surrounding hydrographic basins. The system helps policymakers determine the most effective action plan to increase the adoption of best management practices by farmers (Zeman & Rodríguez, 2019).

After reviewing the functions for which the DSS have been developed, it is worth noting that the main objective is focused on determining land use, managing water resources in agriculture, optimizing productivity, influencing the climate, and reduce the negative environmental impact of economic activity. In summary, all DSS are focused on issues related to the agricultural production process and its relationship with the environment. Only two DSS have a slightly different approach: the MPMAS developed in 2010, and the NitroShed developed in 2019. Both seek to predict the future behavior of farmers on different scenarios, proposing different possible public policies in order to establish which would be most advisable. These two DSS were developed using Artificial Intelligence (AI) and agent-based models.

Figure 1 shows a curve showing the historical development of DSS applied to the formulation of agricultural public policies.

As observed in Figure 1, 2009 is the year when the designing and implementation of DSS applied to the formulating of agrarian policies grew. Although the developments did not stop after this year, most of the systems were already existing and updated to enhanced versions in order to better adjust to the needs of their stakeholders. Therefore, the

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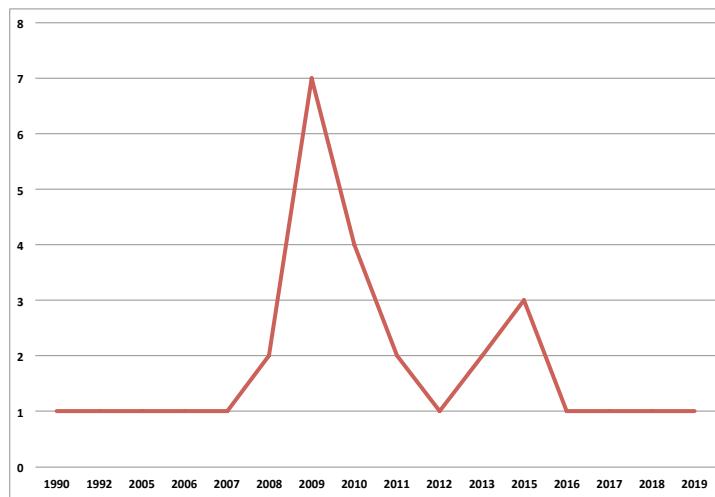
Figure 1. Historical Development of DSS applied to Formulation of Agrarian Policies.

Source: Authors.

development of DSS applied to formulating of the agricultural policies has shown progress during the last 10 years.

Figure 2 presents the percentage distribution of the DSS regarding the countries of origin. Several DSS were developed in collaboration with researchers from different countries, as can be seen in Table 1.

As seen in Figure 2, the country that has developed most DSS is the United States of America, followed by Spain, Netherlands, China, Germany, Australia, France, Italy, and Canada. It is worth noticing that most of the countries that developed these systems belong to Europe or North America, and all of them are considered developed countries, except for China; but China is the second largest economy in the world. It is also interesting that all these countries do not belong to the tropical zone. Therefore, there is an interest in developed countries and those with greater economies for improving their agrarian policy formulation processes using tools such as DSS. Moreover, there is a need to develop these types of tools for countries located in the tropical zone, so that the characteristics of this region may be taken into consideration.

Currently one of the greatest concerns for developed and developing countries is the formulation of policies that promote sustainable development. Such is the concern that the United Nations promulgated the 17 sustainable development goals in 2015 (United Nations Development Program, 2019), and the policies that promote these goals become more relevant, and the agricultural sector becomes one of the fundamental axes for achieving these goals. The sustainable development goals related to agricultural public policies and the development of SSD systems are compared below.

The first related goal is the end of poverty: 17.2% of the population of rural areas are living in poverty, which is more than three times the rate in urban areas (UN, 2020). The agricultural sector is the most relevant in rural areas, so promoting policies to generate decent employment in the agricultural sector will help reduce poverty rates. Nevertheless, DSS for agricultural policy formulation usually do not take this aspect into consideration.

Another goal is zero hunger. According to the World Food Program, currently 135 million people in the world suffer from severe hunger, which is also a consequence of the economic impact generated by the Covid-19 pandemic (World Food Program, 2020). Thus, the need to reform the world agri-food system (UN, 2019b). Among the DSS analyzed, not one was found that considers this characteristic, so

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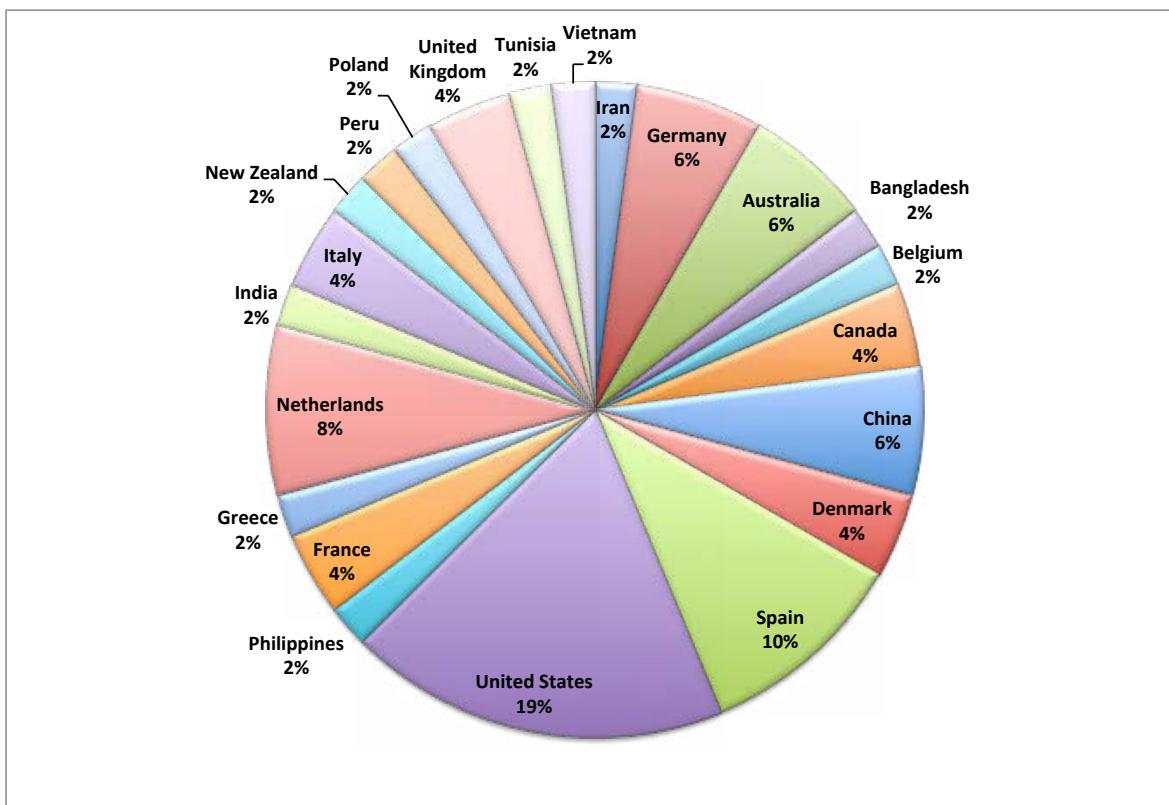
Figure 2. Percentage distribution of DSS for the formulating of agricultural policies.

Source: Authors.

there is still a need to include this variable when developing DSS.

Another related goal is clean water and sanitation. It has been established that billions of people do not have access to drinking water, especially those located in rural areas (UN, 2015). Several systems were developed to improve decision-making in the management of water resources in the agricultural sector, they would be useful for the development of policies that promote the fulfillment of this sustainable objective.

The goal of decent work and economic growth is closely related to the goal of ending poverty. The development of agricultural policies that promote the economic growth of the sector are useful in this case, and so will be the DSS that contribute to the formulating process in this area. Most of the systems developed so far seek to improve productivity and

the resource management, which align with the fulfillment of this objective.

The objective of responsible production and consumption is the closest to the agricultural sector. This objective consists of decoupling economic growth from environmental degradation, increasing resource efficiency, and promoting sustainable lifestyles (UN, 2017). Therefore, DSS that seek to develop sustainable agriculture and help reduce the negative environmental impact will be consistent with the achievement of the objective.

Lastly, climate action is one of the objectives worth mentioning. This objective raises the need to create strategies to mitigate the effects generated by climate change (UN, 2019a). Therefore, DSS that include climate as one of their variables will help formulate better agricultural policies (Sánchez C., Rodriguez M., & Montenegro M., 2020).

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Tools like DSS can be very useful to develop agricultural policies that contribute to the fulfillment of the sustainable development objectives. However, these systems need to take into account characteristics such as poverty in rural areas and food security. These changes would make the systems more robust, so they contribute more comprehensively to meeting goals such as those mentioned above. These characteristics are suggested as lines of future research in this area.

CONCLUSIONS

Decision support systems (DSS) developed so far aim mainly to improve agricultural production processes and reduce the negative impact of agricultural production on the environment; besides, they can help meet the sustainable development goals, but it is necessary to implement new features to these systems so that they take into account variables like poverty and food security.

Also, two DSS have been identified to predict the future behavior of farmers with different public policies and use an Artificial Intelligence tool called agent-based models.

The interest of the most economically developed countries in improving their agricultural policy formulation processes using tools such as DSS is evident.

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Análisis del impacto del sector de la construcción en la economía colombiana

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Abstract

Objective: Construction is one of the fastest growing and most important economic sectors worldwide, mainly due to its impact on job creation, trade in materials and the creation of essential infrastructure for social development. However, the behavior of the global market has recently been immersed in an environment of economic and political uncertainty, causing trade and industrial production to show signs of vulnerability. Despite the unfortunate ones established in the global economy, there will be moderate growth in rankings of developing countries like Colombia in different sectors.

Methodology: This research focuses on analyzing the construction sector. The analysis is carried out from its historical impact on Colombian economic development and its relationship with external phenomena, to the evaluation of macroeconomic indicators (supply and demand), infrastructure, and job creation through the formulation of projects in this sector. In particular, these projects are differential for having a public investment effect in the construction of houses and civil works.

Results and Conclusions: It was concluded that there is a weak recovery in the general market in relation to the factors surrounding the construction sector, allowing for a glimpse and focus on the trends and impact on the formulation of construction projects in the Colombian economy.

Financing: Universidad EAN.

Keywords: Colombian economy, construction, construction sector, social interest housing.

Resumen

objetivo: La construcción es uno de los sectores económicos de mayor crecimiento e importancia en a nivel mundial, principalmente por su impacto en la generación de empleo, el comercio de materiales y la creación de infraestructura esencial para el desarrollo social. Sin embargo, el comportamiento del mercado global recientemente ha estado inmerso en un ambiente de incertidumbre económica y política, ocasionando que el comercio y la producción industrial muestren signos de vulnerabilidad. A pesar de los desafortunados pronósticos en economía a nivel

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global, se prevé un crecimiento moderado en clasificaciones de países en vía de desarrollo como Colombia en diferentes sectores.

Metodología: La investigación se enfocó en analizar el sector de la construcción partiendo de su incidencia histórica en el desarrollo económico colombiano y su relación con fenómenos externos, hasta la evaluación de indicadores macroeconómicos, la oferta y demanda en bienes de capital, la infraestructura y la generación de empleo mediante la formulación de proyectos en este sector, los cuales son diferenciales por tener un efecto de inversión pública en la construcción de vivienda y obras civiles.

Resultados y Conclusiones: Se dedujo una débil recuperación del mercado general en relación con los factores alrededor del sector de la construcción, permitiendo vislumbrar y focalizar las tendencias e impacto en la formulación de proyectos de construcción en la economía colombiana.

Financiamiento: Universidad EAN

Palabras clave: construcción, economía colombiana, sector de la construcción, vivienda de interés social.

INTRODUCTION

The global economy is currently in an environment of economic and political uncertainty, volubility in markets, and economic growth reduction. Besides, the upsurge of commercial tensions continue further that forecasted, and this includes the recent upscale between the main economies, a deceleration of the global investing, and the decline of trust and investment (FMI, 2018; World Bank Group, 2019a). These hardenings in financial conditions and the weakening of the fiscal stimulus are the main boosters of the deceleration in economic growth that upsurged in 2019, where commerce and the manufacturing industry showed signs of marked weakness (World Bank Group, 2019a).

Part of this growth has been maintained due to public investment according to forecasts, thus the construction and commerce sectors contribute to the increase of GDP; so, there were early signs of recovery in the first quarter of 2019 (Global Construction Perspectives and Oxford Economics, 2015; World Bank Group, 2019b). Therefore, the IMF (2019) foresees that developing countries of low income and several emerging market economies should create work opportunities and improve public infrastructure, such as the ones related to services that satisfy the needs of populations in fast expansion and urbanization. In consequence, the social expense and fiscal policies in every country should follow the rate of change of the working and product markets, which are caused by the technological advances and the deepening of commercial and financial links in order to adapt the policies to global trends, fomenting long-term economic growth, and co-helping the reestablishment of trust of the citizens towards institutions.

Part of the function of the construction sector is focused on meeting the needs of companies and citizens through buildings, structures, houses, and other new or renovated projects. This function is limited by the value of effective demand of said products and determined by the amount of investment in fixed assets assigned to this end, where the public sector invests capital according to social functions, and the private sector executes the construction previous to the formulation of the project. Therefore, national economics and financing altogether determine the volume of constructions that can be made, so investments play a major role in the evaluation of present and future. Therefore, the adaptating and focusing of projects contributes to the growth and development of the markets, and it highlights the most important aspects for the elaboration of a long-term prevision in the construction industry through the adoption of social objectives (Kamenetskii, 2013).

Over the last decade, the main part of the growth in construction came from emerging countries, while developed markets have not yet recovered their usual volumes previous to the crisis (ANDI, 2019; Hatzius et al., 2018). This paper evaluated

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the historical development of the Colombian economy, specially within the construction sector, its performance in the promoting of public infrastructure and its impact in the national economic development. Macroeconomic indicators were evaluated, as well as their incidence in the supply and demand of capital goods, and public investment in housing construction, allowing a glimpse of the trends and impact of the construction sector in the Colombian economy.

METHODOLOGY

The construction sector experiments sharper activity cycles than other branches of economic activity; it is also susceptible to international economic variations. Therefore, it is considered one of the main economic indicators given the influence it has on the variations of the economy cycle (DANE, 2019a). As a result, and in order to establish the effect of this sector in the Colombian economy, historical information from the government entities responsible for the analysis of global economic activities was used. The researched entities were mainly the National Statistical Administration Department (DANE, in Spanish) and the National Planning Department (DNP, in Spanish). Also, investigations and data previously processed by the Colombian Construction Chamber (CAMACOL, in Spanish) were incorporated.

Regarding the historical information properly depurated, the macroeconomic variations related to the supply and demand of construction of housing were analyzed, while aiming establish representative phenomena. The selected data is presented below:

1. Selection of the gross production in billions of Colombian pesos, separating the values related to importation taxes, nondeductible Value Added Tax (VAT), product taxes, grants for the product with original data published quarterly by the DANE over the last 15 years (2005-2020); here the accumulated production value of the last quarter was selected as representative. Likewise, the 12 initial activity groups according to the latest Classification of Economic Activities (DANE, 2012) were selected,

as well as the subsectors that conform the construction sector.

2. Evaluation of the gross production of the construction sector and subsectors through the selection of data provided by the DANE with the classification of 25 economic activity groups in the country, according to Section CIIU Rev. 4 A.C, in billions of pesos. Annual variation rates were evaluated, taking values from the last quarter as the representative value and annual accumulated of the last fifteen years (2005-2020). Likewise, the evaluation of the residential building subsector was done through supply and demand of housing in square meters in the same lapse of fifteen years; price discrimination was taken according to the classification established in the development national plan (Law 1955 of 2019), differencing price ranks between Priority Interest Housing (VIP), social interest (VIS), and non-VIS.

3. Evaluation of employment through data collected in the big integrated home poll (GEIH, in Spanish), which supplies basic information related to the size of the work force of the country and is made monthly by the DANE. Data of population occupied in the construction sector was used, taking the annual average as representative value as well as annual variation rate.

The information collected was compared with external economic phenomena by analyzing recurring reports supplied by economic research centers; it was also compared with reports from private associations and several commerce chambers, especially CAMACOL, in order to relate the productivity of the construction sector and subsectors (and their employment generation) with various external and internal dynamics.

RESULTS

Development of the productivity of the Colombian economy

The GDP information analysis from a production approach (DANE, 2019b) measures billions of pesos in constant prices from the 12 main economic activity branches of the country in the last fifteen years and

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gives a global scenario of the performance of these sectors altogether with the impact of external phenomena and its incidence in the economy (Figure 1).

Figure 1 presents the GDP from a production approach. the activities are classified based on the fourth review of the CIIU in Colombia (DANE, 2012). Due to stational and calendar effects, it registers the historical evaluated and corrected production in billions of pesos at constant total production prices during the last fifteen years (2005-2019). Generally, all economic activities have grown at a constant rate in the last fifteen years, and the main sectors of the Colombian economy are led by wholesale and retail commerce, repairing of automotive vehicles and motorcycles, transportation, storage, accommodation, and food services. The second place in economic production consists of public administration, defense, social security plans, education, health care activities, and social services. The third place consists of the manufacture industry. These three groups generate the 55% of all the GDP of Colombia, approximately.

Moreover, the construction sector has occupied the fifth place in economic importance and has remained steady with an R2 of 0,92 as the measure of reliability degree or goodness of fit for the model adjusted to a data set. Likewise, it evidences a somewhat constant growth of $567,5x109 pesos per year (in average 162x106 USD). Figure 1 shows two outstanding periods. One of them occurred at the beginning of 2008 and is related to the international financial crisis named "Great Recession" and considered the deepest recession after World War II. This crisis was generated by the collapse of stock markets, the fall of housing prices, and the drastic increase in bankrupts and foreclosures; all of this conceived by the real state sector of the United States, through the use of high-risk mortgage rates, credit facilities, expansion of the assets with mortgage collaterals, among others. Subsequent to this crisis, many banks and financial institutions of the United States and foreign countries faced a considerable pressure in their financial obligations, giving place to a risk in the assets in arrears higher than usual, generating a recession in the global markets and interventions from central banks and governments all around the world (Erkens, Hung, & Matos, 2012; International Monetary Fund, 2009; Mehdian, Rezvanian, & Stoica, 2019).
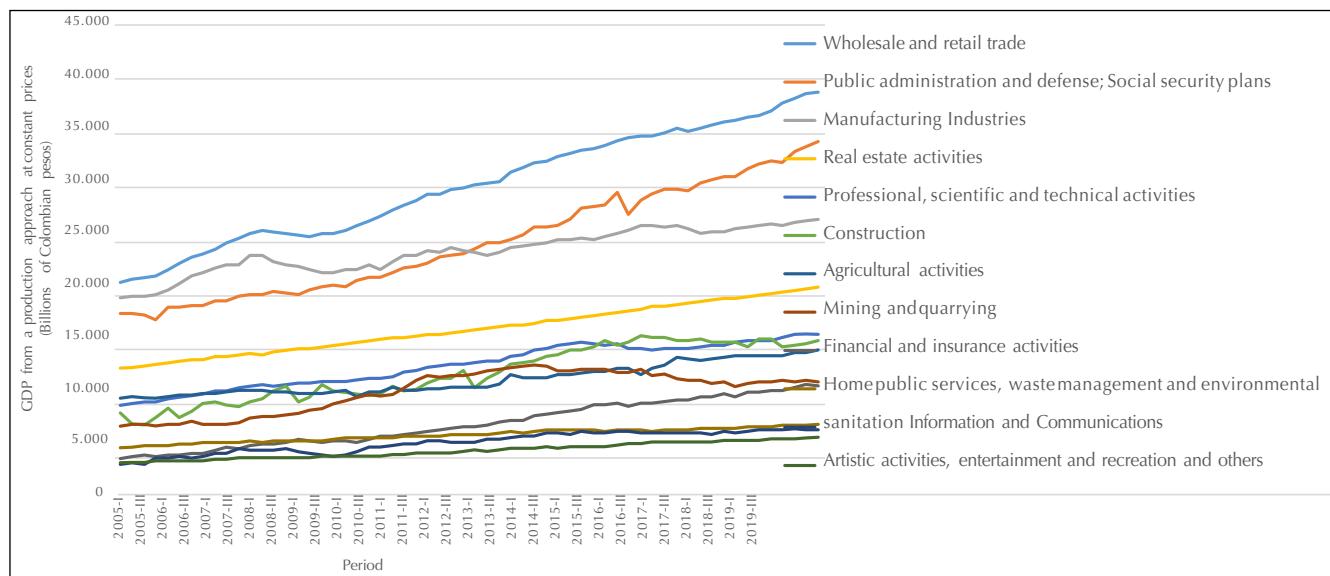
Figure 1. GDP of the production of the main branches of the Colombian economy.

Source: Own elaboration with data from the DANE.

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The generated impact in Colombia can be seen clearly at the beginning of 2008 (Figures 1 and 2), registering an unexpected fall of the GDP (2,5%) higher than 5 points compared to the achieved GDP of 2007 (7,5%). The fall of traditionally productive sectors deteriorated the job market and the complex international panorama previously exposed (Mesa, Constanza & Aguirre, 2008). In the same way, there is an influence related to the global markets starting in 2014, when the external national income reduced in the middle of the fall of the international oil prices, affecting the Colombian economy, generating economic and political uncertainty, market volubility and reduction of the economic growth (FMI, 2018; World Bank Group, 2019a). This hardened the financial conditions and the weakening of the fiscal stimulus, impacting the manufacture industry (World Bank Group, 2019a). Likewise, the reduction of non-renewable raw material exports for the generation of energy, like carbon, and the volatility of the oil and gas markets, affect the production and generate a deceleration of the growth. Also, reduction in the investing in projects of exploration, exploitation, and production of hydrocarbons, which translates in the reduction of fiscal collection and impact on public finances and investment (Departamento de Estudios Económicos y Técnicos, 2017a; Corficolombiana, 2019b; World Bank Group, 2019a).

Construction in Colombia and its challenges

As a consequence of the macroeconomic joint previously exposed, nowadays the construction sector has experienced a change of internal policies, as well as problems in the execution or development of on-going projects. This generates a deceleration in the sector from mid-2016 and starting 2017, when the sector registered an annual contraction of -7.4%, which was the worst biannual result of this century (CAMACOL, 2019b; Departamento de Estudios Económicos y Técnicos, 2017). However, construction keeps a noticeable growth because this sector is one of the most dynamic activities of the Colombian economy and, at the same time, is

fundamental for the productivity in other economic sectors. Therefore, a change in the production trend is observed in the construction subsectors, where the construction of roads and railways, public service projects, and other civil engineering construction was superior to residential and non-residential construction. In consequence, There is a trend to migrate the type of projects to formulating in agreement with the historical context, given the investing in subsectors of the economy. Figure 2 exposes the historical participation of the production of the construction subsectors.

As seen in Figure 2, the subsector of civil constructions different from buildings led the production of the sector during 2019. Conversely, the subsector of buildings (once the leader) has reduced its production steadily since 2016. As a result, the construction sector has exhibited in recent years a weak performance, although it has tried to slightly correct a descendant tendency through the investing in civil constructions since 2017, as seen in Figure 3. On the other hand, 2019 showed a fall of 1.5%, mainly explained by the decline in the 7,0% in the building subsector, which cannot be compensated by the 8,8% growth in civil constructions.

The poorly dynamics of the building subsector since 2016 is configured as a liability of the construction growth, showing a significant deterioration starting that same year. Therefore, it is highly likely that the building subsector will continue to register annual negative variations in the present year, and the leading indicators in the sector (i.e. civil engineering projects) present a slow recovery (Corficolombiana, 2019). Thus, companies dedicated to the formulation and execution of projects need to foresee these dynamics in order to adapt and search for methodologies that help configure better opportunities in spite of the problems.

Impact of the construction sector in jobs

The construction sector stands out for the chaining in several sectors of the economy and generating jobs as a government policy in recession or economic deceleration times. Figure 4 shows phenomena

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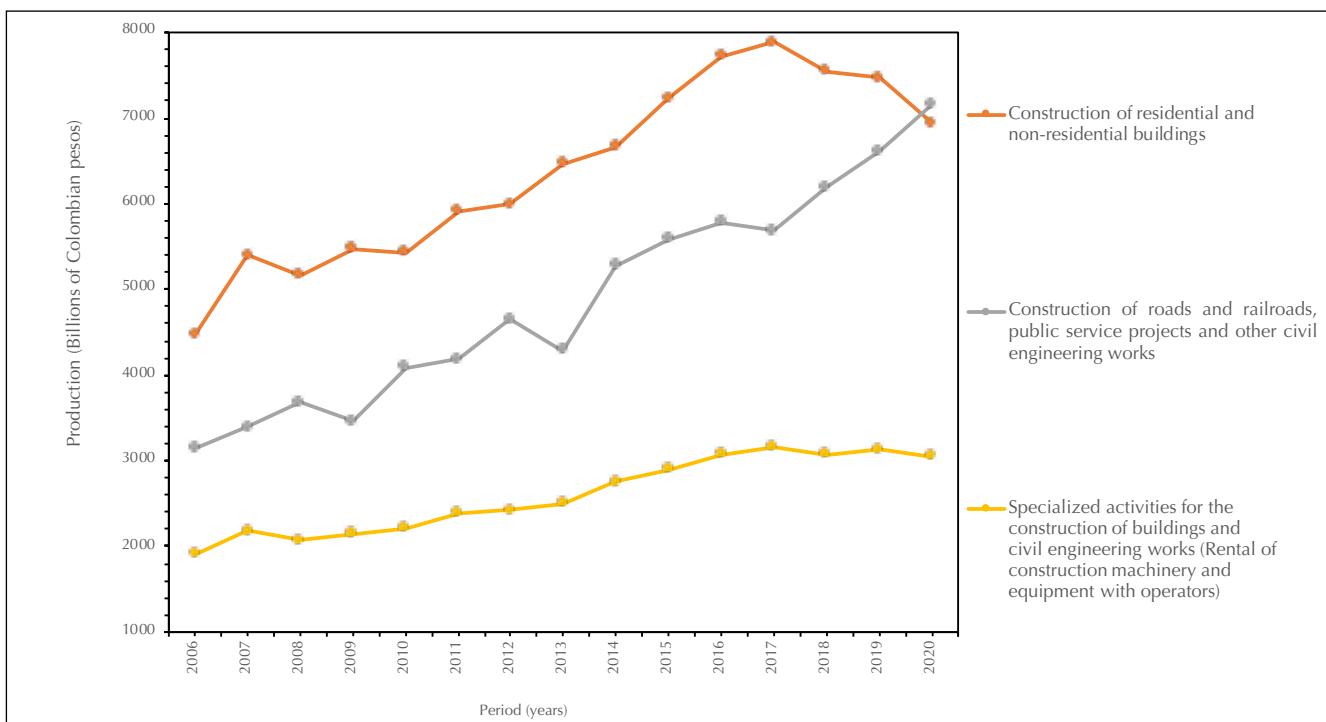
Figure 2. Production of the construction subsectors.

**Source:** Own elaboration with data from the DANE.
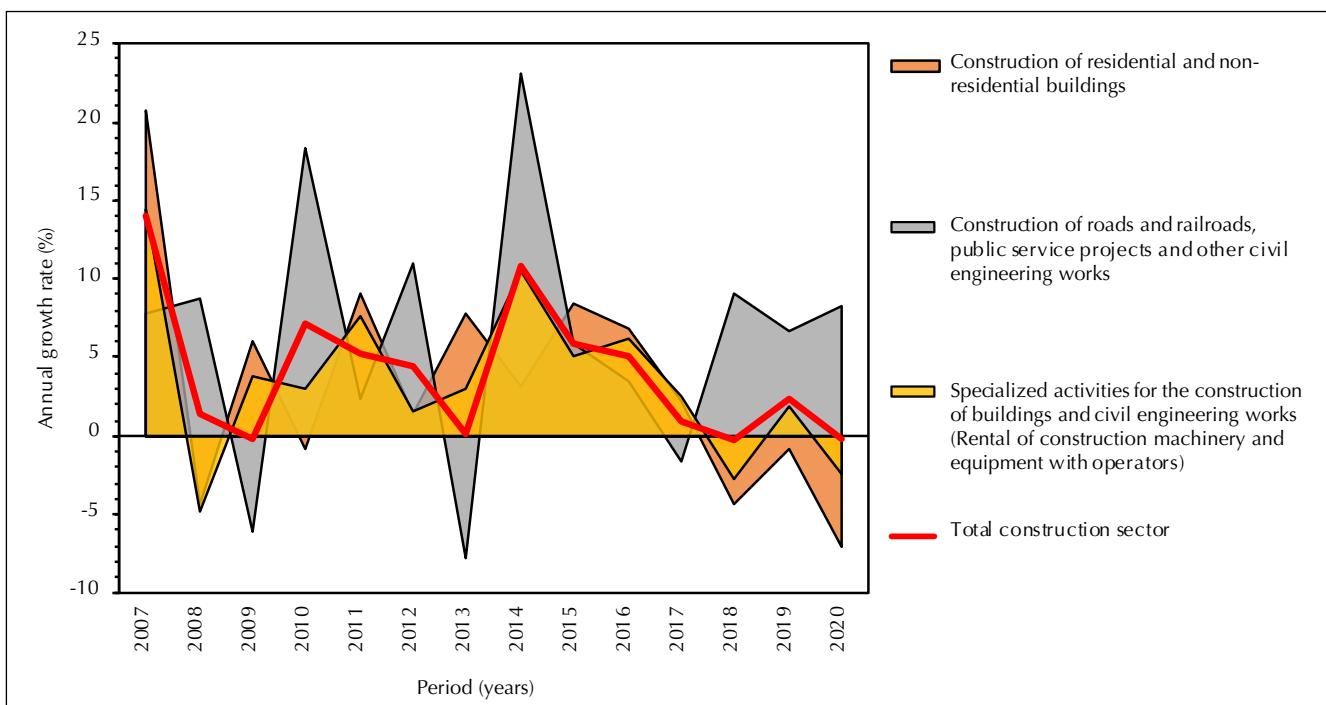
Figure 3. Annual variations of construction and its subsectors

Source: Own elaboration with data from the DANE.

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denoting that every sector of the economy (including construction) was affected during the economic crisis of the recent years, especially during 2008, 2010, and 2016. However, the sector is a protagonist in the later generation of employment as a measure to overcome these difficulties.

Figure 4 exposes the generation of jobs by this sector and shows a constant growth with some decelerations in the previously mentioned economic crisis; however, after these crises, job growth tends to grow. In average, the number of jobs occupied by the construction sector in 2019 was 1,514,293 workers; this is 3.2% more than what the same period of 2018 showed. This represents a participation of 6.8% of national jobs. Additionally, the generation is mainly driven by the civil construction subsector and its growth at the beginning of 2019, and the estate aided too. This counteracted the negative results of the building subsector and increased job opportunities (CAMACOL, 2019a; Corficolombiana, 2019).

Housing Construction

The adequate performance of the building construction sector is associated to the promotion of economic and social development due to the capacity to generate jobs, demand supplies from other economic sectors, and the fact that building houses improves the life quality of the population. This conceives the building construction as a central activity in the social and economic development of the country, especially in a developing place like Colombia, where a considerable housing deficit is evident, and it allows to generate policies that include budget allocation. This allocation can be done directly or through financial institutions, and it usually activates the construction sector, creating job opportunities and an important movement of raw materials throughout the territory (Córdova & Alberto, 2018). At the same time, it considers an economic exploitation made by a natural or legal person; however, it must focus on elaborating
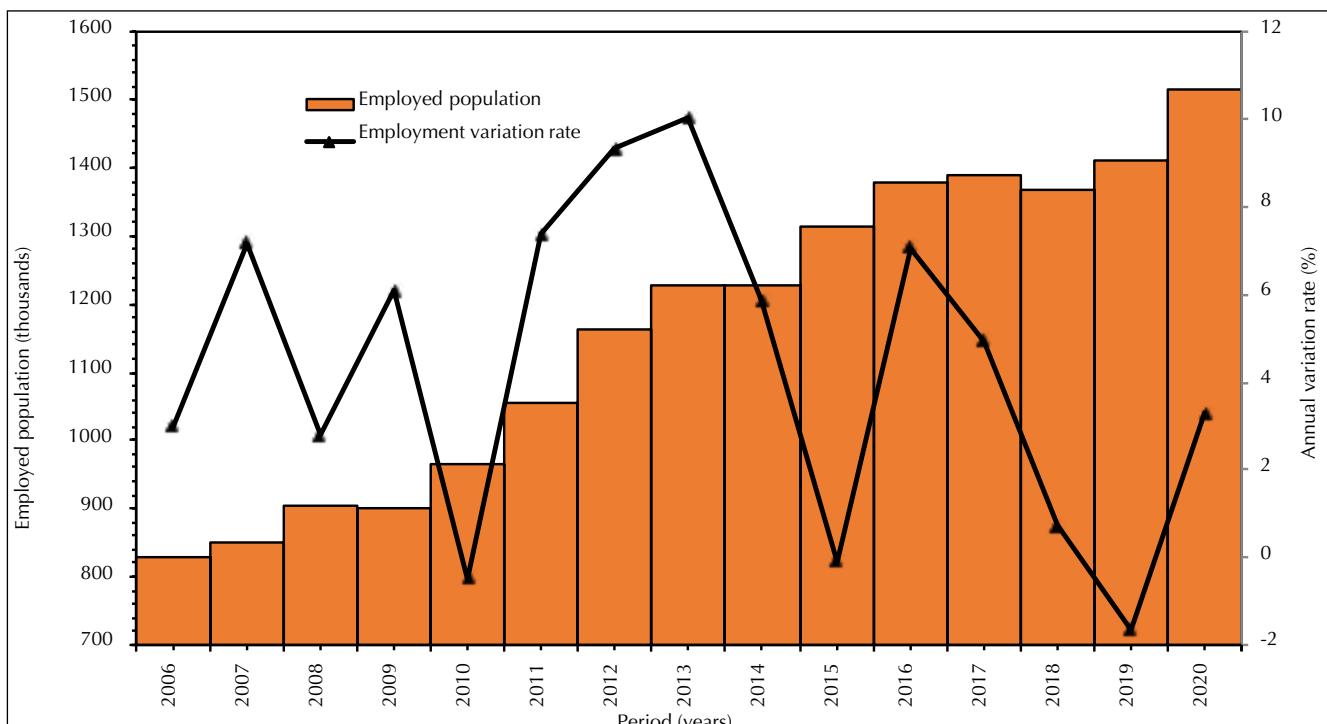
Figure 4. Impact of the job generation from the construction sector

Source: Own elaboration with data from the DANE.

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projects that involve the urgent needs of the actors involved and later executing them (Project Management Institute, 2017).

Therefore, the reduction of the built area is coherent with the decrease of the demand of housing in the country, where the non-VIS houses has reduced its participation considerably despite once dominating the market (Figure 5). Since 2016, the area of built housing with a price range higher than 350 minimum monthly salary has decreased 62%, and houses with a price range between 136 and 350 minimum monthly wage have decreased up to 73%. On the other hand, the social interest house (VIS, in Spanish) building has grown with a 55%, specifically the number of houses with a range between 111 and 135 minimum monthly wage. Likewise, the discharge of VIS of 2,055,176 m2 has meant a higher national growth in the last ten years. Nonetheless, VIS houses with a range between 91 and 110 minimum monthly wage have reached a reduction of

50%, like the priority interest houses (VIP, in Spanish), according to Law 1955 (Congreso de la República de Colombia, 2019), under 90 minimum monthly wage have reduced its participation in the market from 32% to 48%. Consequently, it is pertinent to have a housing approach according to the demand, which allows facilitating the productivity of the companies without drastically affecting their income from the formulation and execution of projects.

According to Figure 5, the deceleration originated by the macroeconomic events aforementioned manifests later in the sector because there might be previously assigned investments starting or in process. In consequence, the reduction of the housing demand is observed in the years of crisis, differentiating the impact in diverse price ranges, especially on VIS houses. Likewise, low-income housing is mainly found in a specific housing range, which corresponds to market trends because this type of housing has better quality materials and construction
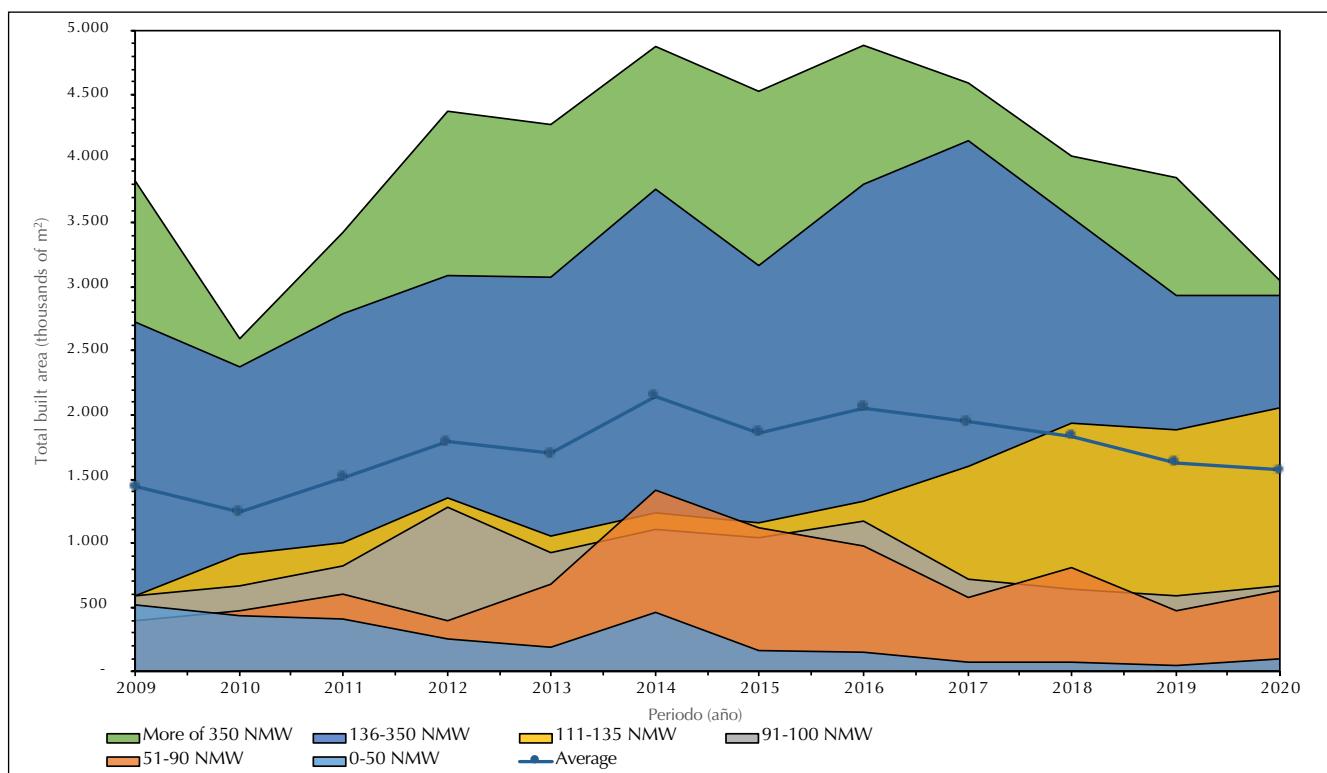
Figure 5. Demand of built housing area, discriminated by price range (NMW=National Minimum Wage).

Source: Own elaboration with data from DANE and CAMACOL.

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processes. They also have higher real state value and appraisal, so the formulation of projects is focused on this kind of houses; actually, part of this expenses is promoted by the public sector (DANE, 2019a). This part of the construction sector registers a national descent of 11% marked out by the construction of houses, specifically non-VIP, which contrasts with the 12.5% growth of the civil projects. Particularly, the area that explains almost the totality of the behavior of the construction sector presented an annual reduction of 16.3% (Corficolombiana, 2019a). In summary, the Colombian economic growth rate relates positively with the public spending in human capital and physical infrastructure (Ortiz et al., 2019). In accordance with the above, the produced domestic demand has been weak, the consumer's trust has deteriorated, the mortgage interest rates are high, and several economy sectors have decelerated. All of this affects the demand for supplies, commercial activity, housing affordability, and job opportunity generated by housing construction.

CONCLUSIONS

The construction sector has may advantageous characteristics such as versatile nature, quick volubility, and susceptibility to both external economic phenomena and internal policies, especially in developing countries as Colombia. This can be observed with the historical analysis, which shows the economic dynamics of the country under current circumstances, particularly those of the construction sector. This analysis allows a certain perspective on the phenomena of immersion and the approach proposed in terms of social and business development.

Thanks to this research, the momentum of the construction sector for the Colombian economy is manifested, through investment in housing and civil constructions; this allows demand to rise, other sectors of the economy become more dynamic, and job opportunities are generated due to public investment and private participation. Therefore, it is important to take into account the historical context when observing the phenomena presented, so that the tools that allow the formulation of pertinent

projects are available; also, it is necessary to consider the external and internal economic effects and the behavior of construction sector.

Although the housing subsector has behaved negatively in recent years, this subsector and the civil construction subsector are essential for the development of the state's social objectives. Hence, the knowledge of the behavior of the construction market, together with the formulation of investment projects and considering the needs based on demand, allows generating a prospect with the appropriate approach.

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Water Footprint: Two Different Methodologies

A Response to Sara Edith Bueno Pérez *et al*.

Libor Ansorge[1]

Keywords: water footprint, volumetric water footprint, LCA water footprint, ISO 14046

Dear editor,

I read with great interest the article *Implementation of the shortage method to determine the water footprint in the coastal area of San Blas, México* on Volume 23 Number 62 (Pérez et al., 2019). The article describes three types of water footprint methodologies: by volume, by impact, and by scarcity. In reality, the one described as "scarcity water footprint" is a special type of impact water footprint. Over the last year, I reviewed several articles that made no distinction between these two methodologies and their principles. It should be noted that both methodologies were developed with different aims and are used for different applications (Hoekstra et al., 2009). The so-called "volumetric" water footprint according to Water Footprint Network (Hoekstra et al., 2011) is a tool for the management of water resources and is based primarily on the desire to illustrate the hidden links between human consumption and water use, and between global trade and water resources management (Ercin & Hoekstra, 2012). Assessing sustainability by volumetric water footprint evaluation considers the environmental, social, and economic dimensions of sustainable water use. This methodology distinguishes three types of water footprints. The blue water footprint (WF_{blue}) refers to the consumption of surface and ground freshwater resources (WC_{blue}). The green water footprint (WF_{green}) is the volume of green water (rainwater) consumed (WC_{green}), which is particularly relevant in crop production. The grey water footprint (WF_{grey}) is an indicator of the contamination degree of freshwater and is defined as the volume of freshwater required to assimilate the pollutant load according to existing environmental water quality standards (Mekonnen & Hoekstra, 2011). The total water footprint is calculated by Equation (1):

$$WF = WF_{blue} + WF_{green} + WF_{grey} = \sum WC_{blue,i} + \sum WC_{green,i} + \sum WC_{grey,i} \tag{1}$$

On the other hand, the LCA water footprint is defined by ISO 14046 (ISO, 2014) and assesses the potential environmental impacts related to water associated with products, processes, or organizations. Economic or social impacts are typically outside the scope of the water footprint assessment under ISO 14046. Impacts related to water are associated with numerous environmental mechanisms, thus numerous category indicators are possible. The water footprint is calculated by Equation (2):

$$WF_j = \sum \left(CF_{i,j} \times WU_{i,j} \right) \tag{2}$$

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Where $WU_{i,j}$ represents water use from resource i important for environmental impact category j, and $CF_{i,j}$ represents the characterization factor derived from a characterization model applied to turn an assigned water use into the environmental impact category. The LCA water footprint methodology also distinguishes between three types of water footprints. The "water availability footprint" assesses the impacts of water use related to products, processes, or organizations, as well as potential environmental impacts related to pressure on water availability. If water availability footprint only considered water quantity, it should be called "water scarcity footprint." The purpose of "water footprints addressing water degradation" is to give an assessment of the contribution of the product, process or organization to potential environmental impacts related to water quality. If only one impact category (e.g., eutrophication, etc.) is selected, then that impact category shall be identified in the qualifier of the water footprint (e.g., "water eutrophication footprint"). Unless all related impact categories are considered, the water footprint assessment cannot be identified without some qualifier (e.g., "non-comprehensive water footprint").

Because the article does not distinguish between these two methodologies, you can read "the fresh water scarcity methodology developed by Pfister, Koehler and Hellweg (2009) is mainly used to assess the water footprint in Latin America." This statement is inconsistent with previously published information (Martínez-Arce et al., 2018).

The next fundamental mistake represents a comparison with the article by Farell Baril et al. (2013). Farell Baril et al. calculated "freshwater ecotoxicity water footprint" based on a different methodological background and their results are incomparable with those reached by Pérez et al.

Since it is the role of independent reviewers to catch these kind of things, it is unfortunate that none of the original reviewers caught these issues.

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DECLARATION OF COMPETING INTEREST

The author have no conflicts of interest to declare.

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INSTRUCCIONES PARA LOS AUTORES

Revista *TECNURA*
Universidad Distrital Francisco José de Caldas
Facultad Tecnológica

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1. ALCANCE Y POLÍTICA EDITORIAL DE LA REVISTA

La revista *Tecnura* es una publicación institucional de la Facultad Tecnológica de la Universidad Francisco José de Caldas, de carácter científico-tecnológico con periodicidad trimestral, que se publica los meses de enero, abril, julio y octubre. Su primer número apareció en el segundo semestre del año 1997 y hasta la fecha ha mantenido su regularidad.

Las áreas temáticas de interés de la revista *Tecnura* están enfocadas a todos los campos de la ingeniería, como la electrónica, telecomunicaciones, electricidad, sistemas, industrial, mecánica, catastral, civil, ambiental, entre otras. Sin embargo, no se restringe únicamente a estas, también tienen cabida los temas de educación y salud, siempre y cuando estén relacionados con la ingeniería. La revista publica únicamente artículos de investigación científica y tecnológica, de reflexión y de revisión. En consecuencia, durante la fase de evaluación editorial inicial se rechazarán los artículos cortos y reportes de caso.

La revista *Tecnura* está dirigida a docentes, investigadores, estudiantes y profesionales interesados en la actualización permanente de sus conocimientos y el seguimiento de los procesos de investigación científico-tecnológica, en el campo de las ingenierías. Tiene como misión divulgar resultados de proyectos de investigación realizados en el área de las ingenierías, a través de la publicación de artículos originales e inéditos, realizados por académicos y profesionales pertenecientes a instituciones nacionales o extranjeras del orden público o privado. Los artículos presentados deben ser trabajos inéditos escritos en español o inglés; sin embargo, tendrán preferencia los artículos que muestren conceptos innovadores de gran interés, que traten sobre asuntos relacionados con el objetivo y cobertura temática de la revista.

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Tecnura es una revista arbitrada mediante un proceso de revisión entre pares de doble ciego. La periodicidad de la conformación de sus comités Científico y Editorial está sujeta a la publicación de artículos en revistas indexadas internacionalmente por parte de sus respectivos miembros.

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Además de la versión impresa, la revista *Tecnura* tiene también una versión digital disponible en su página web: http://revistas.udistrital.edu.co/ojs/index.php/Tecnura

2. TIPOS DE ARTÍCULOS ACEPTADOS

De acuerdo con la clasificación del Índice Nacional de Publicaciones Científicas y Tecnológicas (Publindex-Colciencias), la revista *Tecnura* recibe postulaciones de artículos inéditos de los siguientes tipos:

Artículos de investigación científica y tecnológica: documento que presenta, de manera detallada, los resultados originales de proyectos de investigación. La estructura generalmente utilizada contiene cuatro apartes importantes: introducción, metodología, resultados y conclusiones.

Artículos de reflexión: documento que presenta resultados de investigación desde una perspectiva analítica, interpretativa o crítica del autor, sobre un tema específico y recurriendo a fuentes originales.

Artículo de revisión: documento resultado de una investigación donde se analizan, sistematizan e integran los resultados de las investigaciones publicadas o no publicadas, sobre un campo en ciencia o tecnología, con el fin de dar cuenta de los avances y las tendencias de desarrollo. Se caracteriza por presentar una cuidadosa revisión bibliográfica de al menos 50 referencias.

3. FORMATO DEL ARTÍCULO

3.1 Del lenguaje y estilo apropiado para la redacción de artículos

- Deben emplearse estructuras de oraciones simples, evitando las que sean demasiado largas o complejas.
- El vocabulario empleado debe ser básico y común. Los términos técnicos deben explicarse brevemente; asimismo, el significado de las siglas debe presentarse la primera vez que estas aparecen en el texto.
- Los autores son responsables de que su trabajo sea conducido de una manera profesional y ética.

3.2 De la extensión de los documentos

Los artículos no deben tener una extensión de más de 25 páginas en tamaño carta y a doble espacio, con márgenes simétricas de 3 cm. Solo en el caso de los artículos de revisión las 25 páginas no incluyen las referencias bibliográficas.

3.3 Del formato de presentación

Los artículos presentados deben ser trabajos inéditos escritos en español o inglés y deben digitarse en Microsoft Word (2003 en adelante), cumpliendo con las siguientes indicaciones:

Letra *Times New Román* de 12 puntos (a excepción de que se requiera lo contrario para algunos apartados).

- Una columna a doble espacio.
- Todas las márgenes de 3 cm.
- Los párrafos se justifican, y no debe haber espacio entre los consecutivos.
- No incluir saltos de página o finales de sección.
- Si se desea resaltar palabras o frases del texto, no usar letra negrita sino letra cursiva.
- Los decimales se deben señalar con coma (,) y no con un punto.

- Los millares y millones se deben señalar con un espacio fino.
- Evitar las notas de pie de página.
- Se debe utilizar nomenclatura arábiga hasta el tercer nivel únicamente.

3.4 De la estructura del documento

Los trabajos deben tener la siguiente estructura y cumplir con los siguientes requisitos:

Composición de un artículo
Todos los artículos remitidos para su evaluación y posible publicación por parte de la revista *Tecnura deben tener por lo menos los siguientes componentes:*

- Título en español e inglés.
- Información de los autores.
- Resumen en español e inglés.
- Palabras clave en español e inglés.
- Introducción.
- Conclusiones.
- Trabajo futuro (opcional).
- Agradecimientos (opcional).
- Referencias bibliográficas.

Si el artículo es de investigación científica y tecnológica deben tener, además de lo anterior, los siguientes componentes:

- Metodología.
- Resultados.
- Financiamiento.

Título
El título del artículo deberá ser corto o dividido en título y subtítulo, atractivo para el lector potencial y escrito en mayúscula sostenida. Este debe aparecer centrado entre las márgenes, escrito con letra *Times New Roman*, en negrita, tamaño de fuente 18. El título del artículo debe ir en español e inglés separado por un espacio doble. Máximo 20 palabras.

Autores
Después del título debe escribirse el (los) nombre(s) completo(s) del (los) autor(es), acompañado de los datos biográficos básicos: título de pregrado, título de posgrado, ocupación o cargo, afiliación institucional (institución donde labora), dependencia, ciudad, país y correo electrónico. La información anterior debe ir inmediatamente debajo del nombre del autor.

Resumen
Debe establecer el objetivo y alcance del trabajo, una descripción clara y concisa de la metodología, los resultados y las conclusiones obtenidas. Máximo 250 palabras.

Palabras clave
Debe escogerse entre tres y diez palabras clave, escritas en español con letra *Times New Roman*, en negrita y cursiva.

Las palabras clave deben estar escritas en orden alfabético y ser de uso estandarizado, para lo cual se sugiere utilizar bases de datos internacionales según el área del conocimiento. Por ejemplo, en el área de Eléctrica y Electrónica se sugiere utilizar el tesauro de la UNESCO que se pueden encontrar en la página:http://databases.unesco.org/thessp.

Abstract
Debe ser una traducción correcta y precisa al idioma inglés del texto que aparece en el resumen en español.

Keywords
Debe ser una traducción correcta y precisa al idioma inglés de la lista de palabras clave en español.

Las *keywords* deben estar escritas en el orden de las palabras clave y ser de uso estandarizado, para lo cual se sugiere utilizar bases de datos internacionales según el área del conocimiento. Por ejemplo, en el área de Eléctrica y Electrónica se sugiere utilizar los Tesauros de la IEEE y/o World Bank que se pueden encontrar en las siguientes páginas respectivamente:http://www.ieee.org/documents/2009Taxonomy_v101.pdf, http://multites.net/mtsql/wb/site/default.asp

Introducción

Debe describir el planteamiento general del trabajo, así como contexto, antecedentes, estado de arte de la temática abordada, objetivo y posible alcance del trabajo.

Metodología

La redacción de este apartado debe permitir a cualquier profesional especializado en el tema replicar la investigación.

Resultados

Explicación e interpretación de los hallazgos. Si es necesario, se puede presentar una discusión breve y enfocada a la interpretación de los resultados.

Conclusiones

Implicación de los resultados y su relación con el objetivo propuesto.

Financiamiento

Mencionar la investigación asociada de la cual se derivó el artículo y la entidad que avaló y financió dicha investigación.

Agradecimientos

Preferiblemente deben ser breves y deben incluir los aportes esenciales para el desarrollo del trabajo.

Ecuaciones

Deben aparecer centradas con respecto al texto principal. Las ecuaciones deben ser referenciadas con números consecutivos (escritos entre paréntesis cerca al margen derecho). Las ecuaciones se citan en el texto principal empleando la palabra ecuación y seguida del número entre paréntesis. Las ecuaciones deben ser elaboradas en un editor de ecuaciones apropiado y compatible con el paquete de software InDesign, por ejemplo, el editor de ecuaciones de Windows.

Tablas

Para el caso de realización de tablas se recomienda que estas no sean insertadas como imágenes, considerando que en este formato no pueden ser modificadas. El encabezado de cada tabla debe incluir la palabra Tabla (en negrita) seguida del número consecutivo correspondiente y de un breve nombre de la tabla. El encabezado debe estar escrito con letra Times New Roman, en cursiva y tamaño de fuente 9.

No se presentan cuadros sino tablas y estas se deben levantar automáticamente desde el procesador de textos. Las tablas deben ir nombradas y referenciadas en el artículo, en estricto orden. Toda tabla debe tener en su parte inferior la fuente de la que fue tomada, o mencionar que es autoría de los autores si es el caso.

Figuras

Todas las figuras o fotografías deben enviarse en formato PNG o TIFF con una resolución mínima de 300 DPI, adaptadas a escala de grises.

El pie o rótulo de cada figura debe incluir la palabra Figura (en negrita) seguida del número consecutivo correspondiente y de una breve descripción del contenido de la figura. El pie de figura debe estar escrito con letra *Times New Roman*, en cursiva y tamaño de fuente 9. Las figuras deben ir nombradas y referenciadas en el artículo, en estricto orden. Toda figura debe tener también la fuente de la que fue tomada, o mencionar que es autoría de los autores si es el caso.

Símbolos

Los símbolos de las constantes, variables y funciones en letras latinas o griegas –incluidos en las ecuaciones– deben ir en cursiva; los símbolos matemáticos y los números no van en cursiva. Se deben identificar los símbolos inmediatamente después de la ecuación. Se deben utilizar las unidades, dimensiones y símbolos del sistema internacional.

Cuando se empleen siglas o abreviaturas, se debe anotar primero la equivalencia completa, seguida de la sigla o abreviatura correspondiente entre paréntesis y en lo subsecuente se escribe solo la sigla o abreviatura respectiva.

Referencias bibliográficas

El estilo de citación de referencias adoptado por la revista **Tecnura** es APA sexta edición. Las citas, referencias bibliográficas e infografía se incluyen al final del artículo. Las referencias bibliográficas deben ordenarse alfabéticamente de acuerdo con el primer apellido del primer autor, sin numeración.

Solo deben aparecer las referencias que fueron citadas en el texto principal del trabajo, en las tablas o en las figuras. Es decir, en la lista no deben aparecer otras referencias aunque hayan sido consultadas por los autores para la preparación del trabajo. Sugerimos utilizar herramientas como: *Citas y bibliografía* de Microsoft Word (para APA sexta edición versión 2013 o superior), *Zotero*, *Mendeley*, entre otras.

El llamado de una referencia bibliográfica se inserta en el texto, en el punto pertinente, bajo ciertas características:

- Si la oración incluye el apellido del autor, solo se debe escribir la fecha dentro de un paréntesis, ejemplo:

  Cuando Vasco (2012), analizó el problema de presentado en ….

- Cuando no se incluye el autor en la oración, debe ir entre el paréntesis el apellido y la fecha.

  La investigación de materiales dio una visión en el área (Martínez, 2012).

- Si el documento u obra tiene más de dos autores, se debe citar la primera vez con todos los apellidos.

  1990. (Fernández Morales, Villa Krieg & Caro de Villa, 2008) ….

- En las menciones siguientes, solo se debe escribir el primer apellido del autor, seguido de un "et al".

  En cuanto al estudio de las aguas, Fernández Morales et al. (2008) encontraron que …

- Cuando el documento u obra tiene más de seis autores, se debe utilizar desde la primera mención el "et al".

A continuación se describen una serie de ejemplos de las referencias más utilizadas, según el estilo de referencias adoptado por la revista *Tecnura:*

Publicaciones Periódicas:

Forma Básica

Apellidos, A. A., Apellidos, B. B. & Apellidos, C. C. (Fecha). Título del artículo. *Título de la publicación*, volumen (número), pp. xx-xx. doi: xx.xxxxxxx

Artículo básico

Guevara López, P., Valdez Martínez, J., Agudelo González, J., & Delgado Reyes, G. (2014). Aproximación numérica del modelo epidemiológico SI para la propagación de gusanos informáticos, simulación y análisis de su error. *Revista Tecnura, 18*(42), 12 -23. doi:http://dx.doi.org/10.14483/udistrital.jour.tecnura.2014.4.a01

Artículo web

Rodríguez Páez, S., Fajardo Jaimes, A., & Páez Rueda, C. (2014). Híbrido rat-race miniaturizado para la banda ISM 2,4 GHZ. *Revista Tecnura, 18*(42), 38-52. Recuperado de http://revistas.udistrital.edu.co/ojs/index.php/Tecnura/article/view/8059/9675

Libros:

Forma Básica

Apellidos, A. A. (Año). *Título*. Ciudad: Editorial.

Apellidos, A. A. (Año). *Título*. Recuperado de http://www.xxxxxx.xxx

Apellidos, A. A. (Año). *Título*. doi: xx.xxxxxxxx

Apellidos, A. A. (Ed.). (Año). *Título*. Ciudad: Editorial.

Libro con autor

Goleman, D. (2000). La inteligencia emocional: Por qué es más importante que el cociente intelectual. México: Ediciones B.

Libro con editor:

Castillo Ortiz, A. M. (Ed.). (2000). Administración educativa: Técnicas, estrategias y prácticas gerenciales. San Juan: Publicaciones Puertorriqueñas

Libro versión electrónica:

Montero, M. & Sonn, C. C. (Eds.). (2009). Psychology of Liberation: Theory and applications. [Versión de Springer]. doi: 10.1007/ 978-0-387-85784-8

Informe técnico:

Forma Básica

Apellidos, A. A. (Año). *Título.* (Informe Núm. xxx). Ciudad: Editorial

Informe con autores

Weaver, P. L., & Schwagerl, J. J. (2009). U. S. *Fish and Wildlife Service refuges and other nearby reserves in Southwestern Puerto Rico*. (General Technical Report IITF-40). San Juan: International Institute of Tropical Forestry.

Informe de una agencia del gobierno

Federal Interagency Forum on Child and Family Statistics. *America's Children: Key National Indicators of Well-Being, 2009*. Washington, DC: U.S. Government Printing Office. Recuperado de http://www.childstats.gov/pubs/index.asp

Tesis

Forma Básica

Apellidos, A. A. (Año). Título. (Tesis inédita de maestría o doctorado). Nombre de la institución, Localización.

Tesis inédita, impresa

Muñoz Castillo, L. (2004). *Determinación del conocimiento sobre inteligencia emocional que poseen los maestros y la importancia que le adscriben al concepto en el aprovechamiento de los estudiantes*. (Tesis inédita de maestría). Universidad Metropolitana, San Juan, PR.

Tesis de base de datos comercial

Santini Rivera, M. (1998). *The effects of various types of verbal feedback on the performance of selected motor development skills of adolescent males with Down syndrome*. (Tesis doctoral). Disponible en la base de datos ProQuest Dissertations and Theses. (AAT 9832765).

Tesis web

Aquino Ríos, A. (2008). *Análisis en el desarrollo de los temas transversales en los currículos de español, matemáticas, ciencias y estudios sociales del Departamento de Educación*. (Tesis de maestría, Universidad Metropolitana). Recuperado de http://suagm.edu/umet/biblioteca/UMTESIS/Tesis_Educacion/ARAquinoRios1512.pdf

Estándares o patentes

Forma Básica

Apellidos, A. A. Título de la patente. País y número de la patente. Clasificación de la patente, fecha de concesión oficial. Número y fecha de solicitud de la patente, paginación.

Hernández Suárez, C. A., Gómez Saavedra, V. A., & Peña Lote, R. A. Equipo medidor de indicadores de calidad del servicio de energía eléctrica para usuario residencial. Colombia., 655. G4F 10/0, 15 de Marzo 2013. 27 de Octubre 2011, 147

4. ENVÍO DE ARTÍCULOS

Los autores deben enviar sus artículos a través de la aplicación para tal fin del Open Journal System en formato digital, adjuntando la carta de presentación y el formato de información artículo-autores.

4.1 Carta de presentación

El artículo debe ir acompañado de una carta de presentación dirigida al director y editor de la revista, Ing. Cesar Augusto García Ubaque, donde incluya:

- Solicitud expresa de considerar su artículo para publicarlo en la revista Tecnura.
- Título completo del trabajo.
- Nombres completos de todos los autores del trabajo.
- Certificación de la originalidad y el carácter inédito del trabajo.

- Exclusividad de su remisión a la revista Tecnura.
- Confirmación de la autoría con la firma de todos los autores.

Esta carta deberá estar firmada por todos los autores, escanearse y enviarse junto con los demás documentos solicitados.

4.2 Formato de información artículo-autores

El artículo además debe ir acompañado de un formato de información sobre el artículo y sus autores, el cual se puede descargar de la página web de la revista *Tecnura*: http://revistas.udistrital.edu.co/ojs/index.php/Tecnura, en la sección "Formatos y Documentos". Es importante completar todos los campos de información solicitados, algunos de ellos tienen comentarios para aclarar mejor lo que se está solicitando. El formato no debe escanearse.

4.3 Artículo

Artículo en formato digital (Word 2003 en adelante) que cumpla con todas las normas de presentación descritas en el capítulo 3, "Formato del artículo", de la presente en las instrucciones a los autores.

5. PROCEDIMIENTO PARA LA PUBLICACIÓN

El procedimiento que sigue la revista *Tecnura* para la evaluación y posible publicación de los trabajos enviados por los autores es el siguiente en orden cronológico:

1. Envío del articulo acompañado de la carta de presentación y el formato de información por parte de los autores.
2. Notificación al autor de correspondencia de la recepción del artículo.
3. Verificación del tema del artículo con respecto a las áreas de interés de la revista.
4. Verificación de las normas de presentación por parte del monitor de la revista.
5. Notificación al autor de correspondencia de la evaluación de las normas de presentación.

6. Envío de las correcciones realizadas por los autores con respecto a la evaluación de las normas de presentación.
7. Envío del artículo a los árbitros seleccionados.
8. Notificación del inicio del proceso de arbitraje del artículo.
9. Notificación a los autores de la decisión tomada por el Comité Editorial y de las evaluaciones hechas por los árbitros.
10. Envío de las correcciones realizadas por los autores con respecto a las evaluaciones de los árbitros.
11. Estudio de la versión final del artículo y de las evaluaciones de los árbitros por parte del Comité Editorial.
12. Envío por parte de los autores de la carta de cesión de derechos al editor de la revista.
13. Envío de la versión con corrección de estilo y diagramada a los autores.
14. Verificación de errores y aprobación final de la versión con corrección de estilo y diagramada por parte de los autores.
15. Publicación del artículo en el número correspondiente de la revista Tecnura.
16. Notificación a los autores de la publicación del número de interés.
17. Envío de un ejemplar de la revista a cada autor del artículo publicado.

6. PROCESO DE ARBITRAJE DE ARTÍCULOS

Considerando la periodicidad trimestral de la revista, el Comité Editorial realiza cuatro convocatorias anuales para la recepción de artículos, aproximadamente en los meses de febrero, mayo, agosto y noviembre. Los artículos serán recibidos hasta la fecha máxima establecida en cada convocatoria.

Una vez recibidos los artículos el monitor de la revista realizará una primera evaluación de forma para verificar que cumplan con todos los elementos mencionados en esta guía de instrucciones a los autores. Luego de recibir nuevamente el articulo con las correcciones de forma solicitadas por el

monitor de la revista, este será sometido a evaluación por tres pares académicos (paulatinamente se espera incorporar un mayor número de pares externos que participen en el proceso).

Cada artículo remitido a la revista *Tecnura* es revisado por dos pares académicos externos a la institución de los autores, mediante un proceso de "revisión entre pares" (*Peer-review*) de doble-ciego, garantizando el anonimato de los autores y evaluadores; se considera confidencial todo trabajo recibido y así se le exige a sus evaluadores.

Las posibles conclusiones de los resultados de la evaluación por parte de los árbitros son únicamente tres: publicar el artículo sin modificaciones, publicar el artículo con modificaciones o no publicar el artículo.

Posteriormente, el Comité Editorial toma la decisión de publicar o no los artículos, con base en los resultados de las evaluaciones realizadas por los árbitros asignados. En caso de existir contradicciones en las evaluaciones con respecto a la publicación de un artículo, el Comité Editorial enviará el artículo a un tercer árbitro y se inclinará por las dos evaluaciones que tengan el mismo concepto respecto a la publicación del artículo.

En cada convocatoria el autor de correspondencia debe sugerir al menos cuatro posibles evaluadores externos a su institución laboral, los cuales deben ser especialistas en el tema específico del artículo remitido, tener al menos maestría y por lo menos dos deben ser internacionales. Los posibles evaluadores pueden pertenecer a una universidad o industria, pública o privada; de estos se debe proporcionar el nombre completo, su formación académica más alta, su afiliación institucional y su correo electrónico. Estos cuatro potenciales

evaluadores serán analizados por el Comité Editorial a fin de ampliar la base de datos de los árbitros de la revista *Tecnura*.

El Comité Editorial de la revista *Tecnura* se reserva los derechos de impresión, reproducción total o parcial del artículo, así como el de aceptarlo o rechazarlo. Igualmente, se reserva el derecho de hacer cualquier modificación editorial que estime conveniente; en tal caso el autor recibirá por escrito recomendaciones de los evaluadores. Si las acepta, deberá entregar el artículo con los ajustes sugeridos dentro de las fechas fijadas por la revista para garantizar su publicación dentro del número programado.

6. CONTACTO

Para cualquier solicitud de información adicional puede comunicarse a través del correo electrónico de la revista *Tecnura:* tecnura@udistrital.edu.co, tecnura@gmail.com, o por mensajería con el Ing. Cesar Augusto García Ubaque, Director y Editor de la revista *Tecnura*, a la dirección:

Revista Tecnura
Sala de Revistas, Bloque 5, Oficina 305.
Facultad Tecnológica
Universidad Distrital Francisco José de Caldas
Transversal 70 B N. 73 a 35 sur
Teléfono: 571 – 3239300 Extensión: 5003
Celular: 57–3153614852
Bogotá D.C., Colombia
Email:
tecnura.ud@correo.udistrital.edu.co, tecnura@gmail.com
Página web:
https://revistas.udistrital.edu.co/ojs/index.php/Tecnura

INSTRUCTIONS FOR AUTHORS

Tecnura journal
District francisco josé de caldas university
Faculty of technology

CONTENT

- **Scope and editorial policy of the journal**
- **Type of accepted articles**
- **Article format**
- **Article submission**
- **Publication procedure**
- **Article arbitration**
- **Contact**

SCOPE AND EDITORIAL POLICY OF THE JOURNAL

Tecnura journal is an institutional publication of the Faculty of Technology from University Francisco José de Caldas. It is a scientific and technological publication with quarterly periodicity, which is published in January, April, July and October. The first issue appeared in the second semester of 1997 and up to now it has maintained its regularity.

The areas of interest of Tecnura journal are focused on all engineering fields such as electronics, telecommunications, electricity, systems, industrial, mechanics, cadastral, civil, environmental, among others. However, it is not restricted to those; it also has room for education and health issues, as long as they are related to engineering. The journal will only publish concerning scientific and technological research, reflection and revision. In consequence, during the initial editorial evaluation, short articles and case reports will be rejected.

Tecnura Journal is addressed for professors, researchers, students and professionals interested in permanent update of their knowledge and follow-up of scientific-technologic processes in the field of engineering. Tecnura Journal has as mission to disseminate results of research projects in the areas of engineering, through the publication of original and unpublished articles, conducted by academics and professionals accredited by public or private national or foreign institutions. Articles submitted to Tecnura journal must be unpublished works written in Spanish or English; nevertheless, preference will be given to articles that show innovative concepts of great interest, related to the objective and scope of the journal.

Tecnura is an academic publication indexed in the Regional Index Scielo Colombia (Colombia) and Redalyc (México); as well as of the following bibliographic databases: INSPEC of the Institution of Engineering and Technology (England), Fuente Académica Premier of EBSCO (United States), CABI (England), Index Copernicus (Poland), Informe Académico of Gale Cengage Learning (México), Periódica from the Universidad Nacional Autónoma de México (México), Oceanet (Spain) and Dialnet from the Universidad de la Rioja (Spain). It is also part of the following directories: Online Regional Information System for Scientific journals from Latin America, Caribbean, Spain and Portugal Latindex (México), Bibliographic Index Actualidad Iberoamericana (Chile), e-Revistas (Spain) , DOAJ (Sweden) and Ulrich of Proquest (United States).

Tecnura is a journal arbitrated by a revision process among double blind peers. The schedule of the conformation of its scientific and editorial committee is subject to the publication of articles in internationally indexed journals by their members.

District University Francisco José de Caldas, its directors, the editor, the editorial and scientific committee are not responsible for the opinions and the criteria expressed in the content of the articles

and they are published under the exclusive responsibility of the authors and do not necessarily reflect the ideas of the editorial committee.

In addition to the printed version, Tecnura journal also has a digital version available in its web page: http://revistas.udistrital.edu.co/ojs/index.php/Tecnura/index

TYPE OF ARTICLES ACCEPTED

According to the classification of the Scientific and Technological Publications National Index (Publindex-Colciencias), *Tecnura* journal receives nominations of unpublished articles on the following topics:

- ***Scientific and technological research articles:*** document that presents, in a detailed manner, the original results of research projects. The generally used structure contains four main parts: introduction, methodology, results and conclusions.
- ***Reflection articles:*** document that presents research results from an analytic, interpretative or critic perspective from the author, dealing with a specific topic and adopting original sources.
- ***Review article:*** document that results from a research where the results of published or unpublished research on a science or technology field are analyzed, systematized and integrated, in order to state the advances and tendencies in development. It is characterized for presenting a careful bibliographical review of at least 50 references.

ARTICLE FORMAT

About the appropriate language and style for articles writing

- Authors must use simple sentence structures, avoiding those too long or complex.
- The vocabulary used must be basic and common. Technical language must be briefly explained; also, the meaning of the acronyms must be given the first time they appear in the text.
- The authors are responsible for their work to be conducted in a professional and ethic manner.

About the length of articles

The articles should not exceed 25 pages in letter size and double space, with symmetric margins of 3 cm. Only in the case of review articles, these 25 pages do not include references.

About the presentation format

Submitted articles must be unpublished works written in Spanish or English, and must be typed in Microsoft Word (2003 and beyond), complying with the following indications:

- *Times New Roman* letter, 12 point (except it is required for some sections).
- One column, double-spaced.
- All the margins 3 cm.
- Paragraphs should be justified without spaces between consecutives and without cutting words.
- Do not include page breaks or section finals.
- If you want to emphasize words or phrases from the text, do not use bold letters but italic.
- Decimals should be pointed with comma (,) and not with period (.).
- Thousands and millions should be pointed with a fine space.
- Avoid footnotes.
- Arabic nomenclature must be used only until the third level.

About the article structure

The papers must have the following structure and comply with the following requirements:

Composition of an article

All the articles submitted for evaluation and possible publication by the Tecnura Journal must have at least the following components:

- Title in Spanish and English.
- Information about the authors.
- Abstract in Spanish and English.

- Key words in Spanish and English.
- Introduction.
- Conclusions.
- Future work (optional).
- Acknowledgements (optional).
- Bibliographical references.

If the article is related to scientific and technological research must have, in addition to the above, the following components:

- Methodology.
- Results.
- Financing.

Title

The title of the article must be short or divided in title and subtitle, attractive for the potential reader and written in capital letters. It should appear centered between the margins, written in *Times New Roman* letter, in bold, font size 18. The title of the article has to be in Spanish and English separated by double space. Maximum 20 words.

Authors

After the title the complete name(s) of the author(s) must be written, with their basic biographical data: undergraduate degree, graduate degree, occupation or position, institutional affiliation (institution where they work), dependency, city, country and e-mail. The above information must be immediately below the author's name.

Abstract

The scope and purpose of the work must be established giving a clear and concise description of the methodology, results presented and the conclusions obtained. Maximum of 250 words.

Keywords

Between three and ten keywords must be chosen, written in English with *Times New Roman* letter in bold and italic.

Key words must be written in alphabetic order and must be as standard as possible, for which it is suggested the use of international databases according to the area of knowledge. For example, in the area of Electrics and Electronics it is suggested to use the IEEE thesaurus and World Bank thesaurus that can be accessed at the following web pages respectively:

http://www.ieee.org/documents/2009Taxonomy_v101.pdf

http://multites.net/mtsql/wb/site/default.asp

Abstract in Spanish

Translation to the Spanish language of the text that appears in the abstract, it must be correct and precise.

Keywords in Spanish

Translation to the English language of the keywords in Spanish, they must be correct and precise.

Keywords must be written in the order of the English version and must be as standard as possible, for which it is suggested the use of international databases according to the area of knowledge. For example, in the area of Electrics and Electronics it is suggested to use the UNESCO thesaurus that can be found at the following web pages:

http://databases.unesco.org/thessp

Introduction

The general idea of the work must be described, its context, backgrounds, state of the art of the topic, objectives and possible scope of the work.

Methodology

The writing of this part must allow any specialized professional in the topic to replicate the research.

Results

Explanation and interpretation of the findings. If necessary, a brief discussion focused on the interpretation of the results can be presented.

Conclusions

Implication of the results and their relation to the proposed objective.

Financing

Mention the associated research from which the article was derived and the entity that endorsed and financed the research.

Acknowledgments

They should preferably be brief and include the essential contributions for the development of the paper.

Equations

Equations must appear centered with respect to the main text. They must be referenced with consecutive numbers (written in parenthesis close to the right margin). Equations are cited in the main text employing the word equation, and followed by the number in parenthesis. Equations must be made in an appropriate equation editor and compatible with "InDesign" software, as for example the equation editor of Windows.

Tables

In the case of implementation of tables, it is recommended that these are not inserted as images, considering that in that format they cannot be modified. The title of each table must include the word table (in italic) followed by the corresponding consecutive number and a brief name of the table. The heading must be written in TNR letter, italic and font size 9.

Charts are not presented but tables and they should be automatically raised from the text processor. Tables should be named and referenced in the article, in strict order. Every table must have at the bottom the source from which it was taken, or to mention self-authorship if it is the case.

Figures

All the figures or pictures have to be sent in JPG or PNG format with a minimum resolution of 300 DPI, adapted to gray scale.

The footnote or name of each figure must include the word figure (in italic) followed by the corresponding consecutive number and a brief description of the content of the figure. The footnote of the figure must be written in *Times New Roman* letter, italic and font size 9. Figures must be named and referenced in the article, in strict order. Every figure must have at the bottom the source from which it was taken, or to mention self-authorship if it is the case.

Symbols

The symbols of the constants, variables and functions in Latin or Greek letters –included in the equations- must be in italic; the mathematical symbols and the numbers do not go in italic. The symbols must be identified immediately after the equation. Units, dimensions and symbols of the international system must be used

When using acronyms or abbreviations, the complete equivalence should be written first, followed by the corresponding acronym or abbreviation in parenthesis and from there it is only written the respective acronym or abbreviation.

Bibliographic references

The adopted reference citation style by *Tecnura* journal is APA sixth edition. The cites, bibliographic references and infography are included in the last part of the article. The bibliographic references must be alphabetically ordered according to the author's first surname, without numbering.

There should only appear the cited references in the main body of the work, in tables or in figures. It means, in the list there should not appear other references although they have been consulted by the authors for the work preparation. We suggest using tools such as: Cites and bibliography from Microsoft Word (for APA sixth edition version 2013 or superior), Zotero, Mendeley, among others.

The call for a bibliographic reference is inserted in the text, at the pertinent point, under certain characteristics:

- If the sentence includes the author's surname, it should only be written the date into a parenthesis, for instance:

Cuando Vasco (2012), analizó el problema de presentado en ….

- When the author is not included in the sentence, surname and date must be into a parenthesis.

La investigación de materiales dio una visión en el área (Martínez, 2012).

- If the document or work has more than two authors, the first cite must include all the surnames. 1990. (Fernández Morales, Villa Krieg & Caro de Villa, 2008) ….

- In the following mentions, it must only be written the author's first surname, followed by "et al.".

En cuanto al estudio de las aguas, Fernández Morales et al. (2008) encontraron que …

- When the document or work has more than six authors, it must be used from the first mention "et al.".

Next it is described a series of examples of the more used references, according to the reference style adopted by *Tecnura* journal:

Periodical Publications:
Basic Form

Surnames, A. A., Surnames, B. B. & Surnames, C. C. (Date). Article's title. *Title of the publication*, volume (number), pp. xx-xx. doi: xx.xxxxxxx

Basic article

Guevara López, P., Valdez Martínez, J., Agudelo González, J., & Delgado Reyes, G. (2014). Aproximación numérica del modelo epidemiológico SI para la propagación de gusanos informáticos, simulación y análisis de su error. *Revista Tecnura*, 18(42), 12 -23. doi:http://dx.doi.org/10.14483/udistrital. jour.tecnura.2014.4.a01

Web article

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