HUMANIDADES E CIÊNCIAS SOCIAIS:

Perspectivas Teóricas, Metodológicas e de Investigação

Luis Fernando González-Beltrán
(organizador)

EDITORA ARTEMIS
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PRÓLOGO

El Volumen IX de la obra “Humanidades e Ciências Sociais: Perspectivas Teóricas, Metodológicas e de Investigação”, ofrece una visión integral sobre los desafíos y las oportunidades que surgen en las áreas de gestión, salud, ambiente, sostenibilidad e innovación tecnológica en el escenario contemporáneo. Reuniendo una variedad de estudios que van desde la sostenibilidad financiera hasta la innovación en políticas públicas y salud, este libro se propone reflexionar sobre las múltiples dimensiones de la evolución social y económica en las sociedades actuales.

En la sección de Gestión, Economía y Desarrollo, los lectores tendrán la oportunidad de explorar cuestiones clave que involucran la sostenibilidad en el ámbito corporativo y social. Desde el estudio de las condiciones de vida y trabajo de los obreros en la industria maquiladora hasta la implementación de sistemas de gestión ambiental en las empresas, los artículos presentan numerosos análisis y hasta un menú soluciones innovadoras para los problemas de gestión, logística y organización. El impacto de la bioeconomía (modelo económico que busca utilizar los recursos biológicos de manera sostenible) y las tecnologías emergentes, como la inteligencia artificial, también son temas tratados, mostrando cómo estas herramientas pueden contribuir a una mayor ética y eficiencia en las prácticas empresariales. Adicionalmente se propone como resolver uno de los mayores problemas en las ciudades modernas que buscan ser sostenibles: la movilidad y el transporte. En los dos casos que se presentan la solución incluye la cooperación, tanto para cambiar actitudes y poder compartir vehículos, como para compartir una caja común en una cooperativa de transporte.

La sección dedicada a Educación para la Salud presenta dos casos interesantes. Primero sobre las Organizaciones de la Sociedad Civil, que de manera increíble de más de 7000 en Brasil, solo 322 se dedican a la salud. De estas destacamos aquí el instituto Vita, dedicado a la atención de atletas de alto rendimiento, que requieren de tratamiento ortopédico y fisioterapéutico sin costo. Se analizan las condiciones para fundar una sociedad así, como llega a consolidarse y qué contribuciones resultaron de esta iniciativa. Segundo, sobre las acciones de las unidades básicas de salud de un municipio de Brasil, que buscan generar conciencia sobre las enfermedades cardiovasculares. Como otras enfermedades crónico-degenerativas, son de enorme impacto en morbilidad y mortalidad, por lo que se busca impulsar un cambio en el estilo de vida hacia uno más sano y preventivo. Estos estudios no solo presentan los desafíos actuales en el ámbito de la salud, sino que también ofrecen ideas para mejorar las prácticas de bienestar en las comunidades y garantizar el acceso a servicios de salud más eficaces e inclusivos.

En Educación ambiental y Desarrollo turístico, el volumen profundiza en la conexión entre la preservación ambiental y el impacto, mayormente negativo, de las acciones humanas. Se revisan los proyectos ambientales de los escolares, que deben encontrar una relación armónica con su ambiente, guiados por un equipo docente de naturaleza interdisciplinar. También se revisa el proyecto de las comunidades rurales, encargadas de la creación sostenible de abejas, cuyo papel es crucial en el balance de los ecosistemas, con repercusiones en los animales y en nosotros mismos. A continuación se propone un turismo responsable, integrando en uno, los tres modelos de turismo, buscando la regeneración, y la participación tanto de la comunidad como de los voluntarios. De igual forma se plantea un turismo rural sostenible tanto en paisajes naturales que contiene registros rupestres, cuevas rocosas habitadas por homínidos, como en complejos arqueológicos prehispánicos, verdaderas maravillas históricas. En conjunto nos permiten reflexionar sobre la importancia de integrar prácticas ecológicas en la vida cotidiana y en las áreas de desarrollo urbano. La sostenibilidad, en este contexto, se considera una necesidad urgente para garantizar un futuro más equilibrado entre el ser humano y el entorno.

Finalmente, la sección Innovación y nuevas tecnologías aborda cómo la creatividad en estas técnicas ha llegado a tener tan grande impacto en las diferentes áreas de nuestras vidas. Desde el uso de sistemas de videovigilancia, de sistemas de baterías desmontables y de fácil reparación para áreas rurales, de las redes sociales pendientes hasta de la vestimenta de las celebridades, hasta la capacitación en habilidades del siglo XXI, los artículos reflejan cómo la tecnología tiene el poder de transformar nuestra manera de trabajar, vivir e interactuar con el mundo.

Este volumen busca no sólo presentar los desafíos contemporáneos en las áreas de gestión, salud, ambiente y tecnología, sino también ofrecer perspectivas innovadoras y soluciones prácticas para un futuro más sostenible, ético e inclusivo. Los autores aquí reunidos, con su diversidad de enfoques y experiencias, nos invitan a reflexionar sobre el papel de las ciencias sociales, la gestión y la tecnología en la construcción de un mundo mejor.

Dr. Luis Fernando González Beltrán
Universidad Nacional Autónoma de México. (UNAM)

SUMÁRIO

GESTIÓN, ECONOMÍA Y DESARROLLO

CAPÍTULO 16

DEVELOPMENT OF SUSTAINABLE BATTERY SYSTEMS WITH SPECIAL FOCUS ON THEIR MAINTAINABILITY

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M.Sc. Robert Kretschmann
Otto von Guericke University Magdeburg
Department of Product Development and Engineering Design
Magdeburg, Saxony-Anhalt, Germany
https://www.lpk.ovgu.de/Lehrstuhl/Team/Wissenschaftliche+Mitarbeitende/M_SC_+ROBERT+KRETSCHMANN-p-112.html
https://orcid.org/0009-0005-7184-0183

Prof. Dr.-Ing. Christiane Beyer
Otto von Guericke University Magdeburg
Department of Product Development and Engineering Design
Magdeburg, Saxony-Anhalt, Germany

ABSTRACT: The demand for electrochemical energy storage systems, both for stationary and mobile applications, has significantly increased recently. Sustainability and repairability have not been the main focus of their development, but they are gaining more importance. Considering these factors is crucial for the long-term success of battery systems. Currently, stationary energy storage is already being used in developing and emerging countries to improve supply infrastructure. One of the central challenges is the repair of systems in case module or cell replacement is necessary. The use of material-locked contacts between different system components complicates this process, leading to various issues under unfavorable conditions. This work focuses on the development of a disassembly and repairable battery module that can be used in various application areas. The main emphasis is on the contacting methods of the battery cells. The current state of the art and the approach to the development of the contribution are presented. Disassembly and repairability should be improved without compromising performance. Based on a literature review, this work presents a range of approaches to avoid material-locked contacts, focusing particularly on the use of novel materials and manufacturing processes. Additionally, the effects of avoiding material-locked contacts on the overall performance and safety of sustainably designed battery systems are investigated. Finally, general design guidelines are outlined to consider repairability with simple means in the future design of battery systems.

KEYWORDS: Battery System. Sustainability. Contacting. Design guidelines.

DESENVOLVIMENTO DE SISTEMAS DE BATERIA SUSTENTÁVEIS COM FOCO ESPECIAL EM SUA CAPACIDADE DE MANUTENÇÃO

RESUMO: Recentemente, houve um aumento significativo na demanda por sistemas de

armazenamento de energia eletroquímica, tanto para aplicações estacionárias quanto móveis. A sustentabilidade e a reparabilidade não têm sido os principais focos de desenvolvimento destes sistemas, mas estão ganhando cada vez mais importância. Considerar esses fatores é crucial para o sucesso a longo prazo dos sistemas de baterias. Atualmente, o armazenamento de energia estacionário já está sendo utilizado em países em desenvolvimento e emergentes para melhorar a infraestrutura de fornecimento. Um dos principais desafios atualmente é o reparo dos sistemas caso seja necessário substituir módulos ou células. O uso de contatos materiais fixos entre diferentes componentes do sistema complica esse processo, levando a vários problemas em condições desfavoráveis. Este trabalho foca no desenvolvimento de um módulo de bateria desmontável e reparável que possa ser utilizado em diversas áreas de aplicação. A ênfase principal está nos métodos de contato das células da bateria. O estado da arte atual e a abordagem para o desenvolvimento da contribuição são apresentados. A desmontagem e a reparabilidade devem ser melhoradas sem comprometer o desempenho. Com base em uma revisão da literatura, este trabalho apresenta uma série de abordagens para evitar contatos materiais fixos, com foco particularmente no uso de novos materiais e processos de fabricação. Além disso, os efeitos de evitar contatos materiais fixos no desempenho geral e na segurança dos sistemas de baterias projetados de forma sustentável são investigados. Finalmente, são delineadas diretrizes gerais de design para a reparabilidade com meios simples nos projetos futuros de sistemas de baterias.
PALAVRAS-CHAVE: Sistema de bateria. Sustentabilidade. Contato. Diretrizes de design.

1 INTRODUCTION

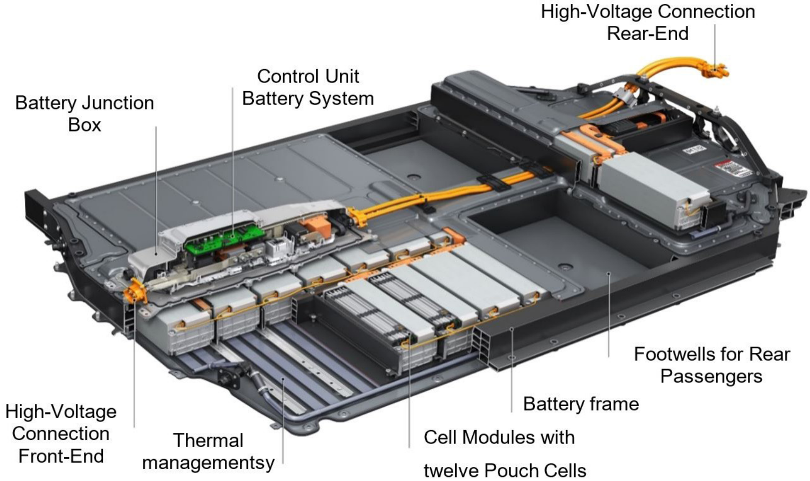
In recent years, large-scale battery systems have significantly gained importance. One application is in the electric powertrain of hybrid vehicles and Battery Electric Vehicles (BEVs), where it serves as a crucial component in determining their lifespan and usability. (Hettesheimer et al., 2017) Another rapidly evolving field is stationary energy storage systems for commercial and residential applications. The battery system plays a pivotal role in maintaining the long-term value of the overall system. However, the development of current battery systems is still heavily influenced by requirements from automatable assembly concepts and established manufacturing processes. Additionally, the average price of battery storage per unit of volumetric energy content has significantly decreased in recent years, further supporting the retention of current concepts. (Bloomberg NEF, 2022)

Nevertheless, battery cells still constitute a major portion of the costs in their respective applications. Due to economic considerations and the consequent necessity for automation of manufacturing processes, aspects of repairability and disassembly take a back seat. A systematic examination of the sustainable design of battery systems is inevitable, particularly in light of increasing demands from the political sphere. (Marco Saddi, 2020) This examination can encompass diverse aspects such as the materials used in the cells and cell design. (Heinicke & Wagenhaus, 2015) The design possibilities, contingent in part upon the chosen cell types, influence the reusability of assemblies and components. Therefore, the goal must be to achieve an overall long service life of the battery system to promote sustainable use. In the development and restructuring of design guidelines for sustainable battery storage, appropriate requirements should be applied early in the product development phase. Furthermore, the incorporation of additive and hybrid manufacturing processes opens up novel design approaches. This enables the enhancement of performance, efficiency, and sustainability of future battery concepts.

When looking at current battery concepts from various manufacturers for both mobile and stationary applications, it is noticeable that the fundamental structure is similar in many aspects. This is understandable due to comparable approaches and requirements during development, but it is not desirable. The focus on automated manufacturing combined with established production processes hinders the optimal design of battery systems. (Kampker, 2014) In these concepts, individual battery cells - regardless of their type - are mostly connected through material-locked joining techniques. The concepts also resemble each other in design, structure, and the materials used. Figure 1 from (*Audi RS e-tron GT | Audi MediaCenter,* 2022) illustrates such a battery concept from a mobile application according to the current state of the art.

The battery modules are embedded in a sturdy frame made of extruded aluminium profiles and consist of individual cells arranged and connected according to the requirements. Thermal regulation is achieved through a fluid-flow system located beneath the battery modules. While this allows for a relatively quick assembly, this approach leads to reduced performance and lifespan due to thermodynamic aspects and limits disassembly and repair options. Additionally, the high weight and partial disregard for sustainable design principles in the current state of the art do not reflect the optimum for a lithium-ion-based battery system.

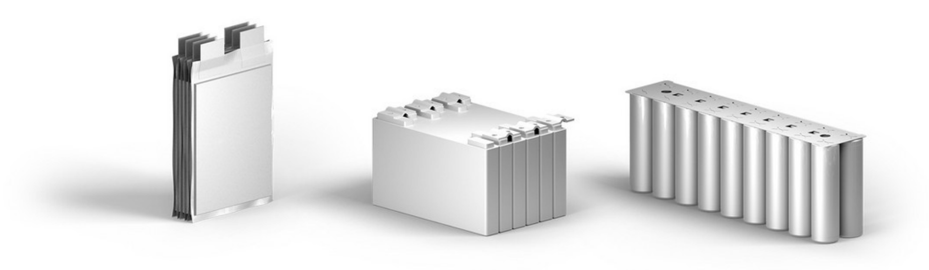
Figure 1: Mobile Battery Concept According to State of the Art.



Upon closer examination of the battery modules - regardless of cell type (see Figure 2) - a focus on material-locked joining processes (welding, bonding, adhesion, etc.) becomes evident. These processes complicate the disassembly of the battery cells in the event of necessary repairs (e.g., cell replacement) or at the end of the product lifecycle. Moreover, they can render reassembly impossible in the absence of correspondingly expensive plant equipment.

The focus of this article is, therefore, the conceptualization of the infrastructure surrounding the battery cell within the battery system, considering disassembly and repairability, with a particular emphasis on ease of implementation and economically viable practices. To illustrate this, the approach will be described using an example.

Figure 2: Material-locked Connection of Different Cell Types (Strama-MPS Maschinenbau GmbH & Co. KG, 2023).

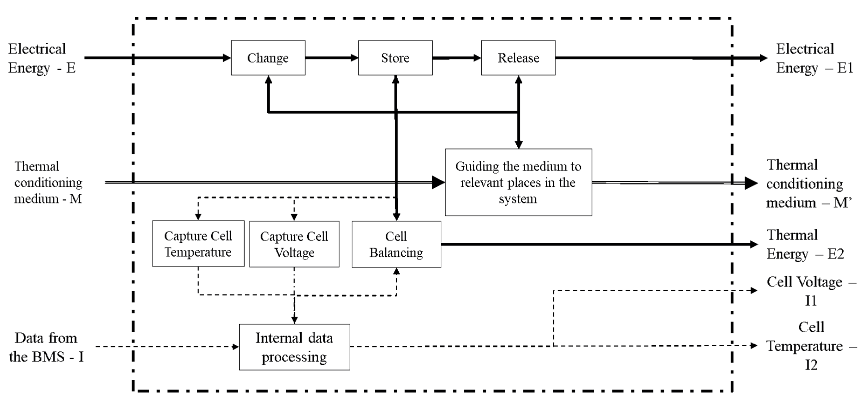


2 METHODOLOGY

Before explaining the approach, the term 'sustainability' will be defined in the context of this article due to its differentiated meanings. The generalized approach by the United Nations (United Nations [Hrsg], 1987, S. 34) provides the foundation but needs further specification. Sustainability, in this context, refers to the longest possible use of cost-intensive components, encompassing both first-use and second-use. Therefore, components that could be recovered and reused in the event of damage or when certain parts of the overall system reach the end of their life must be integrated into the overall system in a way that enables their intact removal. This facilitates their reintegration into primary or secondary applications with minimal effort and promotes the sustainable use of these components.

To link these aspects early on with efficiency and performance in future battery systems, a preselection of recoverable components is made based on a functional structure (see Figure 3) and the fundamental requirements of the battery system. This selection also considers the financial aspects of (VDI-Richtlinien) regarding material cycle suitability and component cycle suitability. The cost elements in the use case depend on the cell technology and cannot be directly influenced. For the assembly-disassembly balance, the goal is to find the optimum that minimizes assembly efforts while ensuring fundamental disassembly capability with reasonable effort and material loss. Throughout the entire product development process, the components are assessed for their recoverability according to Formula (1) (VDI-Richtlinien). The component is suitable for recycling, i.e., economically recyclable, if $KE_K > 1$.

Figure 3: Basic Functional Structure of a Battery System.



$$KE_K = \frac{Costs\ of\ new\ part\ (e.g.\ battery\ cell) +\ disposal\ costs\ in\ Euro}{Recycling\ costs\ of\ old\ part\ in\ Euro} \qquad (1)$$

From the early stages of product development, additive and hybrid manufacturing processes are taken into account. Additionally, in the development process and early in the functional development during cell selection, the proportion of non-destructive components is determined. The recoverable components, which can be introduced into a new system in the event of damage or at the end of the first-life cycle, now determine both the manufacturing and joining technology used, and, in logical alignment with its properties, the necessary auxiliary structures. Based on these insights, the development of a battery module takes place, as in this assembly, in current concepts, as outlined in Chapter 1, mainly material-locked joining methods are used. The result of these considerations, including the assembly-disassembly balance in the Stage-Gate process following Cooper (R. G. Cooper, 1983), is presented in Chapter 3.

3 RESULTS AND DISCUSSION

The fundamental requirements for the battery module are defined in advance. These include not only the aforementioned focus on disassembly and repairability but also the integration of efficient components for the thermal regulation of the battery cells. These components require the largest possible surface area for heat transfer to ensure optimal temperature levels with minimal effort. The outlined constraints directly influence the choice of cell type (cylindrical, prismatic, pouch) and thus significantly impact the design of the battery system. A pouch cell is chosen (see Figure 4), for which the recyclability according to (VDI-Richtlinien) must first be determined. The values needed for this are summarized in Table 1.

Table 1: Values for Determining Recyclability.

Variables Formula (1)	Value
Costs of new part	130,00€
Disposal costs	5,00€
Recycling costs of old parts (Disassembly, Processing, Logistics)	20,50€

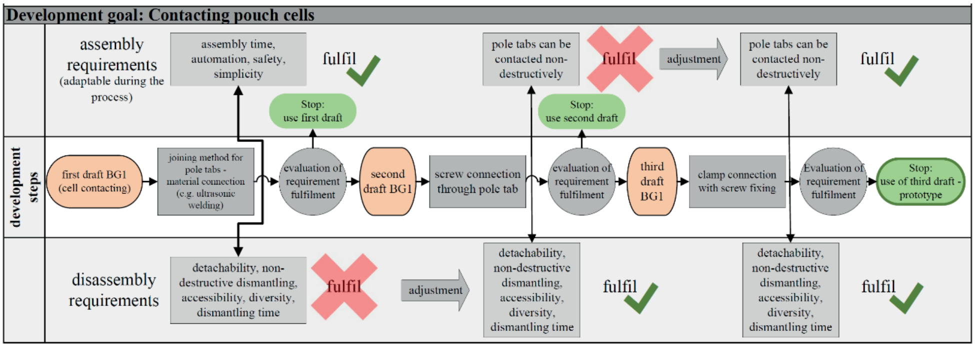
Figure 4: Pouch cell (own elaboration).

The values for recycling costs depend directly on the concept and fine design of the system and therefore must be continuously monitored throughout the product development process. Applying Formula (1), the factor is obtained. The battery cell as a single component is thus suitable for recycling and economically recyclable, as long as the performance data (e.g., SOH - State of Health, temperature behaviour over charge and discharge cycles, etc.) still meet the reuse requirements.VDI 2243 recommends non-destructive disassembly for connection types used in such components. (VDI-Richtlinien) Based on these findings, the conceptualization of the battery module can take place under the condition that the individual battery cells can be non-destructively removed from the system (disassembly), reinserted (repairability), or used in repurpose applications (second-life). The further procedure will be illustrated using the example of interconnecting the terminal tabs.

3.1 MAINTAINABILITY ILLUSTRATED THROUGH THE ELECTRICAL CONNECTION OF POUCH CELLS

The interconnection of battery cells can be achieved in various ways based on requirements such as safety aspects, performance, automatability, etc. Besides the material-locked joining methods mentioned in Chapter 1, there are different force-fitting and form-fitting variations that differ in their respective advantages and disadvantages. The exclusive use of screw connections, which connect the terminal tabs using corresponding holes, is easily mountable and demountable using simple means. However, this can lead to short circuits, increasing contact resistances, and a decrease in the performance of the electrical interconnection due to damage to the terminal tabs and local stress concentrations in the edge region of the screw connection. To avoid these consequences of the design, a broad clamping surface with evenly distributed surface pressure is required. An iterative design of the terminal tab interconnection is carried out from this tension field of requirements using the Stage-Gate process represented in Figure 5 (in abbreviated form). The result is shown in Figure 6.

Figure 5: Stage-Gate Process for developing the terminal tab interconnection through assem-bly-disassembly alignment.



This clamping connection consists of two shells reinforced by a copper bar. The shells are secured using screw connections outside the conductive contact areas. This design is characterized by simple, non-destructive assembly and disassembly, which can be used for both first-life and second-life applications. The integration of different sensors (temperature and voltage) allows detailed data acquisition throughout the product life cycle, facilitating the decision on the reusability of the battery cells. Lastly, a majority of the components used are realized using common additive manufacturing processes, enabling repair of the interconnection with relatively simple means. This significantly lowers the barriers to deployment in developing and emerging countries compared to electrical interconnection using material-locked joining methods. The performance and safety of the connection are currently being investigated through 4-terminal resistance measurements and shaker tests. Initial results show comparability with material-locked joining methods regarding the performance of the electrical connection. A detailed analysis is pending and will be part of further contributions.

Figure 6: Prototype clamp connection as a result of the presented approach.

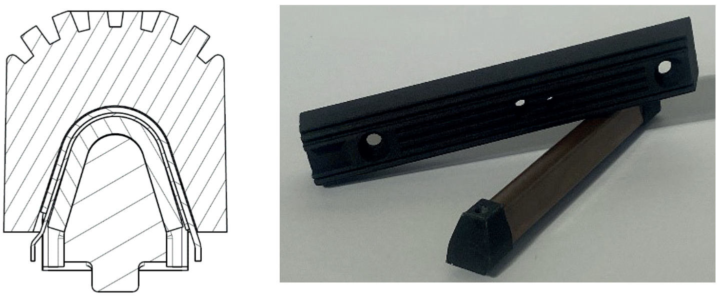
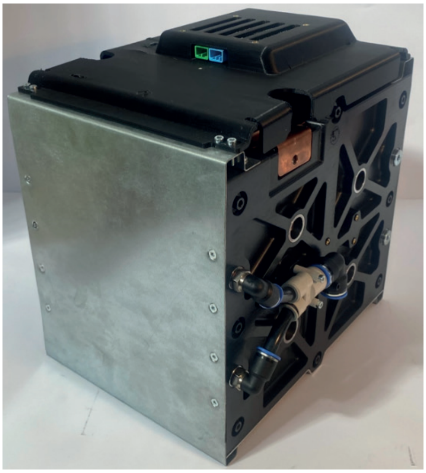


Figure 7: easy maintainable 48V-Battery module.



4 CONCLUSIONS

The present article succinctly presents a possible approach to the further development of modern battery systems, considering disassembly and repairability. The subsequent application field is not the primary focus. The emphasis is on the consistent use of established methods of sustainable product development and subsequent realization with a special focus on concepts that enable the repairability of battery systems while maintaining performance. The presented example of terminal tab interconnection represents only a small part of the considerations in the design of the battery system. The approach is applied analogously to all relevant components and assemblies. This creates a basis that, in further exploring the topic, allows the derivation of universally applicable design guidelines for battery systems that are highly repairable with minimal effort. An example of such a repairable battery system is shown in Figure 7.

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SOBRE O ORGANIZADOR

Luis Fernando González-Beltrán- Doctorado en Psicología. Profesor Asociado de la Facultad de Estudios Superiores Iztacala (FESI) UNAM, Miembro de la Asociación Internacional de Análisis Conductual. (ABAI). de la Sociedad Mexicana de Análisis de la Conducta, del Sistema Mexicano de Investigación en Psicología, y de La Asociación Mexicana de Comportamiento y Salud. Consejero Propietario perteneciente al Consejo Interno de Posgrado para el programa de Psicología 1994-1999. Jefe de Sección Académica de la Carrera de Psicología. ENEPI, UNAM, de 9 de Marzo de 1999 a Febrero 2003. Secretario Académico de la Secretaría General de la Facultad de Psicología 2012. Con 40 años de Docencia en licenciatura en Psicología, en 4 diferentes Planes de estudios, con 18 asignaturas diferentes, y 10 asignaturas diferentes en el Posgrado, en la FESI y la Facultad de Psicología. Cursos en Especialidad en Psicología de la Salud y de Maestría en Psicología de la Salud en CENHIES Pachuca, Hidalgo. Con Tutorías en el Programa Alta Exigencia Académica, PRONABES, Sistema Institucional de Tutorías. Comité Tutoral en el Programa de Maestría en Psicología, Universidad Autónoma del Estado de Morelos. En investigación 28 Artículos en revistas especializadas, Coautor de un libro especializado, 12 Capítulos de Libro especializado, Dictaminador de libros y artículos especializados, evaluador de proyectos del CONACYT, con más de 100 Ponencias en Eventos Especializados Nacionales, y más de 20 en Eventos Internacionales, 13 Conferencia en Eventos Académicos, Organizador de 17 eventos y congresos, con Participación en elaboración de planes de estudio, Responsable de Proyectos de Investigación apoyados por DGAPA de la UNAM y por CONACYT. Evaluador de ponencias en el Congreso Internacional de Innovación Educativa del Tecnológico de Monterrey; Revisor de libros del Comité Editorial FESI, UNAM; del Comité editorial Facultad de Psicología, UNAM y del Cuerpo Editorial Artemis Editora. Revisor de las revistas "Itinerario de las miradas: Serie de divulgación de Avances de Investigación". FES Acatlán; "Lecturas de Economía", Universidad de Antioquía, Medellín, Colombia, Revista Latinoamericana de Ciencia Psicológica (PSIENCIA). Buenos Aires, Revista "Advances in Research"; Revista "Current Journal of Applied Science and Technology"; Revista "Asian Journal of Education and Social Studies"; y Revista "Journal of Pharmaceutical Research International".

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