Integration of circular economy principles for developing sustainable development competences in higher education: an analysis of bachelor construction management courses

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***Abstract*—The integration of Circular Economy (CE) principles into higher education programs can be seen as an important step in achieving true sustainability in higher education. Even though the adoption of CE in higher education has improved in recent years, there has been little research about the effective integration of CE principles into academic programs. The aim of this paper is to present an analysis of the redesign and restructuring of an undergraduate construction management course integrated with CE principles as a methodology to impart sustainable development (SD) competencies; this research was done within the framework of the Tec21 educational model that has been in the process of implementation in the Tecnologico of Monterrey university system throughout its 26 campuses in Mexico. Although the new educational model calls for the development of SD competencies, among others, there is no information available on the current status of the integration of CE principles into bachelor-level courses in Construction Management. Therefore, this study contributes to research by providing a detailed analysis and documentation of the design process for the efficient incorporation of CE principles into such a course. The results of the study show that it is necessary to incorporate CE principles into the structure of course content in order to develop the SD competencies that are demanded by industry now and in the future.**

Keywords— circular economy, sustainability, construction management, educational innovation, Tec-21, higher education.

I. BACKGROUND

Due to the sustainable development (SD) challenges that our societies are facing in the modern era, universities have been integrating sustainability into their educational, research, outreach, and operational models more as a requirement than a desirable feature [1-5]. In this respect, the "circular economy" (CE) is considered to be the principal means to reach sustainability by shifting to closed-loop supply chains, circular business models, and circular value chains [6,7]. This shift is transforming the conceptualization of the management of the world's resources and the theorization of the processes, methods, and stakeholders involved in all productive industries. Therefore, the integration of CE principles in higher education programs can be seen as an important step in achieving true education for sustainable development.

Within education, SD competencies have to be defined, courses on sustainability and CE have to be designed, manuals and methods for teaching SD have to be developed and integrated into the curricula, and the existing degree courses have to be structured according to CE principles and models [3]. On the one hand, the field of management education is particularly controversial because the resistance to change by business organizations towards sustainable business models is considered to be a major cause of modern sustainability crises [1]. On the other hand, the construction industry is considered a major contributor to the global environmental load caused by human activities. From a life-cycle perspective, the construction industry is responsible for about 30% of global annual Greenhouse Gas (GHG) emissions, 40% of energy consumption, 32% of world resource depletion, 12% of water consumption, and 40% of waste to landfills [8-10]. Therefore, there is an urgent need to integrate competencies for SD in construction management education programs effectively.

A. Sustainable Development Competencies in Education

In this paper, we define competence as "the ability to successfully meet complex demands in a particular context through the mobilization of psychological prerequisites (including both cognitive and non-cognitive aspects)" [11]. Several studies have demonstrated the benefits of promoting and implementing competency-based formation in higher education [1-3,11]. A correct competency-based education enables students to gain the knowledge, skills, values, and attitudes that are necessary for a successful professional and

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personal life [3]. Similarly, studies have demonstrated the urgent need and importance for the effective integration of sustainability in higher education [12,13]. Therefore, introducing key competencies for SD in higher education academic programs increases the likelihood of achieving this integration.

In this respect, some authors have pointed out the key SD competencies for higher education for the 21st century [1,3]. For the purposes of this study, we use the five-pillar framework for SD competencies proposed by Olalla and Merino [1]. In their work, the authors define five categories for classifying key competencies for sustainability. The five categories are Learning to Know (LK), Learning to Do (LD), Learning to Live together (LL), Learning to Be (LB), and Learning to Transform oneself and society (LT). Even though much work has been done covering the complete educational process through competencies (such as defining competencies, describing integration strategies and methodologies to achieve and assess competencies, etc.), little research has been done regarding the integration of SD competencies into existing academic programs [3] nor the drivers that enhance their implementation.

B. Towards Circular Economy in Higher Education

The pedagogical innovations that nurture sustainable development in higher education are accelerating [13,14]. Kilkis and Kilkis [15] highlighted in their work that the adoption of sustainability in higher education has improved in recent years because the difficulties and barriers to this in disciplinary contexts are lessening. In this context, the CE theory is seen as an effective pathway to SD [6,7]. CE is especially relevant in management education because it involves the transition from the traditional resource-based management model to a closed-loop one. Unfortunately, only a few scholars have started outlining educational approaches and tools to integrate CE into academic programs [16]. To the knowledge of the authors of this research, there is no study that critically describes and discusses the integration of CE principles into the structure of construction management courses.

The concept of the circular economy is forcing a change of value in the supply chains in all industries, including construction [17]. CE is defined as a system where material and energy loops could either be closed by minimizing resource input and waste production or be slowed down by maximizing the reusability of products [18]. In a CE, the reuse of building materials and components in multiple life cycles increases resource efficiency and eliminates waste [19]. CE is considered as the main precursor to converting current production and consumption supply chains into sustainable supply chains [6,18,20,21]. Therefore, construction management education must align with the transition of the construction industry to CE models such as closed-loop supply chains, circular business models, and circular value chains [6,7]. The integration of CE principles in construction management education is critical in order to prepare the engineering students with the necessary tools to face the challenges of the new era in the construction industry.

II. Research Questions

1. How are sustainability and CE principles changing the structures of the academic programs and course syllabi in higher education?
2. How do CE principles impact the development of SD competencies in undergraduate construction management courses?
3. How can CE principles be integrated effectively into undergraduate construction management courses?

III. Knowledge Gap

The aim of this paper is to develop an analysis of the redesign and restructuring of an undergraduate construction management course in order to integrate CE principles for developing SD competencies. The proposed redesign is carried out under the framework of the new Tec21 Educative Model in the higher education institution, Tecnologico de Monterrey, in Mexico. This paper aims to contribute to the nascent body of literature on the integration of CE principles in engineering education.

IV. Method

A. Situating the Case

Higher educational institutions throughout the world are undergoing transcendental transformation due to new 21st-century challenges and demands in education, such as the integration of individuals into a globalized world, technological advancements, and the demand for new kinds of competencies by the employment market [22]. This transformation underlies the implementation of different educational models that provide relevant educational services to the new generations of students, models that have the objective of developing the competencies in their graduates that are necessary for their professional success in modern society. Therefore, in 2013, a new educational model was proposed by Tecnologico de Monterrey to be developed and implemented by 2019. The Tecnologico de Monterrey university system has over 90,000 undergraduate and postgraduate students attending on twenty-six campuses in Mexico. The university system employs more than 10,000 professors and over 500 researchers [23]. According to the 2019 QS World University Ranking, Tecnologico de Monterrey was ranked the 158th in the world, 5th in Latin America, and 1st in Mexico [24].

The objective of the new educational model is to provide comprehensive training and improve the competitiveness of students in their professional fields by developing in them the required competencies that allow them to become the leaders who face the challenges and opportunities of the 21st century [23]. Some studies have explored the benefits of the new educational model, such as the advantages of a student-centered approach [25], the development of competencies through collaborative, interdisciplinary work [26], and the enrichment of the learning experience through self-management [27] and the use of information and communication technologies [28]. In this new educational model, there are two types of competencies, namely, disciplinary and transversal. The disciplinary competencies are the necessary knowledge, skills, attitudes, and values for professional development. The transversal competencies are developed during the training process of any discipline; they are the "soft" competencies that are useful for the successful insertion of the student into the professional environments of the real world, and they enhance the quality of the professional performance.

The new Tec21 educational model is structured in semesters that are comprised of *formation units* (FUs). The

FUs can be *subject-matters* or *subject-blocks*. By definition, a subject-matter is a set of learning contents and activities that provides theoretical and applied education. A subject-matter is oriented to a single discipline; it contains the fundamentals of that discipline, and it links the course contents to a real-world problem or challenge to be solved [29]. A subject-block is comprised of challenges and sub-modules designed to develop competencies. On the other hand, a *subject-block* focuses on promoting the learning of processes, methods, and strategies. A subject-block is oriented to multiple disciplines.

In the context of the new educational model, the university periodically organizes national workshops to design the formation units (FUs) for each discipline. These workshops unite professors from all the campuses to collaborate on the design of the FUs in their specific disciplines and specialties. The research of this study was developed during the National Design Workshop of Formation Units of the School of Engineering and Sciences in 2019. The workshop registered a total of 338 professors to create the design of 176 FUs.

B. Methodology

Although the new educational model is oriented to the development of SD competencies, there is no information available on the current status of the integration of CE principles in bachelor-level construction management courses. Therefore, this study carries out a detailed comparative analysis and documentation of the design process to efficiently incorporate CE principles. For the purposes of this study, the five-pillar framework for SD competencies in education was used as a reference [1], and the design process was based on the Backcasting and Eco-design for Circular Economy (BECE) approach (see Fig. 1). In this context, the BECE approach is used to identify areas of intervention and to evaluate opportunities for the development of innovative CE initiatives [14]. According to Mendoza et al. [30], BECE empowers organizations to implement CE initiatives in an effective and holistic way at the design and operation stages. As displayed in Fig. 1, the BECE approach can be applied in

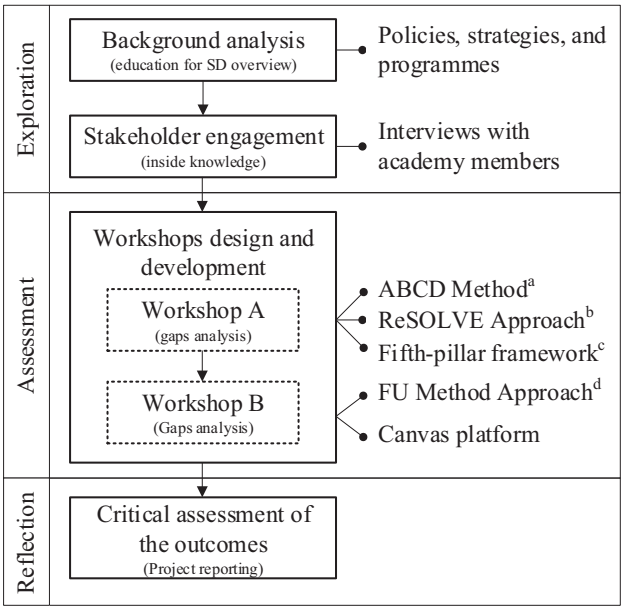

Fig. 1. Action-led research Backcasting and Eco-design for Circular Economy (BECE) methodology for the implementation of circular economy strategies in the design of bachelor-level construction management courses ([a][34];[b][35];[c][1];[d][68]).

three stages: exploration, assessment, and reflection. Exploration consists of two steps: 1) background analysis to determine the scope of policies and practices developed by the university in the matter of education for sustainable development (SD), and 2) stakeholder engagement to learn about the effectiveness of those policies and practices through interviews with academy members. As a result, the level of implementation of CE thinking by the University can be determined, including the identification of gaps and opportunities for improvement [14]. The assessment stage entails the development of collaborative workshops to analyze gaps and opportunities and to propose a strategy for the implementation of CE principles in the structure of a specific subject-matter. In our project, the first workshop involves the development of two research activities: 1) envisioning a strategy for implementing CE principles in a construction management course (subject-matter) that aligns with the core priorities of the university, and 2) identifying gaps and opportunities. The second workshop is aimed at the development of two design activities: 1) designing CE content for the subject-matter, and 2) implementing the designed content in the subject-matter structure. Finally, the reflection stage is a critical assessment of the information generated in the previous stages.

V. Analysis

A. Exploration

The background analysis involved the scope assessment of policies, strategies, and action plans in the matter of education for SD. This analysis included the new educational model Tec 21 [31], the Tecnologico de Monterrey Strategic Plan 2030 [23], the Professional Formative Programs Model Tec21 [32], and the Civil Engineering Educational Program [33]. These documents provided a clear vision of the university philosophy and its objectives as well as a detailed evaluation of progress toward the university goals. Although there is no explicit mention of the CE concept in any of the university strategies, the institution promotes CE thinking indirectly. Examples include the commitment to SD as a guiding principle and innovation as part of the institutional vision [23], the inclusion of SD competencies for the professional formative programs [32], and a strong emphasis on the commitment to the environment and ethical and social responsibility for the learning outcomes [33]. These strategies contribute to critical thinking about improving the use of natural resources by implementing disruptive and innovative ideas, which are key requirements for CE.

Subsequently, the stakeholders, in this case, a group of five construction-management-oriented academics, participated in individual, semi-structured interviews to get inside knowledge of the effectiveness of the University's strategies for developing education for SD. The stakeholders are experts in the field of construction management and sustainability in the construction industry, and they belong to the civil and environmental faculty of the university. The participants were usually involved in decision-making processes within the educative programs in the past. Consequently, they were considered an appropriate study group from whom to obtain a holistic perspective and enriching dialogue on the challenges and opportunities related to the principles of CE implementation. The stakeholders' interviews demonstrated that the University's strategies had been developed without including CE thinking explicitly due to the lack of complete understanding of the implications and applications of the

concept. The stakeholders also highlighted the lack of appropriate decision-support frameworks, guidelines, and key performance indicators that would facilitate the insertion of CE thinking in the University's programs. As a result, there were no initiatives or practices in the Construction Management courses which fully incorporated the CE philosophy and principles.

B. Assessment

The construction management course analyzed in this study is the subject-matter, Business Management in the Construction Industry, in the undergraduate Civil Engineering program. The assessment process was based on the literature review in the topic, face to face workshops, and the collaborative work of faculty members to discuss the course content (conceptual, procedural, and attitudinal). The conceptual content is related to the theoretical concepts, principles, models, and concepts of a specific subject. The procedural content is the techniques, methodologies, aptitudes, and abilities that are necessary for the implementation of the conceptual content. The attitudinal content is related to the philosophies and values that lead the decisions and approaches in professional life.

After the interviews, two participatory workshops were held. For consistency, the workshop participants were those previously interviewed. The workshop's programs, with a brief description of their purpose and practical activities, were sent to the participants before the development of the workshops. Each workshop had a duration of 5 hours in two sequential days. The evidence of the group discussions was recorded for their analysis. Once the workshops ended, the outcomes were summarized, and the feedback about the quality and organization of the workshops was collected.

1) Workshop A:

The first group activity of Workshop A involved co-creating an overreaching vision for improving learning outcomes in the construction management course, Business Management in the Construction Industry, in terms of CE principles and SD competencies. In order to facilitate a better understanding of the full scope of important concepts such as CE, education for SD, and SD competencies and to encourage CE thinking, an introductory session was presented for the participants. Here, the ABCD method was used to envision a strategy towards sustainability and CE in education. The ABCD method is a procedure that supports the execution of backcasting planning and redesigns for sustainability; it has been demonstrated to be useful for structuring transdisciplinary academic education and research [34]. The ABCD method consists of four steps, namely, awareness and visioning, baseline assessment, creative solutions, and devising a plan. The participants were encouraged to build a vision that would guide the university to take simple, incremental steps rather than implement radical and disruptive changes [14]. Thus, the participants suggested adopting the following definition of the CE concept in the current vision for the Construction Engineering course:

"'Business Management in the Construction Industry' is an advanced-level management course that aims to facilitate the tools, administration, and financing concepts for the construction industry in the context of circular economy (CE), as well as to develop the competencies for sustainable development needed for decision-making and control of a construction company. In the construction industry, CE is a restorative and regenerative design system that aims to keep products, components, and materials at their highest utility and value as much as possible along the construction supply chains."

For the purposes of this study, the participants used as a reference the Ellen Macarthur Foundation (EMF) reports [21,35] to define CE concepts and principles. According to Mendoza et al. [14], it is practical and beneficial to use a simple definition of CE because the concept is still evolving, and there is no consensus on its definition yet. Therefore, the EMF-based CE vision proposed by the participants was considered appropriate for the purposes of this study. The following questions were formulated to facilitate a discussion about the alignment of this vision with the sustainability goals of the University. These questions allowed participants to start designing the new structure of the Construction Management course to align with the vision and scope of the new educational model.

- What does success stand for in this vision?
- What significance and impact do we have to have?
- What are the potential benefits and the main drivers?
- What are the potential risks, disadvantages, and barriers?
- What are the success criteria?

The second part of Workshop A involved the identification of the drivers, barriers, and opportunities for the adoption of the CE-compliant vision for the Construction Management course (see Table 1). The participants developed an analysis of the internal and external drivers and barriers for the implementation of the vision. The result was the identification of opportunities for the course structure and content. The participants agreed that improving the course content through the implementation of CE concepts for the construction industry, such as closed-loop supply chains [17,36,37], circular business models [20,38], and implementation of CE technologies [39,40], could be a practical way to develop SD competencies in students efficiently. Accordingly, the implementation of CE principles could help the University to attain its educational objectives and vision in Education for SD set out in the Tecnologico de Monterrey Strategic Plan 2030 [23]. The ReSOLVE framework was used to structure the analysis and classification of potential CE innovations. ReSOLVE is a guideline to help organizations with the transition to CE. This guideline proposes six CE strategies [35], namely, regenerate, loop, share, virtualize, optimize, and exchange. These all follow the CE principle to improve the use of natural resources from a life-cycle perspective.

The workshop participants also pointed out that the implementation of CE principles can serve as a platform to introduce more complex CE concepts, techniques, and methods in construction, such as advanced deconstruction methods [41,42] (e.g., selective disassembly, deconstruction planning, and LCA dismantling optimization), digitalizing the built environment [43-45] (e.g., 3D scan to BIM, automated geometrical characterization, and CE computational algorithms), and marketplace platforms for reused components/materials [46,47] (e.g., refurbished components marketplace, material mapping on building stocks, and design configurators for reused components). All of the above have been recognized as state-of-the-art research areas in the field of CE in the construction industry. Therefore, in the future, these will be the novel concepts, techniques, and methods that

TABLE I. OPPORTUNITIES AND BARRIERS TO IMPLEMENTING CE PRINCIPLES IN A CONSTRUCTION MANAGEMENT COURSE

CE strategy	*Opportunities*	*SD competencies*	*Barriers and challenges*
Virtualize (dematerialize; access to product-as-services)	Enhancing resource management through digital marketplace platforms (new and reused components); enabling data gathering for the technical cycle (smart technologies, IoT, RFID tags).	Interdisciplinary learning; planning and implementation skills; strategic thinking, action-orientation, and change-agent skills.	Lack of available commercial technology and research in this field; impossibility of digitalizing effectively the vast, existing built environment.
Share (maximize assets use; prolong service life)	Implementing the basis for closed-loop supply chains and circular business models; enabling a shared economy perspective where ownership loses importance (virtual offices, peer-to-peer sharing of privately-owned products, public sharing of a pool of products, consolidation center for construction).	Systems thinking, competence to deal with uncertainty.	Fragmented and not-well integrated supply chains in the construction industry.
Optimize (increase system efficiency; reverse logistics)	Supporting sustainable building project optimization through Life Cycle Assessment (LCA), Life Cycle Cost (LCC), and Social Life Cycle Assessment (SLCA); integration of digital manufacturing and construction technologies (automation, big-data, remote steering).	Understanding of interconnectedness, and handling of complexity, acting fairly and ecologically, participation in shaping sustainable development processes.	High complexity and lack of heterogeneity of the assessment tools and methods. Incomplete datasets for certain assessments.
Loop (energy and material closed loop)	Conceptualizing buildings and infrastructure as future material banks; designing fixed assets for future adaptive reuse; promoting advanced deconstruction methods to take advantage of the build environment.	Participation in shaping sustainable development processes; cooperative action and conflict resolution; self-motivation and motivating others	Radical change on the traditional capital project delivery of buildings and infrastructure; technical and practical impossibility of taking advantage of the existing build environment.
Exchange (transference to advanced renewable goods)	Implementation of new technologies in construction (3D printing of building components, refurbishment of reused building components). Using finitely recyclable construction materials.	Competence to take action to bring change; competence to deal with uncertainty.	Resistance to change towards new alternatives and ideas (disruptive alternatives).
Regenerate (shift to renewable energy and materials)	Using innovative solutions in construction (regenerative materials, restoration of the build environment); buildings as regenerative assets (photovoltaic generators, technologies for cleaning air, rain water harvesting)	Long-term, anticipatory, foresighted, and futures thinking; acting fairly and ecologically.	Perception that the new clean energies and materials are more expensive than regular products.

should be included in higher education for construction engineers.

2) Workshop B:

The FU approach in the design of course-subject-matter is formed by eight main steps and three design precursor elements (see Fig. 2). The design process has highly intensive interactions between the design steps and the design elements. The design precursor elements are an active *literature review* of the state-of-the-art contents for the subject-matter, *collaborative workshops* to combine the expertise of a group of knowledgeable professors in the field, and the formation of the subject-matter in the digital platform, Canvas®. For the integration of CE principles, the analysis focused on the three design precursor elements and the first three steps of the FU approach.

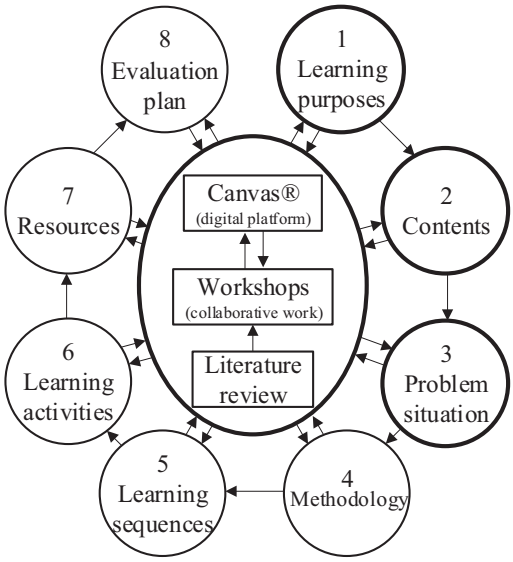

Fig. 1. Formation Unit (FU) Method Approach for the design of a subject-matter. SOURCE: Own creation based on [29].

In the first step, the learning purposes were determined according to the domain levels of competencies and sub-competencies specified in a global distribution of the new academic program. These domain levels contain the competencies that the students should develop during the learning process of the course.

In the second step, the syllabus structure and the content of the previous academic program were used as a starting point to establish the new course content (conceptual, procedural, and attitudinal). In this stage, the old course content was updated and aligned with the learning purposes of the previous stage. All the suggested changes passed through a discussion, debate, and consensus process during the FU design workshop. Also, the changes were supported by the literature review on the topic done by the experts. During this process, it was noticed that the old course structure did not include any explicit content related to CE in the construction industry. Therefore, it was necessary to investigate and include the content related to CE for construction management, such as the transformation of the construction industry to CE [10,48,49], capital project planning for a CE [37], and the effects of CE on the strategical planning of construction companies [50]. CE is considered as a practical

means to reach sustainability; therefore, the inclusion of CE principles in the subject-matter structure is fundamental to developing the SD competencies established as learning purposes. In this second step, a descriptive and explanatory study was performed based on a content analysis of syllabi. Syllabus content analysis is a common and effective technique for examining pedagogic approaches in education and educational content [51,52]. Syllabi are symbolic data or representations of what to expect in a course; therefore, they are a valid representation of the course intentions regarding the competencies to be developed [52,53].

The structure of the problem situation or challenge to be used in the subject-matter was designed in the third step. A problem situation is a circumstance, event, or condition that formulates realistic rhetorical questions (e.g., what, when, how, etc.) whose answers lead to the contents that will be included in the subject-matter [29]. The problem situation is a step in the design of a subject-matter. The problem situation design includes the interaction of all the other steps in a way that the contents are studied deeply and incorporate effective learning techniques; in addition, the acquisition of competencies is evaluated in an effective way.

C. Reflection

The information generated during the exploratory and assessment stages was analyzed and validated. The final result was a synthesis report on the three first steps of the FU subject-matter course, Business Management in the Construction Industry, for the new Civil Engineering academic program. Also, the participants made concluding remarks about the deliverables of each development stage.

VI. Results

In the first stage, the learning purposes for the subject-matter were established as well as the competencies. The SD competencies identified were: 1) (LK) interdisciplinary learning; long-term, anticipatory, foresighted, and futures thinking; systems thinking, understanding of interconnectedness, and handling of complexity, 2) (LD) planning and implementation skills; participation in shaping sustainable development processes; strategic thinking, action-oriented and change-agent skills; and competency to effect changes through actions, 3) (LL) cooperative action and conflict resolution, 4) (LB) self-motivation and ability to motivate others; and competence to deal with uncertainty, and 5) (LT) competency to effect changes through actions, and acting fairly and ecologically. Also, in this stage, the opportunities and barriers to implementing CE principles in the subject-matter content (see Table 1) were identified in order to start the debates about the affordability and importance of their implementation. As a result, the participants agreed on the CE ideas that must be incorporated into the final structure of the subject-matter.

In the second stage, the conceptual content of the subject-matter syllabus was enriched with the CE principles described above. A correlation analysis of the new content and the SD competencies for the subject-matter was developed. Each one of the conceptual content topics was analyzed in order to adjust its content, scope, and approach to include CE vision in the construction industry. Measured in terms of class-hours, the content changed approximately 16% in comparison to the previous academic program. The following topics are just the modified and restructured syllabus topics:

1. *Evolution and development of management in the construction industry*: Construction management is a discipline having systematic approaches to control project outcomes. The traditional school of thinking was focused on the three-pillar approach of time, cost, and quality grounded in a resource-based, linear economy [54]. However, this scope is not sufficient for the emerging environmental challenges in the 21st century and the transition towards a CE in the construction industry [37]. Therefore, it is necessary to include a more holistic view directed towards control and assessment of the project outcomes in terms of life-cycle [55] (e.g., Life Cycle assessment [LCA], Life Cycle Cost [LCC], and Social Life Cycle Assessment [SLCA]). All the above is in the context of an era of vertiginous technological advancements that support the more complex and realistic analyses in construction projects (e.g., Building Information Modeling [BIM], City Information Modeling [CIM], and digital twins).
2. *The construction industry in Mexico*: The construction industry plays a fundamental role in the economic growth of Mexico. Also, it is one of the major industries responsible for producing a large amount of negative environmental impacts. In order to reduce this imbalance, the construction industry must implement new technologies [56] (e.g., 3D printing of building components and refurbishment of reused building components) and innovative solutions [57] (e.g., regenerative materials and restoration of the built environment) that allows the economic growth without compromising the sustainable development.
3. *Strategic planning of a construction company*: The construction industry is passing through a fundamental transformation towards a CE [37]. This transformation is reshaping the fundamentals of the traditional capital project delivery and creating new schemes of business trade (national and international), such as closed-loop supply chains, circular business models, and circular value chains [6,7]. Strategic planning is defined as the process of defining a business strategy or direction and making decisions on the allocation of resources to pursue this strategy. Because the strategic planning and the business positioning of a construction company have a long-term time horizon, it is important to be aware of the emerging areas of opportunity inside the new CE business lines in order to increase sustainability in the construction industry.
4. *The objective of strategic planning*: In the construction industry, the objective of strategic planning has evolved from a vision focused only on economic profitability [54] to one with multiple objectives that promote a more sustainable development [37,58]. According to Gutterman [59], strategic planning for sustainability recognizes that businesses must act in a manner that addresses and satisfies their current goals and needs reasonably while not compromising the ability of future generations to meet their own goals and needs. In this respect, the strategic planning of construction companies has to be analyzed according to the needs and opportunities in the context of sustainable development and CE.

5. *Financial management and accounting of construction companies - Case studies*: The financial management of a construction company includes monitoring the company's profitability, liquidity, and solvency while ensuring timely and accurate financial reporting and making sure that the company has established and maintains an effective set of internal accounting controls. It has been argued that in a CE scheme and closed-loop value supply chains, the organizational structure is more complex and dynamic than the traditional vision [37,46]. Therefore, the financial management and accounting of construction companies must be studied properly. In this matter, there are some case studies of successful CE business models in the construction industry, such as adaptive reuse of buildings [37,42], design for future adaptability [60-62], designing with reused building components [63,64], cradle-to-cradle building design [49,65], and designing buildings as future raw material banks [66,67].

After establishing the new structure of the conceptual content for the subject-matter, the procedural and the attitudinal content were proposed accordingly. In the last stage, the theoretical structure of the problem situation was designed to align with the final content of the course.

VII. Conclusions

According to the background presented in this study, the incorporation of CE principles into the structure of the content of a higher education Construction Engineering course is desirable in order to develop SD competencies in students. This study analyzes the case of a construction management course at an important university in Mexico. This study shows that CE principles could be discovered within the course structure, though in a partial, implicit, and fragmented way, thus not covering all the necessary fields of knowledge, skills, and attitudes. This calls for an adjustment of the course content structure to develop competencies for SD clearly and explicitly, especially those related to the engineering problem solution, construction management, innovative entrepreneurship, and action-taking.

This study explores some of the potential benefits of incorporating CE principles in construction management education for increasing sustainability in the construction industry. The field of management education is particularly controversial because business organizations have been established under the obsolete resource-based, linear economic model. Therefore, business organizations have a natural resistance to change to sustainable business models. The incorporation of CE principles in construction management education has the potential to help in the transition from the linear obsolete economic model to a sustainable one. As in other industries, this transformation must be done gradually and according to the needs of the historical context. The authors hope that the implementation of the new course may pave the road towards the transition. It is important to highlight that the approach of this study is focused on enriching and complementing the existing structures and contents of the old educational model and course contents with the new trends and concepts for sustainable development, not creating a completely new content structure.

Also, this study demonstrates the affordability of the implementation of CE principles into the structure of a construction management course. By using theoretical outlines such as the ABCD method, the ReSOLVE approach, and the Fifth-pillar theory for SD competencies, it was possible to determine the areas of opportunity, the drivers, and the barriers to the implementation of CE fundamentals. This framework can serve as a guideline for the redesign process of other construction management courses in the context of educational innovation, such as the new Tec21 educational model of Tecnologico de Monterrey. What is more, the implementation of the new educational model and the structure of the construction management course contents can serve as a reference guide for its replication in other educational systems and universities in Mexico and Latin America.

One of the limitations of the present study is the lack of involvement of operative actors from the construction industry. The involvement of operative actors, such as industry experts, managers, and technicians, could add more dimensions to the presented methodology. These actors are the customers of academia and, therefore, their feedback should be taken into account.

Finally, the effective use of information and communication technologies was a crucial component in the coordination of the work described in this study. As explained in section IV, most of the work was developed through face-to-face workshops of participants from different campuses of the university system. However, the processing, organizing, and final detailing of the deliverables were done remotely. In this matter, it was very useful and critical to count on the robust information system Canvas® in order to coordinate the final display of the deliverables in a unified platform.

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References

[1] C. Benito Olalla and A. Merino, "Competences for sustainability in undergraduate business studies: A content analysis of value-based course syllabi in Spanish universities," Int. J. Mgmt. Edu., vol. 17, *(2),* pp. 239-253, 2019.

[2] E. Faham, A. Rezvanfar, S. H. Movahed Mohammadi and M. Rajabi Nohooji, "Using system dynamics to develop education for sustainable development in higher education with the emphasis on the sustainability competencies of students," Technol. Forecast. Soc. Change., vol. 123, pp. 307-326, 2017.

[3] W. Lambrechts, I. Mulà, K. Ceulemans, I. Molderez and V. Gaeremynck, "The integration of competences for sustainable development in higher education: an analysis of bachelor programs in management," J. Clean. Prod., vol. 48, pp. 65-73, 2013.

[4] T. Stough, K. Ceulemans, W. Lambrechts and V. Cappuyns, "Assessing sustainability in higher education curricula: A critical reflection on validity issues," J. Clean. Prod., vol. 172, pp. 4456-4466, 2018.

[5] P. J. Ramísio, L. M. C. Pinto, N. Gouveia, H. Costa and D. Arezes, "Sustainability Strategy in Higher Education Institutions: Lessons learned from a nine-year case study," J. Clean. Prod., vol. 222, pp. 300-309, 2019.

[6] S. Badi and N. Murtagh, "Green supply chain management in construction: A systematic literature review and future research agenda," J. Clean. Prod., vol. 223, pp. 312-322, 2019.

[7] M. Geissdoerfer, P. Savaget, N. M. P. Bocken and E. J. Hultink, "The Circular Economy A new sustainability paradigm?" J. Clean. Prod., vol. 143, pp. 757-768, 2017.

[8] B. Unalan, H. Tanrivermis, M. Bulbul, A. Celani and A. Ciaramella, "Impact of embodied carbon in the life cycle of buildings on climate change for a sustainable future," Int. J. Hous. Sci. Appl., vol. 40, *(1),* pp. 61-71, 2016.

[9] C. Langston, F. K. W. Wong, E. C. M. Hui and L. Shen, "Strategic assessment of building adaptive reuse opportunities in Hong Kong," Build. Environ., vol. 43, *(10),* pp. 1709-1718, 2008.

[10] F. Pomponi and A. Moncaster, "Circular economy for the built environment: A research framework," J. Clean. Prod., vol. 143, pp. 710-718, 2017.

[11] D. S. Rychen and L. H. Salganik, *Key Competencies for a Successful Life and Well-Functioning Society.* Hogrefe Publishing, 2003.

[12] A. Zorio-Grima, "Driving factors for having visibility of sustainability contents in university degree titles," J. Clean. Prod., vol. 242, pp. 114746, 2020.

[13] P. Molthan-Hill, N. Worsfold, G. J. Nagy, W. Leal Filho and M. Mifsud, "Climate change education for universities: A conceptual framework from an international study," J. Clean. Prod., vol. 226, pp. 1092-1101, 2019.

[14] J. M. F. Mendoza, A. Gallego-Schmid and A. Azapagic, "Building a business case for implementation of a circular economy in higher education institutions," J. Clean. Prod., vol. 220, pp. 553-567, 2019.

[15] Ş Kılkış and B. Kılkış, "Integrated circular economy and education model to address aspects of an energy-water-food nexus in a dairy facility and local contexts," J. Clean. Prod., vol. 167, pp. 1084-1098, 2017.

[16] J. Kirchherr and L. Piscicelli, "Towards an Education for the Circular Economy (ECE): Five Teaching Principles and a Case Study," Resour. Conserv. Recycl., vol. 150, pp. 104406, 2019.

[17] E. Leising, J. Quist and N. Bocken, "Circular Economy in the building sector: Three cases and a collaboration tool," J. Clean. Prod., vol. 176, pp. 976-989, 2018.

[18] Ellen Macarthur Foundation. (Dec 12, 2019). *Towards the Circular Economy: Opportunities for the consumer goods sector*. Available: www.ellenmacarthurfoundation.org/business/reports.

[19] S. Witjes and R. Lozano, "Towards a more Circular Economy: Proposing a framework linking sustainable public procurement and sustainable business models," Resour. Conserv. Recycl., vol. 112, pp. 37-44, 2016.

[20] M. Geissdoerfer, S. N. Morioka, M. M. de Carvalho and S. Evans, "Business models and supply chains for the circular economy," J. Clean. Prod., vol. 190, pp. 712-721, 2018.

[21] Ellen Macarthur Foundation. (Dec 15, 2019). *Towards the circular economy: Accelerating the scale-up across global supply chains*. Available: www.ellenmacarthurfoundation.org/business/reports.

[22] World Economic Forum, *New Vision for Education: Unlocking the Potential of Technology.* British Columbia Teachers' Federation, 2015.

[23] Instituto Tecnológico y de Estudios Superiores de Monterrey (ITESM). (2019, Dec 15). *Rumbo al 2030 Tecnologico de Monterrey*. Available: https://miespacio.itesm.mx/sites/planestrategico2020/Paginas/documentos.html.

[24] QS Quacquarelli Symonds. (2019, Dec 15). *QS World University Ranking*. Available: https://www.topuniversities.com/university-rankings/world-university-rankings/2020.

[25] M. X. Rodriguez-Paz, J. A. Gonzalez-Mendivil, J. Rojas and M. E. Núñez, "Use of an offline video repository as a tool to improve students' performance in engineering courses versus real-time long distance courses," in 2019 IEEE Global Engineering Education Conference (EDUCON), 2019, pp. 544-551.

[26] J. A. González-Mendívil, M. X. Rodríguez-Paz, E. Caballero-Montes, C. L. Garay-Rondero and I. Zamora-Hernández, "Measuring the developing of competences with collaborative interdisciplinary work," in 2019 IEEE Global Engineering Education Conference (EDUCON), 2019, pp. 419-423.

[27] M. E. Núñez, J. Rojas and M. X. Rodriguez-Paz, "Real-time distance courses to improve satisfaction and competence - A case study on the performance of students observing their grades," in 2019 IEEE Global Engineering Education Conference (EDUCON), 2019, pp. 519-525.

[28] M. X. Rodríguez-Paz, J. A. González-Mendivil, J. A. Zárate-García and L. O. Peña-Ortega, "The positive effects on student performance of using social networks in courses of applied mechanics," in Proceedings of the ASME 2018 International Mechanical Engineering Congress and Exposition (IMECE), 2018, .

[29] Instituto Tecnológico y de Estudios Superiores de Monterrey (ITESM), "Taller de diseño de unidades de formación - agosto 2019" 2019.

[30] J. M. F. Mendoza, M. Sharmina, A. Gallego-Schmid, G. Heyes and A. Azapagic, "Integrating Backcasting and Eco-Design for the Circular Economy: The BECE Framework" J. Ind. Ecol., vol. 21, *(3),* pp. 526-544, 06/01; 2019/11, 2017.

[31] Instituto Tecnológico y de Estudios Superiores de Monterrey (ITESM). (2019, Dec 15). *Modelo educativo TEC 21*. Available: http://modelotec21.itesm.mx/files/folletomodelotec21.pdf.

[32] Instituto Tecnológico y de Estudios Superiores de Monterrey (ITESM). (2019, Dec 15). *Modelo de Programas Formativos de Profesional TEC21*. Available: https://miespacio.itesm.mx/sites/planestrategico2020/Paginas/documentos.html.

[33] Instituto Tecnológico y de Estudios Superiores de Monterrey (ITESM). (2019, Dec 15). *Syllabus Civil Engineering*. Available: https://samp.itesm.mx/Programas/VistaPrograma?clave=IC%2011&modoVista=Default&idioma=EN&cols=0#.

[34] G. I. Broman and K. Robèrt, "A framework for strategic sustainable development," J. Clean. Prod., vol. 140, pp. 17-31, 2017.

[35] Ellen Macarthur Foundation. (Dec 15, 2019). *Towards a circular economy: business rationale for an accelerated transition*. Available: https://www.ellenmacarthurfoundation.org/publications.

[36] O. O. Akinade and L. O. Oyedele, "Integrating construction supply chains within a circular economy: An ANFIS-based waste analytics system (A-WAS)," J. Clean. Prod., vol. 229, pp. 863-873, 2019.

[37] B. Sanchez and C. Haas, "Capital project planning for a circular economy," Constr. Manage. Econ., vol. 36(6), pp. 303-312, 02/15, 2018.

[38] M. Geissdoerfer, D. Vladimirova and S. Evans, "Sustainable business model innovation: A review," J. Clean. Prod., vol. 198, pp. 401-416, 2018.

[39] Y. Kalmykova, M. Sadagopan and L. Rosado, "Circular economy – From review of theories and practices to development of implementation tools," Resour. Conserv. Recycl., vol. 135, pp. 190-201, 2018.

[40] E. Iacovidou, P. Purnell and M. K. Lim, "The use of smart technologies in enabling construction components reuse: A viable method or a problem creating solution?" J. Envr. Mgmt., vol. 216, pp. 214-223, 2018.

[41] B. Sanchez, C. Rausch and C. Haas, "Deconstruction programming for adaptive reuse of buildings," Autom. Constr., vol. 107, pp. 102921, 2019.

[42] B. Sanchez and C. Haas, "A novel selective disassembly sequence planning method for adaptive reuse of buildings," J. Clean. Prod, vol. 183, pp. 998-1010, 2018.

[43] C. Rausch, B. Sanchez and Esnaashary Esfahani, M. & Haas, C., "Computational algorithms for digital twin support in construction," in ASCE Construction Research Congress (CRC) March 8-10, 2020, Tempe, Arizona, USA, 2020 (in press), .

[44] C. Rausch, B. Sanchez and C. Haas, "Spatial parameterization of non-semantic CAD elements for supporting automated disassembly planning," in 2019 Modular and Offsite Construction (MOC), Banff, AB, Canada, 2019, pp. 108-115.

[45] J. K. Whyte and T. Hartmann, "How digitizing building information transforms the built environment," Build. Res. Inf., vol. 45, *(6),* pp. 591-595, 2017.

[46] B. Sanchez, C. Rausch and Rodriguez-Paz, M.X. & Haas, C., "A framework for integrating emerging technologies to improve the supply chain for reused building components," in 2020 International Conference on Resource Sustainability 30th June - 2nd July 2020 University College Dublin, Dublin, Ireland, 2020 (in press), .

[47] A. Stephan and A. Athanassiadis, "Quantifying and mapping embodied environmental requirements of urban building stocks," Build. Environ., vol. 114, pp. 187-202, 2017.

[48] P. Ghisellini, M. Ripa and S. Ulgiati, "Exploring environmental and economic costs and benefits of a circular economy approach to the construction and demolition sector. A literature review," J. Clean. Prod., vol. 178, pp. 618-643, 2018.

[49] P. Lacy and J. Rutqvist, *Waste to Wealth: The Circular Economy Advantage.* London, UK: Palgrave Macmillan, 2015.

[50] B. Sanchez, "Methodology for Improving the Net Environmental Impacts of New Buildings through Product Recovery Management." , University of Waterloo, Waterloo, Canada, Ontario, 2019.

[51] P. E. Priester, J. E. Jones, C. M. Jackson-Bailey, A. Jana-Masri, E. X. Jordan and A. Metz, "An analysis of content and instructional strategies in multicultural counseling courses," J. Multicult. Couns. Devel., vol. 36, *(1),* pp. 29-39, 2008.

[52] Debbi D. Brock and Susan Steiner. (February 16, 2009). *Social entrepreneurship education: is it achieving the desired aims?*. Available: https://ssrn.com/abstract=1344419.

[53] V. L. Crittenden and E. J. Wilson, "Content, Pedagogy, and Learning Outcomes in the International Marketing Course," J. Teach. Int. Bus., vol. 17, *(1-2),* pp. 81-101, 07/01, 2006.

[54] C. Cho, "Development of the Project Definition Rating Index (PDRI) for Building Projects." , Department of Civil Engineering, University of Texas at Austin, 2000.

[55] B. Sanchez, M. Esnaashary Esfahani and C. Haas, "A methodology to analyze the net environmental impacts and building's cost performance of an adaptive reuse project: a case study of the Waterloo County Courthouse renovations," Environ. Syst. Decis., vol. 39, *(4),* pp. 419-438, 2019.

[56] B. Sanchez, C. Rausch, C. Haas and R. Saari, "A selective disassembly multi-objective optimization approach for adaptive reuse of building components," Resour. Conserv. Recycl., vol. 154, *(104605),* 2020.

[57] B. Sanchez, C. Bindal-Gutsche and Hartmann, T. & Haas, C., "A building information modeling approach for adaptive reuse building projects," in ASCE Construction Research Congress (CRC) March 8-10, 2020 Arizona State University, Tempe, Arizona, USA, 2020 (in press), .

[58] Y. Kang, C. Kim, H. Son, S. Lee and C. Limsawasd, "Comparison of preproject planning for green and conventional buildings," J. Constr. Eng. Manage., vol. 139, *(11),* pp. 4013018, 2013.

[59] A. S. Gutterman, *Strategic Planning for Sustainability: A Guide for Sustainable Entrepreneurs.* Kindle, 2019.

[60] C. J. Kibert, "The next generation of sustainable construction," Build. Res. Informat., vol. 35, *(6),* pp. 595-601, 2007.

[61] S. Conejos, M. Y. L. Chew and E. H. K. Yung, "The future adaptivity of nineteenth century heritage buildings," Int. J. Build. Path. Adapt., vol. 35, *(4),* pp. 332-347, 2017.

[62] J. Douglas, *Building Adaptation.* (2nd edition ed.) London, UK: Routledge, 2006.

[63] P. Sassi, "Defining closed-loop material cycle construction," Build. Res. Inf., vol. 36, *(5),* pp. 509-519, 2008.

[64] M. Gorgolewski, "Designing with reused building components: Some challenges," Build. Res. Inf., vol. 36, *(2),* pp. 175-188, 2008.

[65] A. Bastein *et al*, "Circular Amsterdam: A vision and action agenda for the city and metropolitan area," 2016.

[66] Turntoo. (2019, Dec 15). *Idea as material*. Available: http://turntoo.com/en/publications/.

[67] Ellen Macarthur Foundation, "Circularity in the built environment: Case studies," Ellen Macarthur Foundation, 2016.

[68] Instituto Tecnológico y de Estudios Superiores de Monterrey (ITESM), "Taller de diseño de unidades de formación," Tecnologico de Monterrey, Monterrey, Nuevo Leon, 2019.